

Effect of various nitrogen levels on growth and yield of different varieties of pearl millet [*Pennisetum glaucum* (L.) R.Br.] under shisham (*Dalbergia sissoo*) based silvi-pastoral system

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Research Article

Keywords: Fodder pearl millet, Silvi-pastoral system, Nitrogen levels, Shisham, and Varieties

Posted Date: April 14th, 2025

DOI: <https://doi.org/10.21203/rs.3.rs-6113698/v1>

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Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Discover Life on October 17th, 2025. See the published version at <https://doi.org/10.1007/s11084-025-09712-6>.

Abstract

A field experiment was conducted during the kharif season of 2022-23 at the Main Experimental Station, Agroforestry, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.). The experimental site is situated at 26°27' N latitude and 82°12' E longitude, with 113 m elevation from mean sea level. Three varieties of pearl millet (V_1 : GK-1183, V_2 : Virat-9, and V_3 : Kaveri Super Boss) were raised in a shisham-based silvi-pastoral system with the application of four nitrogen levels (N_0 : control, N_1 : 60 kg ha⁻¹, N_2 : 80 kg ha⁻¹, and N_3 : 100 kg ha⁻¹) to examine the effect of different nitrogen levels on the growth and yield performance of different varieties of pearl millet. The field experiment was laid out in a two-factorial randomized complete block design with three replications. Among all three varieties, Kaveri Super Boss represents significantly higher plant height, number of nodes and internodes, leaf area index, number of leaves, shoot fresh weight, shoot dry weight, and green and dry fodder yield but does not have a significant effect on initial and final plant population. Nitrogen levels had variable responses on plant population, plant height, number of leaves, nodes and internodes, leaf area index, shoot fresh weight, shoot dry weight, and green and dry fodder yield at harvest, and maxima of these parameters was recorded for the application of 100 kg nitrogen ha⁻¹. Net returns and B: C ratio was highest for the combination of Kaveri Super Boss (V_3) and 100 kg nitrogen ha⁻¹.

1. Introduction

Pearl millet [*Pennisetum glaucum* (L.) R.Br.], belonging to the Poaceae family, is one of the hardiest warm-season crops and is classified as a cereal [1]. It ranks sixth in terms of cultivated area worldwide [2], with approximately 42% of global production [3], following rice, wheat, maize, barley, and sorghum. Pearl millet (*Pennisetum glaucum*) is a vital crop in semi-arid and dry regions that is cultivated on about 8.3 million hectares of land in India for both food and animal feed, and it ranks as the fourth most widely cultivated cereal crop after rice, wheat, and maize [3, 4]. Due to the recent spike in the price of wheat, rice, and maize as well as the rising demand for non-food use (such as the starch and alcohol industries, livestock and poultry feed sectors), pearl millet is now a more affordable alternative source [1]. Furthermore, pearl millet is high in fiber and beneficial to diabetics and heart patients, their nutritional content present significant opportunity for the development of value-added products in new health-conscious customer categories [4]. Compared to wheat and rice, pearl millet could provide all the necessary nutrients at a lower cost, as it is among the most nutrient-rich cereals, especially in iron, calcium, and zinc [5].

India is primarily an agricultural nation, with over 75% of the inhabitants living in villages and relying mostly on forestry, agriculture and animal husbandry. Although land is the primary natural resource for humans, animals, and plants, about 53% of its surface is degraded in one way or another. Nation's limited resource base must provide the everyday needs of people and cattle for food, pasture, fuel wood, and lumber [6]. Agroforestry is a good option to utilize these natural resources efficiently and sustainably without degrading the land. The term "agroforestry" refers to a group of land-use practices that coexist with crops, animals, and/or trees. Different agroforestry systems contain a variety of fruits and forest trees in addition to agricultural crops [7, 8, 9]. The four fundamental pillars of agroforestry are complexity, profitability, competition and sustainability. For best outcomes, these pillars should be well balanced. Agroforestry systems have several drawbacks, such as allelopathic effects, trees and crops competing for resources, trees growing quickly and taking up space in crops, etc. [9]. To maximize the benefits of agroforestry systems, negative concerns of these systems should also taken into account. Any agroforestry system's sustainability and effectiveness are mostly dependent on how positive and negative elements interact and complement one another. To produce favorable outcomes, good interactions must predominate over negative ones [9, 10].

Among the different trees associated with the agroforestry system, shisham is one of the favorable and valuable trees species for foresters, local people and farmers because of its exceptional attributes as lumber, field hardiness, and superior growth compared to other local species [11]. Within the sub-Himalayan region of India, shisham can be found in numerous regions up to 900 meters height, with sporadic ascents to 1500 meters height. With differing degrees of success, the tree has been introduced into Java, Nigeria, Mauritius, Sri Lanka, Kenya, and other nations [12]. Only the sub-Himalayan and Bhabar regions are home to shisham; it has been brought elsewhere by humans [13]. It is a 10–30 m tall, medium sized tree with trunk of 2–4 m, comes under deciduous category. Shisham can be cultivated successfully in combination with a number of different crops, including fruit crops, grasses and agricultural crops [14]. The integration of fodder crops with shisham is known as the silvi-pastoral system and has significant ecological, economic, and social benefits. Silvi-pastoral systems offer a sustainable solution to the conflict

between agricultural production and ecosystem conservation by integrating trees, forage, livestock, and crops within the same land unit [15]. These systems enhance productivity and profitability while improving resource use efficiency and resilience to climate change [16], and provide multiple benefits, including increased forage quality, enhanced carbon sequestration, improved soil fertility, and better water retention. Additionally, they promote biodiversity, reduce livestock heat stress, and diversify farm income through timber and fruit production. Compared to conventional pastures, these systems contribute to long-term agricultural sustainability by maintaining ecosystem functions and restoring degraded lands [15, 17].

