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OPTIMISATION OF YIELD AND ASSESSING THE ECONOMIC VIABILITY OF IRRIGATED SORGHUM (*SORGHUM BICOLOR* L.) THROUGH (INM) APPROACH

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ABSTRACT

An examination into the effects of combined applications of inorganic fertilizer and organic manure, along with foliar application of plant growth-promoting rhizobacteria, on growth, yield, nutrient uptake and economics of sorghum (*Sorghum bicolor* L.) under irrigated conditions the experiment was conducted during March to June 2023 at the Experimental Farm, department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar – 608002. The soil of the experimental field was clayey loam in texture with a pH of 7.5. The experiment was laid out in randomized block design (RBD) with ten treatments and replicated thrice by using the sorghum variety (K12). The treatments comprised of T_1- Absolute control (without application), T_2-100% (recommended dose of fertilizer 90:45:45 kg ha^{-1} of N, P, and K), T_3-125% recommended dose of fertilizer, T_4-150% Recommended dose of fertilizer, T_5-100% recommended dose of fertilizer + enriched farmyard manure (EFYM), T_6-125% Recommended dose of fertilizer + enriched farmyard manure (EFYM), T_7 - 150% Recommended dose of fertilizer + enriched farmyard manure (EFYM), T_8-100% Recommended dose of fertilizer + enriched farmyard manure (EFYM) + plant growth- promoting rhizobacteria (PGPR), T_9-125% recommended dose of fertilizer + enriched farmyard manure (EFYM) + plant growth-promoting rhizobacteria (PGPR), T_{10}-150% recommended dose of fertilizer + enriched farmyard manure (EFYM) + plant growth-promoting rhizobacteria (PGPR). The results of the study concluded that the application of 150% recommended dose of fertilizer + enriched farmyard manure (EFYM) + plant growth-promoting rhizobacteria (PGPR) significantly influenced the growth, yield, nutrient uptake of sorghum, and economic viability of sorghum under irrigated condition.

***Keywords*:** Recommended dose of fertilizer (RDF), Enriched farm yard manure (EFYM), Plant growth-promoting rhizobacteria (PGPR), Partial budgeting.

Introduction

Sorghum is also known as camel crop which can produce quite well even in unfavourable weather circumstances like high temperatures and little soil moisture even though it responds well to irrigation. It is a crop with a short growing season, a wide range of adaptations, shallow roots, high water usage efficiency, and a rapid rate of sugar buildup. It is grown on low fertility soils under rainfed circumstances. Low production is the outcome of nutrition and moisture stress in such growth circumstances.

In India sorghum is grown in an area of about 5.02 million hectares with 4.80 million tonnes of production and 956 kg ha^{-1} of productivity. In Tamil Nadu, total area under sorghum is 3.85 lakh hectares with a production of 4.30 lakh tonnes and a productivity of 1117 kg ha^{-1} Pallavi *et al.* (2020). Sustainable nutrient management includes the judicious use of all the major sources of plant nutrients from organic and inorganic resources to get spectacular yield, improvement or to maintain the soil physical and chemical properties and provide crop nutrition package which are technically sound, economically attractive,

practically feasible and environmentally safe Gaikwad *et al*. (2018).

Manure from enhanced farm yards is a useful resource that can greatly increase plant growth and soil richness. Farm yard manure that has been enhanced produces a premium organic fertilizer that infuses the soil with necessary nutrients, humus, and healthy bacteria.

Bioinoculants must be used in sustainable agriculture in order to reduce plant pests and boost output. Plant growth promoting rhizobacteria (PGPR) have therefore, become a viable substitute for the application of synthetic fertilizers and pesticides, which are hazardous to the environment and human health. PGPR plays a vital role in the enhancement of plant growth and yield. PGPR releases different hormone including auxin, cytokinin, and gibberellin that enhances the growth of the plants. PGPR directly stimulate the growth of plants by increasing nutrient availability through different direct mechanisms of action such as nitrogen fixation, mineral solubilization, and phytohormone production Khan and Bano (2016).

