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Sravani Arem
Ph.D. Scholar, Department of
agronomy, College of Agriculture,
PJTSU, Rajendranagar,
Hyderabad, Telangana, India

Dr. G Manjulatha
Professor, Department of
Agronomy, Agricultural College,
Adilabad

Dr. Ch. Pragathi Kumari
Professor, Department of
Agronomy, Agricultural College,
Palem

Dr. Kiran Reddy Gade
Assistant Professor, Department of
Soil Science, Agricultural College,
Huzurnagar

Dr. D Srinivasa Chary
Professor, Department of Applied
Agriculture and Basic sciences,
College of Agricultural
Engineering, Kandi

Corresponding Author:
Sravani Arem
Ph.D. Scholar, Department of
agronomy, College of Agriculture,
PJTSU, Rajendranagar,
Hyderabad, Telangana, India

Optimization of foxtail millet legume intercropping system for sustainable growth, yield performance and resource use efficiency

Sravani Arem, G Manjulatha, Ch. Pragathi Kumari, Kiran Reddy Gade and D Srinivasa Chary

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Abstract

A field investigation entitled “Optimization of foxtail millet legume intercropping system for sustainable growth, yield performance and resource use efficiency” was conducted during *khari*f, 2023-24 and 2024-25, at Agricultural Research Station, Karimnagar, Telangana. The experiment was laid out in a Randomized Block Design with three replications and fourteen treatments viz., T₁: Finger millet + Greengram (4:2), T₂: Finger millet + Greengram (6:2), T₃: Finger millet + Blackgram (4:2), T₄: Finger millet + Black gram (6:2), T₅: Finger millet + Pigeon pea (4:1), T₆: Finger millet + Pigeon pea (5:1), T₇: Foxtail millet + Green gram (4:2), T₈: Foxtail millet + Greengram (6:2), T₉: Foxtail millet + Black gram (4:2), T₁₀: Foxtail millet + Black gram (6:2), T₁₁: Foxtail millet + Pigeon pea (4:1), T₁₂: Foxtail millet + Pigeon pea (5:1), T₁₃: Sole finger millet and T₁₄: Sole foxtail millet. All the growth and yield parameters viz., plant height, number of tillers m⁻² and dry matter ha⁻¹, number of panicle m⁻², length of panicle, panicle weight, grain weight panicle⁻¹, 1000 grain weight, grain yield, stalk yield, biological yield and harvest index were recorded higher in T₁₁ and T₁₂ i.e., Foxtail millet + Pigeonpea in (4:1) and (5:1) row ratio than other intercropping treatments. However, T₁₄ i.e., sole foxtail millet recorded higher growth and yield contributing characters and was on par with foxtail millet intercropped with pigeonpea in 4:1 and 5:1 ratio and blackgram in 4:2 ratio during 2023-24 and 2024-25 respectively.

Keywords: Blackgram, foxtail millet, greengram, intercropping, legumes and pigeonpea

1. Introduction

Foxtail millet is a short duration small millet known for its remarkable drought tolerance and versatility to different agroecological regions, especially under rainfed conditions as it requires less water and external inputs than major cereals and ability to withstand adverse weather conditions makes foxtail millet suitable climate resilient crop for semi-arid regions. However, sole cultivation of foxtail millet may not fully utilize available resources, that limit plant growth and yield particularly under low fertile soils. In semi-arid region is characterised by uneven distribution of rainfall, poor soil fertility, climatic uncertainties, prolonged dry spells necessitating the adoption of intercropping system is an effective strategy for achieving sustainable crop productivity. Among the various intercropping combinations, millet legume based intercropping system gained considerable attention in semi-arid regions, due to its ability to improve soil fertility, resource use efficiency and risk of total crop failure, if one crop fails due to drought or pest incidence, the companion crop will provide additional yield and income, thereby improving crop resilience. All these characters make foxtail millet an alternate crop for subsistence farmers during the failure of monsoons in major crop growing areas (Renganathan *et al.*, 2020) [15].