There are conflicting reports on the impact of introducing trees alongside cereal crops on crop yield [18]. [19] showed a decrease in grain yield under an agri-horticulture system; however, [20] found that crop yield rises as crop distance from the tree increases. Numerous studies have evaluated the impact of varying nitrogen levels on the growth and yield of pearl millet [18, 21–23]. However, there is limited research on the combined effect of nitrogen levels and the presence of nearby trees on the growth and yield of pearl millet. Taking into account this research gap and the divergent perspectives on the growth and development of cereals alongside trees, a study was carried out to evaluate the impact of different nitrogen levels on the growth and yield of pearl millet (*Pennisetum glaucum*) in the shisham based silvi-pastoral system in eastern Uttar Pradesh.

2. Materials and Methods

2.1. Location of Experimental Site

The experiment was carried out at Main Experimental Station, Agroforestry, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, India during 2022-23 in alley cropping system. The experimental site is located at 26°27'N latitude and 82°12'E longitude with altitude of 113 meters above mean sea level under Middle Gangetic Plains of Uttar Pradesh (Fig. 1).

2.2. Soil and Climate

Study area comes under humid subtropical climate characterized by dry winter and wet summer. Generally, December and January are the coldest months while, May and June are hottest. Mean annual rainfall of the area is 1000–1100 mm. June to September are the months in which most of the rainfall occur. The texture of soil was silt loam, with pH in alkaline range (7.0 to 8.5). The structure of the soil was fine with less organic matter; the total N, P, K and S content ranged between 150–200 kg ha⁻¹, 15–20 kg ha⁻¹, 120–140 kg ha⁻¹ and 10–20 mg ha⁻¹, respectively.

2.3. Experimental Details

The experiment followed a two-factorial Randomized Complete Block Design (RCBD) with three replications. There are total twelve treatments made by the combination of three varieties of pearl millet and four nitrogen levels (Table 1). Varieties of pearl millet and nitrogen levels were selected based on previous studies by reviewing the literature. Selecting appropriate nitrogen levels for pearl millet is essential for optimizing growth, yield, and nutrient use efficiency while maintaining soil health and economic viability. It also allows for assessing environmental impacts and addressing research gaps. Choosing multiple varieties enables the evaluation of yield stability under different nitrogen conditions. This approach ensures practical relevance, promotes sustainable agricultural practices, and leading to enhanced productivity and profitability.

Table 1
Treatments

S. No.	Combinations	Combinations Details	Symbols
1	V ₁ N ₀	GK -1183 without nitrogen application	T ₁
2	V ₁ N ₁	GK -1183 with nitrogen application @60 kg ha ⁻¹	T ₂
3	V ₁ N ₂	GK -1183 with nitrogen application @80 kg ha ⁻¹	T ₃
4	V ₁ N ₃	GK -1183 with nitrogen application @100 kg ha ⁻¹	T ₄
5	V ₂ N ₀	Virat-9 without nitrogen application	T ₅
6	V ₂ N ₁	Virat-9 with nitrogen application @60 kg ha ⁻¹	T ₆
7	V ₂ N ₂	Virat-9 with nitrogen application @80 kg ha ⁻¹	T ₇
8	V ₂ N ₃	Virat-9 with nitrogen application @100 kg ha ⁻¹	T ₈
9	V ₃ N ₀	Kaveri Super Boss without nitrogen application	T ₉
10	V ₃ N ₁	Kaveri Super Boss with nitrogen application of 60 kg ha ⁻¹	T ₁₀
11	V ₃ N ₂	Kaveri Super Boss with nitrogen application of 80 kg ha ⁻¹	T ₁₁
12	V ₃ N ₃	Kaveri Super Boss with nitrogen application of 100 kg ha ⁻¹	T ₁₂

Field was ploughed with the help of tractor to prepare it well for sowing of seed, cleaning and leveling was done manually. After the field preparation plots of 3 × 4 m² were made in the alley of trees as per requirement of treatments (Fig. 2). Seeds of the experimental crop were sown manually with seed rate of 4 kg per hectare in month of July, as an intercrop with a spacing of 45 × 45 cm in the rows of 9-year-old shisham trees, which were planted in August 2012 at a spacing of 5 × 5 m. Hand weeding was done at 15 and 30 days after sowing to control the growth of weed. The crop was irrigated two times using flood irrigation system. The recommended doses of phosphorus (60 kg ha⁻¹) and potassium (40 kg ha⁻¹) were applied using single super phosphate (SSP) and muriate of potash (MOP), respectively. Nitrogen was supplied through urea according to the treatment guidelines, with half applied as a basal dose and the remainder top-dressed 30 days after sowing. The crop was harvested at maturity in the month of October.

