

Optimizing sowing window and planting density for enhanced growth, productivity and biochemical quality of senna (*Cassia aungustifoli Vahl.*)

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Optimizing sowing window and planting density for enhanced growth, productivity and biochemical quality of senna (*Cassia aungustifoli* Vahl.)

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Abstract

Background

Cassia aungustifoli Vahl. (senna) is an economically important medicinal plant cultivated for its sennoside-rich leaves. Crop establishment practices, particularly sowing time and plant density, regulate canopy development, nutrient acquisition, and biomass production; however, their interactive effects on growth, nutrient-use efficiency, and leaf quality under semi-arid conditions remain poorly understood.

Results

Field experiments were conducted during the Rabi seasons of 2023–24 and 2024–25 using a split-plot design comprising five sowing windows and three planting densities. Early sowing during September II fortnight (S₁) and October I fortnight (S₂) significantly enhanced plant height, canopy spread, branching, leaf area, leaf area index, SPAD chlorophyll, carotenoid content, nutrient uptake, and fresh and dry leaf yields compared with delayed sowing. The 45 × 30 cm planting density (D₂) produced the highest leaf yield, crude protein content, nutrient uptake, and economic returns while the results of sennoside yield remained non-significant, whereas 60 × 30 cm (D₃) promoted greater individual plant growth. The S₁D₂ interaction consistently recorded the highest biomass production, nutrient uptake, nutrient-use

efficiency, and benefit–cost ratio. Early sowing also reduced residual soil nitrogen, phosphorus, and potassium, indicating greater resource acquisition and utilization by the crop.

Conclusions

Early sowing, particularly the September II fortnight, improved vegetative growth, physiological traits, nutrient uptake and leaf biomass, while 45 × 30 cm spacing maximized dry leaf yield per unit area and economic returns. Wider spacing (60 × 30 cm) favoured individual-plant growth, but did not maximize yield per hectare. Sennoside concentration was statistically unaffected by the tested sowing windows and planting densities. Under the conditions of this two-year study, September II or October I sowing combined with 45 × 30 cm spacing provided a practical strategy for high leaf biomass and economic productivity.

1. Introduction

Cassia angustifoli Vahl. (senna) is an important medicinal crop cultivated for its anthraquinone glycosides, particularly sennosides A and B, which are the principal bioactive constituents responsible for its laxative properties (Anon, 1985; Husain, 1992). The productivity and phytochemical quality of senna are strongly influenced by environmental conditions and agronomic management. Appropriate sowing time determines the thermal and moisture regimes experienced during crop development, whereas planting density regulates light interception, canopy architecture, soil moisture utilization, and inter-plant competition, thereby influencing vegetative growth, biomass accumulation, yield, and sennoside content (Tripathi, 1999; Sastry *et al.*, 2015). Despite its economic importance, senna cultivation remains inadequately standardized, and optimized agronomic practices for improving crop productivity and quality under diverse agro-climatic conditions are still limited (Sastry *et al.*, 2015). Therefore, this study investigated the individual and interactive effects of sowing window and planting density on growth, nutrient uptake, yield, and sennoside content of *C. angustifolia* to identify agronomic practices that improve resource-use efficiency and crop productivity.

