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Research article

Production potential of dual-purpose pearl millet (*Pennisetum glaucum*) as an alternate crop under changing climatic conditions

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Abstract

A field experiment was conducted at Jammu, India, to evaluate the production potential of pearl millet (*Pennisetum glaucum*) as an alternate crop under changing climatic conditions. The experiment was laid out in a factorial randomized block design with three cultivars and five fertility levels, with three replications. Pearl millet cultivar MBC-2 recorded significantly higher growth, yield attributes, yield, net returns (41258.27 Rs ha^{-1}) and B:C ratio (1.52) compared to Pusa Composite-383 and the local variety. Whereas, among the fertility levels, F5-80:50:25 kg ha^{-1} of $N:P_2O_5:K_2O$ + 25 kg N through Farm Yard Manure (FYM) produced significantly higher growth and yield attributes, though it remained statistically at par with F_4 (65:40:20 kg ha^{-1} of $N:P_2O_5:K_2O$ + 25 kg N through FYM). A strong positive correlation (r=0.87) was observed between dry matter accumulation and heat use efficiency.

Keywords: Cultivars, Fertility levels, FYM, Pearl millet, Rainfed

Introduction

Pearl millet (*Pennisetum glaucum* L.), popularly known as bajra, is a multipurpose cereal belonging to the Poaceae family and is widely cultivated in semi-arid regions of Africa and Asia for food, feed and forage purposes (Shahikumara *et al.*, 2024). Globally, pearl millet production is mainly concentrated in the developing countries, which account for more than 95% of the total area and production. It is the sixth most important cereal crop in the world and the fourth most important food grain in India after rice, wheat and maize (Wadile *et al.*, 2009). In India, the area under pearl millet during 2022-23 declined by about 26% compared to the 1980s, but production increased by 19% owing to a 48% rise in productivity (Anonymous, 2022). India continues to be the largest producer of pearl millet in the world, with a production of 9.77 million tonnes from an area of 7.32 million hectares. Major pearl millet growing states include Rajasthan, Uttar Pradesh, Gujarat and Maharashtra, which together account for more than 90% of the total acreage (Anonymous, 2023).

In the context of climate change, ensuring adequate, safe and nutritious food for the growing global population has become a major challenge. Global food demand is expected to double by 2050 due to rapid population growth and changing dietary patterns (Van Dijk *et al.*, 2021). In India, the demand for food is projected to increase substantially, requiring a significant rise in crop production to meet future needs (Searchinger *et al.*, 2014). Climate variability further aggravates the problem by adversely affecting crop productivity, particularly for smallholder farmers who possess limited adaptive capacity (Onyutha, 2019). In this scenario, climate-resilient crops such as pearl millet play a vital role in sustaining agricultural productivity. Pearl millet is known for remarkable adaptability to harsh environmental conditions, including drought, high temperatures and poor soil fertility (Goswami *et al.*, 2023). It is traditionally one of the hardiest warm-season dryland crops and can be successfully cultivated in areas where other cereals like sorghum and maize fail to produce economic yields. The crop possesses a short growth duration, high growth rate and efficient resource utilization, making it suitable for cultivation under marginal and stress-prone environments (Yadav and Rai, 2013). These characteristics, along with improved crop management practices, make pearl millet an important crop for ensuring food and nutritional security under changing climatic conditions.

Besides grain production, pearl millet also plays a crucial role in livestock feeding systems. The stover of pearl millet serves as an important source of fodder during lean periods, particularly in dry regions where it often becomes the only available feed for livestock (Ramesh *et al.,* 2006). The fodder quality of pearl millet is superior to that of sorghum and maize because it does not contain hydrocyanic acid and generally has higher crude protein content. Its profuse tillering, multicut potential and ability to grow under poor soil fertility further enhance its importance as a fodder crop. Although pearl millet is often grown on low-fertility soils, being an exhaustive cereal crop, it responds well to nitrogen fertilization. Consequently, appropriate nutrient management is essential for realizing its full yield potential (Sheoran *et al*., 2016).