Materials and Methods

Experimental Site

A field experiment was conducted at the Experimental Farm, Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Tamil Nadu, India during March-June, 2023 to study the effect of integrated nutrient management practices in sorghum under irrigated conditions. The experimental area comes under the north eastern Agro Climatic Zone of Tamil Nadu. The experimental farm is geographically located at 11° 24' N Latitude and 79° 44' E Longitude at an altitude of +5.79m above the mean sea level (MSL). The soil of the experimental field is classified as *udic chromustert* clayey loam in texture with a pH of 7.5 and EC of 0.35 dSm^{-1}. The fertility status was low in available nitrogen (222 kg ha^{-1}), medium in available phosphorous (18 kg ha^{-1}) and high in available potassium (301 kg ha^{-1}).

Experimental design and treatments

The experiment was laid out in randomized block design (RBD) with ten treatments and replicated thrice. The details of the treatment are **T_1**-Absolute control (without application), **T_2**-100% (recommended dose of fertilizer 90:45:45 kg ha^{-1} of N, P, and K), **T_3**-125% recommended dose of fertilizer, **T_4**-150% Recommended dose of fertilizer, **T_5**-100% recommended dose of fertilizer + enriched farmyard manure (EFYM), **T_6**-125% Recommended dose of fertilizer + enriched farmyard manure (EFYM), **T_7**-150% Recommended dose of fertilizer + enriched farmyard manure (EFYM), **T_8**-100% Recommended dose of fertilizer + enriched farmyard manure (EFYM) + plant growth- promoting rhizobacteria (PGPR), **T_9**-125% recommended dose of fertilizer + enriched farmyard manure (EFYM) + plant growth-promoting rhizobacteria (PGPR), **T_{10}**-150% recommended dose of fertilizer + enriched farmyard manure (EFYM) + plant growth- promoting rhizobacteria (PGPR). The recommended dose of 90:45:45 kgs of NPK ha^{-1} in the form of urea, SSP and muriate of potash. The enriched farm yard manure was applied to the respective plots @ 750 kg ha^{-1}. The plant growth-promoting rhizobacteria was applied to the respective plots @ 10 kg ha^{-1}.

Crop management

Maize variety sorghum K12 (TKSV 0809) was chosen for the study, which is high yielding, dual-purpose sorghum variety, it is a photo-insensitive variety suitable for growing in all seasons of Tamil Nady. 45 × 15 cm is the Spacing adapted for the trail. As per the treatment, fertilizer was applied in the respective plots before sowing. Full dose of phosphorus and potassium and half dose of nitrogen were applied as basal at the time of sowing. Remaining half of the nitrogen were applied at 30 days after sowing (DAS) as per the treatments. The nutrient source for nitrogen, phosphorus and potash were urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O), respectively. All recommended agronomic practices and timely need-based plant protection measures were taken to establish healthy maintenance of crop. The plant growth-promoting rhizobacteria was applied to the respective plots @ 10 kg ha^{-1}.

Preparation of Enriched farmyard manure (EFYM)

Firstly, the farmyard manure was collected from Dairy farm, Division of Animal Husbandry, Annamalai University, Chidambaram, Tamil Nadu and ensured that the FYM was partially or fully decomposed. The enriched farmyard manure (EFYM) was prepared by using calculated quantity of single super phosphate for sorghum crop (Recommended dose of phosphorus is 45 kg ha^{-1}), which was thoroughly mixed with well decomposed, powdered farmyard manure and made into a heap like structure and it was maintained under shaded condition with some moisture. After 45 days, enriched farmyard manure was incorporated to the respective plots as a rate of 750 kg ha^{-1}as per the treatment schedule. The nutrient content of enriched farmyard manure (EFYM) was Organic carbon 210 g kg^{-1}, C: N ratio 20:1, Available Nitrogen 1.49%,

Available Phosphorous 5.79%, Available Potassium 0.79%.

