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Dimple KT
Department of Agronomy, Acharya NG
Ranga Agricultural University, Guntur,
Andhra Pradesh, India

Gundupalli Krishna Reddy
Department of Agronomy, Acharya NG
Ranga Agricultural University, Guntur,
Andhra Pradesh, India

Gajanan Sawargaonkar
International Crops Research Institute for
the Semi-Arid Tropics, Patancheru,
Hyderabad, Telangana, India

P Sudhakar
Department of Crop Physiology, Acharya NG
Ranga Agricultural University,
Guntur, Andhra Pradesh, India

Pushpajeet Choudhari
International Crops Research Institute for
the Semi-Arid Tropics, Patancheru,
Hyderabad, Telangana, India

M Raveendra Reddy
Department of Microbiology, Acharya NG
Ranga Agricultural University, Guntur,
Andhra Pradesh, India

Prasad J Kamdi
International Crops Research Institute for
the Semi-Arid Tropics, Patancheru,
Hyderabad, Telangana, India

Rakesh Savan
International Crops Research Institute for
the Semi-Arid Tropics, Patancheru,
Hyderabad, Telangana, India

Santosh Kale
International Crops Research Institute for
the Semi-Arid Tropics, Patancheru,
Hyderabad, Telangana, India

Akash Paul
International Crops Research Institute for
the Semi-Arid Tropics, Patancheru,
Hyderabad, Telangana, India

Ankit Kumar Shridhar
International Crops Research Institute for
the Semi-Arid Tropics, Patancheru,
Hyderabad, Telangana, India

Ramesh Singh
International Crops Research Institute for
the Semi-Arid Tropics, Patancheru,
Hyderabad, Telangana, India

Corresponding Author:
Ramesh Singh
International Crops Research Institute for
the Semi-Arid Tropics, Patancheru,
Hyderabad, Telangana, India

Cropping system-driven variability in pearl millet growth under regenerative agricultural practices in Alfisol

Dimple KT, Gundupalli Krishna Reddy, Gajanan Sawargaonkar, M Raveendra Reddy, Pushpajeet Choudhari, P Sudhakar, Prasad J Kamdi, Rakesh Savan, Santosh Kale, Akash Paul, Ankit Kumar Shridhar and Ramesh Singh

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Abstract

Declining soil health due to monocropping and imbalanced nutrient management necessitates adopting regenerative agricultural practices. A two-year field experiment was conducted during *kharif*, 2023 and 2024 on *Alfisols* at ICRISAT, Hyderabad, to evaluate the influence of cropping systems and regenerative practices on the growth dynamics of pearl millet. The experiment was laid out in a split-plot design with three cropping systems as main plots M₁: pearl millet + pigeonpea (2:1), M₂: groundnut + pearl millet (4:1)-sunflower, and M₃: pearl millet - groundnut. Three regenerative practices as subplots S₁: soil test-based fertilizer (STBF), S₂: STBF + mulch, and S₃: STBF + mulch + biological consortia. Results indicated that cropping systems significantly influenced growth parameters. The groundnut + pearl millet (4:1) - sunflower system (M₂) recorded significantly higher plant height, dry matter accumulation, crop growth rate (CGR), and absolute growth rate (AGR), while the pearl millet-groundnut system (M₃) exhibited higher leaf area. Among regenerative practices, S₃ (STBF + mulch + biological consortia) resulted in superior plant height, leaf area, dry matter production, CGR, and AGR compared to S₂ and S₁. Interaction effects between cropping systems and regenerative practices were non-significant across all parameters. The study highlights that integration of diversified cropping systems with regenerative practices, particularly the combined application of STBF, mulch, and biological consortia, enhances the growth performance of pearl millet in *Alfisols* under semi-arid conditions.