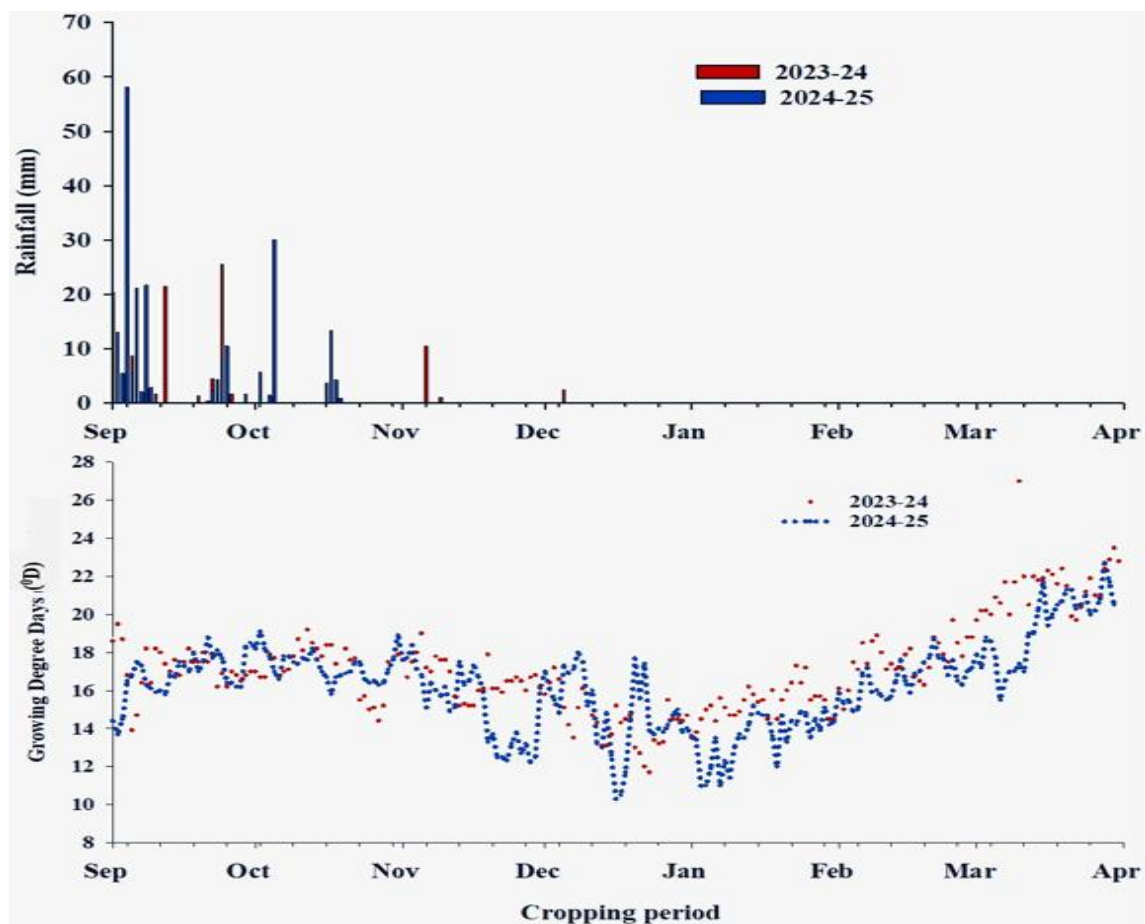


Fig 1: Rainfall and Growing Degree Days (°D) during the cropping period (2023-24 and 2024-25)