Data collection

Five sample plants from each treatment plot were chosen at random and labelled for recording various biometric observations at different stages of crop growth, such as plant height, leaf area index, dry matter production, No. of. earheads m^{-2}, No. of. Filled grains $earhead^{-1}$, grain yield, stover yield, nutrient uptake and partial budgeting. The total yield was computed and recorded as kg ha^{-1}. The data collected on various characteristics during the field investigations were analysed statistically according to the methods outlined by Gomez and Gomez (1984).

Statistical analysis

Significant differences among treatments were evaluated using the 'F' test and critical differences were determined at a 5% probability level to draw statistical conclusions. Treatments showing no significant differences were labelled as "NS".

Results and Discussion

Growth attributes

The various growth characters of Sorghum, such as plant height, leaf area index, dry matter production, were significantly influenced by conjoint application of 150% RDF + enriched farm yard manure (EFYM) @750 kg ha^{-1} along with foliar application of plant growth-promoting rhizobacteria (PGPR) (T_{10}) (Table.1). Treatment (T_{10}) registered a maximum plant height of 70.5, 210.9, and 248.5 cm, This is due to the combined application of inorganic fertilizers and organic manures along with foliar spray in which inorganic fertilizer releases nitrogen (N) at a faster rate that is readily available at crop earlier stages only and further more crop need for nutrient was fulfilled by enriched farm yard manure that releases nutrients and supplies steadily balanced nutrients through mineralization , which in turn enriched the soil owing to providing sufficient amounts of nutrients that are needed for various metabolic processes Yadav *et al*. (2024). And foliar application of plant growth-promoting rhizobacteria that play a vital role in N_2 fixing and P-solubilizing may be important for plant nutrition by increasing N and P uptake by the crop plants. The result was closely related to the work Srinivasaperumal *et al*. (2019), Mounde *et al*. (2014).

The highest dry matter production of 2396, 10398, and 14997 kg ha^{-1}. This was attributed to the nature of variety that tends to produce more DMP and in addition enriched farmyard manure mineralizes the essential nutrients and foliar application of plant growth - promoting rhizobacteria enhances dry matter production through beneficial organisms which involve the mineralization of soil unavailable nutrients into readily available form Rachel *et al.* (2023). The maximum values of LAI (5.94 and 4.41). The inorganic fertilizer effectively fulfills the crop's early nutrient requirements and increases the crop growth and crop canopy establishment Sandeep *et al*. (2022). And the enriched farm yard manure contains essential nutrients and slowly releases plant nutrients over a long period of time Meena *et al*. (2020). Leaf area is the product of leaf length and breadth and it is a measure of the size of the assimilatory system of food in plants. The foliar application of foliar sprays of plant growth promoting rhizobacteria enhances the nutrient availability in rhizosphere have favoured higher nutrient uptake resulting in better crop growth leading to higher LAI Rizvi *et al*.(2024). While, the shorter plants of 45.0, 149.8 and 175.0 cm, minimum dry matter production of 717, 3159, and 5025 kg ha^{-1}, the minimum values of LAI (3.55 and 2.90) were marked under the treatment (T1) Absolute control at different growth stages of the crop.

Yield attributes

The findings of the field experiment on sorghum revealed that the various treatments tested in this study exerted significant influence on yield components (table 2). Among various treatments, the application of 150% recommended dose of fertilizer and enriched farmyard manure, along with the foliar application of plant growth-promoting rhizobacteria, registered higher yield attributes (No. of. earheads m^{-2}, No. of. filled grains $earhead^{-1}$). Treatment (T10) registered the highest number of ear heads m^{-2} of 14.81, the highest number of filled grains $earhead^{-1}$ of 1210. This was due to the combined application of inorganic fertilizer and organic manures, which enhance nutrient availability to the crop over a long period of time and which synthesize the soil unavailable nutrients into available form for the plant, which in turn enhances the growth of the plant, which leads to higher yield attributes Srivastav *et al*. (2020). While, the lower number of ear heads m^{-2} of 13.83, the lowest number of filled grains $earhead^{-1}$ of 455 were marked under the treatment (T1) at the harvest stage of sorghum.