Keywords: Cropping systems, growth, pearl millet, physiology and regenerative agriculture

1. Introduction

Pearl millet (*Pennisetum glaucum*) is the fifth most important cereal after rice, wheat, maize, and sorghum, which is being cultivated on around 27 M ha worldwide. It is a member of the Poaceae family, serves as a vital staple food for millions of people, especially in the arid and semi-arid regions of Asia and Africa (Jukanti *et al.*, 2016) [8]. Its remarkable ability to flourish under harsh conditions where many other cereals fail makes it a key contributor to global food security (Shrestha *et al.*, 2023) [26]. Notably, pearl millet exhibits exceptional resilience, thriving in environments characterized by higher temperatures, limited rainfall, and poor soil fertility (Satyavathi *et al.*, 2021) [22]. This enables pearl millet to thrive in areas where most other crops cannot, making it an essential contributor to food security in harsh and unpredictable climates (Daduwal *et al.*, 2024) [4]. Pearl millet provides a balanced source of carbohydrates, proteins, essential fatty acids, and dietary fiber, which supports digestive health (Kumar *et al.*, 2024) [10]. In addition, it is abundant in essential micronutrients, including iron, zinc, magnesium, calcium, phosphorus, and B vitamins, all of which are vital for metabolic functions and immune health (Saleh *et al.*, 2013) [20]. The grain also contains bioactive compounds including flavonoids, polyphenols, and tannins that contribute to its strong antioxidant and anti-inflammatory properties. According to Babypriyanka *et al.* (2024) [1], these compounds help mitigate oxidative stress, regulate inflammatory processes, and may even reduce the risk of chronic diseases.

Conventional farming methods involving frequent tillage, monocropping, and non-judicious application of fertilizers were replaced markedly with more attention paid towards maintaining soil health in all aspects without compromising on yield. This reduces soil erosion, reduces evaporative loss of soil moisture, and augments organic carbon storage (Madarasz *et al.*, 2021) ^[13]. Regenerative agriculture encompasses a wide range of farming and grazing practices aimed at restoration and sustainable management of soil health through sequestration of soil organic carbon (C). It comprises system-based conservation agriculture (CA), which includes no-till farming in conjunction with residue mulching, cover cropping, integrated nutrient and pest management, complex rotations, and integration of crops with trees and livestock (Lal, 2020; Sawargaonkar *et al.*, 2025) ^[12, 24]. The judicious application of nutrients, if supplemented with the addition of biologicals, is more promising, impacting important metabolic functions such as phosphate solubilizing, nitrogen fixation, and synthesis of growth hormones (Sheteiwy *et al.*, 2021) ^[25]. Under irrigation deficit conditions, mulching is used to retain water in the soil, resulting in higher yield and better water use efficiency (Chakraborty *et al.*, 2008) ^[3]. This practice boosts soil fertility and reduces soil erosion (Sarker *et al.*, 2025) ^[21]. Pearl millet is grown in pure and complex mixed systems. Since its sole cultivation is often risky and to avoid risks in rainfed areas, generally farmers in the arid and semi-arid regions practice mix/intercrop pearl millet with legumes to increase productivity per unit area or avoid the risk of failure of crops. Cropping diversity and intercropping improve the system's resilience by interrupting pest and disease cycles, while enhancing soil carbon, fertility, and biodiversity (Wang *et al.*, 2024; Sawargaonkar *et al.*, 2025) ^[30, 24]. This practice optimizes resource use, increases productivity, and improves land-use efficiency (Bandyopadhyay *et al.*, 2016) ^[2], especially in areas where climate change is shortening the growing season and making traditional sequential cropping more difficult (Jabbar *et al.*, 2010) ^[7]. The basic concept of intercropping is to make better use of resources and to reduce risk. To obtain more information on the complementary effects of pearl millet in cropping systems and regenerative agriculture practices on growth analysis, the current study was conducted.