The Northwestern Himalayan region of India presents a unique agro-climatic environment characterized by diverse altitudes, variable microclimates and marginal soils. Traditional cereal crops often face challenges in these conditions due to climatic unpredictability, low soil fertility and limited water availability. Despite the known resilience of pearl millet in arid and semi-arid regions, its adaptability and productivity under the cooler and relatively moisture-rich environments of the Himalayan region remain inadequately explored. Considering its drought tolerance, adaptability and superior fodder quality, pearl millet has the potential to serve as a climate-resilient crop capable of supporting integrated crop livestock farming systems in this region. Therefore, the present study was undertaken to evaluate the potential of pearl millet as a sustainable crop for the northwestern Himalayan region, with emphasis on enhancing food, nutritional and fodder security under changing climatic conditions.

Materials and Methods

Experimental site: The study was carried out for three consecutive seasons (*Kharif* 2020 to 2022) at the Research Farm of the Advanced Centre for Rainfed Agriculture (ACRA), Rakh Dhiansar of Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu. The soil of the experimental trial (Table 1) was sandy loam in texture, neutral in reaction (pH 6.9) and having EC 0.17 dS m^{-1}. The experimental site was low in organic carbon (2.7 g/ha), available nitrogen (167.31 kg ha^{-1}) and potassium (98.64 kg ha^{-1}) but medium in available phosphorus (12.4 kg ha^{-1}).

The study area has a sub-tropical climate with hot summer and cold winter seasons, and is well recognized for the cultivation of field crops both under irrigated and rainfed conditions. Average monthly maximum and minimum temperature for the pearl millet growing period of July to October was found to vary from 31.7 to 34.9°C and 20.8 to 25.2°C, respectively. The climate of this region is influenced by the south-west monsoon in *kharif* and the western disturbances in *rabi*. The rainfall received during the crop growth period is 850 mm.

Treatment details: The experiment consisted of fifteen treatment combinations arranged in a factorial randomized block design (FRBD) with three replications. The details of treatment are presented below in Table 2.

Crop husbandry: Pearl millet crop varieties, *viz.,* Pusa composite 383, MBC-2 and local variety, were sown with the onset of rains (monsoon) with a seed rate of 5 kg ha^{-1}, in rows with row spacing of 45 cm. At the time of sowing, half of the nitrogen, along with a full dose of phosphorus, potassium and 5 tonnes of FYM, was applied as a basal dose. The remaining half of the nitrogen was top-dressed 35 days after sowing (DAS). Urea, SSP and muriate of potash were used as sources of nitrogen, phosphorus and potassium, respectively. Weed control was done by applying Atrazine @ 0.75 kg ai ha^{-1}, two days after sowing. Intercultural operations and plant protection measures were adopted whenever required, from sowing to the crop harvest. Pearl millet biomass yield from each net plot after threshing was recorded separately as kg plot^{-1} and then converted to kg ha^{-1}. Stover yield of the pearl millet crop was calculated by subtracting grain yield from the total biomass of respective treatments.

Observations recorded: Plant height of five tagged plants was measured from the ground to the tip of the topmost fully opened leaf using a meter scale at 40 DAS and at harvest and the mean value was used for statistical analysis. For dry matter accumulation, plant samples were sun-dried for one day and then oven-dried at 65°C for 48 to 72 hours until constant weight was obtained. Leaf area index (LAI) was determined by collecting leaves from five plants used for dry matter studies at 40 DAS and at harvest, measuring leaf area with a leaf area meter and calculating LAI using the formula (Watson, 1958): LAI = Total leaf area/ Total ground area.

The number of earheads per square meter was recorded from five randomly selected plants in each net plot and averaged. 1000-grain weight was determined by randomly selecting and manually counting 1000 grains from each treatment and weighing them in grams (g). The number of grains per earhead was obtained by counting grains from earheads of five labelled plants in each net plot and averaging the values. Grain yield was recorded after harvesting, drying, threshing and cleaning earheads from each net plot and yield per hectare was calculated and expressed in kg ha^{-1}. Stover yield was obtained by cutting plants at the base of the net plot, air drying for about ten days, recording weight, and converting it into kg ha^{-1}. Soil samples were analyzed for pH, electric conductivity (EC), organic carbon (OC) and available nitrogen (N), phosphorus (P) and potassium (K) using standard procedure, while processed plant samples were