Yield

All the yield parameters were positively influenced by the imposition of different treatments which in turn led to a cumulative increase in yield (Table 2). Among 10 different treatments, the conjoint application of a 150% recommended dose of fertilizer

and organic manure-enriched farmyard manure (EFYM) along with a foliar spray of plant growth-promoting rhizobacteria (PGPR) treatment (T10) marked the highest grain yield of 5105 kg ha^{-1} the grain yield, which depends on the synthesis and accumulation of photosynthates and their distribution among various plant parts, as well as the extent of translocation into sinks (grains), and also on plant growth and development during the early stages of crop growth, which in turn depends on the availability of nutrients Bharathi *et al*. (2020). And the highest stover yield of 12025 kg ha^{-1}. The enhancement in various agronomic yields due to PGPR has been reported because of the production of growth stimulating phytohormones such as Indole acetic acid (IAA), Gibberellic acid (GA3), Zeatin, Ethylene and Abscisic acid (ABA) Sindhi *et al*. (2022). The lower grain yield of 1055 kg ha^{-1}, stover yield of 4196 kg ha^{-1} and harvest index of 20.09 per cent were registered under Absolute control (T1).

Nutrient uptake by crop

The results revealed that, the nutrient uptake by sorghum was greatly influenced by the various treatments imposed (Table 2). Among the ten treatments tested, the conjoint application of 150% recommended dose of fertilizer + enriched farmyard manure (EFYM) @750 kg ha^{-1} + plant growth-promoting rhizobacteria (PGPR) treatment (T10) registered significantly maximum N uptake of 166.5 kg ha^{-1}, P uptake of 63.5 kg ha^{-1} and K uptake of 190.5 kg ha^{-1} by sorghum, respectively. The combined application of inorganic fertilizer and organic manures which creates a favourable condition for both chemical and microbial activity. Thus, enhanced soil chemical and microbial activity, which leads to mineralization and mobilization of nutrients, thereby resulting in better availability of nutrients throughout the crop growth facilitating the increased uptake of nutrients by the plants Tudu *et al*. (2023). While, the least N uptake of 81.3 kg ha^{-1}, the least P uptake of 17.6 kg ha^{-1} and the least K uptake of 93.7 kg ha^{-1} were marked under Absolute control treatment (T1).

Economics

Economic efficiency and viability of crop cultivation are mainly referred to as the outcomes of the crop. In general, higher crop productivity is based on the cost of cultivation and translates into improved economic metrics like net income and BCR. The net return and benefit cost ratio were greatly influenced by the addition of inorganic and organic manures with foliar nutrition. Among the different graded levels of inorganic fertilizers and organic manures along with foliar application registered the highest profitability and monetary returns in terms of net income of Rs. 96879 ha^{-1} and the benefit cost ratio of 2.56. The higher gross income was also recorded by the treatment (T10), could be due to a higher yield. The highest economic yield of sorghum may be ascribed to a more profitable treatment, which consists of 150% recommended dose of fertilizer and enriched farmyard manure (EFYM) along with foliar application of plant growth-promoting rhizobacteria (PGPR) Reddy *et al*. (2023), Surve *et al*. (2020). When the nutrient is not supplied through inorganic, organic fertilizers which resulted in poor accumulation of photosynthates from source to sink, because all crops need nutrients at their initial stage of growth. So due to this factor the crop was not able to produce sufficient yields. So the decrease in economic parameters *viz*., gross income, net income and BCR is majorly due to reduced grain yield.

Partial budgeting (Rs. ha^{-1})

For verifying the financial stability of the best treatment (T_{10})-combined application of inorganic fertilizer 150% RDF and enriched farm yard manure (EFYM) @ 750 kg ha^{-1} along with foliar application of plant growth-promoting rhizobacteria (PGPR) with treatment (T_2) 100% RDF, partial budgeting (Table 4) was worked out Johl and Kapur (1973). The net gain estimated using partial budgeting was Rs. 42616 ha^{-1}.

