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Impact of Combining Microbial Enriched Organic Manures with Inorganic Nutrients on Physiological Characteristics and Productivity of Pearl Millet (*Pennisetum glaucum L.*)

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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

The present investigation was undertaken to validate the integrated use of inorganic fertilizers and biofertilizers inoculated in organic manures on the physiological attributes and of pearl millet in the School of Agricultural Science, Karunya Institute of Technology and Sciences, Coimbatore, India. The experiment was laid out in Randomized Block Design (RBD) with three replications, during the rabi season of 2023-24. Results outlined that the integrated nutrient management practice of

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applying Azospirillum & PSB enriched vermicompost @ 6 t ha^{-1} + 100% Recommended dose of N, P_2O_5 & K_2O has significantly increased the physiological attributes (leaf area index, crop growth rate, chlorophyll index), and yield (grain yield and stover yield) of pearl millet. This was statistically on par with the treatment Azospirillum & PSB enriched FYM @12.5 t ha^{-1} + 100% RDF dose of N, P_2O_5 & K_2O.

Keywords: Pearl millet; microbial enriched FYM; microbial enriched vermicompost; crop growth rate; leaf area index; chlorophyll index; integrated nutrient management.

1. INTRODUCTION

Pearl millet (*Pennisetum glaucum L.*) is a coarse cereal crop commonly cultivated in arid and semi-arid tropical countries of the world. It is the warm season and most broadly grown drought tolerant crop [1]. In India pearl millet is the 4th most important cereal crop grown next to, rice, wheat, and maize. According to Directorate of Economics and Statistics India contributes about 40.51% of global pearl millet production, cultivated in an area of 6.84 million ha, with a production of 9.78 million tonnes and a productivity of 1430 kg/ha [2]. Pearl millet stands out among other cereals due to its superior food value, characterized by high protein content, a well-balanced array of amino acids, and relatively elevated vitamin A levels [3]. They are gluten – free and have low glycaemic index making them ideal for people with diabetics. Despite being considered a poor man's crop, it can produce excellent outcomes in a short growing season with appropriate crop management procedures [3]. In India, pearl millet's average production falls short of its potential due to its poor management practices, fluctuating rainfall, and marginal land usage [4]. Enhancing pearl millet productivity requires implementing appropriate agronomic practices, given that we cannot alter the environmental conditions such as climate and marginal land usage. In most of the pearl millet cultivation regions, continuous use of inorganic fertilizers has deteriorated the soil health and nutrient availability, which has triggered poor productivity of the crop [5]. The unbalance use of fertilizers and non-application of organic manure and limited organic matter in soil often leads to nutritional deficiencies and yield reduction in pearl millet. Thus, focusing on integrated nutrient management (INM) strategy as a comprehensive approach to focuses on maintaining the soil fertility, ensuring optimal plant nutrient availability and achieving enhanced crop productivity is a viable option. By combining inorganic fertilizers, organic manures, and biofertilizers, we can ultimately enhance the crop productivity in an environmentally and economically sustainable manner. The combined application of mineral nutrients with organic amendments improves the soil organic carbon and microbial communities, which aids in soil nutrient cycles and increase the crop yield [6]. Application of organic manure such as farmyard manure (FYM) improves crop nitrogen usage efficiency, soil organic carbon, accessible nitrogen and phosphorus, in soil. Vermicompost an effective organic manure is known for reduced C:N ratio improves the soil humus content, and provides plants with nutrients like nitrogen, phosphorus, potassium, calcium, and magnesium. Biofertilizers like *Azospirillum brasilense* (Azospirillum) is known to fix significant amounts of nitrogen in the rhizosphere, which is effective in promoting root growth in cereal crops. increase mineral intake, encourages early root development, produce organic acids and yield. Using Azospirillum inoculants can save approximately 25-30% of chemical nitrogen fertilizer. This biofertilizer is, Phosphorus solubilizing bacteria (PSB) like *Bacillus var. megatherium* play a vital role in mobilizing the insoluble phosphatic compounds. Adding PSB as biofertilizer improves the phosphorus uptake and production of crops. Azospirillum, when used alone or in conjunction with PSB, enhances the crop yield [7]. Considering the aforementioned facts, this study aimed to explore the impact of combining chemical fertilizers with organic manures like vermicompost and farmyard manure, inoculated with bio inoculants such as *Azospirillum brasilense and Bacillus var. megatherium*, on the physiological properties and productivity of pearl millet crop.