2. Materials and Methods

The experiment was conducted during *kharif* 2023 and 2024 (sowing years) for two years on *Alfisols* at ICRISAT, located at 17.50° N latitude, 78.27° E longitude, at an altitude of 484 m above mean sea level, in the Southern Agro-Climatic Zone of

Telangana. The weekly mean evaporation day-1 was 5.3 mm day-1 against total rainfall of 782.80 mm and 918.7.7 mm respectively in 2023-24 and 2024-25 (Fig.1). The experimental soil was neutral in reaction (pH of 7.27), low in organic carbon (0.35%), low in available nitrogen (217.56 kg ha⁻¹), medium in available phosphorus and potassium (18.21 and 156.41 kg ha⁻¹, respectively). The plot size was 13.5 m x 22.5 m. BBFs were formed using the BBF Former before sowing in the first year of experimentation. Mechanized sowing was performed with a zero-till dryland multicrop planter, which allows simultaneous sowing of multiple seeds while maintaining appropriate spacing between crops. The experiment was designed with three cropping systems as main plot treatments and three regenerative agriculture practices as subplot treatments. The cropping systems included M₁: pearl millet + pigeonpea (2:1), M₂: groundnut + pearl millet (4:1) - sunflower, M₃: pearl millet - groundnut, whereas regenerative agricultural practices were S₁: Soil Test-Based Fertilizer (STBF), S₂: STBF + mulch, and S₃: STBF + mulch + biological consortia, and were replicated thrice. The pearl millet variety tested was Pioneer Hybrid 86M94. Fertilizer application with urea, DAP, and MOP was based on soil test results, and the main crop dosage was determined (Table 1). The basal 1/3rd portion of pearl millet straw, while complete pigeonpea stalk and sunflower straw are used as mulch for the next season's crops in the treatments STBF+ mulch (S₂) and STBF+ mulch + biological consortia (S₃) (Table 2). Biological consortia @ 10 ml kg⁻¹ seed were applied as a seed treatment, containing Rhizobia, Phosphorus Solubilizing Bacteria (PSB), and Potassium Solubilizing Bacteria (KSB). The composition details of biological consortia were given in Table 3.

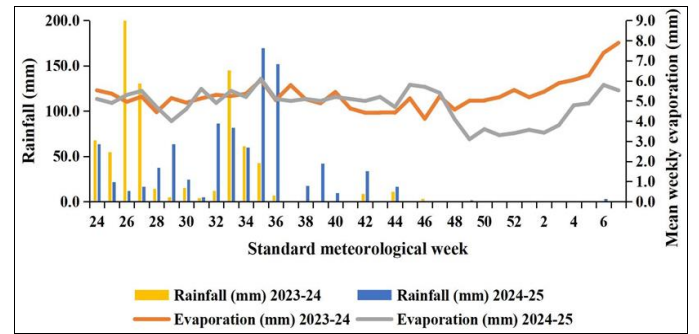


Fig 1: Total rainfall (mm) and mean evaporation (mm) during crop growth period at ICRISAT during both years.

Table 1: Quantity of mulch (kg ha⁻¹) applied during experimentation

Treatment		Kharif maincrop		Kharif intercrop		Rabi crop		Total	
		2023	2024	2023	2024	2023-24	2024-25	2023	2024
M ₁ : Pearl millet + Pigeonpea (2:1)	S ₂	1171	1274	3552	3795			4723	5069
	S ₃	1358	1302	3721	3998			5079	5300
M ₂ : Groundnut + Pearl millet (4:1) - Sunflower	S ₂			728	817	3947	4294	4675	5111
	S ₃			778	854	4166	4623	4944	5477
M ₃ : Pearl millet- Groundnut	S ₂	1614	1507					1614	1507
	S ₃	1624	1707					1624	1707

Table 2: STBF recommendation during the research period

Cropping system	Crop	RDF	STBF		
			N (low)	P (medium)	K (medium)
M ₁ : Pearl millet + Pigeonpea (2:1)	Pearl millet	60-30-20	75	30	20
	Groundnut	20-40-40	25	40	40
M ₂ : Groundnut + Pearl millet (4:1) - Sunflower	Sunflower	60-60-30	75	60	30
	Pearl millet	60-30-20	75	30	20
M ₃ : Pearl millet- Groundnut	Groundnut	20-40-40	25	40	40

