



Effect of Different Legume-Based Intercropping Systems on Vegetative and Phenological Attributes of Maize (*Zea mays* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Maize-based intercropping offers a sustainable approach to improving maize productivity by enhancing resource-use efficiency and crop performance. A two-year field experiment (2024-2025) was conducted to evaluate the effect of ten maize-based intercropping systems on the growth and phenological development of maize under a randomised block design. Significant differences were observed among treatments for all measured parameters. The maize + cowpea + marigold system (T₁₀) consistently recorded the highest plant height (224.9 cm), leaf area index (4.34), stem diameter (2.85 cm), dry matter accumulation (180.0 g plant⁻¹), crop growth rate (33.47 g m⁻² day⁻¹), relative growth rate (0.035 g g⁻¹ day⁻¹), and SPAD chlorophyll index (55.8), while sole maize recorded the lowest values. The same treatment also accelerated crop phenology, resulting in earlier tasselling (54.6 days), silking (57.3 days), and physiological maturity (109.2 days). Improved crop performance under T₁₀ was associated with better utilisation of light, water, and nutrients, leading to enhanced vegetative growth and timely reproductive development. Overall, the maize + cowpea + marigold intercropping system proved to be the most effective strategy for improving maize growth and developmental efficiency, highlighting its potential as a sustainable alternative to sole maize cultivation.

Keywords: *Zea mays*; cereal-legume intercropping; cowpea; resource-use efficiency; crop growth; phenological development; sustainable agriculture.

1. Introduction

Maize (*Zea mays* L.) is one of the world's most important cereal crops, serving as a major source of food, feed, industrial raw material, and bioenergy. However, sustaining maize productivity is increasingly challenged by climate variability, declining soil fertility, inefficient nutrient use, and the environmental impacts of intensive monocropping. Consequently, sustainable production systems that enhance resource-use efficiency while maintaining productivity have become a global research priority (Fu *et al.*, 2023; Liu *et al.*, 2024). Recent synthesis further indicates that legume intercropping can strengthen resource-use efficiency, soil functioning, and production resilience, although outcomes depend on crop selection and management context (Akchaya *et al.*, 2025).

Legume-based intercropping has emerged as a promising agroecological strategy that improves crop productivity through complementary resource use, biological nitrogen fixation, enhanced soil fertility, and greater biodiversity (Liu *et al.*, 2024; Suárez Salazar *et al.*, 2025). Compared with sole maize, maize-legume intercropping has been shown to increase leaf area index, chlorophyll content, photosynthetic rate, plant height, root growth, and dry matter accumulation, leading to improved assimilate partitioning and grain yield (Fu *et al.*, 2023; Wei *et al.*, 2022; Pierre *et al.*, 2022; Pandey *et al.*, 2024; Sowiński, 2024; Yavas & Unay, 2016). Field evidence also indicates that maize-legume diversification can alter soil physicochemical conditions and belowground microbial communities relative to maize monoculture, providing an additional ecological basis for diversified systems (Jalloh *et al.*, 2024). Recent maize-cowpea research further shows that varietal combination and relative planting time can influence crop growth, yield, and land-use efficiency, reinforcing the importance of system-specific intercrop configuration (Ofori *et al.*, 2025).

Intercropping also enhances soil organic matter, nitrogen availability, nutrient-use efficiency, and land productivity, as reflected by higher land equivalent ratio (LER), area time equivalent ratio (ATER), and maize equivalent yield (Liu *et al.*, 2024; Sahoo *et al.*, 2024; Shafiqullah *et al.*, 2026). However, yield responses vary with legume species, spatial arrangement, and management practices, indicating the need to optimise intercrop configurations (Talukdar *et al.*, 2023; Pierre *et al.*, 2022; Schulz *et al.*, 2020). Despite substantial evidence on growth and productivity benefits, the effects of legume-based intercropping on maize phenological development remain less well understood. Available studies suggest that planting geometry and temporal niche differentiation influence crop competition, light interception, and reproductive development, ultimately affecting grain yield (Kinyua *et al.*, 2024; Pierre *et al.*, 2022; Jakhad *et al.*, 2025; Sabitha *et al.*, 2024; Abate & Alemayehu, 2018). Where companion crops are incorporated for ecological pest management, push-pull and habitat-manipulation approaches likewise emphasize the need to select compatible plant combinations and management practices for the target crop-pest context (Yadav *et al.*, 2025).