Conclusion

In light of the above experimental results, it could be concluded that the application of 150% recommended dose of fertilizer and enriched farmyard manure (EFYM) along with foliar sprays of plant growth-promoting rhizobacteria (PGPR) was highly impressive and had a remarkable effect on growth character, yield attributes, yield, nutrient uptake, postharvest soil available nutrient status, and economics without affecting soil health. It was also found to be suitable and sustainable integrated nutrient management practices for the sorghum crop. Also, this package holds promise as an agronomically sound, ecologically safe, and cost-effective method for farmers. Therefore, this practice is recommended as a better option for adoption by the farming community

Table 1 : Impact of inorganic fertilizers and organic manure along with foliar spray of PGPR on growth attributes.

Treatments	Plant height (cm)			Leaf Area Index		Dry matter production (kg ha^{-1})		
	30 DAS	60 DAS	At harvest	Flowering Stage	Harvest Stage	30 DAS	60 DAS	At Harvest
T1- Absolute control	45.0	149.8	175.0	3.5	2.9	717	3159	5025
T2- 100% RDF	51.7	180.0	212.0	4.3	3.3	1551	8568	11655
T3- 125% RDF	54.2	184.8	216.9	4.5	3.4	1680	8897	12233
T4- 150% RDF	58.2	192.0	225.4	4.8	3.7	1864	9297	12963
T5- 100% RDF + EFYM	57.1	189.8	222.3	4.7	3.6	1817	9212	12829
T6- 125% RDF +EFYM	62.2	198.9	234.1	5.2	3.9	2053	9703	13663
T7- 150% RDF +EFYM	67.0	205.8	242.4	5.6	4.2	2257	10103	14379
T8- 100% RDF +EFYM +PGPR	61.2	196.9	231.1	5.1	3.9	1999	9598	13524
T9- 125% RDF +EFYM +PGPR	65.7	203.8	240.1	5.5	4.1	2202	10003	14269
T10- 150% RDF +EFYM +PGPR	70.5	210.9	248.5	5.9	4.4	2396	10398	14997
S.Ed	**1.15**	**1.66**	**2.28**	**0.09**	**0.05**	**39.02**	**135.64**	**264.15**
CD (P=0.05)	**2.42**	**3.50**	**4.81**	**0.19**	**0.12**	**82**	**285**	**555**

Table 2 : Impact of inorganic fertilizers and organic manure along with foliar spray of PGPR on yield attributes, yield and nutrient uptake.

Treatments	No. of. Earheads m^{-2}	No. of. filled grains earhead^{-1}	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Nutrient uptake (kg ha^{-1}) in plants		
					N	P	K
T1- Absolute control	13.8	455	1055	4196	81.38	17.65	93.75
T2- 100% RDF	14.5	891	3415	9688	119.79	51.17	138.68
T3- 125% RDF	14.5	942	3686	10113	128.99	53.16	147.89
T4- 150% RDF	14.6	1014	4056	10623	138.70	56.17	159.68
T5- 100% RDF + EFYM	14.6	996	4005	10513	136.97	55.07	156.89
T6- 125% RDF +EFYM	14.7	1087	4402	11120	149.31	59.13	171.59
T7- 150% RDF +EFYM	14.7	1158	4760	11625	159.30	61.68	182.35
T8- 100% RDF +EFYM +PGPR	14.6	1071	4337	11018	147.69	58.04	168.60
T9- 125% RDF +EFYM +PGPR	14.7	1143	4727	11525	157.51	60.66	180.10
T10- 150% RDF +EFYM +PGPR	14.8	1210	5105	12025	166.50	63.53	190.56
S.Ed	**0.01**	**23.79**	**84.57**	**180.86**	**1.40**	**0.76**	**3.18**
CD (P=0.05)	**0.03**	**50**	**177.69**	**380**	**2.95**	**1.60**	**6.69**

Table 3 : Impact of inorganic fertilizers and organic manure along with foliar spray of PGPR on net income, gross income and Benefit cost ratio