Intercropping foxtail millet with legumes viz., greengram, blackgram and pigeonpea provides positive interaction that improve the overall system efficiency as, legumes fix atmospheric nitrogen in the soil through symbiotic association, thereby reduce the dependence on external fertilizers (Stagnari *et al.*, 2017 and Meena *et al.*, 2018) [17, 9]. Furthermore, after harvesting of pods, legume crop residues are incorporated in to the soil to add organic matter, improve soil

physical, chemical and biological properties which enhances long term soil fertility, considered legumes as an inevitable choice for intercropping systems (Jena *et al.*, 2022) [8]. The contrasting rooting patterns of both main and intercrops enable the efficient use of water, nutrients, light and space which reduce the interspecific competition among crops and improve crop growth and development.

2. Materials and Methods

A field experiment was carried out during *kharif* season, 2023-24 and 2024-25 at Agricultural Research Station, Karimnagar, Telangana, India. The experimental soil was sandy loam in texture, neutral in (pH 6.6), low in EC (0.2), medium in organic carbon (0.6 per cent) and low in available nitrogen (207 kg ha⁻¹), high in available phosphorus (28.8 kg ha⁻¹) and potassium (303.3 kg ha⁻¹). The experiment was laid out Randomized Block Design with fourteen treatments replicated thrice. The treatments viz., T₁: Finger millet + Greengram (4:2), T₂: Finger millet + Greengram (6:2), T₃: Finger millet + Blackgram (4:2), T₄: Finger millet + Black gram (6:2), T₅: Finger millet + Pigeon pea (4:1), T₆: Finger millet + Pigeon pea (5:1), T₇: Foxtail millet + Green gram (4:2), T₈: Foxtail millet + Greengram (6:2), T₉: Foxtail millet + Black gram (4:2), T₁₀: Foxtail millet + Black gram (6:2), T₁₁: Foxtail millet + Pigeon pea (4:1), T₁₂: Foxtail millet + Pigeon pea (5:1), T₁₃: Sole finger millet and T₁₄: Sole foxtail millet. Both the millet as well as component crops greengram and blackgram were sown by dibbling with 30 × 10 cm and pigeonpea 60 × 20 cm by adopting all the standard package of practices. Fertilizers were applied as per PJTAU recommendations to all crops based on area occupied by respective crops. As both the millets are morphologically different separate analysis for each crop was done.

3. Results and Discussion

3.1 Plant height of foxtail millet (cm)

The data on plant height at 30, 60, 90 DAS and at harvest stage of foxtail millet is significantly influenced by millets + legume intercropping during *kharif*, 2023-24 and 2024-25 (Table 1).

Among foxtail millet based intercropping systems, foxtail millet + pigeonpea (4:1) ratio (T₁₁) recorded the higher plant height at 30, 60, 90 DAS and at harvest stage (53.2 and 48.5 cm), (116.2 and 113.3 cm), (126.2 and 122.4 cm) and (128.7 and 131.3 cm) during 2023-24 and 2024-25 respectively. It was on par with T₁₂ (52.4 and 48.2 cm), T₉ (51.7 and 45.5 cm) and T₇ (48.6 and 45.0 cm) at 30 DAS during 2023-24 and 2024-25 respectively and T₁₀ (44 cm) during 2024-25 and at 60 DAS, T₁₂ (112.9 and 111.8 cm), T₉ (107.2 and 105.9 cm) during 2023-24 and 2024-25 respectively and T₇ (104.3 cm) during 2024-25. However, at 90 DAS and harvest T₁₁ was on par with T₁₂ (123.2 and 119.7 cm) and (125.7 and 130.3 cm), T₉ (121.2 and 118.7 cm) and (123.7 and 130 cm) during 2023-24 and 2024-25 respectively. However, on other hand, sole foxtail millet (T₁₃) recorded significantly higher plant height at 30, 60, 90 DAS and at harvest stage (56.9 and 50.8 cm), (118.3 and 115.7 cm), (129.0 and 126.4 cm) and (132.1 and 134.8 cm), which is on par with T₁₁ and T₁₂ during 2023-24 and 2024-25 respectively and statistically on par with foxtail millet + pigeonpea based intercropping systems. While, statistically lower plant height was recorded with foxtail millet + greengram (6:2) ratio (T₈) at 30, 60, 90 DAS and harvest (48.6 and 45.0 cm), (100.8 and 98.6 cm), (110.4 and 109.2 cm) and (112.9 and 112.9 cm) during

2023-24 and 2024-25 respectively.

