E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(12): 625-628
Received: 10-10-2025
Accepted: 15-11-2025

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Enhancing foxtail millet (*Setaria italica* L.) productivity with legume intercrops

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DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i12i.4437

Abstract
A field investigation entitled "Enhancing Foxtail millet (*Setaria italica* L.) productivity with legumes intercrops" was conducted in kharif season of 2024- 2025 at the Instructional Farm, Post -Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri. The experiment was laid out in Randomized Block Design (RBD) with three replications and eleven treatments *viz*., T_1: Foxtail millet + Green gram (2:2), T_2: Foxtail millet + Black gram (2:2), T_3: Foxtail millet + Horse gram (2:2), T_4: Foxtail millet +Soybean (2:2), T_5: Foxtail millet + Moth bean (2:2), T_6: Sole Foxtail millet, T_7: Sole Green gram, T_8: Sole Black gram, T_9: Sole Horse gram, T_{10}: Sole Soybean, T_{11}: Sole moth bean.
All the growth contributing data *viz*., plant height (112.04 cm), total number of tillers plant^{-1} (5.00), number of leaves plant^{-1} (12.43), leaf area plant^{-1} (4.29 dm^2), leaf area index (1.43) and dry matter plant^{-1} (18.27 g) accumulation at harvest were recorded highest in intercropping treatment T_4 i.e., Foxtail millet + Soybean intercropped in 2:2 row proportion than the treatment T_6 i.e., Sole Foxtail millet which recorded the lowest values of corresponding growth contributing characters. However, there were slight difference in the days to 50% flowering among the different intercropping treatments. Yield and yield-related traits of Foxtail millet were also numerically impacted by treatment T_4 i.e., Foxtail millet + Soybean intercropped in 2:2 row proportion which produced the highest number of productive tillers plant^{-1} (5.00), number of panicles plant^{-1} (3.27), panicle length (18.12 cm), panicle weight (9.02 g), grain yield (1135 kg ha^{-1}) and straw yield (1934 kg ha^{-1})) than the treatment T_6 i.e., Sole Foxtail millet which recorded lowest respected values of 3.75, 2.26, 14.29 cm, 7.36 g, 1598 kg ha^{-1}, 272 kg ha^{-1}.
The intercropping assessment indicated that treatment T_4 i.e., Foxtail millet + Soybean intercropped in 2:2 row proportion recorded the highest values for Land Equivalent Ratio (1.43), Area Time Equivalent Ratio (1.43), Foxtail Millet Equivalent Yield (2158.18 kg ha^{-1}), system productivity (3293.04 kg ha^{-1}), and system profitability (₹964.23 ha^{-1} day^{-1}). Interestingly, this treatment also exhibited the lowest aggressivity towards the main crop, with a value of -0.005.

Keywords: Intercropping, foxtail millet, sole, row proportion

Introduction
Millets are the ancient grains cultivated from the Neolithic age for the purpose of food, feed and forage. They have been called as 'Nutri grains' since they are rich in micronutrients, minerals, dietary fibers and energy. Millets have inherent capacity of early maturity, higher yield, resistant to abiotic stress and can withstand in adverse climatic conditions with low carbon footprints in agriculture. Also being C_4 type of plant millets can harness atmospheric CO_2 and convert it into biomass. They can yield better even in a poor soil under low rainfall and poor management conditions; hence they are popularly known as 'climate resilient' crops in Indian agriculture. Among different millets cultivated across the world pearl millet (Pennisetum glaucum L) and Sorghum (Sorghum bicolor L) are considered as major millets and rest of all other including Foxtail millet (Setaria italica L.) are placed under category of small or minor millets. On an account of the health benefits and nutritional composition of foxtail millet it consists of 60 g carbohydrates, 12.3 g protein, 4.30 g fat and 331 Kcal energy per 100 g. In case of minerals, it consists of 31 mg Ca, 188 mg P, 81 mg Mg, 2.40 mg Zn, 2.80 mg Fe per 100 g. Foxtail millet is also rich in several vitamins and contains 0.59 mg Thiamine, 0.11 mg Riboflavin, 3.20 mg Niacine and 15 mg of Folic acid per 100 gm. More importantly it is low in glycemic index and it is gluten free thus has positive health benefits among diabetics and thus it is called as wonder

grain. In addition, with this it has several health benefits like it improves the immunity, boosts cardiac health, aids in weight loss etc. India's rapidly growing population presents not only the challenge of increasing food production in limited per capita land availability under cultivation along with the reduction in soil fertility, but also highlights the urgent need to address nutritional security, especially in the face of adverse climatic changes and escalating environmental pollution. Therefore, the strategy called inter cropping of millets with legumes has become essential not only to improve yield stability and food availability but also to enhance soil health by replenishing its nutrient content.