Table 1. Physico-chemical characteristics of soil of experimental field

Soil characteristics	Units	2020		2021		2022	
		0-15 cm					
		Pre- sowing	Post- harvest	Pre- sowing	Post- harvest	Pre- sowing	Post- harvest
pH		6.90	6.89	6.88	6.87	6.87	6.87
EC at 25^0 C	dSm^{-1}	0.17	0.16	0.16	0.15	0.15	0.15
Organic carbon	g kg^{-1}	2.7	2.8	2.9	3.00	3.01	3.02
Available N	kg ha^{-1}	167.37	168.46	169.25	169.94	170.14	170.21
Available P	kg ha^{-1}	12.4	12.95	13.12	13.28	13.36	13.42
Available K	kg ha^{-1}	98.64	99.42	100.12	100.26	100.98	101.20

analyzed for N, P and K content and nutrient uptake was calculated by multiplying nutrient content (ppm and mg kg^{-1}) with respective seed and stover yield (kg ha^{-1}). Growing degree days (GDD) were calculated by accumulating daily mean temperature above the base temperature using the formula (Nuttonson 1955).

$$GDD = \frac{Tmax + Tmin - Tbase}{2}$$

where Tmax: Daily maximum temperature (°C); Tmin: Daily minimum temperature (°C); Tbase: Base temperature of 10°C

Heat use efficiency (HUE) was calculated as the ratio of yield to accumulated heat units.

$$HUE = \frac{Seed\ yield/Total\ dry\ matter}{Accumulated\ heat\ units\ (°C\ day)}$$

Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined using standard detergent fibre procedures and expressed as a percentage of dry matter (Van Soest *et al*., 1991).

Net returns were determined by subtracting the total cost of cultivation from gross returns and expressed as Rs ha^{-1}. The benefit-cost ratio was calculated by dividing net returns by the total cost of cultivation to identify the most cost-efficient treatment.

Statistical analysis: The observations recorded during the experimentation were subjected to analysis of variance (ANOVA). The critical difference (CD) at $p \leq 0.05$ was calculated to determine statistically significant differences among treatments. Principal component analysis (PCA) and Pearson correlation analysis among parameters were performed using the OriginPro software (version 2025).

Results and Discussion

Table 2. Treatment details

Treatment No.	Treatment details
Factor A	
V_1	Pusa composite 383
V_2	MBC-2
V_3	Local variety
Factor B	
F_1	Control
F_2	25 kg N through FYM
F_3	50:30:15 kg ha^{-1} of $N:P_2O_5:K_2O$ + 25 kg N through FYM
F_4	65:40:20 kg ha^{-1} of $N:P_2O_5:K_2O$ + 25 kg N through FYM
F_5	80:50:25 kg ha^{-1} of $N:P_2O_5:K_2O$ + 25 kg N through FYM

Effect of cultivars and fertility levels on crop growth: The results (Table 3) showed that plant heights of pearl millet crop at 40 DAS and at harvest were significantly maximum (76.01 and 153.59 cm) in the local variety, followed by MBC-2 and Pusa composite 383. Whereas MBC-2 exhibited a significant increase in leaf area index (LAI) and dry matter accumulation compared to other cultivars, at both. Further, correlation analysis showed a positive relationship between dry matter accumulation and heat use efficiency at 5% level, with a correlation coefficient of 0.87 (Fig 1). This was due to the interception, absorption and utilization of radiant energy more efficiently. It resulted in higher accumulation of photosynthates and finally higher dry matter accumulation. The differences in plant height, LAI and dry matter accumulation might be due to the variation in their genetic character and inter- nodal length. Among fertility levels, significantly higher plant height (79.94 and 161.53 cm), leaf area index (1.85 and 2.45) and dry matter accumulation (423.33 and 627.57 g m^{-2}) were recorded under F_5 (80:50:25 kg/ha of $N:P_2O_5:K_2O$ + 25 kg N through FYM) than other fertility levels but remained at par with F_4 (65:40:20 kg ha^{-1} of $N:P_2O_5:K_2O$ +

Table 3. Effect of cultivars and fertility levels on crop growth in pearl millet (Pooled 2020-22)