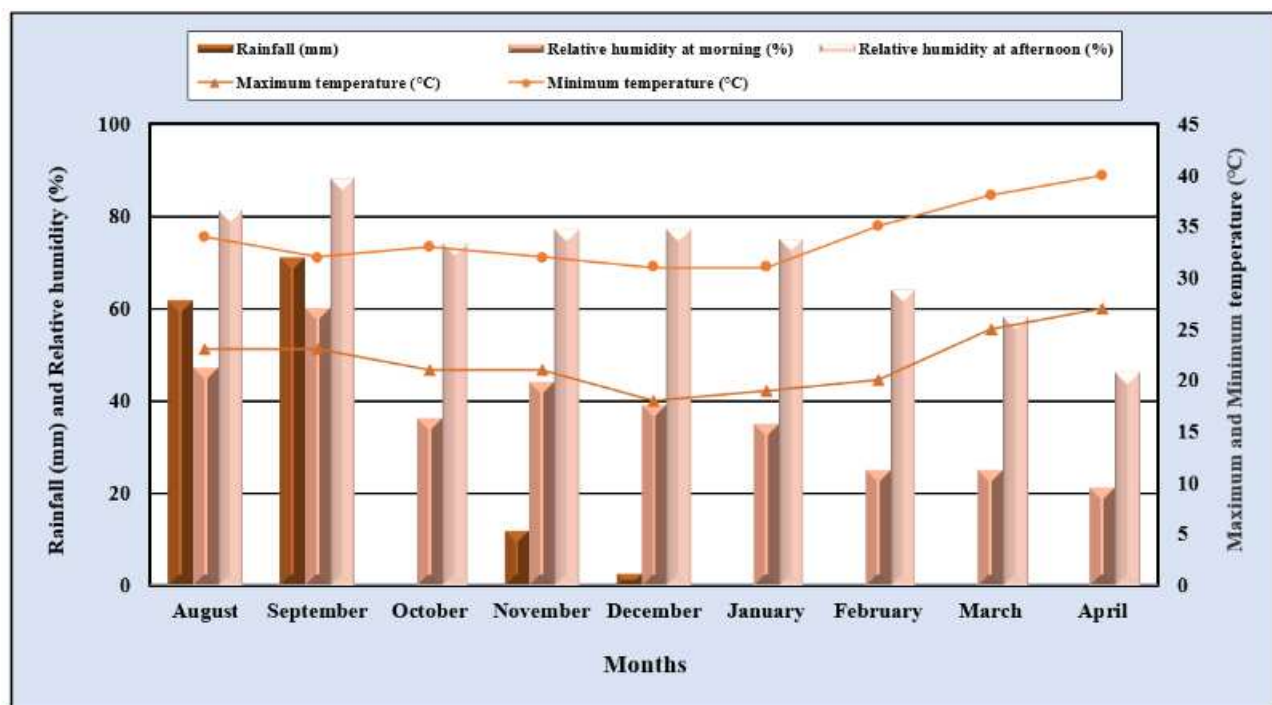


Fig 2: Meteorological observations for the cropping year 2023-24

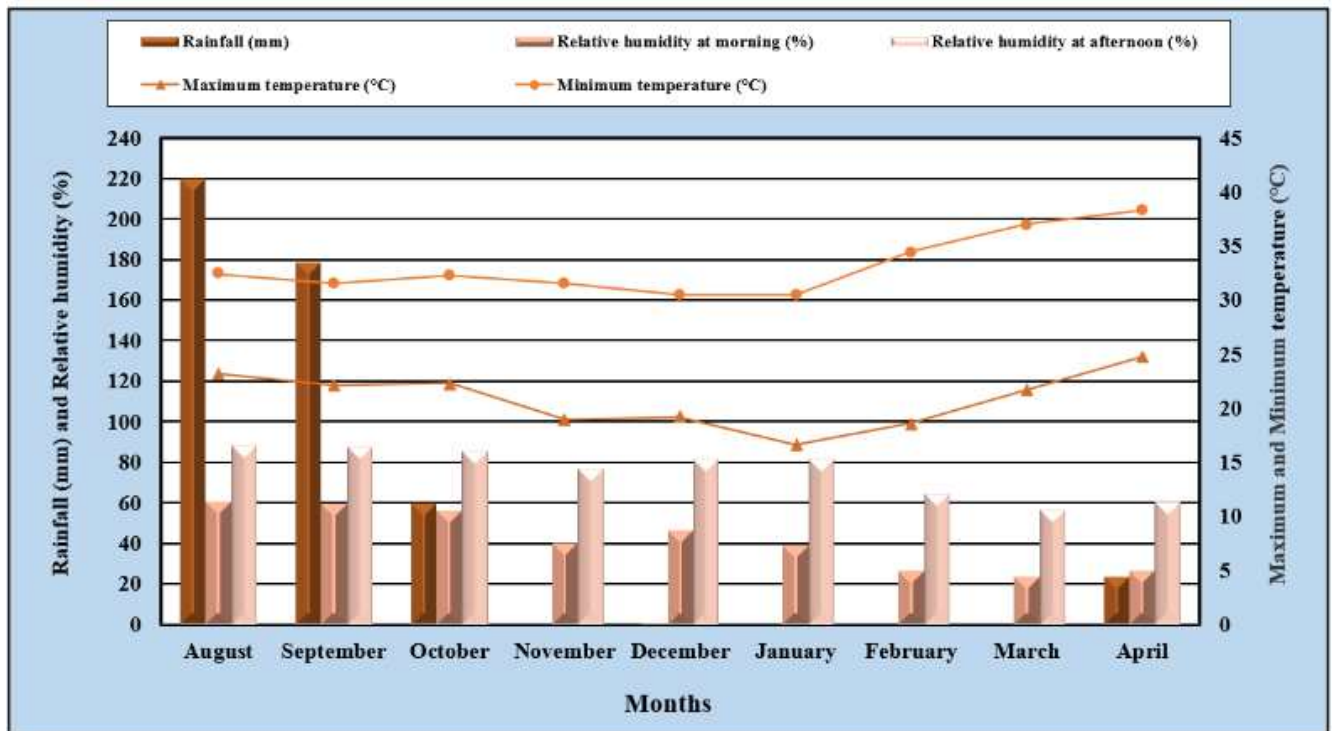


Fig 3: Meteorological observations for the cropping year 2024–25



Fig. 4: General view of experimental site

Results

Plant height

Plant height was not significantly affected by sowing window or planting density at 30 DAS (Table 1 and 1a & figures 8 and 9). Significant differences were observed from 60 DAS onwards. At 60 and 90 DAS, S₁ recorded the tallest plants (44.82 and 51.07 cm, respectively), which were statistically on par with S₂, whereas S₅ produced the shortest plants (38.53 and 43.23 cm, respectively). Among planting densities, D₃ consistently recorded the greatest plant height (47.50 and 54.52 cm at 60 and 90 DAS, respectively), while D₁ recorded the lowest values. The S × D interaction was significant at 90 DAS, with S₁D₃ (57.30 cm) and S₂D₃ (57.05 cm) producing the tallest plants, whereas S₅D₁ (37.23 cm) recorded the minimum height (Table 2a).

Plant spread

Plant spread was not significantly influenced by sowing window or planting density at 30 DAS (Table 1 and 1a & fig. 5). From 60 DAS onwards, significant differences were observed. S₁ recorded the highest plant spread at 60 and 90 DAS (2648.67 and 2825.55 cm², respectively), remaining statistically comparable with S₂, whereas S₅ recorded the lowest values (2099.33 and 2192.33 cm², respectively). Among planting densities, D₃ (60 × 30 cm) resulted in the greatest plant spread at 90 DAS (3090.33 cm²), followed by D₂, while D₁ recorded the lowest (1989.30 cm²). A significant S × D interaction was observed at 90 DAS, with the maximum plant spread under S₁D₃ (3431.33 cm²) and S₂D₃ (3372.00 cm²) and the minimum under S₅D₁ (1766.50 cm²) (Table 3a).