Among foxtail millet intercropping system, higher plant height recorded in foxtail millet + pigeonpea (4:1) and (5:1) ratio and blackgram with 4:2 ratio may be attributed to pigeonpea, being a slower-growing and deep-rooted crop, exerted minimal competition above and below ground from the early stages, enabling foxtail millet to take advantage of improved light penetration and reduced canopy competition. Increase in plant height of sole foxtail millet than all other intercropping systems might be due to absence of interspecific competition, which allow the crop to fully exploit all available resources, resulting in better vegetative growth. Dharshan reported that higher growth parameters were observed in sole treatments compared to 4:2 and 2:1 row ratio of millets and legume intercropping system because resources were used more effectively, there was space between rows of browntop millet for proper distribution of resources, which led to an increase in cellular components, particularly protoplasm, which increased the turgidity of plant cells and caused an expansion of the cell wall. Ghosh (2004) [5] also observed that intercropping legumes with cereals generally led to increase in plant height of cereals and reduced plant height in leguminous crops like pulses. Nandini and Sridhara (2019) [10] noted that the improvement in plant height was due to interaction effect of spacing and genotype on proper establishment of crop. Similar findings also reported by Basavarajappa *et al.* (2003) [3].

3.2 Number of tillers (m⁻²) in foxtail millet

The data on number of tillers per m² at 60, 90 DAS and at harvest stage of foxtail millet is significantly influenced by millets + legume intercropping during *kharif*, 2023-24 and 2024-25 (Table 2).

In foxtail milled based intercropping systems, foxtail millet + pigeonpea (4:1) ratio (T₁₁) recorded higher number of tillers at 60 DAS (79.2 and 87.8 m⁻²), during 2023–24 and 2024–25, respectively. It was statistically on par with T₁₂ (76.2 and 87.4 m⁻²) and T₉ (75.6 and 82.2 m⁻²) and T₇ (72.7 and 80.6 m⁻²) during 2023–24 and 2024–25, respectively.

As there was no change or increase in tiller production from 90 DAS to harvest stage in foxtail millet during 2023-24 and 2024-25 respectively, number of tillers at harvest stage was mentioned. At harvest stage, foxtail millet + pigeonpea (4:1) ratio (T₁₁) registered higher tiller count at harvest (97.2 and 96.1 m⁻²), on par with T₁₂ (94.2 and 95.8 m⁻²) and T₉ (93.6 and 90.2 m⁻²) during 2023-24 and 2024-25 respectively. Significantly, higher number of tillers m⁻² was recorded in sole foxtail millet (T₁₄) at 60 DAS (82.4 and 90.0 m⁻²) and harvest (99.1 and 97.7 m⁻²) than all other intercropping treatments but it was statistically comparable with T₁₁ and T₁₂ during 2023-24 and 2024-25 respectively. On the other hand, significantly lower number of tillers m⁻² was recorded in T₈ (65.4 and 77.3 tillers m⁻²) and (83.4 and 85.9 m⁻²) at 60 DAS and harvest stage.

Foxtail millet intercropped with pigeonpea, Pigeonpea with erect plant architecture, slow growing and deep rooting nature of pigeonpea reduced the competition with foxtail millet during its peak vegetative stage. Sole foxtail millet recorded significantly higher tillers m⁻² due to unrestricted access to soil moisture, nutrients, sunlight and space, which favoured tiller initiation and survival. Foxtail millet + vegetable cowpea intercropping system, increase in number of tillers due to compatible rooting pattern leads to tillers survival by Arvind *et al.* (2023).