2. MATERIALS AND METHODS

The field experiment was carried out in the instructional farm of the School of Agricultural Sciences, Karunya Institute of Technology and Science, Coimbatore. The farm is geographically located at 10° 56’ N latitude and 76° 44’ E longitude at an elevation of 474 m above the mean sea level. The soil was silty clay loam in texture, medium in available nitrogen (298.4 kg

ha^{-1}), available phosphorus (14.6 kg ha^{-1}) and potassium (162.2 kg ha^{-1}). The soil was slightly alkaline in reaction with a pH of 7.61 and high in organic carbon (0.46%). During the crop period, the total precipitation recorded was 326.6 mm. The average maximum temperature was 28.63 ^{o}C, associated with an average minimum temperature of 18.99 ^{o}C. The mean maximum relative humidity was 88.3 %, while the average minimum relative humidity was 65.5 %.

The experiment was laid out in a randomized block design with 9 treatments, which were replicated thrice. The treatments are: T_1 - 100% Recommended dose of N, P_2O_5 & K_2O; T_2 - FYM @12.5 t ha^{-1} + 100% Recommended dose of N, P_2O_5 & K_2O; + T_3 - Vermicompost @ 6 t ha^{-1} + 100% Recommended dose of N, P_2O_5 & K_2O; T_4 - Azospirillum & PSB enriched FYM @12.5 t ha^{-1} + 100% RDF dose of N, P_2O_5 & K_2O; T_5 - Azospirillum & PSB enriched vermicompost @ 6 t ha^{-1} + 100% Recommended dose of N, P_2O_5 & K_2O; T_6 - Azospirillum & PSB enriched FYM @12.5 t ha^{-1} + 75% Recommended dose of N, P_2O_5 & K_2O; T_7 - Azospirillum & PSB enriched vermicompost @ 6 t ha^{-1} + 75% Recommended dose of N, P_2O_5 & K_2O; ; T_8 - Azospirillum & PSB enriched FYM @12.5 t ha^{-1} + 50% Recommended dose of N, P_2O_5 & K_2O; T_9 - Azospirillum & PSB enriched vermicompost @ 6 t ha^{-1} + 50% Recommended dose of N, P_2O_5 & K_2O. Pearl millet variety CO 10 seeds, purchased from the Department of Millets, Tamil Nadu Agricultural University, was used for the study with a seed rate of 5 kg ha^{-1}. The seedlings were raised in a nursery bed and transplanted at 18 days after sowing in the main field, with a uniform spacing of 45 x 15 cm. The recommended dose of fertilizer adopted for pearl millet was 70 kg N, 35 kg P_2O_5, and 35 kg K_2O per hectare. According to the treatments, the recommended dose of fertilizers got varied as 100%, 75%, and 50% for different treatment plots. The entire quantity of phosphorous and potassium, and half of the nitrogen were provided as basal application. The remaining nitrogen was top dressed at 15 and 30 DAT. The *Bacillus var. megatherium* (PSB) and *Azospirillum brasilense* (Azospirillum) enriched organic manures of FYM and vermicompost were prepared inoculating the mentioned microbial inoculants at a ratio of 10 litres (5 litres of PSB + 5 litres of Rhizobium) per 50 kilograms of substrate.

The physiological growth attributes of Leaf area index (LAI), chlorophyll index and crop growth Rate were estimated for the study by adopting the following methodologies.

Leaf area index (LAI): It is the ratio of leaf area to ground area. It was worked out by using the formula suggested by Balakrishnan et al. [8]

$$LAI = \frac{Leaf\ area}{Ground\ area\ (m^2)}$$

Where,

Leaf area = L × B × N × K
L – Length of the leaf,
B – Breadth of the leaf,
N – Number of leaves,
K – Constant factor [0.75]

Chlorophyll index: The Soil Plant Analysis Development (SPAD) chlorophyll meter, was utilized for assessing the chlorophyll index of crops in the field, The measurement process was just by placing the sample leaf into the device's measuring area, and then closing the measuring head.

Crop growth rate (CGR): The crop growth rate is defined as the rate of increase in dry weight per unit area per unit of time. The CGR was computed using the formula suggested by Watson [9] and expressed in g m^2 day^{-1}.

$$CGR = \frac{W_2 - W_1}{p\ (t_2 - t_1)}$$

Where, W1 and W2 are the initial and final dry weights of plants, respectively at time t1 and t2. P is the ground area occupied by the plant in m^2.

