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Enhancing Bajra (Pennisetum Glaucum L.) Growth And Yield With Combined Organic And Inorganic Fertilizers

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Abstract
A field experiment entitled "Enhancing bajra (Pennisetum glaucum L.) growth and yield with combined organic and inorganic fertilizers" was conducted during rabi season of 2024 at Research Farm, Guru Kashi University, Talwandi Sabo, Bathinda (Punjab). The experiment was conducted in Randomized Complete Block Design (RCBD) with one control and 7 treatments with three replications. The treatments consisted of T_1: Control (No fertilizer), T_2: 75% of Recommended dose of nitrogen (RDN), T_3: 75% RDN + Farmyard manure (FYM) @ 5 t/ha, T_4: 75% RDN + FYM @ 5 t/ha + $ZnSO_4$@ 16 kg ha^{-1}, T_5: 75% RDN + Vermicompost @ 2 t/ha, T_6: 75% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}, T_7: 100% RDN, T_8: 100% RDN + FYM @ 5 t/ha, T_9: 100% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}, T_{10}: 100% RDN + Vermicompost @ 2 t/ha, T_{11}: 75% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$@ 16 kg ha^{-1}. Results revealed that significant improvements in plant height, dry matter accumulation, number of tillers, ear length, and yield components under integrated nutrient treatments. The combination of 100% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg/ha (T_9) and 100% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg/ha (T_{11}) recorded the highest grain yield, stover yield and nitrogen content in both grain and stover. These treatments also provided the highest gross returns (₹83,596 and ₹78,330/ha, respectively), net returns (₹51,272 and ₹44,940/ha), and benefit-cost ratios (1.58 and 1.34, respectively). The findings underscore the synergistic effect of combining inorganic fertilizers with organic manures and zinc in enhancing crop productivity, profitability, and soil nutrient uptake. Integrated nutrient management practices, particularly the inclusion of vermicompost and $ZnSO_4$, hold promise for sustainable bajra cultivation under semi-arid conditions.
Key words: *Bajra, Benefit-cost ratios, Grain yield, Organic and Inorganic.*

INTRODUCTION

Bajra (Pennisetum glaucum L.), commonly known as pearl millet, is one of the most important cereal crops cultivated in arid and semi-arid regions of India and Africa. It is highly resilient to drought, heat, and poor soil fertility, making it an ideal crop for resource-poor farmers and rainfed agro-ecosystems. In India, bajra occupies a prominent position among millet crops due to its adaptability, low input requirement, and nutritional richness, especially in iron, fiber, and essential amino acids (Yadav et al., 2012). It occupies approximately 6.70 million hectares, with an annual production of 9.62 million tonnes and an average productivity of 1436 kg/ha (Anonymous, 2025). Among the major pearl millet-growing states, Rajasthan ranks first in both area (3.74 million ha) and production (3.75 million tonnes), although the productivity remains relatively low at 1004 kg/ha. The crop is predominantly grown in the arid (62% of total area) and semi-arid (12.60%) zones of Rajasthan, especially in districts such as Barmer, Nagaur, Jodhpur, Jalore, Churu, Jaipur, Alwar, Sikar, and Jhunjhunu.

Pearl millet exhibits superior adaptability to harsh agro-climatic conditions, outperforming other cereals due to its higher photosynthetic efficiency, rapid dry matter accumulation, and tolerance to drought and high temperatures. Nutritionally, it is superior to many other grains, being rich in minerals, thiamine, riboflavin, and easily digestible nutrients (Pal et al., 1996). It contains approximately 9–13% protein, 5–7% fat, 1.2 g/100 g dietary fibre, and is a good source of carbohydrates, energy, and natural antioxidants such as coumaric acid (Kumari et al., 2018). Moreover, pearl millet is a gluten-free grain and uniquely retains its alkaline properties even after cooking, making it especially suitable for individuals with gluten intolerance or grain allergies (Chauhan et al., 2015). Despite its high nutritional value, the bioavailability of nutrients is often constrained due to the presence of anti-nutritional compounds such as phytic acid and polyphenols (Kumari et al., 2018).