Table 1: Plant height (cm) of foxtail millet as influenced by foxtail millet + legume intercropping system during *kharif*, 2023-24 and 2024-25

Plant height (cm) of foxtail millet						
Treatments	At 30 DAS			At 60 DAS		
	2023-24	2024-25	Mean	2023-24	2024-25	Mean
T ₇ : Foxtail millet + Greengram (4:2)	48.6	45.0	46.8	105.1	104.3	104.7
T ₈ : Foxtail millet + Greengram (6:2)	44.5	42.6	43.5	100.8	98.6	99.7
T ₉ : Foxtail millet + Blackgram (4:2)	51.7	45.5	48.6	107.2	105.9	106.5
T ₁₀ : Foxtail millet + Blackgram (6:2)	46.5	44.0	45.2	104.6	98.9	101.7
T ₁₁ : Foxtail millet + Pigeon pea (4:1)	53.2	48.5	50.8	116.2	113.3	114.7
T ₁₂ : Foxtail millet + Pigeon pea (5:1)	52.4	48.2	50.3	112.9	111.8	112.4
T ₁₄ : Sole foxtail millet	56.9	50.8	53.8	118.3	115.7	117.0
S. Em ±	1.60	1.59		3.71	3.32	
CD	4.79	4.77		11.12	9.94	
Treatments	At 90 DAS			At harvest		
	2023-24	2024-25	Mean	2023-24	2024-25	Mean
T ₇ : Foxtail millet + Greengram (4:2)	115.1	110.6	112.8	117.6	118.5	118.1
T ₈ : Foxtail millet + Greengram (6:2)	110.4	109.2	109.8	112.9	112.9	112.9
T ₉ : Foxtail millet + Blackgram (4:2)	121.2	118.7	120.0	123.7	130.0	126.9
T ₁₀ : Foxtail millet + Blackgram (6:2)	114.6	109.4	112.0	117.1	117.0	117.0
T ₁₁ : Foxtail millet + Pigeon pea (4:1)	126.2	122.4	124.3	128.7	131.0	129.9
T ₁₂ : Foxtail millet + Pigeon pea (5:1)	123.2	119.7	121.5	125.7	130.3	128.0
T ₁₄ : Sole foxtail millet	129.0	126.4	127.7	132.1	134.8	133.5
S. Em ±	3.44	3.55		3.52	3.85	
CD	10.31	10.63		10.57	11.55	

Table 2: Number of tillers m⁻² of foxtail millet as influenced by foxtail millet + legume intercropping during *kharif*, 2023-24 and 2024-25

Number of tillers m ⁻² of foxtail millet									
Treatments	At 60 DAS			At 90 DAS			At harvest		
	2023-24	2024-25	Mean	2023-24	2024-25	Mean	2023-24	2024-25	Mean
T ₇ : FTM + GG (4:2)	72.7	80.6	76.6	90.7	88.6	89.7	90.7	88.6	89.7
T ₈ : FTM + GG (6:2)	65.4	77.3	71.3	83.4	85.9	84.7	83.4	85.9	84.7
T ₉ : FTM + BG (4:2)	75.6	82.2	78.9	93.6	90.2	91.9	93.6	90.2	91.9
T ₁₀ : FTM + BG (6:2)	68.6	78.8	73.7	86.6	87.2	86.9	86.6	87.2	86.9
T ₁₁ : FTM + PP (4:1)	79.2	87.8	83.3	97.2	96.1	96.6	97.2	96.1	96.6
T ₁₂ : FTM + PP (5:1)	76.2	87.4	82.0	94.2	95.8	95.0	94.2	95.8	95.0
T ₁₄ : Sole FTM	82.4	90.0	86.2	99.1	97.7	98.4	99.1	97.7	98.4
S. Em ±	2.37	2.63		2.00	2.71		2.00	2.71	
CD	7.09	7.87		5.99	8.12		5.99	8.12	

Note: FTM: Foxtail millet GG: Greengram BG: Blackgram PP: Pigeonpea

3.3 Dry matter production (kg ha⁻¹) in foxtail millet

Dry matter production (kg ha⁻¹) at 30, 60, 90 DAS and at harvest stage of foxtail millet as influenced by millets + legume intercropping during *kharif*, 2023-24 and 2024-25 (Table 3).