2.4. Observations

To investigate the growth and yield potential of pearl millet varieties data was recorded for initial plant population (plant per m²), final plant population (plant per m²), plant height (cm), number of tillers per plant, number of leaves per plant, leaf area index, number of nodes per plant, number of internodes per plant, fresh shoot weight (g), dry shoot weight (g), green fodder yield, dry fodder yield. As farmers are more often interested in profit therefore economic estimation was also carried out to examine the economic viability of the crop under shisham based agroforestry system. For economic estimation all the inputs and outputs of experiment are converted into monetary value to estimate the cost of cultivation, gross return, net return and benefit cost ratio. Cost of cultivation was calculated by adding the cost of inputs like labour, fertilizer, machine, seed and cultural operation as per local prevailing rate (Supplementary Tables 1 & 2). Gross return was calculated by multiplying the yield with the local market rate (Supplementary Table 3). Net return was calculated by subtracting the cost of cultivation from gross return. Benefit cost ratio was estimated by dividing the net return by cost of cultivation.

2.5. Formulas used for economic estimation

$$\text{Net return } (\text{₹ ha}^{-1}) = \text{Gross return } (\text{₹ ha}^{-1}) - \text{Cost of cultivation } (\text{₹ ha}^{-1})$$

$$\text{Benefit cost ratio} = \frac{\text{Net Return } (\text{₹ ha}^{-1})}{\text{Cost of cultivation } (\text{₹ ha}^{-1})}$$

2.6. Statistical analysis

Statistical analysis of data was carried out for analysis of variance in two factorial randomized block design with the help of OPSTAT online agricultural data analysis tool developed by Computer Section, CCS Haryana Agricultural University, Hisar, Haryana, India.

3. Results and Discussion

3.1. Initial and final plant population

The study observed significant variations in initial and final plant population across different nitrogen levels and varieties, while their interaction was non-significant (Table 2). Variety V_3 exhibited the highest initial (21.64 plants/m²) and final (19.70 plants/m²) plant population, whereas V_1 had the lowest initial (20.41 plants/m²) and final (18.84 plants/m²) plant population. Among nitrogen levels, N_3 resulted in the highest initial (22.63 plants/m²) and final (20.31 plants/m²) plant population, while N_0 had the lowest initial (19.21 plants/m²) and final (17.97 plants/m²) plant population. The highest initial and final plant population was observed for N_3 (100 kg ha⁻¹), might be due to the increased availability of nitrogen. This aligns with the findings of [24], who reported that nitrogen fertilization enhances plant population. Similar results have also been documented by [25–27].

Table 2
Effect of nitrogen levels on initial and final plant population of pearl millet

Agroforestry System	Initial Plant Population (m ²)					Final Plant Population (m ²)				
Varieties	Nitrogen Levels				Mean V	Nitrogen Levels				Mean V
	N_0	N_1	N_2	N_3		N_0	N_1	N_2	N_3	
V_1	19.12	19.54	20.89	22.09	20.41 ^a	17.37	18.51	19.52	19.98	18.84 ^a
V_2	19.39	19.77	20.93	22.00	20.52 ^a	18.10	19.41	19.86	20.23	19.40 ^b
V_3	19.13	21.45	22.19	23.78	21.64 ^b	18.44	19.56	20.08	20.73	19.70 ^b
Mean N	19.21 ^a	20.25 ^b	21.34 ^c	22.63 ^d		17.97 ^a	19.16 ^b	19.82 ^c	20.31 ^d	
Factors	CD at 5%		SE(d)	SE(m)		CD at 5%		SE(d)	SE(m)	
V	0.59		0.28	0.19		0.33		0.16	0.11	
N	0.68		0.33	0.23		0.38		0.18	0.13	
V x N	NS		0.56	0.39		NS		0.32	0.23	

Means followed by same letter within a row or column indicate non-significant variation, while different letters signify significant variation.

3.2. Plant height and number of tillers

The study analyzed plant height and the number of tillers per plant based on different nitrogen levels and varieties. Both factors significantly affected plant height and tiller count, though their interaction was significant only for plant height (Table 3). The highest plant height (200.15 cm) and tiller count (2.54) were recorded for variety V_3 , while the lowest values were observed for V_1 (193.14 cm, 2.39 tillers). Among nitrogen levels, N_3 (100 kg ha⁻¹) resulted in the tallest plants (211.56 cm) and the highest tiller count (3.28), whereas N_0 had the lowest values (183.73 cm, 1.49 tillers). Among the interaction, the highest plant height (218.73

cm) was noted for V_3N_3 , while the lowest (183.58 cm) was recorded for V_1N_0 . The highest plant height was observed for N_3 (100 kg ha⁻¹), likely due to role of nitrogen in increasing the number and length of internodes, ultimately leading to greater plant height [21, 28]. Nitrogen is a vital primary nutrient essential for crop growth and development [22]. Similar findings have been reported in previous studies [18, 21–23, 29, 30] on nitrogen application. Likewise, the highest number of tillers per plant was recorded for N_3 (100 kg ha⁻¹), possibly due to nitrogen's ability to enhance the production of new meristematic tissues, which promotes tiller formation [22]. Studies by [18, 22, 31, 32] have also confirmed that nitrogen application increases tiller production by stimulating the development of meristematic tissues.