The gathered data were statistically analysed using the procedures for randomized block design (RBD). Fisher's method of analysis of variance (ANOVA) was employed to statistically assess the experimental data, following the approach outlined by Gomez & Gomez [10] Critical Difference (CD) values were computed wherever the 'F' test yielded significance at the 5 per cent level.

3. RESULTS AND DISCUSSION

3.1 Physiological Growth Attributes

3.1.1 Leaf area index

The data pertaining to the mean leaf area index of pearl millet recorded at 15 DAT, 45 DAT and

harvest stages are shown in Table 1 and Fig. 1. Among the treatments there were no significant differences in leaf area index at 15 DAT. The treatment T5 – Azospirillum & PSB enriched vermicompost @ 6 t ha^{-1} + 100% Recommended dose of N, P_2O_5 & K_2O recorded a higher leaf area index of 3.49 and 1.63 at 45 DAT, and harvest stage respectively. This was statistically on par with the treatment T4 - Azospirillum & PSB enriched FYM @12.5 t ha^{-1} + 100% RDF dose of N, P_2O_5 & K_2O. The treatment T1 - 100% Recommended dose of N, P_2O_5 & K_2O recorded a lower leaf area index of 1.12, 2.23 and 1.04 at 15 DAT, 45 DAT and harvest stages respectively. The application of microbial enriched organic manures of vermicompost and FYM along with the inorganic chemical fertilizers, might have led to an improved soil nutrition status, leading to better nutrient uptake by the crop, this would have eventually led to the development of better shoot and leaf development. The increased nitrogen availability through N fixation by Azospirillum in the rhizosphere region, and higher solubilization of native and applied phosphorus by the phosphorus solubilizing bacteria might have influenced the formation of new tissues and sturdy shoots, leading to an increase in leaf area. These findings are in conformity with the results of the experiments conducted by Divya and Vani [11] and Kumar et al. [12].

3.1.2 Chlorophyll index

The data pertaining to the mean chlorophyll index of pearl millet recorded at 15 DAT (vegetative stage) and 45 DAT (flower initiation stage) are shown in Table 1 and Fig. 2. The treatment T5 – Azospirillum & PSB enriched vermicompost @ 6 t ha^{-1} + 100% Recommended dose of N, P_2O_5 & K_2O registered on increased chlorophyll index values of 56.37 at 15 DAT and 56.86 at 45 DAT over rest of the treatments, but it was statistically on par with the treatment T4 - Azospirillum & PSB enriched FYM @12.5 t ha^{-1} + 100% RDF dose of N, P_2O_5 & K_2O. The treatment T1 - 100% Recommended dose of N, P_2O_5 & K_2O recorded a lower chlorophyll index with values of 38.14, 41.15 at 15 DAT and 45 DAT respectively. This could be due to the efficient nutrient supplied to the crop through the combined application of inorganic fertilizers with the microbial enriched organic manures of vermicompost and FYM. This might have resulted in enhanced plant growth and development leading to increased biomass accumulation. This would have been ably supported by the efficient N fixation by Azospirillum resulting in higher chlorophyll content. These findings are in accordance with the findings of Bhargavi et al. [7] and Chandrasekhar et al. [1].

Table 1. Impact of combining microbial-enriched organic manures with inorganic nutrients on physiological growth attributes and yield of pearl millet

Treatments	Leaf Area Index			Chlorophyll index		Crop Growth Rate (g m^2 day^{-1})		Yield (q ha^{-1})	
	15 DAT	45 DAT	harvest	15 DAT	45 DAT	15-45 DAT	45 DAT-harvest	Grain	Stover
T1	1.12	2.23	1.04	38.14	41.15	0.76	3.75	25.02	51.30
T2	1.14	2.26	1.07	38.47	41.22	0.79	3.77	25.12	51.49
T3	1.15	2.29	1.09	38.78	41.25	0.80	3.82	25.19	51.64
T4	1.85	3.39	1.60	54.18	56.75	2.47	5.59	35.21	73.79
T5	1.86	3.49	1.63	56.37	56.86	2.49	5.61	35.22	73.86
T6	1.34	2.62	1.26	43.27	46.51	1.34	4.51	29.96	63.21
T7	1.36	2.63	1.27	43.59	46.54	1.37	4.51	30.26	63.45
T8	1.31	2.59	1.22	43.17	46.24	1.08	4.40	29.89	62.26
T9	1.33	2.60	1.25	43.20	46.37	1.27	4.46	29.94	62.30
Mean	1.39	2.68	1.27	44.35	46.99	1.38	4.49	29.53	61.48
SE(d)	0.07	0.10	0.05	2.06	2.06	0.13	0.27	2.19	4.66
CD (p=0.05)	0.15	0.22	0.11	4.37	4.37	0.27	0.58	4.64	9.89