Despite the reported advantages of maize-legume intercropping, comparative evidence remains limited on the simultaneous effects of different legume species and row arrangements, together with a maize-cowpea-marigold system, on both vegetative growth and phenological development of maize under the same field conditions. A direct comparison of these configurations is therefore needed to determine whether differences among intercropping systems are expressed consistently across growth and developmental traits.

Therefore, the present study was undertaken to evaluate the effect of different legume-based intercropping systems on the vegetative growth and phenological development of maize under field conditions.

2. Materials and Methods

2.1 Experimental Site

The field experiment was conducted during the kharif seasons of 2024 and 2025 at the Instructional Farm, School of Agricultural Sciences, Career Point University, Kota, Rajasthan, India. The region is characterised by a subtropical monsoon climate with hot summers, mild winters, and rainfall predominantly concentrated between June and September. Meteorological data, including daily maximum and minimum temperature, relative humidity, and rainfall, were obtained from the Agro-meteorological Observatory of IES University and used to interpret crop growth and pest dynamics.

2.2 Soil Characteristics

Prior to sowing, composite soil samples (0–15 cm depth) were collected from the experimental field and analysed for soil pH, electrical conductivity (EC), organic carbon, available nitrogen (N), phosphorus (P), and potassium (K) using standard analytical procedures described by Jackson (1973), Subbiah and Asija (1956), Olsen *et al.* (1954), and Hanway and Heidel (1952), respectively. The soil was classified as sandy clay loam with neutral pH (7.48), electrical conductivity of 0.32 dS m⁻¹, organic carbon content of 0.58%, available nitrogen of 276.4 kg ha⁻¹, available phosphorus of 19.8 kg ha⁻¹, and available potassium of 328.6 kg ha⁻¹. Soil samples were collected again after harvest to evaluate treatment-induced changes in soil fertility.

2.3 Experimental Design and Treatments

The experiment was conducted using a randomised complete block design (RCBD) comprising ten treatments with three replications. Sole maize (T₁) was considered as the control treatment, while the remaining treatments comprised different maize-based legume intercropping systems. The treatments included sole maize (T₁), maize + cowpea (1:1) (T₂), maize + cowpea (2:1) (T₃), maize + soybean (1:1) (T₄), maize + soybean (2:1) (T₅), maize + blackgram (2:1) (T₆), maize + greengram (2:1) (T₇), maize + groundnut (2:1) (T₈), maize + pigeonpea (2:1) (T₉), and maize + cowpea (1:1) integrated with marigold (*Tagetes erecta* L.) as a trap crop (T₁₀).

In all intercropping treatments, maize was maintained as the principal crop, while the respective legume species were established according to the prescribed row ratios. In T₁₀, marigold (*Tagetes erecta* L.) was incorporated as a trap/companion crop along the plot borders and at predetermined intervals within the maize + cowpea (1:1) intercropping system. The inclusion of marigold was intended to support ecological pest management by providing floral resources for beneficial insects and potentially reducing insect pest incidence.

Each experimental plot measured 5.0 × 4.0 m (20 m²). With ten treatments and three replications, the total experimental area comprised 600 m², excluding irrigation channels, bunds and pathways. The treatments were randomly assigned within each replication to minimise the influence of field heterogeneity and ensure unbiased estimation of treatment effects. The prescribed row ratios were maintained consistently throughout the experimental period, and all other recommended agronomic practices were followed uniformly across treatments.

2.4 Crop Establishment and Management

Maize hybrid HQPM-1 and certified seeds of the respective intercrops were sown according to the prescribed treatment-wise row arrangements. Maize was planted at a spacing of 60 × 20 cm, whereas intercrops were maintained according to their recommended agronomic practices. In the trap crop treatment, nursery-raised marigold (*Tagetes erecta* L. cv. Pusa Narangi Gaiinda) seedlings were transplanted along plot borders and at every tenth row within the maize–cowpea intercropping system.

A uniform fertilizer dose of 120:60:40 kg N: P₂O₅:K₂O ha⁻¹ was applied to all treatments through urea, single superphosphate, and muriate of potash. One-third of the nitrogen together with the full doses of phosphorus and potassium was applied as basal, while the remaining nitrogen was top-dressed in two equal splits at the knee-high and tasselling stages. No additional fertilizers were applied to the intercrops.