Table 3
Effect of nitrogen levels on plant height and number of tillers per plant

Agroforestry System	Plant height (cm)					Number of tillers plant ⁻¹				
Varieties	Nitrogen Levels				Mean V	Nitrogen Levels				Mean V
	N ₀	N ₁	N ₂	N ₃		N ₀	N ₁	N ₂	N ₃	
V ₁	183.58	184.47	196.45	208.05	193.14 ^a	1.47	2.30	2.59	3.23	2.39 ^a
V ₂	183.69	184.42	202.42	207.90	194.61 ^a	1.48	2.37	2.68	3.25	2.44 ^a
V ₃	183.92	191.21	206.75	218.73	200.15 ^b	1.51	2.40	2.89	3.36	2.54 ^b
Mean N	183.7 ^a	186.6 ^b	201.8 ^c	211.56 ^d		1.49 ^a	2.35 ^b	2.72 ^c	3.28 ^d	
Factors	CD at 5%	SE(d)	SE(m)			CD at 5%	SE(d)	SE(m)		
V	2.54	1.22	0.86			0.07	0.08	0.02		
N	2.94	1.41	0.99			0.08	0.75	0.03		
V x N	5.09	2.44	1.72			NS	0.53	0.05		

Means followed by same letter within a row or column indicate non-significant variation, while different letters signify significant variation.

3.3. Number of leaves and leaf area index

The study found that both variety and nitrogen level significantly affected the number of leaves per plant and leaf area index (LAI). However, their interaction was significant only for the number of leaves per plant, not for LAI (Table 4). Among the varieties, V_3 exhibited the highest values for both traits (27.31 leaves per plant and LAI of 3.78), while V_1 had the lowest number of leaves (21.72) and V_1 recorded the lowest LAI (3.54). In terms of nitrogen levels, N_3 (100 kg ha⁻¹) resulted in the highest number of leaves (29.79) and the highest LAI (3.97), whereas N_0 recorded the lowest values (19.60 leaves and LAI of 3.33). The highest leaf count and LAI under N_3 application might be attributed to vital role of nitrogen in metabolic processes, as well as its ability to stimulate cell division and elongation [33]. Similar findings were reported by [34].

Table 4
Effect of nitrogen levels on number of leaves per plant and leaf area index

Agroforestry System	Number of Leaves Plant ⁻¹					Leaf Area Index				
Varieties	Nitrogen Levels				Mean V	Nitrogen Levels				Mean V
	N ₀	N ₁	N ₂	N ₃		N ₀	N ₁	N ₂	N ₃	
V ₁	20.04	20.99	21.21	24.65	21.72 ^a	3.22	3.36	3.84	3.85	3.57 ^a
V ₂	19.39	20.41	22.91	26.27	22.24 ^a	3.18	3.42	3.76	3.82	3.54 ^a
V ₃	19.37	21.64	29.82	38.43	27.32 ^b	3.59	3.71	3.57	4.23	3.78 ^b
Mean N	19.60 ^a	21.01 ^b	24.64 ^c	29.79 ^d		3.33 ^a	3.49 ^a	3.72 ^b	3.97 ^c	
Factors	CD at 5%		SE(d)	SE(m)		CD at 5%		SE(d)	SE(m)	
V	0.86		0.41	0.29		0.17		0.08	0.06	
N	0.99		0.47	0.34		0.20		0.09	0.07	
V x N	1.71		0.82	0.58		NS		0.17	0.12	

Means followed by same letter within a row or column indicate non-significant variation, while different letters signify significant variation.

3.4. Number of nodes and internodes per plant

The study evaluated the number of nodes and internodes per plant across different nitrogen levels and varieties. Significant variations were observed among varieties and nitrogen levels, though their interaction was not statistically significant (Table 5). Variety V₃ exhibited the highest number of nodes (8.05) and internodes (7.19), while V₂ recorded the lowest (7.50 nodes, 6.58 internodes). Among nitrogen levels, N₃ (100 kg ha⁻¹) resulted in the highest node (8.73) and internode (7.51) counts, whereas N₀ had the lowest (7.11 nodes, 6.33 internodes). The highest number of nodes and internodes was observed in N₃ (100 kg ha⁻¹), might be due to the direct influence of nitrogen on their development. An increase in nitrogen application corresponded with a higher number of nodes and internodes [28]. These findings are consistent with previous studies [21, 34].