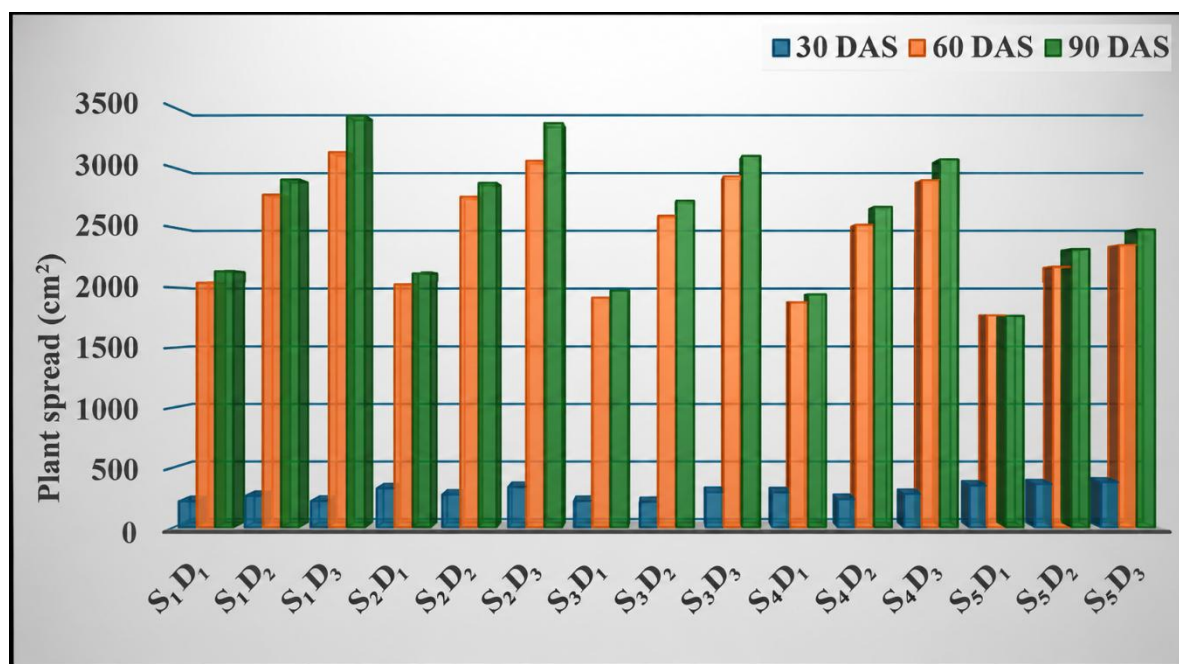


Fig. 5: Plant spread (cm²) of senna at 90 DAS as influenced by different sowing window and planting density

Number of branches per plant

The number of branches was unaffected by sowing window, planting density, and their interaction at 30 DAS, but significant differences emerged at later growth stages (Table 1 and 1a & figures 8 and 9). At 90 DAS, S₁ produced the highest number of branches (8.66), remaining statistically at par with S₂ (8.60), whereas S₅ recorded the lowest (6.86). Among planting densities, D₃ (60 × 30 cm) recorded the maximum number of branches (9.27), followed by D₂ (8.44), while D₁ (30 × 30 cm) recorded the minimum (6.40). The significant S × D interaction showed that S₁D₃ produced the highest number of branches (10.00), whereas S₅D₁ recorded the lowest (5.00) (Table 4a).

Number of compound leaves per plant

The number of compound leaves was not significantly affected by sowing window, planting density, or their interaction at 30 DAS, whereas significant differences were observed at 60 and 90 DAS (Tables 2 and 2a & fig. 8 and 9). At 90 DAS, S₁ produced the highest number of compound leaves (89.90), remaining statistically at par with S₂ (89.15), while S₅ recorded the lowest (74.25). Among planting densities, D₃ (60 × 30 cm) recorded the maximum number

of compound leaves (94.99), followed by D_2 (85.44), whereas D_1 (30×30 cm) recorded the minimum (71.36). A significant $S \times D$ interaction was observed, with S_1D_3 (103.70) and S_2D_3 (102.55) producing the highest number of compound leaves, while S_5D_1 recorded the lowest (63.20).

Leaf Area (cm²)

Leaf area was not significantly influenced by sowing window, planting density, or their interaction at 30 DAS, whereas significant differences were observed at 60 and 90 DAS (Tables 2 and 2a & fig. 6). At 90 DAS, S_1 recorded the highest leaf area (586.50 cm²), remaining statistically at par with S_2 (580.50 cm²), while S_5 recorded the lowest (518.83 cm²). Among planting densities, D_3 (60×30 cm) produced the maximum leaf area (609.40 cm²), followed by D_2 (571.90 cm²), whereas D_1 (30×30 cm) recorded the minimum (501.80 cm²). A significant $S \times D$ interaction was observed, with S_1D_3 (641.00 cm²) and S_2D_3 (634.50 cm²) recording the highest leaf area, while S_5D_1 recorded the lowest (471.00 cm²).