Despite its adaptability, the productivity of bajra remains low in many areas due to poor soil fertility, limited use of fertilizers, and imbalanced nutrient management. Traditionally, farmers rely on either organic or inorganic nutrient sources, but their sole application often fails to meet the complete nutritional demands of the crop (Ghosh et al., 2010). Therefore, integrated nutrient management (INM), involving the combined use of organic and inorganic sources, has emerged as a sustainable approach to enhance crop yield, improve soil health, and maintain long-term productivity (Pathak et al., 2011). Organic sources such as farmyard manure (FYM), compost, and vermicompost improve soil structure, enhance microbial activity, and increase nutrient availability, but they release nutrients slowly and may not fully meet the crop's peak demands (Sharma and Mittra, 1991). On the other hand, inorganic fertilizers provide quick nutrient supply, but their excessive and sole use may lead to soil degradation and decline in soil biological activity (Subba Rao, 1999). Hence, a judicious combination of organic and inorganic sources is necessary to maximize nutrient use efficiency and sustain soil fertility (Choudhary et al., 2014). In this context, the present study was undertaken to evaluate the effect of organic and inorganic nutrient sources, alone and in combination, on the growth, yield, and nutrient uptake of bajra under field conditions. The findings aim to contribute to developing an economically viable and environmentally sustainable nutrient management strategy for improving bajra productivity.

MATERIAL AND METHODS

The present investigation entitled "Enhancing bajra (Pennisetum glaucum L.) growth and yield with combined organic and inorganic fertilizers" was carried out at Research Farm of Guru Kashi University, Talwandi Sabo (Bathinda) during kharif season of 2024. Talwandi sabo (Bathinda) is situated at 29°33' N latitude and 74°38' E longitude at a height of 208 metres above the mean sea level. The soil of the experimental field was loamy sand in texture which has pH 7.10 with low electrical conductivity (0.21 dSm^{-1}). The soil was low in organic carbon content (0.30%). The available nitrogen (114.3 kg ha^{-1}) and available phosphorus (8.17 kg ha^{-1}) were low, whereas the and available potassium (102.6 kg ha^{-1}) was medium. The experiment includes eleven treatments viz., T_1: Control (No fertilizer), T_2: 75% of Recommended dose of nitrogen (RDN), T_3: 75% RDN + Farmyard manure (FYM) @ 5 t/ha, T_4: 75% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}, T_5: 75% RDN + Vermicompost @ 2 t/ha, T_6: 75% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}, T_7: 100% RDN, T_8: 100% RDN + FYM @ 5 t/ha, T_9: 100% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}, T_{10}: 100% RDN + Vermicompost @ 2 t/ha, T_{11}: 75% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}, replicated thrice. The bajra variety 'PCB 165' was sown at 2.5 cm depth with a seed drill at row spacing of 50 cm on June 15, 2024. Seed rates of 3.7 kg ha^{-1} for bajra was used. Urea, FYM, vermicomposting and $ZnSO_4$ were applied, as per treatment. P, K nutrients were applied through DAP (18% N, 46% P_2O_5) and MOP (60% K_2O) fertilizers uniform in all plots as basal application. The harvesting of bajra was done manually from the net plot area. The harvested crop was tied in well labeled bundles and kept for sun drying. Then the threshing was carried out. Five plants per plot were selected randomly to measure the height from ground level to the tip of longest leaf at 20 days after sowing (DAS), up to the base of top most fully opened leaf at 60 DAS and up to the base of the ear at harvest. Total number of tillers per m row length was recorded at 30 DAS and at harvest from two sites in each plot. The plants collected for leaf area measurement at various growth stages (20, 40, 60 DAS and at harvest) were preserved for dry matter accumulation, and data were recorded after drying them first in the sun and subsequently in an oven at 60-70°C until a constant weight was achieved. The tagged plants were used for recording the number of ear heads $plant^{-1}$.One thousand grains from produce of each plot were taken and their weight was recorded. The thousand grain weight was expressed in grams. The total produce was weighed in bundles after harvesting and threshed thereafter. The weight of grains was recorded. The stover weight was obtained after deducting the weight of grains from total bundle weight. Grain and stover yield were computed and expressed as q ha^{-1}. HI was calculated by dividing economic (grain) yield by the total biological (grain + straw) yield and expressed as percentage.

$$\text{HI (\%)} = \frac{\text{Economic yield}}{\text{Biological yield (Grain + Straw)}} \times 100$$

Analysis of variance was performed using Proc GLM procedure of SAS version 9.4 (SAS. 2017) and significant mean differences were tested using Fisher's protected least significant difference (LSD) test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Effect on growth

Plant height is a crucial indicator of vegetative growth and reflects the cumulative effects of genetics, nutrients, and environmental factors. In the present study, significant variation in plant height of bajra was observed among the treatments at all growth stages (20 DAS, 40 DAS, 60 DAS, and at harvest) due to differential application of organic and inorganic fertilizers (Table 1). The integrated application of 100% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg/ha (T_{11}) was the most effective combination for maximizing plant height at all stages. Organic fertilizers (both FYM and vermicompost) improved performance over inorganic fertilization alone, with vermicompost outperforming FYM likely due to better nutrient balance and faster nutrient availability. Zinc application enhanced growth at all stages, reinforcing its role as a critical micronutrient in bajra production. The increase in plant height is attributed to the availability of nutrients which lead to more cell division and helped in increasing plant height Rathore (2006) and Neelam (2009).