The experiment was conducted primarily under rainfed conditions, with supplemental irrigation applied during prolonged dry spells to avoid moisture stress. Weed management consisted of two manual weedings followed by earthing-up, and no herbicides were applied to prevent interference with insect pest populations and natural enemy activity. No insecticides were used throughout the experiment to allow natural infestation of fall armyworm and associated insect communities. All other agronomic practices were maintained uniformly across treatments.

2.5 Data Collection

Plant height was measured at 30, 60, and 90 days after sowing (DAS) and at harvest from five randomly selected plants in each plot using a measuring scale from the soil surface to the tip of the highest plant part, and the average value was expressed in centimetres (cm). The number of fully expanded green leaves was counted from the same tagged plants at 30, 60, and 90 DAS, and the mean was expressed as leaves plant⁻¹. Leaf area was measured at 45 and 75 DAS using a leaf area meter, and leaf area index (LAI) was calculated as the ratio of total leaf area to the ground area occupied by the crop. Stem diameter was recorded at 60 DAS using a digital Vernier caliper approximately 5 cm above the soil surface from five tagged plants, and the average was expressed in centimetres (cm). Dry matter accumulation was determined at 30, 60, and 90 DAS by oven-drying representative plant samples at 70 ± 2 °C until constant weight, and the results were expressed as g plant⁻¹. Crop Growth Rate (CGR) and Relative Growth Rate (RGR) were computed for the intervals of 30–60 and 60–90 DAS using successive dry matter observations and expressed as g m⁻² day⁻¹ and g g⁻¹ day⁻¹, respectively. Leaf chlorophyll content was estimated at 45 and 75 DAS using a SPAD-502 Plus chlorophyll meter, and the mean of three readings from each of five tagged plants was recorded as the SPAD chlorophyll index. Phenological observations included the number of days to 50% emergence, 50% tasselling, 50% silking, and physiological maturity, which were recorded as the number of days from sowing until the respective developmental stage was attained by the specified proportion of plants in each experimental plot.

2.6 Statistical Analysis

The experimental data were analysed using analysis of variance (ANOVA) appropriate for a Randomised Complete Block Design (RCBD). Treatment means were compared using the critical difference (CD) at the 5% level of significance ($P \leq 0.05$). Statistical analyses were performed using OPSTAT.

3. Results and Discussion

3.1 Vegetative Parameters

Plant height of maize was significantly ($P < 0.05$) influenced by the different legume-based intercropping systems at all growth stages during both years and in the pooled analysis (Fig. 1A). In the pooled analysis of the two experimental years, the maize + cowpea + marigold system (T_{10}) consistently recorded the tallest plants (50.6, 147.7, 220.7 and 224.9 cm at 30, 60, 90 DAS and harvest, respectively), followed by maize + cowpea (1:1) (T_2), whereas sole maize (T_1) produced the shortest plants throughout the crop growth period. The superiority of T_{10} was consistent across both years. The greater plant height observed under T_{10} may be attributed to improved nitrogen availability, complementary resource utilisation, enhanced photosynthetic activity, and better crop vigour. The combined effect of cowpea and marigold likely created a favourable rhizosphere environment, resulting in improved vegetative growth compared with sole maize (Lithourgidis & Dordas, 2010).

The number of leaves per plant differed significantly ($P < 0.05$) among the intercropping systems throughout crop growth (Fig. 1B). In the pooled analysis of the two experimental years, treatment T_{10} produced the highest number of leaves (9.0, 15.4 and 16.5 leaves plant⁻¹ at 30, 60 and 90 DAS, respectively), followed by T_2 , whereas sole maize (T_1) recorded the lowest values. Similar treatment responses were observed during both years. The increased leaf production under T_{10} may be associated with improved nutrient availability and enhanced physiological activity, which promoted leaf initiation and expansion. A larger leaf canopy enhanced light interception and photosynthetic efficiency, thereby supporting greater biomass production (Wangiyana *et al.*, 2020). Leaf area index was significantly ($P < 0.05$) affected by the different legume-based intercropping systems at both 45 and 75 DAS (Fig. 1C). The highest pooled LAI was recorded under T_{10} (2.85 and 4.34), followed by T_2 (2.71 and 4.15), whereas sole maize (T_1) recorded the lowest values (2.10 and 3.21). The treatment trend remained consistent during both years. The higher LAI under T_{10} indicates improved canopy development resulting from efficient utilisation of light, water, and nutrients (Fu *et al.*, 2023). Enhanced leaf expansion increased the photosynthetically active surface area, leading to greater assimilate production and improved crop growth (Suhi *et al.*, 2022).

