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Physiological growth behaviour of pigeonpea (*Cajanus cajan* L.) under intercropping systems and integrated nutrient management

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Abstract

A field experiment was conducted during the kharif seasons of 2023–24 and 2024–25 at the AICRP Experimental Farm on Dryland Agriculture, Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra to evaluate the influence of pigeonpea-based intercropping systems and integrated nutrient management on physiological growth parameters of pigeonpea (*Cajanus cajan* L.). A split-plot experimental design was adopted, with four intercropping systems assigned to the main plots, viz., pigeonpea + soybean (1:4), pigeonpea + pearl millet (1:4), pigeonpea + sesame (1:4) and pigeonpea + sorghum (1:4), and the sub-plot treatments consisted of four integrated nutrient management practices, namely F₁: 100% recommended dose of fertilizers (RDF); F₂: 75% RDF supplemented with 1.5 t FYM ha⁻¹ and 0.5 t vermicompost ha⁻¹ along with foliar application of NAA and KNO₃; F₃: 50% RDF combined with 3.0 t FYM ha⁻¹ and 1.5 t vermicompost ha⁻¹ along with foliar application of NAA and KNO₃; and F₄: control. Physiological parameters including absolute growth rate (AGR) of plant height, dry matter accumulation, and crop growth rate (CGR) were recorded at different growth stages. Growth parameters increased up to 90 DAS, reaching peak values during 61–120 DAS, then declined towards harvest. Pigeonpea intercropped with soybean recorded the highest dry matter accumulation and CGR during the active growth phase, while pigeonpea + pearl millet exhibited relatively higher AGR of plant height. Among nutrient management practices, the combination of 75% RDF + 1.5 t FYM ha⁻¹ + 0.5 t vermicompost ha⁻¹ + foliar spray of NAA and KNO₃ sprays produced the highest AGR and CGR, followed by 100% RDF, whereas the control recorded the lowest values. Therefore, pigeonpea + soybean intercropping integrated with 75% RDF and 1.5 t FYM ha⁻¹ + 0.5 t vermicompost ha⁻¹ + foliar spray of NAA and KNO₃ proved most effective in enhancing physiological growth of pigeonpea under rainfed conditions.

Keywords: Pigeonpea (*Cajanus cajan* L.), intercropping systems, integrated nutrient management (INM)

1. Introduction

Pigeonpea (*Cajanus cajan* (L.) Millsp.), a prominent grain legume of the semi-arid tropics, is extensively cultivated in India for its versatile role in food systems and soil health improvement. Belonging to the Fabaceae family, pigeonpea holds a special place in Indian agriculture due to its drought resilience, deep rooting system, and ability to thrive in marginal lands under rainfed conditions. India is the largest producer of red gram (*Cajanus cajan*) globally. During the 2023–24 cropping year, the country produced approximately 4.34 million tonnes of red gram, cultivated over an area of 5.05 million hectares, resulting in an average productivity of 859 kg per hectare (ANGRAU Redgram outlook Report, 2023-24). Red gram is extensively grown across various states, with Karnataka leading in area under cultivation (1.33 million hectares), followed by Maharashtra (1.11 million hectares), Uttar Pradesh (0.35 million hectares), Andhra Pradesh (0.23 million hectares), Gujarat (0.22 million hectares), and Jharkhand (0.185 million hectares) (agriwelfare.gov.in). The extended growth duration and wider plant spacing of the crop provide ideal conditions for intercropping, as the slow early growth creates sufficient inter-row space that can be effectively utilized by suitable companion crops to maximize land and resource use efficiency. In contrast, modern intensive agricultural systems have increasingly shifted toward simplified monocropping practices, coupled with excessive dependence on chemical fertilizers and pesticides to meet the growing demand for food production. However, this approach has led

to significant farmland biodiversity loss and has negatively impacted the environment and ecosystem functions, posing serious threats to food security and long-term agricultural sustainability (Yu *et al.*, 2025) [8]. Intercropping, a practice wherein two or more crops are cultivated simultaneously on the same piece of land, is a time-tested strategy in rainfed agriculture. The core idea behind intercropping is to maximize overall productivity per unit area and time, while also ensuring fair and efficient use of land, labor, and other farming resources (Boto and Bassa, 2025) [3].