Table 5
Effect of nitrogen levels on number of node and internodes per plant

Agroforestry System	No. of Nodes plant ⁻¹					No. of Internodes plant ⁻¹				
Varieties	Nitrogen Levels				Mean V	Nitrogen Levels				Mean V
	N ₀	N ₁	N ₂	N ₃		N ₀	N ₁	N ₂	N ₃	
V ₁	7.22	7.36	8.14	8.77	7.87 ^a	6.22	6.36	6.81	7.43	6.71 ^a
V ₂	6.85	7.52	7.79	7.85	7.50 ^a	6.18	6.52	6.79	6.85	6.58 ^a
V ₃	7.26	7.31	8.04	9.57	8.05 ^b	6.59	6.71	7.24	8.23	7.19 ^b
Mean N	7.11 ^a	7.39 ^a	7.99 ^b	8.73 ^c		6.33 ^a	6.53 ^a	6.95 ^b	7.51 ^c	
Factors	CD at 5%		SE(d)	SE(m)		CD at 5%		SE(d)	SE(m)	
V	0.41		0.19	0.14		0.26		0.13	0.09	
N	0.47		0.23	0.16		0.31		0.15	0.10	
V x N	NS		0.39	0.27		NS		0.25	0.18	

Means followed by same letter within a row or column indicate non-significant variation, while different letters signify significant variation.

3.5. Fresh and dry shoot weight per plant

The data presented in Table 6, indicate significant variations in fresh and dry shoot weight due to different nitrogen levels and varieties, while their interaction remained non-significant. Among the varieties, V₃ exhibited the highest fresh (169.95 g) and dry shoot weight (27.73 g), whereas V₃ recorded the lowest fresh (152.21 g) and dry shoot weight (23.37 g). Regarding nitrogen levels, N₃ resulted in the maximum fresh (169.19 g) and dry shoot weight (30.26 g), while N₀ had the lowest values (146.44 g and 21.41 g, respectively). The highest fresh and dry shoot weight observed at N₃ (100 kg ha⁻¹) might be attributed to the increased nitrogen availability, which enhances chlorophyll content and subsequently improves the plant's photosynthetic efficiency [22]. These findings are consistent with the results reported by [21, 35–37].

Table 6
Effect of nitrogen levels on fresh and dry shoot weight per plant

Agroforestry System	Shoot Fresh Weight (g)					Shoot Dry Weight (g)				
	Nitrogen Levels				Mean V	Nitrogen Levels				Mean V
	N ₀	N ₁	N ₂	N ₃		N ₀	N ₁	N ₂	N ₃	
V ₁	143.22	153.36	160.17	165.51	155.57 ^a	20.71	21.65	26.88	29.65	24.72 ^a
V ₂	142.85	150.42	154.76	160.82	152.21 ^b	20.16	20.74	24.57	28.02	23.37 ^b
V ₃	153.26	170.71	174.57	181.23	169.95 ^c	23.37	26.64	27.82	33.10	27.73 ^c
Mean N	146.44 ^a	158.16 ^b	163.17 ^c	169.19 ^d		21.41 ^a	23.01 ^b	26.42 ^c	30.26 ^d	
Factors	CD at 5%		SE(d)	SE(m)		CD at 5%		SE(d)	SE(m)	
V	2.43		1.16	0.82		1.09		0.53	0.37	
N	2.80		1.34	0.95		1.27		0.61	0.43	
V x N	NS		2.34	1.64		NS		1.05	0.74	

Means followed by same letter within a row or column indicate non-significant variation, while different letters signify significant variation.

3.6. Green and dry fodder yield

The data on green and dry fodder yield, presented in Table 7, reveals significant differences across nitrogen levels, varieties, and their interactions. Among the varieties, V₃ achieved the highest green (274.86 q ha⁻¹) and dry fodder yield (75.49 q ha⁻¹), while V₁ recorded the lowest green (259.69 q ha⁻¹) and dry fodder yield (70.80 q ha⁻¹). Regarding nitrogen levels, N₃ resulted in the highest green (293.87 q ha⁻¹) and dry fodder yield (81.62 q ha⁻¹), whereas N₀ produced the lowest green (235.61 q ha⁻¹) and dry fodder yield (66.44 q ha⁻¹). Among the interaction the highest green (308.50 q ha⁻¹) and dry fodder yield (82.86 q ha⁻¹) was observed for V₃N₃, while the lowest green and dry fodder yield was recorded for V₂N₀ and V₁N₀, respectively. The greater green and dry fodder yield recorded for N₃ (100 kg ha⁻¹) might be attributed to the well-established relationship between nitrogen application and yield enhancement, as nitrogen promotes yield-attributing characteristics. These findings align with previous studies [38–42].

Table 7
Effect of nitrogen levels on green and dry fodder yield

Agroforestry System	Green Fodder Yield (q ha ⁻¹)					Dry Fodder Yield (q ha ⁻¹)				
Varieties	Nitrogen Levels				Mean V	Nitrogen Levels				Mean V
	N ₀	N ₁	N ₂	N ₃		N ₀	N ₁	N ₂	N ₃	
V ₁	235.84	245.86	271.19	285.88	259.69 ^a	65.67	67.98	68.83	80.73	70.80 ^a
V ₂	235.16	267.44	277.86	287.24	266.92 ^b	66.53	70.94	77.52	81.26	74.06 ^b
V ₃	235.83	267.23	287.87	308.50	274.86 ^c	67.12	71.58	80.40	82.86	75.49 ^c
Mean N	235.61 ^a	260.1 ^b	278.97 ^c	293.87 ^d		66.44 ^a	70.17 ^b	75.58 ^c	81.62 ^d	
Factors	CD at 5%		SE(d)	SE(m)		CD at 5%		SE(d)	SE(m)	
V	3.31		1.58	1.12		1.06		0.51	0.36	
N	3.82		1.83	1.29		1.22		0.59	0.42	
V x N	6.61		3.17	2.24		2.12		1.02	0.72	

Means followed by same letter within a row or column indicate non-significant variation, while different letters signify significant variation.