Stem diameter at 60 DAS was significantly ($P < 0.05$) influenced by the different legume-based intercropping systems during both years and in the pooled analysis (Fig. 1D). The maximum pooled stem diameter was recorded under T_{10} (2.85 cm), followed by T_2 (2.69 cm), whereas sole maize (T_1) produced the minimum stem diameter (2.08 cm). The treatment trend remained consistent across both experimental years. The greater stem diameter under T_{10} may be attributed to improved nutrient availability, enhanced assimilate production, and efficient resource utilisation, which promoted stem thickening and overall crop vigour (Liu *et al.*, 2023). In contrast, sole maize exhibited comparatively thinner stems due to greater intraspecific competition and reduced nutrient availability.

Dry matter accumulation differed significantly ($P < 0.05$) among the legume-based intercropping systems at 30, 60, and 90 DAS (Fig. 2A). Treatment T_{10} consistently recorded the highest dry matter accumulation (15.7, 80.4, and 180.0 g plant⁻¹), followed by T_2 (15.0, 77.3, and 174.0 g plant⁻¹), while sole maize (T_1) accumulated the least biomass (11.6, 63.5, and 144.0 g plant⁻¹), respectively. Similar trends were observed during both years. Higher biomass accumulation under T_{10} may be associated with improved nitrogen availability, greater photosynthetic efficiency, and enhanced partitioning of assimilates throughout the growth period (Fu *et al.*, 2023). Better canopy development and complementary resource use contributed to continuous biomass production compared with sole maize (Ngwenya *et al.*, 2024).

Crop growth rate was significantly ($P < 0.05$) affected by the intercropping systems during both the 30–60 and 60–90 DAS intervals (Fig. 2B). The highest pooled CGR was recorded under T_{10} (24.32 and 33.47 g m⁻² day⁻¹), followed by T_2 (23.43 and 32.20 g m⁻² day⁻¹), whereas sole maize (T_1) recorded the lowest values (18.73 and 27.16 g m⁻² day⁻¹). The treatment response remained consistent across both years. The higher CGR observed under T_{10} reflects sustained dry matter production resulting from efficient utilisation of nutrients, moisture, and solar radiation (Ngwenya *et al.*, 2024). Improved crop vigour and continuous biomass accumulation under intercropping enhanced growth rate compared with the monocropping system (Liu *et al.*, 2024).

Relative growth rate varied significantly ($P < 0.05$) among the intercropping systems during both growth intervals (Fig. 2C). Treatment T_{10} recorded the highest pooled RGR during 30–60 DAS (0.070 g g⁻¹ day⁻¹) and 60–90 DAS (0.035 g g⁻¹ day⁻¹), followed by T_2 , whereas the lowest values were observed under sole maize (0.059 and 0.027 g g⁻¹ day⁻¹, respectively). RGR declined during the later growth stage across all treatments. The higher RGR under T_{10} indicates greater efficiency of biomass production during the active vegetative phase due to improved nutrient availability and physiological activity (Liu *et al.*, 2024). The decline in RGR during later growth stages reflects the normal transition from vegetative growth to reproductive development (Ngwenya *et al.*, 2024).

The SPAD chlorophyll index was significantly ($P < 0.05$) influenced by the legume-based intercropping systems at both 45 and 75 DAS (Fig. 2D). Treatment T_{10} recorded the highest pooled SPAD values (48.6 and 55.8), followed by T_2 (47.2 and 54.0), whereas sole maize (T_1) recorded the lowest values (38.8 and 44.6). Similar treatment responses were observed during both years. The higher SPAD chlorophyll index under T_{10} indicates improved leaf nitrogen status and chlorophyll biosynthesis, resulting in enhanced photosynthetic capacity. Greater chlorophyll retention under intercropping contributed to improved crop growth and biomass production compared with sole maize (Ngwenya *et al.*, 2024).