In this study, four intercrops *i.e.*, soybean, pearl millet, sesame, and sorghum were evaluated in combination with pigeonpea to assess the biological and economic viability of different intercropping systems. Each of these intercrops brings unique traits that contribute to the performance of the system. These various crop combinations *i.e.*, legume + legume, legume + millet, legume + oilseed, and legume + cereal, each offer specific advantages that merit comparative evaluation under similar environmental and management conditions. The differences in rooting patterns, nutrient demands, and growth durations help in efficient resource partitioning, ultimately improving the stability and profitability of farming systems. Evaluating these systems helps in identifying the most suitable combinations for specific agro-climatic zones and resource availability.

In addition to crop choice, nutrient management plays a pivotal role in determining the success of intercropping systems. Integrated Nutrient Management (INM), which involves the combined use of chemical fertilizers, organic manures such as farmyard manure (FYM), and bio-fertilizers, aims to maintain soil fertility while sustaining high crop yields. The rationale behind INM is to optimize the nutrient supply by harnessing the strengths of both organic and inorganic sources. For instance, pairing 50% of recommended fertilizer dose with vermicompost in pigeonpea + greengram systems increased yields by over 25% compared to chemical-only regimens (Sharma *et al.* 2010) [6]. In intercropping systems, where different crops may have varying nutrient requirements and uptake rates, INM helps in balancing nutrient availability throughout the cropping period. As part of improved agronomic practices under Integrated Nutrient Management (INM), foliar application of potassium nitrate (KNO₃) and naphthalene acetic acid (NAA) at the flower initiation stage in pigeonpea has gained prominence due to its positive physiological and yield-enhancing effects. Another critical aspect of this research is the adoption of the Broad Bed and Furrow (BBF) method of land configuration. In rainfed areas like Marathwada, where water availability is limited and rainfall is often erratic, conserving soil moisture becomes crucial for sustaining crop growth and productivity. Such structural interventions are especially important in Marathwada's semi-arid conditions, where the challenge lies in managing both surplus and deficit rainfall scenarios within a single cropping season (Garud *et al.*, 2019) [4]. The integration of pigeonpea-based intercropping systems with INM and BBF land configuration offers a holistic approach to enhance crop productivity, improve soil health, and ensure resource-use efficiency under rainfed conditions.

2. Materials and Methods

A field experiment was conducted during the *kharif* seasons of 2023–24 and 2024–25 at the AICRP Experimental Farm on Dryland Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (Maharashtra), to evaluate the effect of pigeonpea-based intercropping systems and integrated nutrient management on physiological growth parameters of pigeonpea.

The experiment was laid out in a split-plot design with three replications, comprising four intercropping systems in main plots—pigeonpea + soybean, pigeonpea + pearl millet, pigeonpea + sesame, and pigeonpea + sorghum in a 1:4 row ratio and four integrated nutrient management practices in sub-plots, including F₁: 100% recommended dose of fertilizers (RDF); F₂: 75% RDF supplemented with 1.5 t FYM ha⁻¹ and 0.5 t vermicompost ha⁻¹ along with foliar application of NAA and KNO₃; F₃: 50% RDF combined with 3.0 t FYM ha⁻¹ and 1.5 t vermicompost ha⁻¹ along with foliar application of NAA and KNO₃; and F₄: control. Physiological parameters such as absolute growth rate for plant height and dry matter accumulation, and crop growth rate were recorded at different growth stages and analyzed statistically using ANOVA appropriate for the split-plot design.