T_1 - 100% Recommended dose of N, P_2O_5 & K_2O; T_2 - FYM @12.5 t ha^{-1} + 100% Recommended dose of N, P_2O_5 & K_2O; + T_3 - Vermicompost @ 6 t ha^{-1} + 100% Recommended dose of N, P_2O_5 & K_2O; T_4 - Azospirillum & PSB enriched FYM @12.5 t ha^{-1} + 100% RDF dose of N, P_2O_5 & K_2O; T_5 - Azospirillum & PSB enriched vermicompost @ 6 t ha^{-1} + 100% Recommended dose of N, P_2O_5 & K_2O; T_6 - Azospirillum & PSB enriched FYM @12.5 t ha^{-1} + 75% Recommended dose of N, P_2O_5 & K_2O; T_7 - Azospirillum & PSB enriched vermicompost @ 6 t ha^{-1} + 75% Recommended dose of N, P_2O_5 & K_2O; ; T_8 - Azospirillum & PSB enriched FYM @12.5 t ha^{-1} + 50% Recommended dose of N, P_2O_5 & K_2O; T_9 - Azospirillum & PSB enriched vermicompost @ 6 t ha^{-1} + 50% Recommended dose of N, P_2O_5 & K_2O.

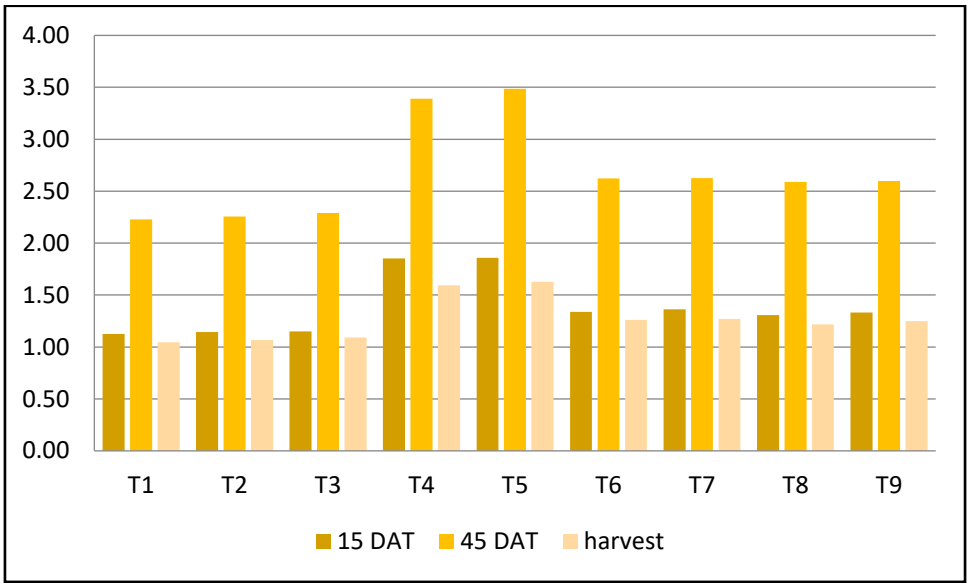

Fig. 1. Impact of combining microbial-enriched organic manures with inorganic nutrients on leaf area index