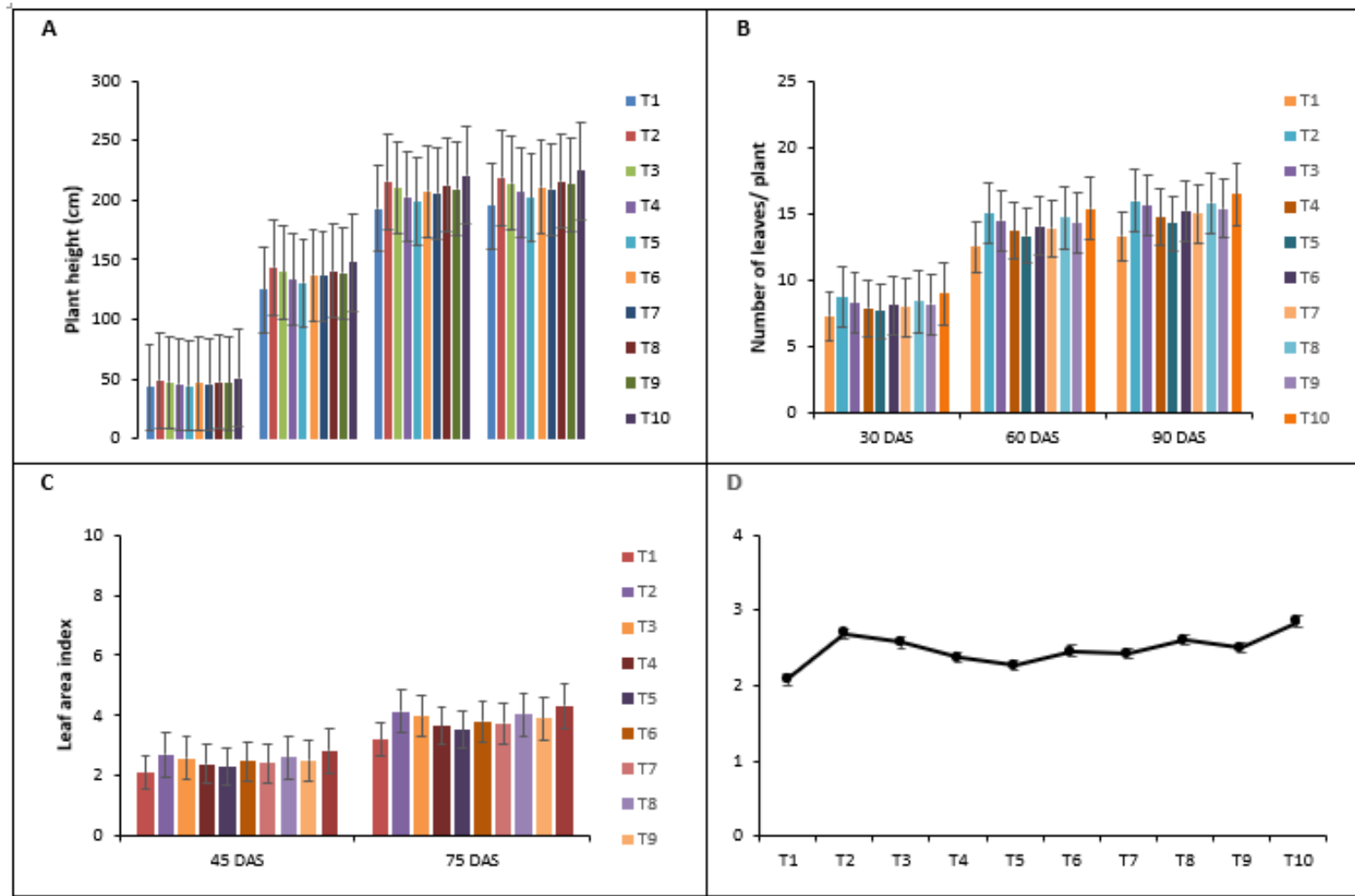


Fig. 1. Effect of different legume-based intercropping systems on vegetative growth attributes of maize (*Zea mays* L.): (A) Plant height, (B) Number of leaves per plant, (C) Leaf area index (LAI), and (D) Stem diameter. Values represent pooled means of two years (2024–2025); error bars indicate $\pm$ SE