Treatments	Plant height (cm)		Dry matter accumulation (g m^{-2})		Leaf area index	
	40 DAS	At harvest	40 DAS	At harvest	40 DAS	At harvest
Cultivars						
V_1	65.35	134.55	350.62	541.26	1.66	2.24
V_2	68.88	144.61	393.75	589.13	1.83	2.42
V_3	76.01	153.59	317.80	500.23	1.58	2.17
SEM (±)	0.97	2.74	4.89	16.03	0.03	0.03
CD (P<0.05)	2.80	7.95	14.17	46.47	0.08	0.09
Fertility levels						
F_1	56.34	120.06	255.20	413.92	1.48	2.05
F_2	64.65	132.45	301.46	499.05	1.62	2.20
F_3	71.03	147.22	378.49	566.18	1.69	2.28
F_4	78.43	159.98	411.81	610.99	1.81	2.40
F_5	79.94	161.53	423.33	627.57	1.85	2.45
SEM (±)	1.25	3.54	6.31	20.70	0.04	0.04
CD (P<0.05)	3.61	10.27	18.29	60.00	0.10	0.11
V × F	NS	NS	NS	S	NS	NS

For details of treatment, please refer table 2

25 kg N through FYM). This may be attributed to higher fertility levels, which enhance nutrient availability and metabolic activity, promoting auxin-mediated cell elongation and cell division in stem tissues, resulting in increased plant height, leaf area and dry matter accumulation. Greater nutrient availability also created a favorable nutritional environment in the root zone, enhancing crop growth and development. An adequate supply of essential nutrients supports physiological processes such as photosynthesis and the synthesis of carbohydrates and amino acids, thus promoting better plant growth. Similar studies carried out on the rice-wheat system in the Indo-gangetic plains showed that increasing fertility levels from 75% of the recommended fertilizer dose to higher doses significantly increased the grain yield and yield attributing characteristics of wheat (Gupta *et al*., 2007).

Effect of cultivars and fertility levels on yield and yield attributes: Yield attributes such as number of ear heads (m^{-2}), 1000 grain weight (g) and number of grains per earhead were significantly influenced by cultivars and fertility levels as presented in Table 4. Significantly higher number of ear heads (20.68 m^{-2}), 1000 grain weight (7.00 g) and number of grains per ear head (1436.78) were recorded in cultivar MBC-2, than Pusa Composite 383 and local variety. The variation in yield attributes among cultivars may be attributed to differences in their genetic potential, resource use efficiency and adaptability to prevailing soil and climatic conditions. Similarly, cultivar MBC-2 recorded significantly higher grain yield (2313.49 kg ha^{-1}) and stover yield (3958.78 kg ha^{-1}) in contrast to other cultivars. This might be due to the fact that overall improvement in growth, as evidenced from higher leaf area index and dry matter accumulation, which ascribes to greater availability of growth inputs, matching with the formation and development of grain and stover yield components. These results confirm the earlier findings of Prasad *et al.* (2014) and Kaur and Goyal (2019).

Among the fertility levels, significantly higher number of ear heads (21.45 m^{-2}), 1000 grain weight (17.56 g) and number of grains per head (1507.16) were observed in treatment F_5 (80:50:25 kg ha^{-1} of $N:P_2O_5:K_2O$ + 25 kg N through FYM) than rest of the treatments, but was found statistically at par with F_4 (65:40:20 kg ha^{-1} of $N:P_2O_5:K_2O$ + 25 kg N through FYM). Similarly, higher grain yield (2389.85 kg ha^{-1}) and stover yield (4175.07 kg ha^{-1}) were recorded in F_5 (80:50:25 kg ha^{-1} of $N:P_2O_5:K_2O$ + 25 kg N through FYM), which was statistically similar to F_4 (65:40:20 kg ha^{-1} of $N:P_2O_5:K_2O$ + 25 kg N through FYM). This can be attributed to the improvement in vigour and crop growth due to better nutritional status of the crop, which was earlier low in N, K and medium in P. The increased supply of fertilizers might have stimulated the rate of various physiological processes in the crop. The results of the present study with the combined application of fertilizers are in line with those of Arora *et al.* (2024).