Among foxtail millet based intercropping systems, foxtail millet + pigeonpea (5:1) ratio (T₁₂) recorded higher dry matter production at 30, 60 and 90 DAS and at harvest (700 and 757 kg ha⁻¹), (3214 and 3371 kg ha⁻¹), (3902 and 4371 kg ha⁻¹) and (3952 and 4466 kg ha⁻¹) during 2023–24 and 2024–25, respectively, which on par with T₁₁ at 60, 90 DAS and at harvest (3140, 3863 and 3908 kg ha⁻¹) during 2023-24. The dry matter production of foxtail millet at 30, 60 and 90 DAS and at harvest recorded significantly higher with sole foxtail millet (T₁₃) (1001, 3479, 5179 and 5230 kg ha⁻¹) and (1008, 3735, 4935 and 5037 kg ha⁻¹) during *kharif*, 2023–24 and 2024–25 respectively than remaining intercropping systems. The lowest drymatter production at all the stages of crop growth was recorded with T₇ (430, 2034, 3493 and 3543 kg ha⁻¹) and (443, 2271, 3371 and 3471 kg ha⁻¹) during 2023–24 and 2024–25, respectively.

Among the foxtail millet legume based intercropping systems, higher dry matter production was under foxtail millet + pigeonpea (5:1) and (4:1) ratio may be attributed to better spatial and temporal complementarity exist between the component crops. The wider row arrangement in pigeonpea provided adequate light penetration and growing space, resulting in

greater interception of sunlight and enhanced biomass production by photosynthesis. Significantly higher dry matter production of foxtail millet recorded with sole foxtail millet throughout the crop growing period may be attributed to rapid canopy development, higher leaf area, photosynthetic efficiency and greater accumulation of assimilates which led to higher biomass production.

Conversely, lower dry matter production under greengram based intercropping systems, particularly with foxtail millet + greengram (4:2) ratio may be due to greater competition for moisture, nutrients and light and space caused by the higher density and quick growth of greengram, restricted the vegetative growth and dry matter accumulation in foxtail millet. Rajani *et al.* (2022) [13] reported that better drymatter accumulation in leaf, stem and reproductive parts due to the absence or less competition in millet + oilseed intercropping system which in turn maximizes total drymatter production by enhancing plant height, tillers and leaf area index.

3.4 Yield attributes and yield of foxtail millet

3.4.1 Number of panicles m⁻² in foxtail millet

The number of panicles m⁻² of foxtail millet was significantly influenced by millet legume based intercropping systems during *kharif*, 2023–24 and 2024–25 (Table 5).

When foxtail millet intercropped with legumes, higher number

of panicles m^{-2} was recorded with foxtail millet + pigeonpea (4:1) (T_5) (96.4 and 94.9), on par with T_6 (93.4 and 94.6) and T_3 (92.8 and 89.0) during 2023–24 and 2024–25, respectively. Among the remaining intercropping systems, T_1 recorded comparatively higher number of panicles m^{-2} (89.9 and 87.4), followed by T_4 (85.8 and 86.0). The lowest number of panicles m^{-2} was recorded with T_2 (82.6 and 84.7) during 2023–24 and 2024–25, respectively. Significantly higher number of panicles m^{-2} was recorded with sole foxtail millet (T_{13}) (97.0 and 96.8) than all other treatments, which was found to be statistically on par with T_5 and T_6 during 2023–24 and 2024–25, respectively. Foxtail millet + pigeonpea (4:1) and (5:1) ratio and foxtail millet + blackgram (4:2) ratio statistically equal with sole foxtail millet

may be attributed to better vegetative growth, higher tiller survival by availability of nitrogen through biological nitrogen fixation and efficient utilization of available resources. Sandesha Anishetra (2019) reported that sesame + foxtail millet (2:4) ratio recorded higher number of panicles over sesame + foxtail millet (1:2) due to least competition among the intercrop for different growth and other resources. Higher number of panicles m^{-2} recorded under sole foxtail millet due to absence of interspecific competition enabled foxtail millet to exploit light, soil moisture, nutrients and space more effectively, resulting in the production of a greater number of productive tillers, which ultimately developed into panicles.