Application of 75% RDN with vermicompost (T_5: 4.85 g) and 100% RDN with vermicompost (T_{10}: 5.10 g) significantly enhanced early biomass (Table 2). Early application of vermicompost and zinc plays a vital role in promoting early plant growth, possibly due to improved soil microbial activity and better nutrient solubilisation at 30 DAS. While all fertilizer treatments improved DMA, zinc fertilization had a noticeable edge during mid-vegetative growth. Enhanced DMA at 60 DAS can be attributed to optimal nutrient availability and efficient translocation, supported by favorable rhizosphere conditions under integrated nutrient treatments. The highest DMA at harvest with T11 suggests that vermicompost, in conjunction with full NPK and Zn, not only promotes early growth but also sustains biomass accumulation till maturity. Treatments with vermicompost consistently outperformed FYM, which can be attributed to better CN ratio, microbial activity, and faster nutrient release from vermicompost.

The results indicate significant differences in tiller number across treatments, both at early growth (30 DAS) and maturity (Table 3). Treatments receiving 100% RDN combined with either FYM or vermicompost along with $ZnSO_4$ had superior tiller count, indicating better tiller initiation under integrated nutrient management. Application of vermicompost and zinc at early stages appears to promote tiller initiation by improving soil aeration, nutrient uptake, and hormonal activity. T_9 (4.18 tillers/plant) again showed the highest tiller retention, followed by T_5 (4.14), T_7 (4.08), and T_{11} (4.05). The lowest tiller number at harvest was recorded in T_1 (3.15), highlighting the importance of fertilizer application for maintaining productive tillers.

Effect on yield and yield attributes

T_9 (2.78) produced the highest number of ears, followed by T_{11} (2.52) and T_6 (2.65) (Table 4). Application of 100% RDN + FYM/Vermicompost + $ZnSO_4$ significantly improved the number of reproductive tillers, contributing to higher ear count. The combination of major nutrients, organic manures, and Zn enhances ear initiation, suggesting strong root-to-shoot signaling and nutrient translocation effects. Maximum ear length was observed in T_{11}, followed closely by T_9 and T_{10}, indicating better spike development under combined nutrient regimes. Organic manures and Zn enhanced panicle elongation, possibly due to their influence on cell division and carbohydrate translocation. T_9 and T_{11} recorded the highest 1000-grain weights (10.6 g), indicating improved grain filling and nutrient partitioning. Treatments with $ZnSO_4$ consistently recorded higher grain weights, showing the role of zinc in protein synthesis and seed development. The lowest test weight (8.4 g) was found in T8, despite receiving 100% RDN + FYM.

Grain yield significantly varied among treatments. T_9 and T_{11} recorded the highest grain yield (30.8 q/ha) (Table 4). Treatments receiving 75% RDN along with organics and $ZnSO_4$ (T_4, T_6) also performed competitively, showing that partial substitution of inorganic N with organics can sustain yield. Control (T_1) recorded the lowest yield (19.8 q/ha), underscoring the need for balanced nutrient application. Stover yield followed a trend similar to grain yield. T_9 (69.1 q/ha) and T_{11} (68.9 q/ha) produced the highest biomass, which indicates better vegetative growth and photosynthetic efficiency. This is supported by previous observations on plant height and dry matter accumulation. Control plots had the lowest stover yield (48.0 q/ha), reflecting poor overall growth. Interestingly, T_8 (100% RDN + FYM) recorded the highest HI, despite moderate yield. This may be due to relatively less stover yield. Treatments T_9, T_{10}, and T_{11}, with HI values of 30–32%, indicate better partitioning of assimilates toward grain. The results corroborated the findings of Dhar et al (2010).