Materials and Methods

A field investigation entitled "Enhancing Foxtail millet (*Setaria italica* L.) productivity with legumes intercrops" was conducted in kharif season of 2024- 2025 at the Instructional Farm, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri. The experiment consists of eleven treatments *viz*., T_1: Foxtail millet + Green gram (2:2), T_2: Foxtail millet + Black gram (2:2), T_3: Foxtail millet + Horse gram (2:2), T_4: Foxtail millet +Soybean (2:2), T_5: Foxtail millet + Moth bean (2:2), T_6: Sole Foxtail millet, T_7: Sole Green gram, T_8: Sole Black gram, T_9: Sole Horse gram, T_{10}: Sole Soybean, T_{11}: Sole moth bean. Line sowing of Foxtail millet and intercrop legumes seeds were done on flat beds at spacing of 30 cm x 10 cm in 2:2 proportion. The recommended dose of fertilizer (60:30:30 kg N: P_2O_5:K_2O ha^{-1}) was applied (Nitrogen is applied in two split doses). Periodical observations on the growth characters, yield contributing characters, grain yield and straw yield along with the assessment of their intercropping assessment were recorded during investigation.

Results and Discussion

Growth parameters

The growth performance of Foxtail millet crop at 30 DAS was almost uniform and not influenced by different intercropping treatments. Numerically it influenced later at 60 DAS, 90 DAS and at harvest respectively. Growth parameters *viz.*, highest plant height of 112.04 cm, along with an increased number of tillers $plant^{-1}$ (5.00), number of leaves $plant^{-1}$ (12.43), leaf area $plant^{-1}$ (4.29 dm^2), leaf area index (1.43) and dry matter (18.27 g) accumulation were recorded in intercropping treatment of T_4 i.e., Foxtail millet + Soybean intercropped in 2:2 row proportion than the treatment T_6 i.e., Sole Foxtail millet.

However, there were slight difference in the days to 50% flowering among the intercropping treatments. Highest dry matter $production^{-1}$ (g) at harvest was recorded in same treatment T_4 i.e., Foxtail millet + Soybean 2:2 intercropped in 2:2 row proportion than the treatment T_6 i.e., Sole Foxtail millet.

The reason behind this was, legumes typically have deeper tap roots, while Foxtail millet has fibrous roots. This spatial separation reduces competition for nutrients and water, allowing both crops to thrive and utilize resources efficiently also root nodules of legumes such as Soybean, Green gram and Moth bean fix atmospheric nitrogen through symbiosis with Rhizobium bacteria. This enriches the soil nitrogen pool, which is readily available to Foxtail Millet, enhancing its vegetative growth and leaf expansion. The results are in conformity with Singh *et al*. (2023) [10], Sharmili *et al*. (2021) [9], Manjunath and Salakinkop (2018) [8], Himashree *et al*. (2017) [5], Srilakshmi P. *et al*. (2020) [11], Jyostna Kiranmai *et al*. (2021) [6]

Table 1: Growth contributing characters of Foxtail millet and intercrop legumes influenced by different intercropping treatments