Table 3: Dry matter production kg ha^{-1} of foxtail millet as influenced by foxtail millet + legume intercropping during *kharif*, 2023-24 and 2024-25

Dry matter production kg ha^{-1} of foxtail millet						
Treatments	At 30 DAS			At 60 DAS		
	2023-24	2024-25	Mean	2023-24	2024-25	Mean
T_7 : Foxtail millet + Greengram (4:2)	430	443	437	2034	2271	2153
T_8 : Foxtail millet + Greengram (6:2)	520	524	522	2493	2521	2507
T_9 : Foxtail millet + Blackgram (4:2)	484	473	479	2737	2345	2541
T_{10} : Foxtail millet + Blackgram (6:2)	546	533	540	2917	2625	2771
T_{11} : Foxtail millet + Pigeon pea (4:1)	664	675	670	3140	3022	3081
T_{12} : Foxtail millet + Pigeon pea (5:1)	700	757	728	3214	3371	3293
T_{14} : Sole foxtail millet	1001	1008	1004	3479	3735	3607
S. Em $\pm$	6	10		64	35	
CD	19	29		192	104	
Treatments	At 90 DAS			At harvest		
	2023-24	2024-25	Mean	2023-24	2024-25	Mean
T_7 : Foxtail millet + Greengram (4:2)	3493	3371	3432	3543	3471	3507
T_8 : Foxtail millet + Greengram (6:2)	3724	3601	3663	3776	3699	3738
T_9 : Foxtail millet + Blackgram (4:2)	3670	3444	3557	3715	3540	3628
T_{10} : Foxtail millet + Blackgram (6:2)	3712	3711	3712	3838	3806	3822
T_{11} : Foxtail millet + Pigeon pea (4:1)	3863	4022	3943	3908	4118	4013
T_{12} : Foxtail millet + Pigeon pea (5:1)	3902	4371	4137	3952	4466	4209
T_{14} : Sole foxtail millet	5179	4935	5057	5230	5037	5134
S. Em $\pm$	49	35		49	35	
CD	148	104		148	104	

Table 4: Number of panicles m^{-2} of foxtail millets as influenced by foxtail millet + legume intercropping during *kharif*, 2023-24 and 2024-25

Treatments	Number of panicles m^{-2}		
	2023-24	2024-25	Mean
T_7 : Foxtail millet + Greengram (4:2)	89.9	87.4	88.7
T_8 : Foxtail millet + Greengram (6:2)	82.6	84.7	83.7
T_9 : Foxtail millet + Blackgram (4:2)	92.8	89.0	90.9
T_{10} : Foxtail millet + Blackgram (6:2)	85.8	86.0	85.9
T_{11} : Foxtail millet + Pigeonpea (4:1)	96.4	94.9	95.6
T_{12} : Foxtail millet + Pigeonpea (5:1)	93.4	94.6	94.0
T_{14} : Sole Foxtail millet	97.0	96.8	96.9
S. Em $\pm$	1.67	2.77	
CD ($p = 0.05$)	4.99	8.30	

3.4.2 The length of panicle (cm), panicle weight (g), grain weight panicle⁻¹ (g) and 1000-grain weight (g) of foxtail millet

The length of panicle (cm), panicle weight (g), grain weight panicle⁻¹ (g) and 1000-grain weight (g) of foxtail millet as influenced by millet legume intercropping systems during *kharif*, 2023–24 and 2024–25 (Table 6).

The length of panicle, grain weight panicle⁻¹ (g) and 1000-grain weight (g) of foxtail millet were not significantly influenced by the intercropping systems during 2023-24 and 2024-25 respectively.

The panicle weight differed significantly among the intercropping systems during 2023-24 and 2024-25. Among foxtail millet legume based intercropping system with legumes, higher panicle weight was recorded with foxtail millet + pigeonpea (4:1) ratio (T_{11}) (7.9 and 7.1 g) and which on par with T_{12} (7.8 and 7.1 g) and T_9 (7.4 and 6.8 g) during 2023–24 and 2024–25, respectively and T_7 (7.2 g) during 2023-24. Significantly, lowest panicle weight was registered with T_2 (7.0 and 6.0 g) during 2023–24 and 2024–25, respectively. Significantly higher panicle weight among all treatments was recorded with sole foxtail millet (T_{14}) (8.0 and 7.3 g), which was found to be statistically on par with T_{11} and T_{12} during 2023-24 and 2024-25 respectively.