Table 3: Composition of biological consortia

Individual organism viable count	CFU (Colony Forming Unit) minimum in a mixture of any 2 or maximum three of the following microorganisms
	CFU minimum Rhizobium 5x10 ⁷ cells per millilitre (ml)
	CFU minimum PSB 5x10 ⁷ cells per millilitre (ml)
	CFU minimum KSB 5x10 ⁷ cells per millilitre (ml)
Total viable count of all the biofertilizers in the product	CFU minimum 1.5x10 ⁸ cells per milliliter (ml)
pH	5.0-7.0

Plant height was recorded from five randomly tagged plants of each net plot by measuring from the base of the stem to the top-most leaf at 20 and 40 DAS, and to the panicle tip at 60 DAS and at harvest. Leaf area was measured from five destructively sampled plants at 20, 40, 60 DAS, and at harvest, and the same plants were oven-dried for dry weight, given as dry matter per plant. The other parameters were studied based on the formulae given below:

2.1 Crop Growth Rate (g m⁻² day⁻¹)

$$CGR = \frac{W_2 - W_1}{(t_2 - t_1)S}$$

Where, W₁ and W₂ = dry weight of the plant at time intervals of T₁ and T₂, respectively S = the land area on which dry weight was observed (Watson, 1952) ^[29]

2.2 Absolute growth rate (g/plant/day)

$$AGR = \frac{W_2 - W_1}{(t_2 - t_1)}$$

Where, W₁ and W₂ = dry weight of the plant at time intervals of T₁ and T₂, respectively (Richards, 1969) ^[19]

The data recorded was subjected to statistical scrutiny by analysis of variance technique for split-plot design suggested by Gomez and Gomez (1984) ^[6].

3. Results

3.1 Cropping systems

3.1.1 Plant height

Cropping systems had no significant influence on plant height of pearl millet at 20 DAS (Table 4). At 40, 60 DAS, and at harvest, groundnut + pearl millet (4:1) - sunflower (M₂) resulted in taller plants, followed by pearl millet + pigeonpea (2:1) (M₁) and pearl millet- groundnut (M₃), with significant differences between any two of the cropping systems.

Groundnut + pearl millet (4:1) - sunflower (M₂) with the advantage of legumes intercropped might have helped pearl millet to uptake more nutrients, which increased meristematic growth, cell division, and elongation, resulting in taller plants. Similar results were reported by Lahane (2021) ^[11].

3.1.2 Leaf area (cm²)

At 20 DAS, cropping systems did not significantly affect the leaf area of pearl millet (Table 5). However, at 40, 60 DAS, and at harvest, higher leaf area was noticed with pearl millet- groundnut (M₃), which was on par with groundnut + pearl millet (4:1) - sunflower (M₂) but significantly higher than pearl millet + pigeonpea (2:1) (M₁) in both the years of study and the pooled mean.

As the pearl millet- groundnut (M₃) received less competition compared to only three plants per bed, leaf area might be higher owing to a good amount of ground area per plant, luxurious light penetration, and leaf expansion. Leaf area increased up to 60 DAS, but at harvest, due to leaf senescence, leaf area decreased. Similar results were reported by Kazemeini and Sadeghi (2013) ^[9].

3.1.3 Dry weight per plant

Significantly higher dry weight was noticed at all the stages of observation in groundnut + pearl millet (4:1) - sunflower (M₂) (Table 6) followed by pearl millet + pigeonpea (2:1) (M₁) and pearl millet- groundnut (M₃) with significant difference between any two of them at 20 and 40 DAS and non-significant variation at 60 DAS and at harvest Improved access to nutrients, water and space compared to other cropping systems might be the reason for higher dry weight in pearl millet- groundnut (M₃).