2.1 Absolute growth rate for plant height

The Absolute Growth Rate (AGR) is the total gain in plant height by the plant within the specific time interval. Absolute growth rate for plant height is expressed as cm day⁻¹ plant⁻¹ and is calculated by the formula given by Richards (1969) [5] as follows.

$$\text{AGR (Plant height) (cm day}^{-1} \text{ plant}^{-1}) = \frac{(H_2 - H_1)}{(t_2 - t_1)} \times 100$$

Where,

H₂ and H₁ are plant height (cm) at time T₂ and T₁, respectively.

The Absolute Growth Rate (AGR) is the total gain in dry matter by the plant within the specific time interval and expressed as g day⁻¹ plant⁻¹ for dry matter accumulation plant⁻¹

$$\text{AGR (Dry matter) (g day}^{-1} \text{ plant}^{-1}) = \frac{(W_2 - W_1)}{(t_2 - t_1)} \times 100$$

Where,

W₂ and W₁ are the dry weight (g) plant at time T₂ and T₁, respectively.

2.2 Crop Growth Rate (CGR) (g m⁻² day⁻¹)

The crop growth rate is commonly used for the determination of production efficiency of plant stand. CGR represents total dry matter productivity of the community per unit land area over a certain time span. CGR enables comparison to be made between stand communities of different types in different habitat (Watson, 1952) [7]. This is determined by using the following formula.

$$\text{CGR (g day}^{-1} \text{ m}^{-2}) = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{p}$$

Where,

W₂ = dry weight of plant at time T₂ (g plant⁻¹)

W₁ = dry weight of plant at time T₁ (g plant⁻¹)

p = spacing

3. Results and Discussion

Physiological growth dynamics

Growth functions are the measures of growth rates in different growth parameters of plant.

3.1 Absolute growth rate (AGR) of height (cm day⁻¹ plant⁻¹)

The data presented in the tables 1 and 2 indicate that the absolute growth rate of pigeonpea increased progressively from sowing up to 61–90 DAS, after which a declining trend was observed towards harvest.

Effect of pigeonpea based intercropping systems

Among the pigeonpea-based intercropping systems, pigeonpea + pearl millet (1:4) recorded comparatively higher AGR during the most active growth phase (61–90 DAS), followed by pigeonpea + sorghum (1:4), while lower values were observed under pigeonpea + soybean (1:4) and pigeonpea + sesame (1:4) at later growth stages.

Effect of integrated nutrient management practices

With respect to integrated nutrient management practices, application of 75% RDF supplemented with FYM, vermicompost and foliar sprays of NAA and KNO₃ resulted in the highest AGR across most growth stages, followed closely by the application of 100% RDF. Reduced fertilizer dose combined with higher organic inputs showed intermediate values, whereas the control treatment consistently recorded the lowest AGR throughout the crop growth period.

Table 1: Mean absolute growth rate (AGR) of plant height (cm day⁻¹ plant⁻¹) as influenced by pigeonpea based intercropping systems and integrated nutrient management practices during 2023–24

Treatments	Mean absolute growth rate of plant height (cm day ⁻¹ plant ⁻¹)					
	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS	151-At Harvest
Main plots (I): Pigeonpea based intercropping systems						
I ₁ : Pigeonpea + Soybean (1:4)	0.798	1.155	1.942	0.641	0.557	0.111
I ₂ : Pigeonpea + Pearl millet (1:4)	0.854	1.331	2.155	0.975	0.336	0.129
I ₃ : Pigeonpea + Sesame (1:4)	0.831	1.163	1.959	0.671	0.585	0.097
I ₄ : Pigeonpea + Sorghum (1:4)	0.835	1.301	1.989	0.915	0.499	0.062
Sub plots (F): Integrated nutrient management practices						
F ₁ : 100% RDF	0.838	1.339	2.119	0.927	0.380	0.103
F ₂ : 75% RDF + 1.5t FYM + 0.5t Vermicompost + NAA and KNO ₃ Spray	0.863	1.400	2.125	0.983	0.603	0.108
F ₃ : 50% RDF + 3t FYM + 1.5t Vermicompost + NAA and KNO ₃ Spray	0.829	1.210	2.061	0.677	0.578	0.070
F ₄ : Control	0.788	1.001	1.741	0.614	0.415	0.119
General Mean	0.830	1.238	2.011	0.800	0.494	0.100