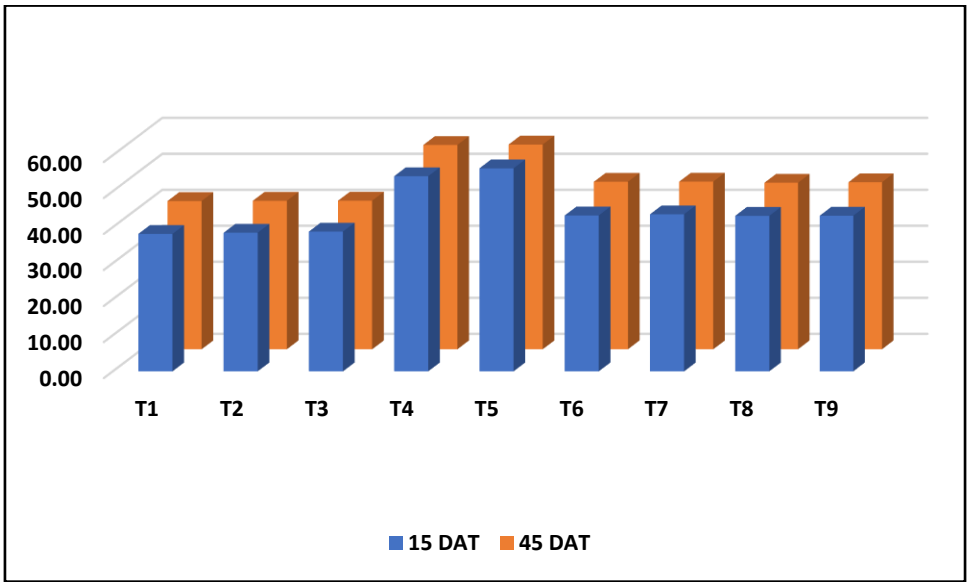

Fig. 2. Impact of combining microbial-enriched organic manures with inorganic nutrients on chlorophyll index

3.1.3 Crop growth rate (CGR)

The data pertaining to the mean CGR of pearl millet recorded at 15 to 45 DAT and 45 to harvest stages of the crop growth are presented in Table 1 and Fig. 3. Among all the treatments, the treatment T5 – Azospirillum & PSB enriched vermicompost @ 6 t ha^{-1} + 100% Recommended dose of N, P_2O_5 & K_2O recorded a maximum CGR values of 2.49 g/m^2/day at 15 to 45 DAT and 5.61 g/m^2/day at 45 to harvest stage over rest of the treatment, but it was on statistically par with the treatment, T4 - Azospirillum & PSB enriched FYM @12.5 t ha^{-1} + 100% RDF dose of N, P_2O_5 & K_2O. The treatment T1 - 100% Recommended dose of N, P_2O_5 & K_2O recorded a lower CGR of 0.76 g/m^2/day, 3.75 g/m^2/day at 15 to 45 DAT and 45 to harvest stages respectively. This could be due to application of integrated sources of nutrients in the form of microbial enriched organic manures with inorganic fertilizers along with inorganic sources of nutrients. This mode of nutrient management could have delivered adequate nutrients in

required time, thereby increased a greater number of functioning leaves and photosynthesizing area, which might have resulted in improved plant growth and development, with a significant effect on crop growth rate. Similar findings were also reported by the authors Rakesh et al. [13] and Rana et al. [14].

3.2 Yield

The data pertaining on the grain yield and stover yield, of pearl millet under different treatments are presented in Table 1 and Fig. 4. Among the treatments, the treatment T5 – Azospirillum & PSB enriched vermicompost @ 6 t ha^{-1} + 100% Recommended dose of N, P_2O_5 & K_2O produced a higher grain yield of 35.22 q ha^{-1} and higher stover yield of 76.60 q ha^{-1} over rest of the treatment, but it was statistically on par with the treatment T4 - Azospirillum & PSB enriched FYM @12.5 t ha^{-1} + 100% RDF dose of N, P_2O_5 & K_2O. The treatment T_1 - 100% Recommended dose of N, P_2O_5 & K_2O recorded a lower grain yield, lesser stover yield of 25.02 q ha^{-1}, 51.02 q ha^{-1}. The reason for the increase in grain and stover yield might be due to the synergistic effect of incorporation of inorganic and organic sources