3.1.4 Crop Growth Rate

CGR shows the dry weight that a crop unit area gains over a specific period of time. Cropping systems significantly influenced CGR. However, interaction was not statistically significant (Fig.2). CGR was not affected significantly at 20 DAS due to cropping systems. At 60 DAS, groundnut + pearl millet (4:1) - Sunflower (M₂) recorded significantly higher CGR, followed by pearl millet + pigeonpea (2:1) (M₁) and pearl millet - groundnut (M₃). CGR attained its peak value at 60 DAS, which may be due to higher accumulation of plant weight during this period that is used to measure CGR. The reproductive phase, which commenced at 60 DAS, might have directly increased the crop growth rate. Groundnut + pearl millet (4:1) - sunflower (M₂) recorded higher CGR in all growth stages. The reason may be attributed to the presence of legume, i.e., groundnut, which helped the pearl millet with nutrients, and it resulted in luxuriant growth. Similar results regarding plant weight was noticed by Pujari (2020) ^[17].

3.1.5 Absolute growth rate

The absolute increase in dry weight per unit time is known as AGR. AGR increased gradually with time up to 60 DAS but reduced at harvest. AGR was found to be significantly influenced by cropping systems, but the interaction effect was non- significant (Fig. 3). At 20 DAS, AGR was affected non-significantly at 20 DAS due to cropping systems. At 60 DAS, higher AGR in the first and second year was realized with groundnut + pearl millet (4:1) - sunflower (M₂), followed by pearl millet + pigeonpea (2:1) (M₁) and pearl millet - groundnut (M₃). This is mainly due to higher dry matter accumulation in groundnut + pearl millet (4:1) - sunflower (M₂) because of the legume effect. Also, at 60 DAS, the reproductive growth might have increased the crop's AGR. Similar findings as plant weight were reported by Reddy (2023) ^[18].

Table 4: Plant height (cm) of pearl millet as influenced by various cropping systems and regenerative agricultural practices

Treatments	20 DAS			40 DAS			60 DAS			At harvest		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Main plots: Cropping systems												
M ₁ : Pearl millet + Pigeonpea (2:1)	24.5	26.0	25.3	78	81	79	134	137	135	142	144	143
M ₂ : Groundnut + Pearl millet (4:1) - Sunflower	26.7	27.7	27.2	105	107	106	160	164	162	167	169	168
M ₃ : Pearl millet- Groundnut	23.2	24.3	23.8	70	74	72	110	115	112	119	121	120
S.E.m±	1.01	1.01	1.00	1.1	1.2	1.1	1.5	3.0	2.4	1.6	1.6	1.6
CD (P=0.05)	NS	NS	NS	4	5	4	6	12	10	6	5	6
Sub plots: Regenerative agricultural practices												
S ₁ : STBF	22.9	24.0	23.5	75	78	76	128	131	129	136	138	137
S ₂ : STBF + Mulch	24.8	25.9	25.4	84	86	85	135	139	137	143	144	144
S ₃ : STBF + Mulch + Biological Consortia	26.9	28.0	27.5	95	98	97	140	147	144	149	151	150
S.E.m±	1.12	1.12	1.11	1.3	1.5	1.3	1.1	1.4	1.4	1.1	1.1	1.1
CD (P=0.05)	NS	NS	NS	4	6	5	4	4	3	4	4	4
Interaction												
M at same level of S												
S.E.m±	1.88	1.88	1.87	2.15	2.18	2.15	2.17	3.57	3.07	2.23	2.23	2.23
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S at same level of M												
S.E.m±	1.74	1.75	1.74	1.89	1.99	1.90	2.55	5.15	4.14	2.73	2.73	2.73
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 5: Leaf area (cm²) of pearl millet as influenced by various cropping systems and regenerative agricultural practices