Table 2: Mean absolute growth rate (AGR) of plant height (cm day⁻¹ plant⁻¹) as influenced by pigeonpea based intercropping systems and integrated nutrient management practices during 2024–25

Treatments	Mean absolute growth rate of plant height (cm day ⁻¹ plant ⁻¹)					
	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS	151-At Harvest
Main plots (I): Pigeonpea based intercropping systems						
I ₁ : Pigeonpea + Soybean (1:4)	0.729	1.091	1.803	0.774	0.418	0.103
I ₂ : Pigeonpea + Pearl millet (1:4)	0.772	1.458	1.929	0.947	0.274	0.099
I ₃ : Pigeonpea + Sesame (1:4)	0.741	1.133	1.907	0.689	0.517	0.081
I ₄ : Pigeonpea + Sorghum (1:4)	0.767	1.254	1.991	0.746	0.479	0.096
Sub plots (F): Integrated nutrient management practices						
F ₁ : 100% RDF	0.751	1.389	1.941	0.960	0.309	0.083
F ₂ : 75% RDF + 1.5t FYM + 0.5t Vermicompost + NAA and KNO ₃ Spray	0.804	1.457	2.020	0.896	0.586	0.092
F ₃ : 50% RDF + 3t FYM + 1.5t Vermicompost + NAA and KNO ₃ Spray	0.748	1.191	1.866	0.820	0.416	0.106
F ₄ : Control	0.705	0.900	1.803	0.481	0.376	0.099
General Mean	0.752	1.234	1.908	0.789	0.422	0.095

3.2 Absolute growth rate (AGR) of dry matter (g day⁻¹ plant⁻¹)

The absolute growth rate (AGR) of dry matter accumulation per plant at different growth stages under various intercropping systems and integrated nutrient management practices during kharif seasons of 2023–24 and 2024–25 is presented in Table 3 and 3.4, respectively. The mean AGR for dry matter increased from 0–30 DAS and attained maximum values during 61–90 DAS, followed by a declining trend from 91 DAS up to harvest during both the years.

Effect of pigeonpea-based intercropping systems

The pigeonpea based intercropping systems showed variation in AGR for dry matter at different growth stages during both years. Pigeonpea + Soybean (1:4) (I₁) recorded comparatively higher

AGR values for dry matter during the peak growth period, followed by Pigeonpea + Sesame (1:4) (I₃) and Pigeonpea + Sorghum (1:4) (I₄). Lower AGR values for dry matter were observed under Pigeonpea + Pearl millet (1:4) (I₂) across most of the growth stages during both the years.

Effect of integrated nutrient management practices

The integrated nutrient management practices differed with respect to AGR for dry matter at various growth stages during both years. 75% RDF + 1.5 t FYM + 0.5 t vermicompost + NAA and KNO₃ spray (F₂) recorded the highest AGR values for dry matter, followed by 100% RDF (F₁) and 50% RDF + 3 t FYM + 1.5 t vermicompost + NAA and KNO₃ spray (F₃). The control treatment (F₄) recorded the lowest AGR values at all growth stages during both the years of study.

Table 3: Mean Absolute Growth Rate (AGR) of dry matter ($\text{g day}^{-1} \text{plant}^{-1}$) as influenced by different treatments during 2023-24.