Effect on nitrogen content

Nitrogen is a major nutrient essential for protein synthesis, vegetative growth, and ultimately grain filling. A notable improvement in N content in grain and stover was observed with integrated nutrient treatments (Table 5). Highest grain N content (1.54%) was observed in T_{11}, followed closely by T_9 and T_6 (1.53%). In stover, T_{11} (0.64%) and T_9 (0.63%) also recorded the highest N concentration. The control (T_1) recorded the lowest N content, indicating poor nutrient availability and uptake. Treatments with zinc ($ZnSO_4$) enhanced N uptake and assimilation, likely due to improved enzyme activity and chlorophyll synthesis.

Effect on economics

Cost varied slightly due to input differences, ranging from Rs 32,250 (T8) to Rs 33,880 (T_2, T_6). Treatments involving FYM or vermicompost had higher costs but delivered proportionally higher returns. T_9 (100% RDN + FYM + $ZnSO_4$) gave the highest gross return (Rs 83,596/ha) and net return (Rs 51,272/ha), followed by T_{11} and T_6. Treatments T4, T6, T7, T11 also achieved net returns above Rs 44,000/ha. The control (T1) had the lowest net return (Rs 21,645/ha), highlighting the importance of nutrient supplementation. Highest BC ratio was observed in T_9 (1.58), indicating superior profitability. Other efficient treatments included T_4 and T_7 (1.36) and T_{11} (1.34). Despite higher costs, treatments with organic amendments and Zn ensured better economic viability through yield and quality enhancement. FYM-based treatments with Zn were more cost-effective than those without Zn, while vermicompost generally showed better benefit-cost performance than FYM.

CONCLUSIONS

It may concluded that the application of 100% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg/ha (T_9) and 100% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg/ha (T_{11}) proved most effective in improving plant height, dry matter accumulation, tiller number, ear length, and grain filling. These treatments also resulted in the highest nitrogen content in grain and stover, indicating improved nutrient uptake and utilization. Economically, both T_9 and T_{11} outperformed the other treatments, with maximum net returns and benefit-cost ratios, demonstrating their viability for adoption by farmers. The inclusion of zinc sulphate played a crucial role in enhancing both productivity and profitability, while vermicompost provided faster nutrient availability compared to FYM.

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Table 1: Effect of organic and inorganic fertilizers on periodic plant height of bajra

Treatment	Plant height (cm)			
	20 DAS	40 DAS	60 DAS	At harvest
T_1: Control (No fertilizer)	28.3	155.0	198.2	230.0
T_2: 75% of RDN	29.2	158.5	202.8	245.0
T_3: 75% RDN + FYM @ 5 t/ha	31.4	160.6	203.8	242.0
T_4: 75% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	31.5	164.8	229.6	248.5
T_5: 75% RDN + Vermicompost @ 2 t/ha	31.4	178.7	226.0	249.0
T_6: 75% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	31.4	179.0	228.4	250.0
T_7: 100% RDN	32.0	180.7	230.1	250.3
T_8: 100% RDN + FYM @ 5 t/ha	32.2	182.3	229.4	251.4
T_9: 100% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	34.8	185.4	231.5	252.0
T_{10}: 100% RDN + Vermicompost @ 2 t/ha	34.2	182.8	232.0	253.0
T_{11}: 100% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	34.7	183.5	234.0	255.6
SEm ±	0.9	0.3	0.6	0.3
CD (P=0.05)	0.5	0.9	2.0	5.6
CV (%)	7.1	5.3	5.8	6.7

Table 2: Effect of organic and inorganic fertilizers on periodic dry matter accumulation of bajra

Treatment	Dry matter accumulation (g $plant^{-1}$)			
	20 DAS	40 DAS	60 DAS	At harvest
T_1: Control (No fertilizer)	3.04	23.8	120.3	147.4
T_2: 75% of RDN	3.38	27.2	124.9	168.6
T_3: 75% RDN + FYM @ 5 t/ha	3.46	27.4	125.3	182.9
T_4: 75% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	4.74	27.7	125.8	188.7
T_5: 75% RDN + Vermicompost @ 2 t/ha	4.85	27.2	126.3	189.3
T_6: 75% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	5.18	28.4	127.2	190.8
T_7: 100% RDN	4.87	27.7	126.2	183.5
T_8: 100% RDN + FYM @ 5 t/ha	4.91	24.4	122.7	182.7
T_9: 100% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	5.30	28.6	127.7	209.0
T_{10}: 100% RDN + Vermicompost @ 2 t/ha	5.10	27.8	126.8	189.3
T_{11}: 100% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	5.27	28.8	126.9	210.1
SEm ±	1.96	0.7	1.0	1.7
CD (P=0.05)	0.16	0.4	2.2	5.4
CV (%)	7.34	8.3	6.5	12.2