Treatments	20 DAS			40 DAS			60 DAS			At harvest		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Main plots: Cropping systems												
M ₁ : Pearl millet + Pigeonpea (2:1)	827	929	878	1323	1477	1428	1828	1853	1840	1364	1443	1403
M ₂ : Groundnut + Pearl millet (4:1) - Sunflower	1161	1285	1223	1700	1836	1748	2376	2537	2457	1886	2002	1944
M ₃ : Pearl millet- Groundnut	1257	1321	1289	1704	1845	1774	2463	2605	2534	1983	2077	2030
S.E.m±	103.9	85.2	89.5	60.1	55.0	48.7	64.6	136.0	91.8	68.4	97.6	39.1
CD (P=0.05)	NS	NS	NS	236	216	191	254	534	360	268	383	154
Sub plots: Regenerative agricultural practices												
S ₁ : STBF	1041	1069	1055	1333	1542	1451	1928	2089	2009	1442	1542	1492
S ₂ : STBF + Mulch	1087	1130	1108	1560	1715	1666	2276	2320	2298	1767	1860	1813
S ₃ : STBF + Mulch + Biological Consortia	1118	1336	1227	1835	1901	1834	2463	2587	2525	2024	2121	2072
S.E.m±	75.4	86.0	41.6	96.4	107.6	91.2	134.5	95.5	83.2	92.2	52.6	58.6
CD (P=0.05)	NS	NS	NS	297	332	281	414	294	256	284	162	180
Interaction												
M at same level of S												
S.E.m±	166.9	171.6	114.9	177.5	194.3	165.3	241.7	214.1	170.8	173.7	133.5	108.7
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S at same level of M												
S.E.m±	130.6	148.9	72.1	167.0	186.3	158.0	232.9	165.4	144.1	159.6	91.0	101.4
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 6: Dry weight (g plant⁻¹) (stem, leaves and panicle) of pearl millet as influenced by various cropping systems and regenerative agricultural practices

Treatments	20 DAS			40 DAS			60 DAS			At harvest		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Main plots: Cropping systems												
M ₁ : Pearl millet + Pigeonpea (2:1)	3.64	3.85	3.75	13.23	13.74	13.49	44.56	44.82	44.67	51.31	53.06	52.17
M ₂ : Groundnut + Pearl millet (4:1) - Sunflower	4.15	4.71	4.43	19.40	19.94	19.64	56.65	57.82	57.18	67.75	72.24	69.94
M ₃ : Pearl millet- Groundnut	2.55	2.67	2.61	10.94	11.27	11.10	45.63	46.26	45.87	57.25	65.48	61.30
S.E.m±	0.073	0.083	0.072	0.482	0.487	0.357	4.670	3.437	3.997	4.071	3.187	3.446
CD (P=0.05)	0.29	0.33	0.28	1.89	1.91	1.40	18.34	13.50	15.69	15.99	12.51	13.53
Sub plots: Regenerative agricultural practices												
S ₁ : STBF	3.18	3.54	3.35	11.67	12.13	11.89	45.07	45.86	45.37	56.45	59.12	57.70
S ₂ : STBF + Mulch	3.51	3.71	3.61	15.13	15.60	15.34	47.54	48.36	47.89	58.93	64.19	61.52
S ₃ : STBF + Mulch + Biological Consortia	3.66	3.98	3.82	16.77	17.22	16.99	54.22	54.68	54.47	60.92	67.47	64.19
S.E.m±	0.246	0.165	0.196	0.623	0.499	0.449	1.930	2.108	1.943	1.747	2.010	1.627
CD (P=0.05)	NS	NS	NS	1.92	1.54	1.38	5.95	6.49	5.99	5.38	6.19	5.01
Interaction												
M at same level of S												
S.E.m±	0.43	0.30	0.35	1.18	0.99	0.86	5.74	5.01	5.23	5.07	4.72	4.45
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S at same level of M												
S.E.m±	0.43	0.29	0.34	1.08	0.86	0.78	3.34	3.65	3.37	3.03	3.48	2.82
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

3.2 Regenerative agricultural practices

3.2.1 Plant height (cm)

Plant height of pearl millet at 20 DAS was significantly untraceable due to regenerative agricultural practices (Table 4). While at 40, 60 DAS and at harvest, STBF + mulch + biological consortia (S_3) resulted in significantly taller plants compared with STBF + mulch (S_2). While significantly shorter plants were with STBF (S_1).