Treatments	Mean absolute growth rate of dry matter accumulation ($\text{g day}^{-1} \text{plant}^{-1}$)					
	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS	151-At Harvest
Main plots (I): Pigeonpea based intercropping systems						
I ₁ : Pigeonpea + Soybean (1:4)	0.153	0.854	2.772	1.128	0.567	0.132
I ₂ : Pigeonpea + Pearl millet (1:4)	0.143	0.759	2.297	0.825	0.685	0.332
I ₃ : Pigeonpea + Sesame (1:4)	0.147	0.854	2.623	1.091	0.425	0.349
I ₄ : Pigeonpea + Sorghum (1:4)	0.147	0.814	2.390	1.061	0.523	0.344
Sub plots (F): Integrated nutrient management practices						
F ₁ : 100% RDF	0.149	0.885	2.833	1.072	0.511	0.254
F ₂ : 75% RDF + 1.5t FYM + 0.5t Vermicompost + NAA and KNO ₃ Spray	0.154	0.949	3.092	1.178	0.437	0.223
F ₃ : 50% RDF + 3t FYM + 1.5t Vermicompost + NAA and KNO ₃ Spray	0.144	0.789	2.492	0.966	0.550	0.215
F ₄ : Control	0.143	0.658	1.666	0.888	0.701	0.465
General Mean	0.148	0.820	2.521	1.026	0.550	0.289

Table 4: Mean Absolute Growth Rate (AGR) of dry matter ($\text{gm day}^{-1} \text{plant}^{-1}$) as influenced by different treatments during 2024-25

Treatments	Mean absolute growth rate of dry matter ($\text{g day}^{-1} \text{plant}^{-1}$)					
	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS	151-At Harvest
Main plots (I): Pigeonpea based intercropping systems						
I ₁ : Pigeonpea + Soybean (1:4)	0.144	0.788	2.618	1.060	0.533	0.145
I ₂ : Pigeonpea + Pearl millet (1:4)	0.133	0.698	2.164	0.792	0.636	0.315
I ₃ : Pigeonpea + Sesame (1:4)	0.139	0.788	2.481	1.029	0.382	0.347
I ₄ : Pigeonpea + Sorghum (1:4)	0.139	0.752	2.258	1.010	0.475	0.319
Sub plots (F): Integrated nutrient management practices						
F ₁ : 100% RDF	0.141	0.818	2.668	1.017	0.475	0.251
F ₂ : 75% RDF + 1.5t FYM + 0.5t Vermicompost + NAA and KNO ₃ Spray	0.146	0.874	2.921	1.123	0.389	0.225
F ₃ : 50% RDF + 3t FYM + 1.5t Vermicompost + NAA and KNO ₃ Spray	0.136	0.731	2.363	0.910	0.496	0.213
F ₄ : Control	0.132	0.605	1.570	0.842	0.667	0.437
General Mean	0.139	0.757	2.380	0.973	0.507	0.282

3.3 Crop Growth Rate (CGR) ($\text{g m}^{-2} \text{plant}^{-1}$)

Crop growth rate values recorded at successive growth stages under different pigeonpea-based intercropping systems and integrated nutrient management practices during the *kharif* seasons of 2023–24 and 2024–25 is presented in Table 5 and 6. Across both seasons, CGR values increased steadily from the early growth phase and were highest during the 61–90 DAS interval. Thereafter, a gradual reduction in CGR was observed from 91 DAS until harvest.

Effect of pigeonpea-based intercropping systems

With respect to intercropping systems, higher CGR values were noted under Pigeonpea + Soybean (1:4) (I₁) during the active growth phase, followed by Pigeonpea + Sesame (1:4) (I₃) and

Pigeonpea + Sorghum (1:4) (I₄) in both the years. Comparatively lower CGR values were recorded under Pigeonpea + Pearl millet (1:4) (I₂) across most of the growth intervals.

Effect of integrated nutrient management practices

Variation in CGR was also evident due to integrated nutrient management practices. The treatment 75% RDF + 1.5 t FYM + 0.5 t vermicompost + NAA and KNO₃ spray (F₂) registered higher CGR values at different growth stages, followed by 100% RDF (F₁) and 50% RDF + 3 t FYM + 1.5 t vermicompost + NAA and KNO₃ spray (F₃). The control treatment (F₄) consistently showed lower CGR values throughout the crop growth period in both seasons.