Treatments	Cost of cultivation (Rs. /ha)	Gross income (Rs. /ha)	Net income (Rs. /ha)	BCR
T1- Absolute control	35190	33748	-1442	0.96
T2- 100% RDF	49952	107294	57342	2.15
T3- 125% RDF	53643	115637	61994	2.16
T4- 150% RDF	57334	126992	69658	2.21
T5- 100% RDF + EFYM	51902	125407	73505	2.42
T6- 125% RDF +EFYM	55593	137620	82027	2.48
T7- 150% RDF +EFYM	59284	148613	89329	2.51
T8- 100% RDF +EFYM +PGPR	54902	135619	80717	2.47
T9- 125% RDF +EFYM +PGPR	58593	147573	88980	2.52
T10- 150% RDF +EFYM + PGPR	62284	159163	96879	2.56

Table 4 : Effect of integrated nutrient management practices on partial budgeting of sorghum cultivation

S. No.	Credit	Amount (Rs. ha^{-1})	S. No.	Debit	Amount (Rs. ha^{-1})
	Added Returns (ha^{-1})			**Added cost (ha^{-1})**	
1.	1690 grain yield @ Rs 30 kg^{-1} 2337 stover yield @ Rs 0.5 kg^{-1}	50700 1168	1.	Urea Single super phosphate Muriate of potash Application charges	587 1265 900 800
			2.	Enriched farm yard manure (EFYM) Application charges	750 1200
			3.	Plant growth promoting rhizobacteria (PGPR) Application charges	3000 750
	Sub Total	**51868**		**Sub Total**	**9252**
	Reduced cost (ha^{-1})			**Reduced returns (ha^{-1})**	
	Nil	-		Nil	-
	Sub Total	-		**Sub Total**	-
	Total (A)	**51868**		**Total (B)**	**9252**

Note: Credit and Debit values were arrived in comparison of treatment T_{10} with treatment T_2 (100% RDF)
Net gain = A-B
= 51868-9252
= 42,616 Rsha^{-1}