Table 4. Effect of cultivars and fertility levels on yield and its attributing traits, and economics in pearl millet

Treatments	**No. of ear heads m-^{2}**	**Test weight (g)**	**No. of grains ear head^{-1}**	**Grain yield (kg ha^{-1})**	**Stover yield (kg ha^{-1})**	**Net returns (Rs ha^{-1})**	**B:C ratio**
Cultivars							
V_1	18.11	5.37	1351.93	1853.98	3374.48	33595.32	1.53
V_2	20.68	7.00	1436.78	2317.93	3958.78	46522.69	2.12
V_3	15.79	5.04	1270.88	1503.02	3207.59	25748.60	1.20
SEM (±)	0.34	0.07	16.46	50.29	51.94	-	-
CD (P<0.05)	0.97	0.21	48.34	145.69	150.46	-	-
Fertility levels							
F_1	14.38	11.44	1158.81	1219.56	2505.60	22217.17	1.44
F_2	16.21	13.56	1247.20	1522.33	3149.99	26615.73	1.30
F_3	18.24	14.67	1319.62	2013.26	3740.90	37394.93	1.62
F_4	20.70	16.67	1465.46	2313.22	3996.51	44334.66	1.86
F_5	21.45	17.56	1507.16	2389.85	4175.07	45881.85	1.84
SEM (±)	0.43	0.33	24.26	64.93	67.05	-	-
CD (P<0.05)	1.25	0.96	71.30	188.09	194.24	-	-
V × F	NS					-	-

For details of treatment, please refer table 2

Interaction effect of cultivars and fertility levels on dry matter accumulation: Data presented in Table 5 revealed that the interaction effect between various cultivars and fertility levels on dry matter accumulation was found to be significant. Higher dry matter was accumulated by cultivars MBC-2 (742.56 g m^{-2}) and Pusa Composite 383 (696.48 g m^{-2}) when the crop was fertilized with 80:50:25 kg ha^{-1} of N:P_2O_5:K_2O + 25 kg N through FYM. Whereas, local cultivar produced higher dry matter (628.66 g m^{-2}) when fertilized with 65:40:20 kg ha^{-1} of N:P_2O_5:K_2O + 25 kg N through FYM. This is because of the fact that an increase in fertilizer application increases nutrient availability to the crop, which enhances meristematic cell division, helps in cell elongation, which aids in more dry matter accumulation of the crop. Moreover, cultivars with higher yield potential required a higher dose of fertilizers compared to the local cultivar. Similar results were reported by Chandana *et al*. (2018).

Table 5. Interaction effect of cultivar and fertility levels on dry matter accumulation (g m^{-2}) at harvest in pearl millet

Fertility levels (N: P_2O_5: K_2O kg ha^{-1})	**Cultivars**		
	V_1	**V_2**	**V_3**
F_1	402.63	452.96	386.16
F_2	453.48	553.67	490.00
F_3	562.32	583.57	552.66
F_4	591.42	612.90	628.66
F_5	696.48	742.56	443.66
SEM (±)	35.86		
CD (P<0.05)	103.92		

For details of treatment, please refer table 2

Effect of cultivars and fertility levels on relative economics: Net returns and B:C ratio were also influenced by different treatment combinations (Table 4) in pearl millet. Cultivar MBC-2 proved to be the best with respect to B:C ratio (2.12) and net returns (46522.2 Rs ha^{-1}). Fertility levels also showed significant variation in net returns and B:C ratio. The results showed that increasing fertility levels up to 80:50:25 kg ha^{-1} of N:P_2O_5:K_2O + 25 kg N through FYM (F_5) increased net return (Rs 45881.8 ha^{-1}) and B:C ratio (1.86) due to higher grain and stover yields of pearl millet. Similar observations were also recorded by Sheoran *et al*. (2016).

***Heat use efficiency*:** Heat use efficiency (HUE) increased from the vegetative growth stage to the reproductive growth stage; however, it decreased slightly at physiological maturity of the crop (Table 6). Pearl millet cultivar MBC-2 showed higher grain as well as stover heat use efficiency, *i.e*., 1.66 and 2.83 kg ha^{-1} °C day$^{-1,}$ than other cultivars. It might be due to the higher grain yield of cultivar MBC-2, which increased the thermal efficiency. Gupta *et al*. (2017) also observed similar results. Among fertility levels, crop fertilized with 80:50:25 kg ha^{-1} of