Millet pigeonpea-based intercropping systems, higher panicle weight was recorded due to less competition for resources from component crop during the critical growth stages of foxtail millet. Sukanya *et al.* (2024) [18] also noted that crop yield attributes with all sole crop is superior to intercropping and this is owing to the low resource struggle with sole cropping. Similar findings also reported with Patil (2010) [12], Ahlawat *et al.* (2005) [1] and Girish (2004) [6]. The absence of interspecific competition under sole foxtail millet facilitated better utilization of light, moisture, nutrients and growing space which leading to enhanced photosynthetic activity and increased accumulation of assimilates in the developing panicles.

3.4.3 Grain, stalk, biological yield (kg ha⁻¹) and harvest index of foxtail millet

The grain, stalk, biological yield (kg ha⁻¹) and harvest index of foxtail millet were influenced by millet legume based intercropping systems during *kharif*, 2023–24 and 2024–25 (Table 7).

Among foxtail millet legume based intercropping systems, higher grain, stalk and biological yield was recorded by foxtail millet + pigeonpea (5:1) ratio (T₁₂) (1935 and 1853 kg ha⁻¹), (1996 and 2590 kg ha⁻¹) and (3952 and 4466 kg ha⁻¹) during 2023-24 and 2024-25 respectively, which on par with T₅ (1935 and 1853 kg ha⁻¹), (1973 and 2266 kg ha⁻¹) and (3908 and 4118 kg ha⁻¹) during 2023-24 and 2024-25 respectively and T₁₀ (1990, 1938 and 3838 kg ha⁻¹) during 2023-24. Significantly higher grain, stalk and biological yield was recorded with sole foxtail millet (T₁₄) (2002 and 1950 kg ha⁻¹), (3228 and 3088 kg ha⁻¹) and (5230 and 5037 kg ha⁻¹) than other intercropping systems, during 2023–24 and 2024–25, respectively, which was found to be statistically similar with T₁₁ and T₁₂ during 2023–24. Significantly, lowest grain, stalk and biological yield was recorded with T₇ (1754 and 1636 kg ha⁻¹), (1789 and 1836 kg ha⁻¹) and (3543 and 3471 kg ha⁻¹) during 2023–24 and 2024–25, respectively.

The harvest index was significantly influenced by the intercropping systems during 2023-24 and 2024-25. Significantly higher harvest index was recorded with T₇, T₈, T₉,

T₁₀, T₁₁ and T₁₂, all recorded (49.50) during 2023–24. During 2024–25, the higher harvest index was recorded with foxtail millet + blackgram (6:2) ratio (T₁₀) (47.25), which was statistically on par with T₈ (47.21), T₉ (47.15) and T₇ (47.12). The lowest harvest index was recorded with sole foxtail millet (T₁₄), registered 38.28 and 38.70 during 2023–24 and 2024–25, respectively.

Among the foxtail millet-based intercropping systems, foxtail millet with pigeonpea at (5:1) and (4:1) ratios produced higher grain, stalk and biological yields than other all intercropping systems. The higher productivity of foxtail millet with pigeonpea based systems may be attributed to deep rooting nature of pigeonpea, which exploits moisture and nutrients from deeper soil layers. This spatial differentiation in resource extraction pattern minimizes interspecific competition. Himasree (2019) [7] reported that higher yield in foxtail millet due to higher vegetative growth, plant height, number of tillers hill⁻¹ and higher dry matter accumulation. Similar results were reported by Ramachandrappa *et al.* (2016) [14] and Nigade *et al.* (2012) [11]. The significantly higher grain, stalk and biological yield recorded under sole foxtail millet and its statistical parity with foxtail millet + pigeonpea (5:1) ratio for grain and biological yield may be attributed to the absence of interspecific competition, which enabled the foxtail millet to utilize all available resources more efficiently

Table 6: Yield attributes of foxtail millets as influenced by foxtail millet + legume intercropping during *kharif*, 2023-24 and 2024-25