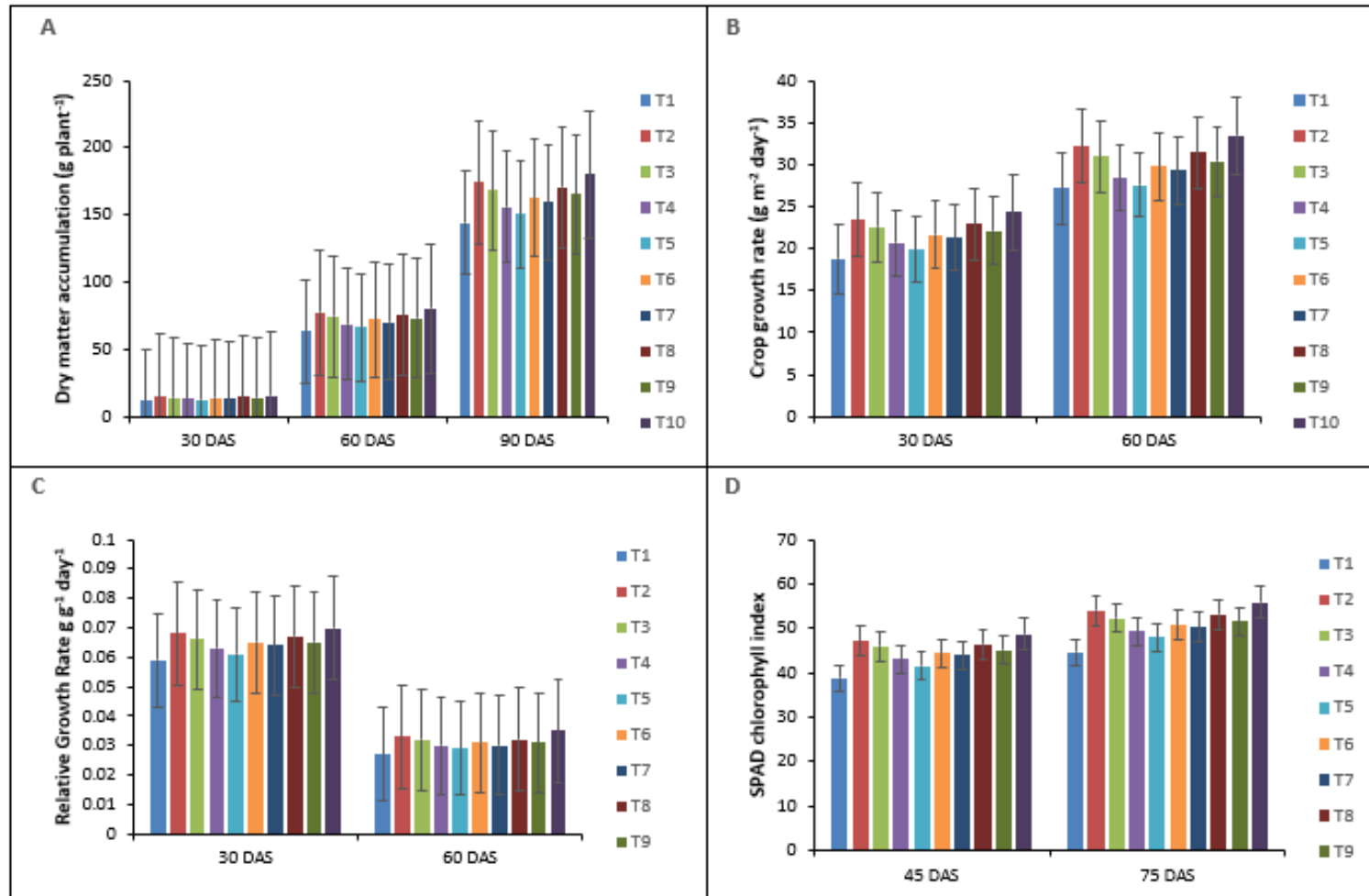


Fig. 2. Effect of different legume-based intercropping systems on physiological growth parameters of maize (*Zea mays* L.): (A) Dry matter accumulation, (B) Crop growth rate (CGR), (C) Relative growth rate (RGR), and (D) SPAD chlorophyll index. Values represent pooled means of two years (2024–2025); error bars indicate $\pm$ SE

3.2 Phenological Parameters

The days required for 50% emergence were significantly ($P < 0.05$) influenced by the different legume-based intercropping systems during both years and in the pooled analysis (Table 1). Treatment T₁₀ recorded the earliest 50% emergence (5.8 days), followed by T₂ (5.9 days), whereas sole maize (T₁) required the longest time (6.3 days). The treatment response remained consistent across both years. Since 50% emergence was recorded during the early establishment phase, before substantial interspecific interactions among the component crops could develop, the observed differences may be associated primarily with treatment-related differences in the immediate soil microenvironment, seed placement, soil moisture and temperature conditions, rather than with nutrient facilitation by the established intercrops. Therefore, the differences in emergence should be interpreted cautiously as an early establishment response to the intercropping arrangements rather than as a direct consequence of interspecific interactions (Jensen *et al.*, 2020).