Table 6. Heat Use efficiency (g °C $day^{-1}x10^{-3}$) of pearl millet as affected by cultivars and fertility levels

Treatments	HUE (g °C $day^{-1}x10^{-3}$)	
	Seed	Stover
Cultivars		
V_1	1.29	2.33
V_2	1.66	2.83
V_3	1.06	2.25
SEM (±)	0.04	0.04
CD (P<0.05)	0.11	2.24
Fertility levels		
F_1	0.83	1.71
F_2	1.05	2.18
F_3	1.42	2.63
F_4	1.64	2.84
F_5	1.73	3.01
SEM (±)	0.09	0.09
CD (P<0.05)	0.26	0.27

For details of treatment, please refer table 2

$N:P_2O_5:K_2O$ + 25 kg N through FYM (F_5) recorded 3.01 kg ha^{-1} °C day^{-1} heat use efficiency of biomass and grain HUE of 1.73 kg ha^{-1} °C day^{-1} at various phenological stages under study. The higher heat use efficiency with F_5 might be due to its higher biomass and grain yield than other levels. Similar results were reported by Gupta *et al*. (2019).

***Fibre contents*:** Pearl millet cultivars showed a non-significant effect on quality parameters such as NDF and ADF, as illustrated in Fig 2. The lowest NDF and ADF (62.78 and 37.95%) were noticed for cultivar MBC-2. Low NDF and ADF values indicate that fodder has a higher energy value and digestibility. Among fertility levels, higher NDF and ADF contents were noticed when the crop was raised without fertilizers, *i.e.*, control (F_1), followed by F_2, *i.e.* crop was raised only 25 kg N through FYM, whereas further increase in fertility levels decreased both NDF and ADF content. The significant decrease in NDF and ADF content with an increase in nutrient level might be due to higher nutrient supply. A similar result was reported by Şahin *et al*. (2024).

***Principal component analysis (PCA) and correlation study*:** On the pooled basis of three years of data (Fig 3), PCA analysis revealed that the first and second principal components accounted for 75.81 and 13.50% of the total variation in the growth, yield attributes and yield of pearl millet, respectively. Besides, the increase in growth and yield attributes of pearl millet was recorded with the application of $N:P_2O_5:K_2O$ + 25 kg N through FYM than

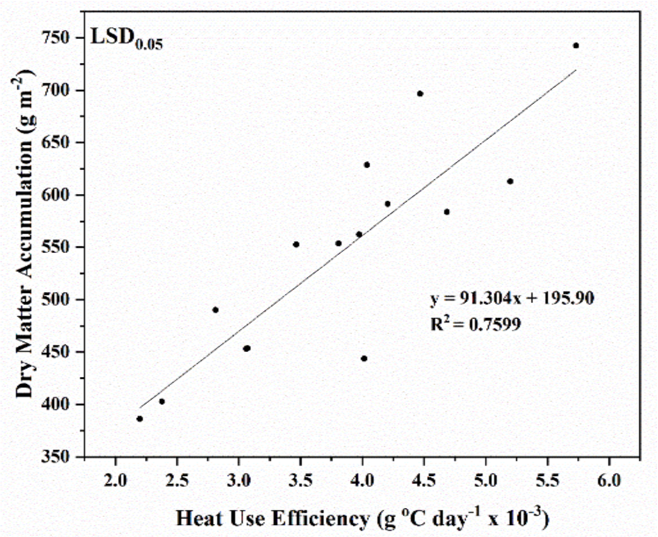

Fig 1. Linear regression analysis between dry matter accumulation (g m^{-2}) and heat use efficiency (g ºC day^{-1} × 10^{-3})