3.7. Economics estimation of the crop

The total cost of cultivating pearl millet varied based on the treatment applied and was calculated by adding the common cost of cultivation (CC) and the treatment cost (TC). The common cost of cultivation was 21,720 ₹ ha⁻¹, covering expenses related to land preparation, layout preparation, seeds, sowing, thinning and weeding, harvesting, and land lease (Supplementary Table 1). The treatment cost, which included expenditures on fertilizers and labor, ranged from 5,439.80 to 6,744.14 ₹ ha⁻¹ (Supplementary Table 2). Consequently, the total cost of cultivation (CC + TC) varied between 27,159.80 and 28,464.14 ₹ ha⁻¹. Gross returns ranged from 70,548 to 92,550 ₹ ha⁻¹, while net returns ranged from 43,388.20 to 64,085.86 ₹ ha⁻¹. The benefit-cost ratio varied between 1.60 and 2.25 (Supplementary Table 3).

Data obtained for economics of crop illustrated in Fig. 3, showed that minimum cost of cultivation (27159.80 ₹ ha⁻¹) was estimated for T₁, T₅, T₉ and maximum (28464.14 ₹ ha⁻¹) cost of cultivation was estimated for T₄, T₈, T₁₂. Among treatments, highest gross return (92550 ₹ ha⁻¹), net return (64085.86 ₹ ha⁻¹) and benefit cost ratio (2.25) was obtained from T₁₂ (Kaveri Super Boss with nitrogen application @100 kg ha⁻¹) and lowest gross return (70752 ₹ ha⁻¹), net return (43388.20 ₹ ha⁻¹) and benefit cost ratio (1.60) was recorded for T₅ (Virat-9 without nitrogen application). Maximum gross return, net return and benefit cost ratio was observed for Kaveri Super Boss with nitrogen application @100 kg ha⁻¹, which might be due to the higher production of yield from this treatment combination in comparison to all other treatments. Similar results were also reported by [43]. Additionally, economic analyses in previous research have emphasized that strategic input management, particularly nitrogen optimization plays a critical role in maximizing profitability in field crops [44, 45]. The integration of shisham with crops also presents long-term financial advantages beyond immediate yield-based returns. Timber revenues from shisham, which accrue over several years, significantly enhance the overall profitability of the system compared to sole cropping. [46] analyzed the economic viability of poplar, melia, and eucalyptus based agroforestry systems. They reported benefit-cost ratios of 0.55, 0.62, 0.14, and 0.46 for main sugarcane, ratoon sugarcane, oat, and wheat, respectively, under a melia-based agroforestry system. Similarly, they found benefit-cost ratios of 0.87, 0.79, 0.26, and 0.70 for the same crops under a poplar based agroforestry system and 0.75, 1.22, 0.38, and 0.85 under a eucalyptus based system. Compared to these findings, the present study demonstrates even greater economic benefits for the farming community. Moreover, agroforestry systems contribute to sustainability by improving soil structure,

enhancing water retention, and providing ecological benefits, making them more resilient to climatic variations than sole cropping systems.

Conclusion

Optimizing nitrogen levels in pearl millet production enhances yield and growth performance while minimizing negative ecological impacts. Sustainable nitrogen management practices, including precision application, integrated nutrient management, and the use of slow-release fertilizers, can improve nitrogen use efficiency while reducing nitrogen runoff, soil degradation, and greenhouse gas emissions. The present study describes about the effect of various nitrogen doses on growth and yield potential as well as economics of different varieties of pearl millet under shisham based silvi-pastoral system. Based on the data obtained from the investigation, among varieties, Kaveri Super Boss was found superior for growth and yield performance in comparison to other two varieties. Among nitrogen levels, maximum growth and yield was recorded for application of nitrogen at the rate of 100 kg ha⁻¹. Additionally, highest return and Benefit Cost Ratio (BCR) was also recorded for Kaveri Super Boss with application of nitrogen at the rate of 100 kg ha⁻¹. Therefore, cultivation of Kaveri Super Boss variety of pearl millet with the application of nitrogen at the rate of 100 kg ha⁻¹ could be more profitable under shisham based silvi-pastoral system in comparison to other two varieties. Since this experiment was conducted only for one season investigation needs to be further validated before recommendation to the farmers of the eastern Uttar Pradesh.

Abbreviations

i.e. – that is, % - percent, ha – hectare, ₹ – rupee, et al. - et alia (co-worker), etc. - Et cetera, amsl – above mean sea level, viz. – videlicet, q – quintal, kg – kilogram, mg – milligram, t – tonne, mm – millimetre, °C – degree celsius, hr – hour, km – kilometre, m – meter, cm – centimeter, g – gram, ppm – part per million, dbh – diameter at breast height, N – nitrogen level, V – variety of pearl millet, V₁ - GK-1183, V₂ - Virat-9, V₃ - Kaveri Super Boss, N₀ – control, N₁ – 60 kg ha⁻¹, N₂ - 80 kg ha⁻¹, N₃ - 100 kg ha⁻¹, sem – standard error of mean, sed – standard error of deviation, CD – critical difference and NS – non significant.