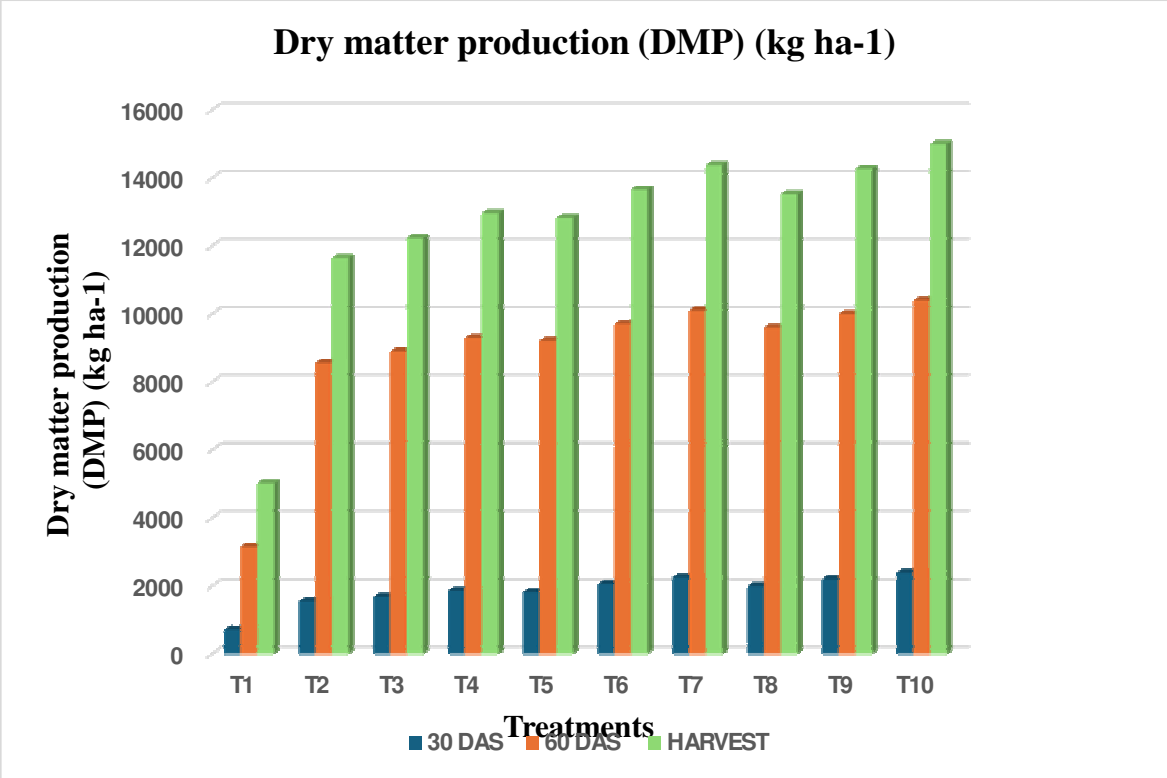

Fig. 1 : Impact of inorganic fertilizers and organic manure along with foliar spray of PGPR on dry matter production (DMP) (kg ha^{-1}) at different growth stages of sorghum