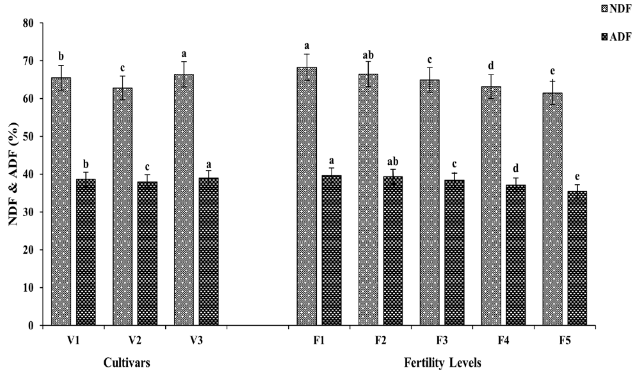

Fig 2. Effect of cultivars and fertility levels on NDF and ADF in pearl millet

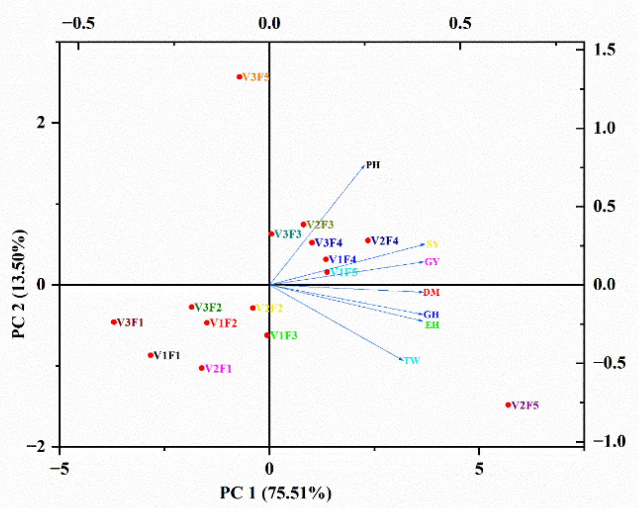

Fig 3. Principal component analysis (PCA) among growth, yield attributes and yield of pearl millet [PH: Plant height; DM: Dry matter accumulation; GH: Grains per head; EH: Number of ear head m^{-2}; TW: Test weight; GY: Grain yield; SY: Stover yield]; For details of treatment, please refer table 2

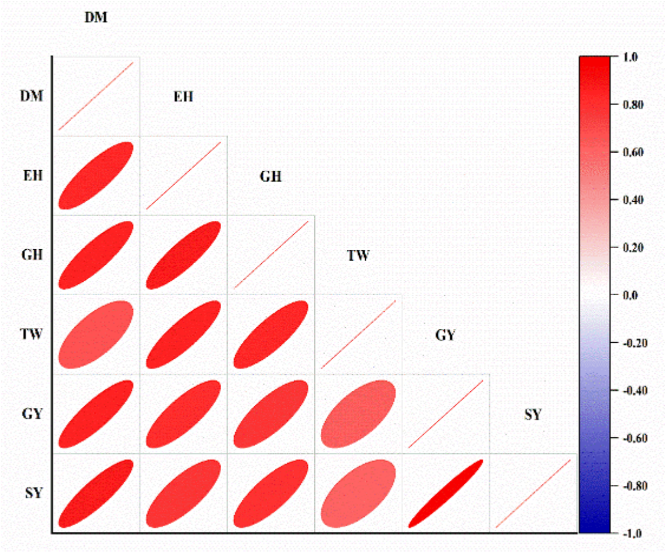

Fig 4. Pearosn's correlation between among growth, yield attributes and yield of pearl millet [PH: Plant height; DM: Dry matter accumulation; GH: Grains per head; EH: Number of ear head m^{-2}; TW: Test weight; GY: Grain yield; SY: Stover yield]; For details of treatment, please refer table 2

all the other treatments. Further, Pearson's correlation analysis (Fig 4) also showed a significant positive correlation among dry matter accumulation, number of ear heads (m^{-2}), number of grains ear^{-1}, test weight, grain and stover yield.

Conclusion

Across three consecutive years of evaluation under rainfed conditions of Jammu, pearl millet cultivar MBC-2 attained significantly higher growth parameters, yield attributes and yield along with F_5 (80:50:25 kg ha^{-1} of N:P_2O_5:K_2O + 25 kg N through FYM). However, F_4 treatment (65:40:20 kg ha^{-1} of N:P_2O_5:K_2O + 25 kg N through FYM) recorded a higher benefit-cost ratio, indicating superior economic efficiency. This suggests that the additional nutrient inputs under F_5 did not result in proportionate economic gains. Therefore, while F_5 may be considered advantageous for maximizing productivity and F_4 emerges as a more economically efficient and sustainable nutrient management option for pearl millet under rainfed agro-ecosystems of Jammu.

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