Table 5: Mean Crop Growth Rate (CGR) ($\text{g day}^{-1} \text{plant}^{-1}$) as influenced by different treatments during 2023-24

Treatments	Mean crop growth rate ($\text{g m}^{-2} \text{day}^{-1}$)					
	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS	151-At Harvest
Main plots (I): Pigeonpea based intercropping systems						
I ₁ : Pigeonpea + Soybean (1:4)	1.704	9.493	30.804	12.533	6.300	1.470
I ₂ : Pigeonpea + Pearl millet (1:4)	1.585	8.430	25.522	9.167	7.611	3.689
I ₃ : Pigeonpea + Sesame (1:4)	1.630	9.489	29.144	12.119	4.719	3.874
I ₄ : Pigeonpea + Sorghum (1:4)	1.637	9.048	26.556	11.793	5.811	3.819
Sub plots (F): Integrated nutrient management practices						
F ₁ : 100% RDF	1.659	9.833	31.474	11.907	5.681	2.819
F ₂ : 75% RDF + 1.5t FYM + 0.5t Vermicompost + NAA and KNO ₃ Spray	1.711	10.548	34.356	13.093	4.859	2.481
F ₃ : 50% RDF + 3t FYM + 1.5t Vermicompost + NAA and KNO ₃ Spray	1.604	8.763	27.693	10.737	6.111	2.385
F ₄ : Control	1.585	7.311	18.511	9.867	7.789	5.167
General Mean	1.639	9.114	28.007	11.402	6.110	3.213

Table 6: Mean Crop Growth Rate (CGR) ($\text{g day}^{-1} \text{ plant}^{-1}$) as influenced by different treatments during 2024-25

Treatments	Mean crop growth rate ($\text{g m}^{-2} \text{ day}^{-1}$)					
	0-30 DAS	31-60 DAS	61-90 DAS	91-120 DAS	121-150 DAS	151-At Harvest
Main plots (I): Pigeonpea based intercropping systems						
I ₁ : Pigeonpea + Soybean (1:4)	1.604	8.759	29.089	11.781	5.926	1.607
I ₂ : Pigeonpea + Pearl millet (1:4)	1.481	7.759	24.048	8.796	7.067	3.504
I ₃ : Pigeonpea + Sesame (1:4)	1.544	8.759	27.567	11.437	4.241	3.859
I ₄ : Pigeonpea + Sorghum (1:4)	1.541	8.359	25.085	11.219	5.278	3.548
Sub plots (F): Integrated nutrient management practices						
F ₁ : 100% RDF	1.567	9.085	29.641	11.296	5.278	2.793
F ₂ : 75% RDF + 1.5t FYM + 0.5t Vermicompost + NAA and KNO ₃ Spray	1.626	9.711	32.452	12.478	4.319	2.500
F ₃ : 50% RDF + 3t FYM + 1.5t Vermicompost + NAA and KNO ₃ Spray	1.511	8.119	26.252	10.107	5.507	2.363
F ₄ : Control	1.467	6.722	17.444	9.352	7.407	4.859
General Mean	1.543	8.409	26.447	10.808	5.628	3.129

4. Conclusion

Physiological growth of pigeonpea was significantly influenced by intercropping systems and integrated nutrient management under rainfed conditions. Pigeonpea intercropped with soybean enhanced dry matter accumulation and crop growth rate during peak growth period, while intercropping with pearl millet recorded higher absolute growth rate of plant height. Application of 75% RDF + 1.5t FYM + 0.5t Vermicompost + NAA and KNO₃ spray proved superior to sole chemical fertilization and the control. Thus, pigeonpea + soybean intercropping combined with integrated nutrient management is an effective approach for improving pigeonpea growth under rainfed conditions.

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