The conjunctive advantage of consortia and mulch in STBF + mulch + biological consortia (S_3) might have helped the plant to extend the availability of nutrients and water and resulted in good growth and taller plants, which accelerated the synthesis of more chlorophyll and amino acids and stimulated the cellular activity, which is useful for the process of cell division. Similar results were reported by Monisha *et al.* (2019) [15], Sivamurugan *et al.* (2018) [27], and Sawargaonkar *et al.* (2013) [23].

3.2.2 Leaf area (cm²)

Leaf area of pearl millet at 20 DAS was significantly untraceable due to regenerative agricultural practices (Table 5).

At 40 DAS, across both years and pooled data, STBF + mulch + biological consortia (S_3) resulted in higher leaf area than STBF + mulch (S_2), which were on par with each other. Significantly lower leaf area was observed with STBF (S_1). During 2023-24 and 2024-25, at 60 DAS, in both years and pooled data, STBF + mulch + biological consortia (S_3) resulted in higher leaf area compared with STBF + mulch (S_2), which were on par with each other. Significantly lower leaf area was observed with STBF (S_1). However, the difference varied significantly between any two of them in the pooled mean. At harvest, STBF + mulch + biological consortia (S_3) resulted in significantly higher leaf area followed by STBF + mulch (S_2) and STBF (S_1) in the order of descent with significant disparity between any two of them. Many beneficial microbes might have synthesized phytohormones like auxins, gibberellins, and cytokinins in the presence of mulch and biologicals, which stimulate leaf initiation, expansion, and overall canopy development. Enhanced leaf area in the presence of biological consortia, as resulted from this work, validates the findings of Upendranaik *et al.* (2018) [28] and Sawargaonkar *et al.* (2013) [23].

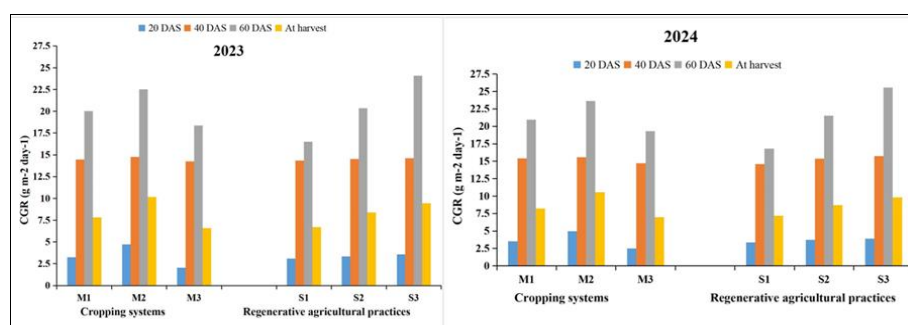


Fig 2: CGR of pearl millet as influenced by various cropping systems and regenerative agricultural practices

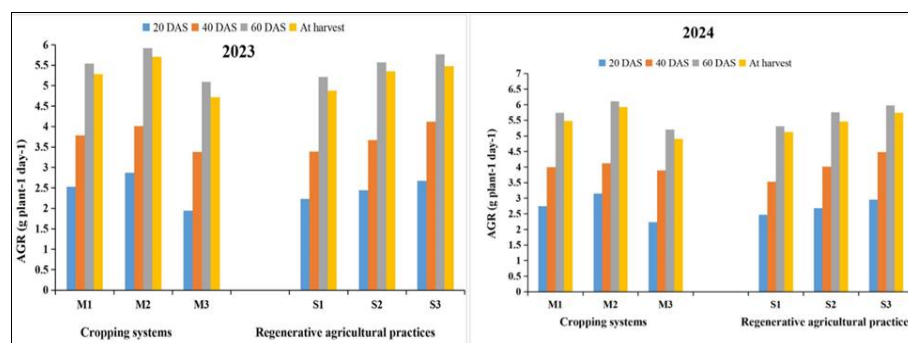


Fig 3: AGR of pearl millet as influenced by various cropping systems and regenerative agricultural practices