Declarations

Author contribution

Conceptualization, I.K. and S.K.V.; validation, formal analysis, writing, I.K., A.P.S., data collection, I.K. and A.P.S methodology, rewriting, review, editing, and supervision, I.K., A.P.S., and S.K.V., software, I.K. and A.P.S. All authors have read and agreed to the published version of the manuscript.

Data availability: The data that support the findings of this study are available on request from the corresponding author, Abhishek Pratap Singh.

Funding: This research was conducted without any external funding.

Code Availability: Not applicable.

Ethics Approval and Consent to Participate: The seeds of the experimental crop used in this study were procured from local markets. These widely recognized varieties are readily available. The experimental protocols were approved by Acharya Narendra Deva University of Agriculture and Technology, Ayodhya, Uttar Pradesh, India, and all procedures adhered to the university's research ethics guidelines.

Clinical Trial Number: Not applicable.

Informed Consent: Not applicable.

Conflict of Interest: The authors declare no competing interests.

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Figures

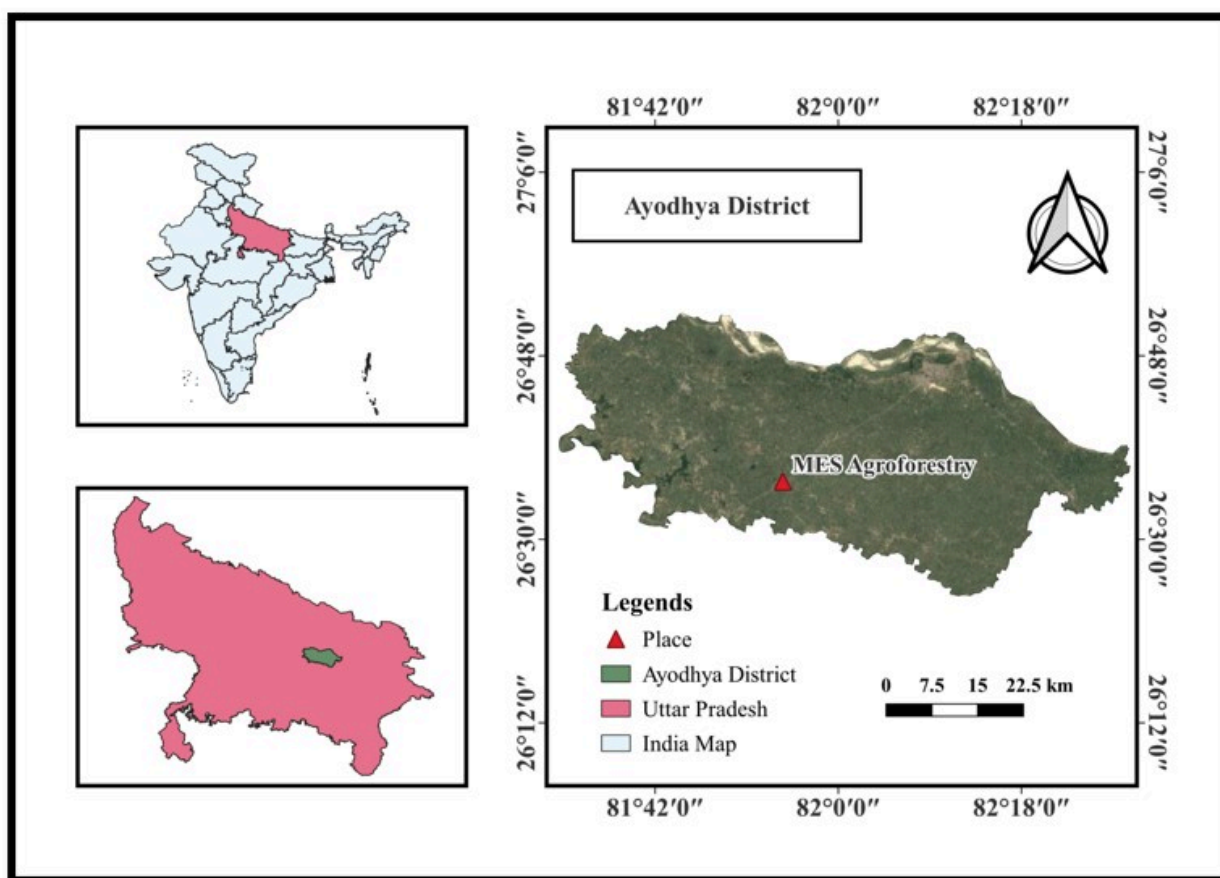


Figure 1

Location map of experimental site

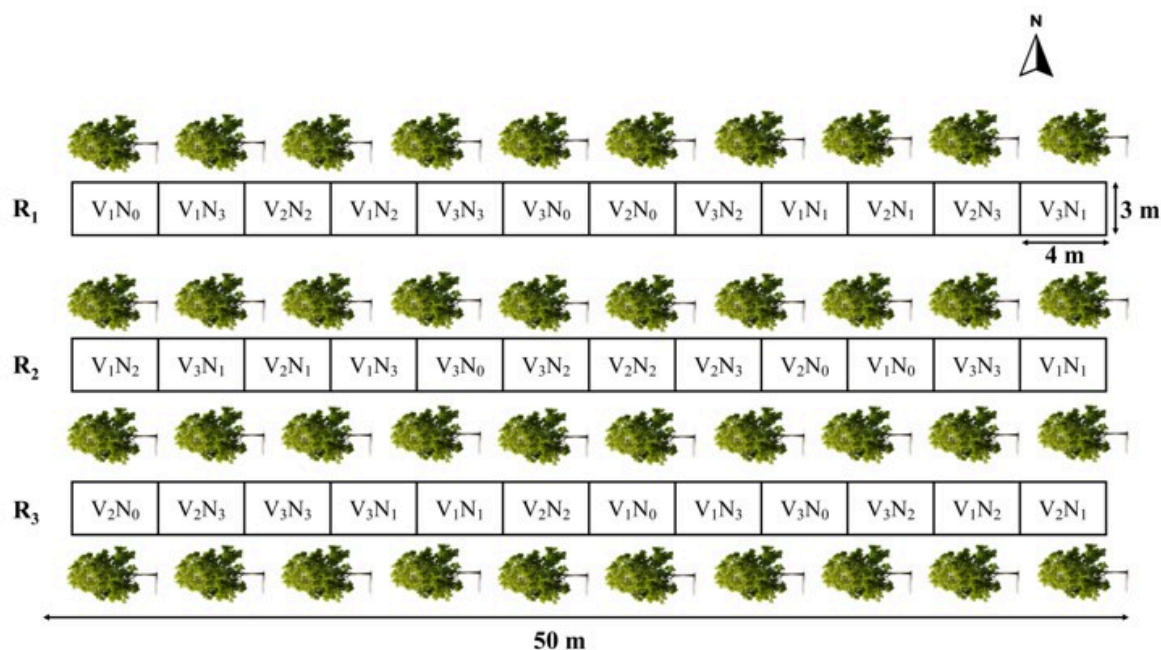


Figure 2

Field layout of experiment

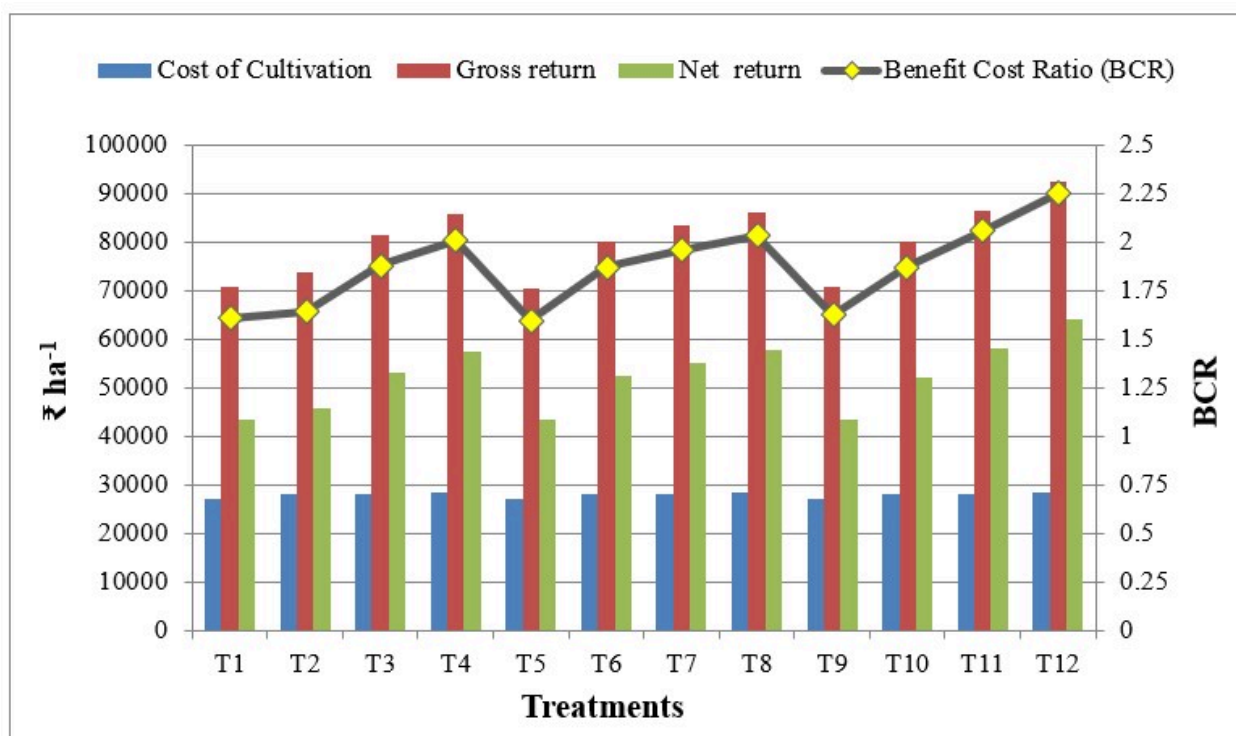


Figure 3

Economic estimation of crop

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