Treatments	Yield attributes of foxtail millet											
	Length of panicle (cm)			panicle weight (g)			Grain weight panicle ⁻¹ (g)			1000 grain weight (g)		
	2023-24	2024-25	Mean	2023-24	2024-25	Mean	2023-24	2024-25	Mean	2023-24	2024-25	Mean
T ₇ : Foxtail millet + Greengram (4:2)	20.5	20.3	20.4	7.2	6.3	6.7	3.2	3.1	3.1	3.0	2.8	2.9
T ₈ : Foxtail millet + Greengram (6:2)	19.8	19.9	19.9	7.0	6.0	6.5	3.1	3.0	3.0	2.7	2.4	2.6
T ₉ : Foxtail millet + Blackgram (4:2)	20.6	20.7	20.7	7.4	6.8	7.1	3.2	3.3	3.3	3.2	2.9	3.1
T ₁₀ : Foxtail millet + Blackgram (6:2)	20.3	19.9	20.1	7.1	6.1	6.6	3.1	3.1	3.1	3.1	2.7	2.9
T ₁₁ : Foxtail millet + Pigeonpea (4:1)	21.0	21.1	21.0	7.9	7.1	7.5	3.5	3.4	3.5	3.5	3.2	3.3
T ₁₂ : Foxtail millet + Pigeonpea (5:1)	20.7	20.7	20.7	7.8	7.1	7.4	3.4	3.4	3.4	3.4	3.1	3.2
T ₁₄ : Sole foxtail millet	21.3	21.4	21.3	8.0	7.3	7.6	3.6	3.7	3.6	3.6	3.2	3.4
S. Em±	0.38	0.46		0.23	0.20		0.23	0.21		0.18	0.16	
CD (p=0.05)	NS	NS		0.70	0.61		NS	NS		NS	NS	

Table 7: Grain, stalk, biological yield (kg ha⁻¹) and harvest index of foxtail millet as influenced by foxtail millet + legume intercropping during *kharif*, 2023-24 and 2024-25

Treatments	Grain yield (kg ha ⁻¹)			Stalk yield (kg ha ⁻¹)			Biological yield (kg ha ⁻¹)			Harvest index		
	2023-24	2024-25	Mean	2023-24	2024-25	Mean	2023-24	2024-25	Mean	2023-24	2024-25	Mean
T ₇ : Foxtail millet + Greengram (4:2)	1754	1636	1695	1789	1836	1812	3543	3471	3507	49.50	47.12	48.31
T ₈ : Foxtail millet + Greengram (6:2)	1869	1747	1808	1907	1953	1930	3776	3699	3738	49.50	47.21	48.36
T ₉ : Foxtail millet + Blackgram (4:2)	1839	1669	1754	1876	1871	1874	3715	3540	3628	49.50	47.15	48.33
T ₁₀ : Foxtail millet + Blackgram (6:2)	1900	1798	1849	1938	2008	1973	3838	3806	3822	49.50	47.25	48.38
T ₁₁ : Foxtail millet + Pigeonpea (4:1)	1935	1853	1894	1973	2266	2119	3908	4118	4013	49.50	44.99	47.25
T ₁₂ : Foxtail millet + Pigeonpea (5:1)	1957	1876	1916	1996	2590	2293	3952	4466	4209	49.50	42.00	45.75
T ₁₄ : Sole Foxtail millet	2002	1950	1976	3228	3088	3158	5230	5037	5134	38.28	38.70	38.49
S. Em±	24	17		25	18		49	35		0.002	0.037	
CD (p=0.05)	73	51		74	53		148	104		0.006	0.112	

4. Conclusion

During two-year field investigation, it can be concluded that intercropping of foxtail millet + pigeonpea at 4:1 and 5:1 row ratio proved to be the most efficient and productive intercropping systems, registering all growth and yield parameters compared to all other millet legume intercropping combinations, which performed on par with sole foxtail millet, indicating that pigeonpea is the most compatible component crop with foxtail millet. Hence, foxtail millet + pigeonpea

intercropping in 4:1 or 5:1 row ratio recommended as a profitable and sustainable cropping system semi-arid tropics of Telangana state.

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