Table 1. Effect of different legume-based intercropping systems on phenological parameters of maize

Treatment	Days to 50% emergence	Days to 50% tasseling	Days to 50% silking	Days to physiological maturity
Sole Maize (Control)	6.37	57.8	60.5	113.0
Maize + Cowpea (1:1)	5.96	55.1	57.8	109.8
Maize + Cowpea (2:1)	6.04	55.6	58.3	110.6
Maize + Soybean (1:1)	6.12	56.5	59.2	111.5
Maize + Soybean (2:1)	6.27	57.2	59.8	112.2
Maize + Blackgram (2:1)	6.18	56.1	58.8	111.2
Maize + Greengram (2:1)	6.14	56.3	59.0	111.3
Maize + Groundnut (2:1)	6.05	55.4	58.1	110.2
Maize + Pigeonpea (2:1)	6.01	55.9	58.6	110.9
Maize + Cowpea + Marigold (2:1:1)	5.88	54.6	57.3	109.2
SEm (±)	0.06	0.29	0.32	0.49
CD (P = 0.05)	0.18	0.86	0.95	1.46

Days to 50% tasselling differed significantly ($P < 0.05$) among the intercropping systems. The earliest tasselling was recorded under T₁₀ (54.6 days), followed by T₂ (55.1 days), whereas sole maize (T₁) required the maximum duration (57.8 days) (Table 1). Similar trends were observed during both years of experimentation. The earlier tasselling observed under T₁₀ may be due to improved nutrient availability and vigorous vegetative growth, which accelerated the transition from vegetative to reproductive development (Liu *et al.*, 2024). Delayed tasselling under sole maize could be associated with comparatively lower growth efficiency under monocropping conditions (Fu *et al.*, 2023).

The different legume-based intercropping systems significantly ($P < 0.05$) influenced days to 50% silking (Table 1). Treatment T₁₀ reached 50% silking earliest (57.3 days), followed by T₂ (57.8 days), while sole maize (T₁) required the longest duration (60.5 days). The treatment response remained consistent during both experimental years. Earlier silking under T₁₀ indicates improved crop nutrition and enhanced physiological activity, which promoted timely reproductive development. In contrast, delayed silking in sole maize suggests relatively slower crop growth and reduced resource-use efficiency (Lithourgidis & Dordas, 2010).

The number of days to physiological maturity was significantly ($P < 0.05$) affected by the legume-based intercropping systems (Table 1). Treatment T₁₀ attained physiological maturity in the shortest duration (109.2 days), followed by T₂ (109.8 days), whereas sole maize (T₁) required the longest period (113.0 days). Similar treatment effects were observed in both years. The earlier physiological maturity under T₁₀ may be attributed to enhanced nutrient availability and efficient utilisation of growth resources, which accelerated crop growth and reproductive development. Faster completion of the crop life cycle under intercropping reflects improved physiological efficiency compared with sole maize (Lithourgidis *et al.*, 2011; Kermah *et al.*, 2017).

4. Conclusion

The present study demonstrated that legume-based intercropping significantly improved the growth and phenological performance of maize compared with sole cropping. Among the evaluated systems, maize + cowpea + marigold (T₁₀) consistently produced superior plant height, leaf area index, stem diameter, dry matter accumulation, crop growth rate, relative growth rate, and SPAD chlorophyll index, while also promoting earlier tasselling, silking, and physiological maturity. These improvements indicate more efficient utilisation of growth resources and enhanced crop vigour under diversified intercropping. Overall, the maize + cowpea + marigold system emerged as the most effective and sustainable production strategy for enhancing maize growth and developmental efficiency. Adoption of this intercropping system can contribute to improved crop productivity and support sustainable agricultural intensification in maize-based production systems.

5. Limitation

The study was conducted over two kharif seasons at a single experimental location, so the observed treatment responses represent the soil, climate, and management conditions of that site. The evaluation focused on vegetative and phenological attributes of maize; therefore, the present results do not by themselves establish the consistency of treatment performance across contrasting environments. Multi-location and longer-term validation would strengthen inference on the stability of the observed responses and support broader agronomic recommendations.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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