Table 3: Effect of organic and inorganic fertilizers on number of tillers/plant in bajra

Treatment	Number of tillers/plant	
	30 DAS	At harvest
T_1: Control (No fertilizer)	3.93	3.15

T_2: 75% of RDN	4.78	3.74
T_3: 75% RDN + FYM @ 5 t/ha	4.86	3.67
T_4: 75% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	5.08	3.81
T_5: 75% RDN + Vermicompost @ 2 t/ha	5.04	4.14
T_6: 75% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	5.19	3.81
T_7: 100% RDN	5.14	4.08
T_8: 100% RDN + FYM @ 5 t/ha	4.64	3.58
T_9: 100% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	5.34	4.18
T_{10}: 100% RDN + Vermicompost @ 2 t/ha	5.17	3.89
T_{11}: 100% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	5.29	4.05
SEm ±	0.35	0.56
CD (P=0.05)	0.39	0.16
CV (%)	4.55	2.24

Table 4: Effect of organic and inorganic fertilizers on yield attributes and yield in bajra

Treatment	Number of ears/plant	Ear length (cm)	1000-grain weight (g)	Grain yield (q/ha)	Stover yield (q/ha)	Harvest index (HI)
T_1: Control (No fertilizer)	1.66	21.4	9.1	19.8	48.0	29.2
T_2: 75% of RDN	2.04	26.0	9.4	21.2	50.2	29.6
T_3: 75% RDN + FYM @ 5 t/ha	2.20	28.1	9.7	24.8	62.6	28.4
T_4: 75% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	2.45	29.6	10.1	28.7	64.3	30.8
T_5: 75% RDN + Vermicompost @ 2 t/ha	2.37	29.9	9.9	25.5	63.4	29.0
T_6: 75% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	2.65	30.1	10.2	28.8	64.8	30.8
T_7: 100% RDN	2.30	31.2	10.3	26.3	61.7	28.2
T_8: 100% RDN + FYM @ 5 t/ha	2.25	31.4	8.4	27.9	59.9	35.2
T_9: 100% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	2.78	31.3	10.6	30.8	69.1	30.8
T_{10}: 100% RDN + Vermicompost @ 2 t/ha	2.44	31.3	10.3	28.7	63.4	32.2
T_{11}: 100% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	2.52	32.4	10.6	30.8	68.9	31.1
SEm ±	0.67	0.6	0.7	2.2	0.9	0.6
CD (P=0.05)	0.16	1.2	0.2	2.1	5.5	1.3
CV (%)	3.88	6.8	8.5	7.5	5.3	0.7

Table 5: Effect of organic and inorganic fertilizers on nitrogen content and economics of bajra

Treatment	N Content (%)		Economics			
	Grain	Stover	Cost of cultivation (INR ha^{-1})	Gross return (INR ha^{-1})	Net return (INR ha^{-1})	Benefit cost ratio
T_1: Control (No fertilizer)	1.33	0.52	32520	54165	21645	0.66
T_2: 75% of RDN	1.35	0.55	33880	57661	23781	0.70
T_3: 75% RDN + FYM @ 5 t/ha	1.34	0.53	33390	68077	34687	1.03
T_4: 75% RDN + FYM @ 5 t/ha + $ZnSO_4$@ 16 kg ha^{-1}	1.40	0.60	32885	77824	44939	1.36
T_5: 75% RDN + Vermicompost @ 2 t/ha	1.31	0.56	32885	69870	36985	1.12
T_6: 75% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	1.53	0.63	33880	78107	44227	1.30
T_7: 100% RDN	1.36	0.54	32324	76520	44196	1.36
T_8: 100% RDN + FYM @ 5 t/ha	1.41	0.61	32250	65370	33120	1.02
T_9: 100% RDN + FYM @ 5 t/ha + $ZnSO_4$ @ 16 kg ha^{-1}	1.53	0.63	32324	83596	51272	1.58
T_{10}: 100% RDN + Vermicompost @ 2 t/ha	1.42	0.55	32500	69869	37369	1.14
T_{11}: 100% RDN + Vermicompost @ 2 t/ha + $ZnSO_4$@ 16 kg ha^{-1}	1.54	0.64	33390	78330	44940	1.34
SEm ±	0.45	0.57	-	-	-	-
CD (P=0.05)	6.45	7.43	-	-	-	-
CV (%)	0.05	0.04	-	-	-	-