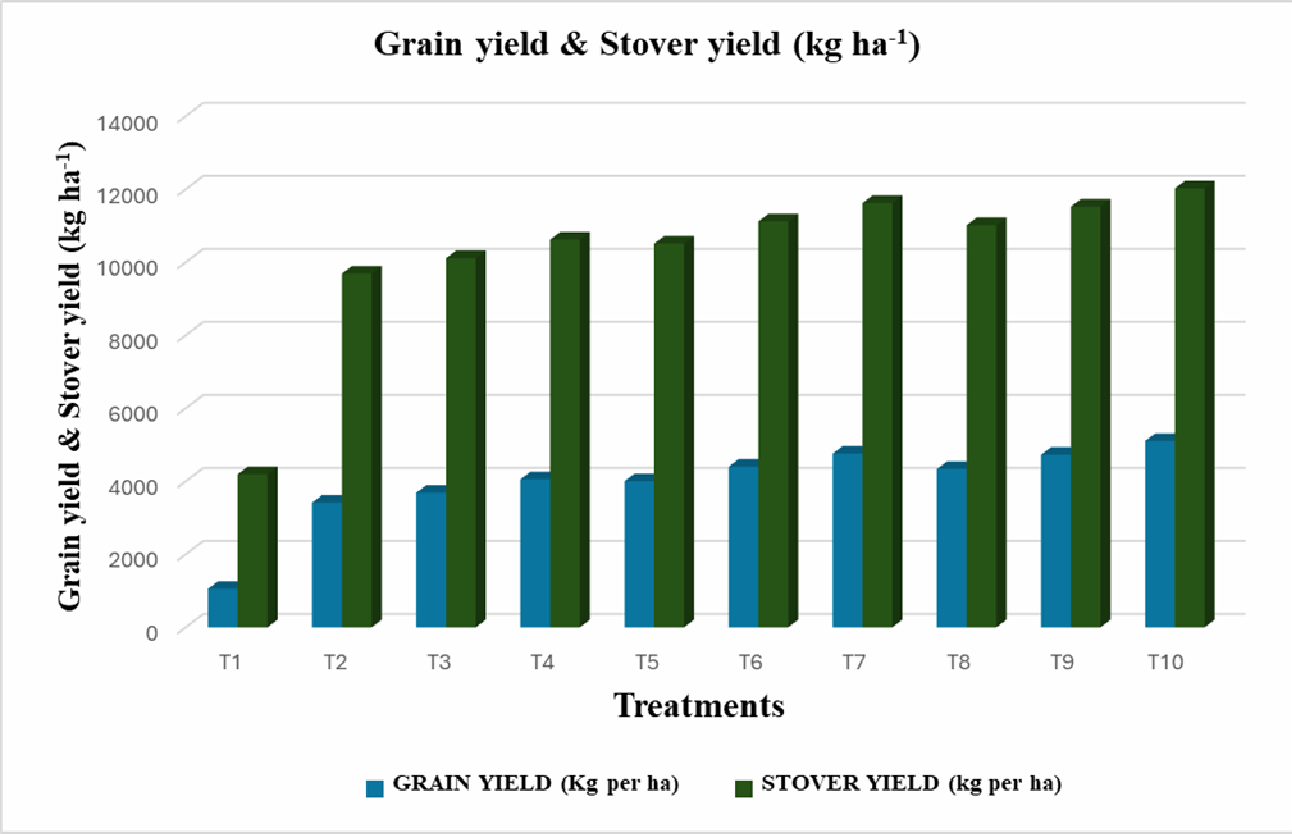

Fig. 2 : Impact of inorganic fertilizers and organic manure along with foliar spray of PGPR on Grain & Stover yield (kg ha^{-1}) of sorghum

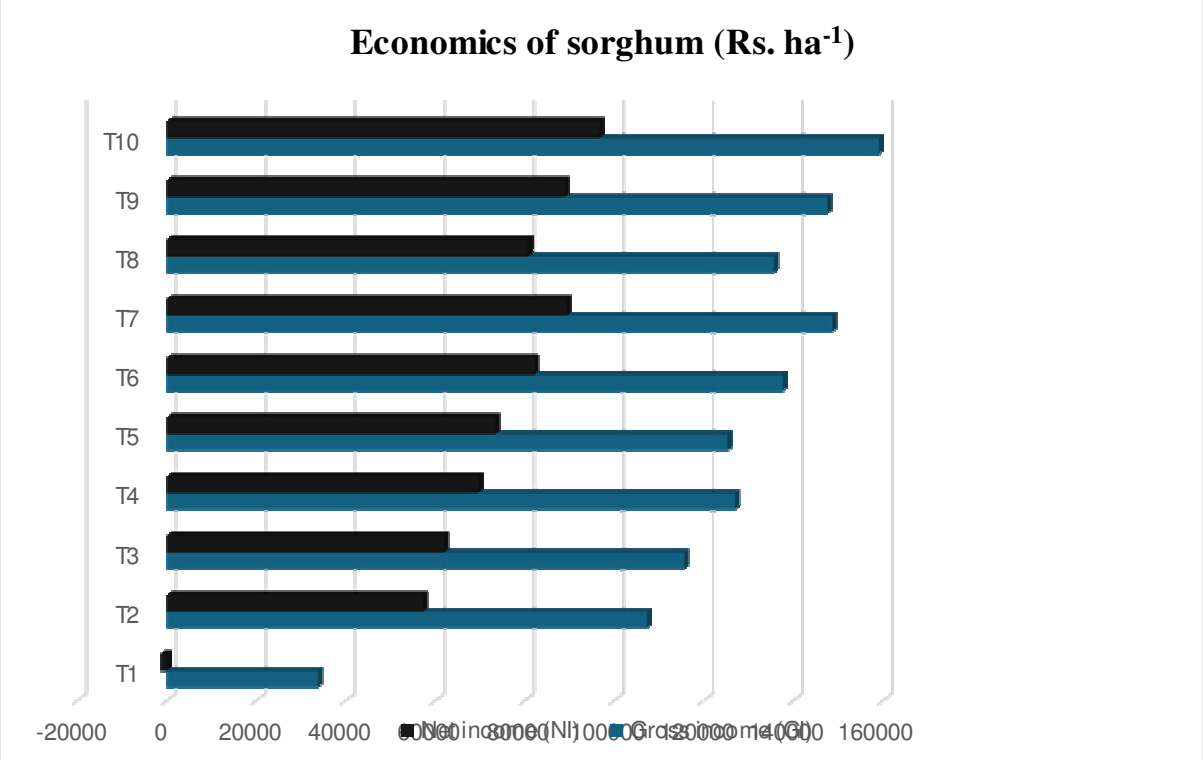

Fig. 3 : Impact of inorganic fertilizers and organic manure along with foliar spray of PGPR on economics (gross income and net income) (Rs. ha^{-1}) of sorghum

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