Tr. No.	Treatment	Growth contributing characters at harvest						
		Plant height (cm)	Total number of tillers $plant^{-1}$/Total number of branches $plant^{-1}$	Total number of leaves $plant^{-1}$	Leaf area $plant^{-1}$ (dm^2)	Leaf area index	Days to 50% flowering	Dry matter production $plant^{-1}$ (g) at harvest
T_1	Foxtail millet + Green gram (2:2)	110.72 (52.09)	4.63 (6.10)	11.00 (10.30)	4.11 (4.3)	1.37 (1.43)	54.33 (32.11)	17.47 (15.57)
T_2	Foxtail millet + Black gram (2:2)	109.84 (48.12)	4.18 (6.25)	10.70 (9.12)	3.78 (4.75)	1.26 (1.58)	53.33 (32.00)	17.57 (12.06)
T_3	Foxtail millet + Horse gram (2:2)	108.84 (40.18)	3.80 (7.37)	10.13 (35.20)	3.45 (21.76)	1.15 (7.25)	55.97 (54.61)	15.47 (18.10)
T_4	Foxtail millet +Soybean (2:2)	112.04 (54.20)	5.00 (4.80)	12.43 (3.02)	4.29 (5.75)	1.43 (1.91)	53.50 (48.00)	18.27 (36.02)
T_5	Foxtail millet + Moth bean (2:2)	109.43 (24.8)	4.10 (3.4)	10.63 (17.01)	3.66 (17.28)	1.22 (5.76)	54.67 (59.00)	16.40 (9.07)
T_6	Sole Foxtail millet	107.5	3.75	10.03	3.36	1.12	53.33	15.40
T_7	Sole Green gram	55.70	6.15	12.88	4.50	1.5	30.02	17.50
T_8	Sole Black gram	52.01	6.30	10.12	4.90	1.63	30.00	13.15
T_9	Sole Horse gram	42.03	8.15	37.8	23.90	6.96	53.50	21.8
T_{10}	Sole Soybean	56.9	5.92	82.54	6.09	1.71	46.86	37.77
T_{11}	Sole Moth bean	26.68	3.99	3.17	18.00	6	57.00	10.45

Note: Figures in parenthesis indicates values of intercrops

Yield Parameters

Yield and yield-related traits of Foxtail millet were numerically impacted by treatment T_4 i.e., Foxtail millet + Soybean intercropped in 2:2 row proportion which produced the highest number of productive tillers $plant^{-1}$ (5.00), number of panicles $plant^{-1}$ (3.27), panicle length (18.12 cm), panicle weight (9.02 g), grain yield (1135 kg ha^{-1}), straw yield (1934 kg ha^{-1}) and harvest index (36.98) than the treatment T_6 i.e., Sole Foxtail millet which have lowest respected values of 3.75, 2.26, 14.29 cm, 7.36 g, 1598 kg ha^{-1}, 272 kg ha^{-1} and 37.00. The results clearly indicates that soybean intercropping had the most positive influence on the performance of foxtail millet. Among all sole treatments of legumes highest grain yield (2715 kg ha^{-1}), straw yield (3753 kg ha^{-1}) and harvest index (41.98) was observed in treatment T_{10} i.e., Sole soybean.

These results were in close resemblance with Binod Kumar and Pankaj Kumar Ray (2020) [3].

Table 1: Yield contributing characters of Foxtail millet and intercrop legumes influenced by different intercropping treatments

Tr. No.	Treatment	Number of productive tillers plants^{-1}	Number of panicle plants^{-1}/ Number of pods plant^{-1}	Panicle length (cm)	Panicle weight (gm)	Number of pods cluster^{-1}	Number of seeds pod^{-1}	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
T_1	Foxtail millet + Green gram(2:2)	4.69 (-)	2.63 (11.80)	17.61 (-)	8.18 (-)	- (3.33)	- (5.47)	1023 (681)	1797 (1150)	36.27 (37.17)
T_2	Foxtail millet + Black gram (2:2)	4.21 (-)	2.43 (10.87)	15.35 (-)	7.97 (-)	- (3.10)	- (5.47)	991 (644)	1763 (1103)	35.98 (36.85)
T_3	Foxtail millet + Horse gram (2:2)	3.80 (-)	2.33 (25.50)	14.80 (-)	7.33 (-)	- (15.40)	- (5.47)	847 (485)	1753 (977)	32.58 (33.19)
T_4	Foxtail millet +Soybean (2:2)	5.00 (-)	3.27 (62.47)	18.12 (-)	9.02 (-)	- (4.63)	- (5.47)	1135 (1893)	1934 (3144)	36.98 (37.58)
T_5	Foxtail millet + Moth bean (2:2)	4.14 (-)	2.40 (72.67)	15.59 (-)	8.00 (-)	- (3.96)	- (5.47)	911 (335)	1648 (573)	35.60 (36.90)
T_6	Sole Foxtail millet	3.75	2.26	14.29	7.36	0.00	0.00	1598	2721	37.00
T_7	Sole Green gram	-	13.66	-	-	4.33	6.93	1152	1940	37.25
T_8	Sole Black gram	-	11.96	-	-	3.61	5.10	1073	1818	37.12
T_9	Sole Horse gram	-	23.22	-	-	14.30	3.76	988	1916	34.01
T_{10}	Sole Soybean	-	64.70	-	-	5.31	4.15	2715	3753	41.98
T_{11}	Sole Moth bean	-	74.46	-	-	4.62	6.16	526	894	37.05