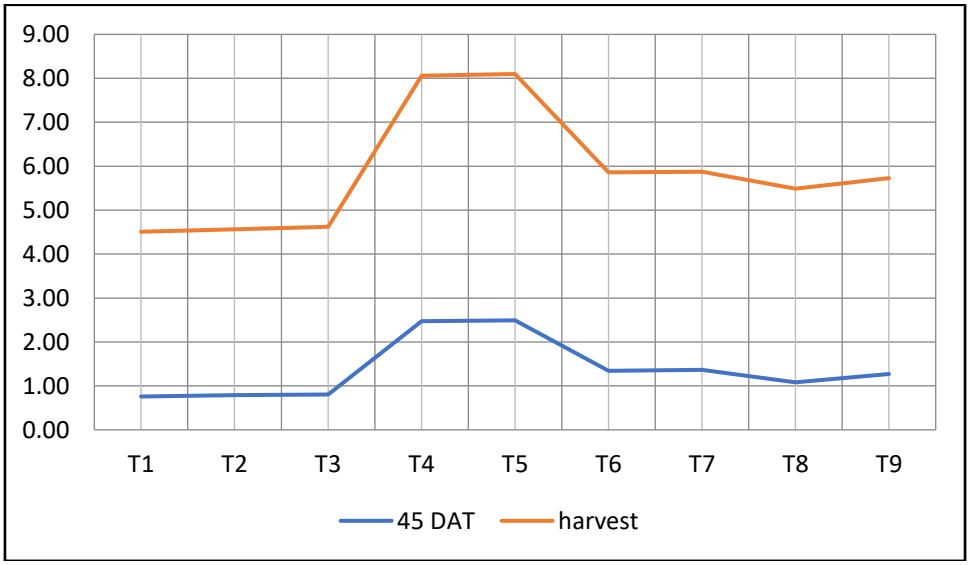

Fig. 3. Impact of combining microbial-enriched organic manures with inorganic nutrients on crop growth rate

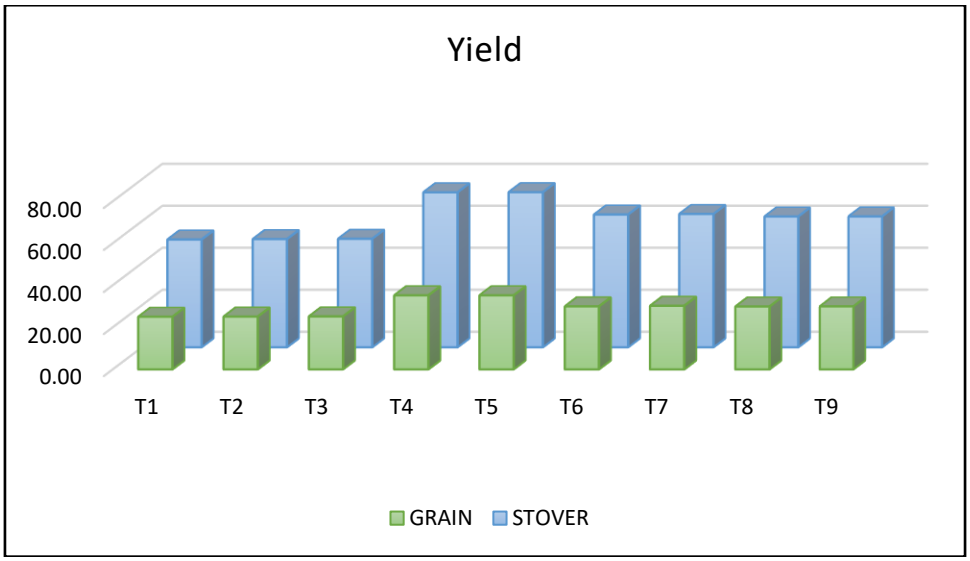

Fig. 4. Impact of combining microbial-enriched organic manures with inorganic nutrients on yield of pearl millet

of nutrients which might have improved the nutrient uptake, accelerated the photosynthetic rate, and increased the biomass production eventually resulting in higher grain yield and stover yield. Additionally, application of biofertilizers (*Bacillus var. megatherium* and *Azospirillum brasilense*) inoculated in organic manure (vermicompost and FYM) would have also enhanced an effective nitrogen fixation and phosphorous mobilization in soil, resulting in increased uptake of nutrients and favouring increased grain yield and stover yield. These results are in accordance with the findings of Samruthi et al*.* [15] and Majeed et al*.* [16].

4. CONCLUSION

Based on the obtained results and discussions made, it can be inferred that among the various nutrient management practices tested, integrating inorganic fertilizers with microbial enriched organic manures of vermicompost or Farmyard Manure (FYM) tends to supply balanced nutrients to plants. This integration enhances the nutrient uptake by promoting soil microflora, resulting in an improved physiological growth of crop and increased crop yield. Moreover, the use of enriched organic manures not only fosters crop growth but also sustains the soil health in a sustainable manner.

For future research, evaluating the adaptability of microbial-enriched organic manures (vermicompost or FYM) combined with inorganic fertilizers across diverse agro-climatic conditions and cropping systems is essential. Such studies aim to establish economically viable and environmentally friendly approaches of integrated nutrient management practices for sustainable agriculture.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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