3.2.3 Dry weight per plant

Dry weight of pearl millet was significantly affected due to regenerative agricultural practices at 40, 60 DAS, and at harvest, but showed a non-significant effect at 20 DAS (Table 6). At 40 DAS in the first year of study, STBF + mulch + biological consortia (S_3) resulted in higher dry weight, followed by STBF + mulch (S_2), which were on par with each other. Significantly lower dry weight was realized with STBF (S_1). In the second year of study and in pooled data, STBF + mulch + biological consortia (S_3) documented significantly higher dry weight, followed by STBF + mulch (S_2), which in turn was significantly higher than that with STBF (S_1).

At 60 DAS in both years of study, STBF + mulch + biological consortia (S_3) documented significantly more dry weight compared with STBF + mulch (S_2), which in turn was statistically comparable with STBF (S_1). At harvest, dry weight followed the order of STBF + mulch + biological consortia (S_3)

followed by STBF + mulch (S_2) and STBF (S_1) in decreasing order with non-significant variation among each other.

Moisture availability due to the presence of mulch might have improved the microclimate and helped the crop stand to establish well. The additional benefits in terms of nutrients and growth-promoting hormones like auxins, gibberellins, and cytokinins drawn with the addition of biological consortia along with the mulch in STBF + mulch + biological consortia (S_3) might be the reason for better photosynthesis and translocation of photosynthates to the plant, which resulted in significantly higher dry weight.

3.2.4 Crop Growth Rate

Among regenerative agricultural practices, higher CGR was noticed with the application of STBF + mulch + biological consortia (S_3) followed by STBF + mulch (S_2) and STBF (S_1) (Fig 2). The difference was non-significant at 20 DAS.

Significantly higher CGR was realized with STBF + mulch + biological consortia (S_3) at 60 DAS and at harvest. Application of STBF + mulch + biological consortia (S_3) had an additive effect of biologicals and mulch, which made the moisture and nutrients available to the crop throughout its growth period. Thus, resulting in higher CGR compared with other STBF (S_1) and STBF + mulch (S_2). Similar results were also reported by Maharana and Singh (2021)^[14], Nikhitha *et al.* (2021)^[16], and Sawargaonkar *et al.* (2013)^[23].

3.2.5 Absolute growth rate

Among regenerative agricultural practices, application of STBF + mulch + biological consortia (S_3) recorded the highest AGR, followed by STBF + mulch (S_2) and STBF (S_1) (Fig. 3). The difference was non-significant at 20 DAS. The highest AGR was noticed at 60 DAS. This is mainly due to the production of more panicles and tillers with the addition of biologicals in STBF + mulch + biological consortia (S_3), which helped the crop to increase AGR. Dawar *et al.* (2023)^[5] reported similar findings regarding plant weight.

4. Conclusion

The present study demonstrated that both cropping system diversification and regenerative agricultural practices significantly influence the growth performance of pearl millet under *Alfisol* conditions. Among cropping systems, groundnut + pearl millet (4:1) - sunflower proved most effective in enhancing plant height, dry matter accumulation, and growth rates, likely due to complementary resource use and the beneficial effects of legume integration. However, the sole pearl millet-groundnut system recorded higher leaf area owing to reduced interspecific competition. Among regenerative practices, the combined application of soil-test-based fertilizers, mulch, and biological consortia (S_3) consistently outperformed other treatments by improving plant growth attributes, including CGR and AGR. This improvement can be attributed to enhanced nutrient availability, better soil moisture conservation, and microbial-mediated growth promotion. The non-significant interaction between cropping systems and regenerative practices indicates that their effects are largely independent. Overall, integrating diversified cropping systems with regenerative practices, particularly STBF combined with mulch and biological consortia, offers a sustainable strategy to improve crop growth and soil health in semi-arid *Alfisols*.

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