Note: Figures in parenthesis indicates values of intercrops

Intercropping assessment

Data pertaining about the intercropping assessment revealed that, treatment i.e., Foxtail millet intercropped with Soybean in 2:2 row proportion showed highest Land equivalent ratio (LER), Area time equivalent ratio (ATER) and Foxtail millet equivalent yield of intercrops (FTEY) (kg ha^{-1}), system productivity (kg ha^{-1}) and system profitability (₹ ha^{-1} day^{-1}) of 1.43, 1.43, 2158.18 kg ha^{-1}, 3293.04 kg ha^{-1}, 964.23 ₹ ha^{-1} day^{-1}respectively. But the same treatment showed least aggression over the main crop with the value of aggressivity of -0.005.

Table 3: Effect different intercropping treatments of legumes on intercropping indices of foxtail millet

Tr. No.	Treatments	Intercropping indices					
		Land equivalent ratio	Area time equivalent ratio	Foxtail millet crop equivalent yield of intercrops (kg ha^{-1})	Aggressivity	System productivity (kg ha^{-1})	System profitability (₹ ha^{-1} day^{-1})
T_1	Foxtail millet + Green gram (2:2)	1.25	1.12	1377.78	0.0015	2400.75	688.28
T_2	Foxtail millet + Black gram (2:2)	1.22	1.10	1110.51	0.08	2101.58	563.45
T_3	Foxtail millet + Horse gram (2:2)	1.12	0.97	562.48	0.02	1409.63	290.46
T_4	Foxtail millet +Soybean (2:2)	1.43	1.43	2158.18	-0.005	3293.04	964.23
T_5	Foxtail millet + Moth bean (2:2)	1.20	1.14	546.32	-0.03	637.32	280.76
T_6	Sole Foxtail millet	1.00	1.00	1598.00	0.0015	2400.75	688.28
T_7	Sole Green gram	1.00	1.00	2317.11	-	-	-
T_8	Sole Black gram	1.00	1.00	1850.86	-	-	-
T_9	Sole Horse gram	1.00	1.00	1149.32	-	-	-
T_{10}	Sole Soybean	1.00	1.00	3096.40	-	-	-
T_{11}	Sole Moth bean	1.00	1.00	858.27	-	-	-

All this results were in close resemblance with Bana *et al.* (2016) [2], Keerthanapriya *et al.* (2019) [7], Biradar *et al.* (2020) [4] on intercropping millets with legumes.

Conclusion

The study on the " Enhancing Foxtail millet productivity with legume intercrops" was conducted during the *kharif* season of 2024 conducted during the kharif season of 2024-2025 demonstrated that the intercropping treatments of Foxtail millet with different legumes numerically influenced growth and yield attributes along with the intercropping indices. Among the different intercropping treatments, treatment T_4 i.e., Foxtail millet intercropped with Soybean in 2:2 row proportion recorded highest plant height of 112.04 cm, along with an increased number of tillers plant^{-1} (5.00), number of leaves plant^{-1} (12.43), leaf area plant^{-1} (4.29 dm^2), leaf area index (1.43) and dry matter production plant^{-1} (18.27 g). Furthermore, it resulted in the maximum grain yield (1135 kg ha^{-1}), straw yield (1934 kg ha^{-1}) alongside a harvest index of 36.98% over other intercropping treatments including the treatment of sole Foxtail millet. The findings indicate that intercropping of Foxtail millet with soybean contributes in increase of growth and yield attributes of Foxtail millet. Overall, the results suggest that intercropping of Foxtail millet with Soybean could optimize its production, monetary returns and benefit cost ratio.

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