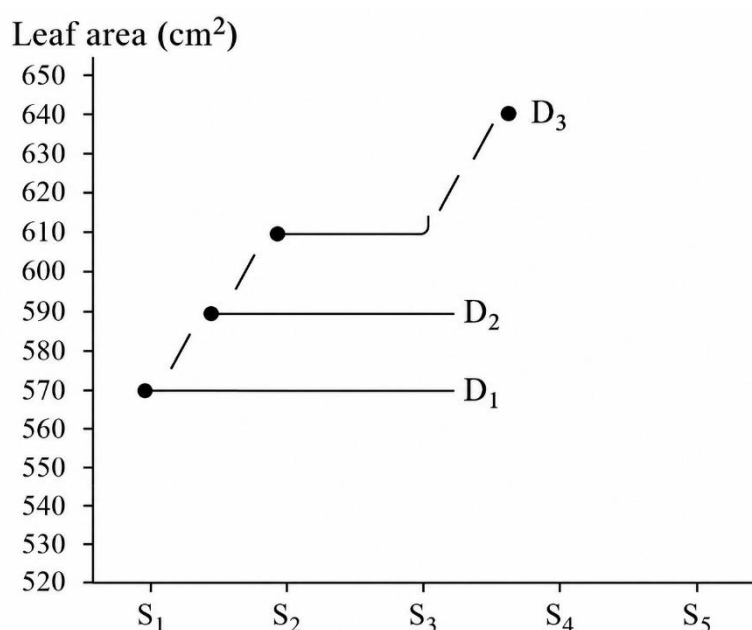


Fig 6: Leaf area (cm²) of senna at 90 DAS as influenced by different sowing window and planting density

Leaf Area Index (LAI)

Leaf area index (LAI) was not significantly affected by sowing window, planting density, or their interaction at 30 DAS, whereas significant differences were observed at 60 and

90 DAS (Tables 2 and 2a). At 90 DAS, S₁ recorded the highest LAI (0.460), remaining statistically at par with S₂ (0.455), while S₃ recorded the lowest (0.409). Among planting densities, D₃ (60 × 30 cm) produced the highest LAI, followed by D₂ (45 × 30 cm), whereas D₁ (30 × 30 cm) recorded the lowest. A significant S × D interaction was observed, with S₁D₃ recording the highest LAI and S₃D₁ the lowest (Tables 7 and 7a).

Chlorophyll content (SPAD values)

Chlorophyll content (SPAD values) was not significantly influenced by sowing window, planting density or their interaction at 30 DAS; however, significant variations were observed at 60 and 90 DAS (Tables 2 and 2a). At 90 DAS, S₁ recorded the highest chlorophyll content (77.25), remaining statistically at par with S₂ (76.78), whereas S₃ recorded the lowest (68.32). Among planting densities, D₃ (60 × 30 cm) recorded the maximum SPAD value (81.47), followed by D₂ (76.45), while D₁ (30 × 30 cm) recorded the minimum (64.44). The significant S × D interaction showed that S₁D₃ (84.90) and S₂D₃ (84.50) recorded the highest chlorophyll content, whereas S₃D₁ recorded the lowest (60.70).

Dry weight of leaves (kg /ha)

Dry leaf yield was significantly influenced by sowing windows, planting density and their interaction during both years and in pooled analysis (Tables 3 and 3a). Among sowing windows, S₁ recorded the highest pooled dry leaf yield (870.04 kg ha⁻¹), remaining statistically at par with S₂ (854.61 kg ha⁻¹), whereas S₃ recorded the lowest (567.97 kg ha⁻¹). Among planting densities, D₂ (45 × 30 cm) produced the maximum dry leaf yield (820.51 kg ha⁻¹), followed by D₃ (60 × 30 cm) (758.76 kg ha⁻¹), while D₁ (30 × 30 cm) recorded the lowest (693.38 kg ha⁻¹). The interaction effect revealed that S₁D₂ (946.52 kg ha⁻¹) and S₂D₂ (925.68 kg ha⁻¹) recorded the highest dry leaf yields, whereas S₃D₃ recorded the lowest (536.11 kg ha⁻¹) dry weight of leaves.

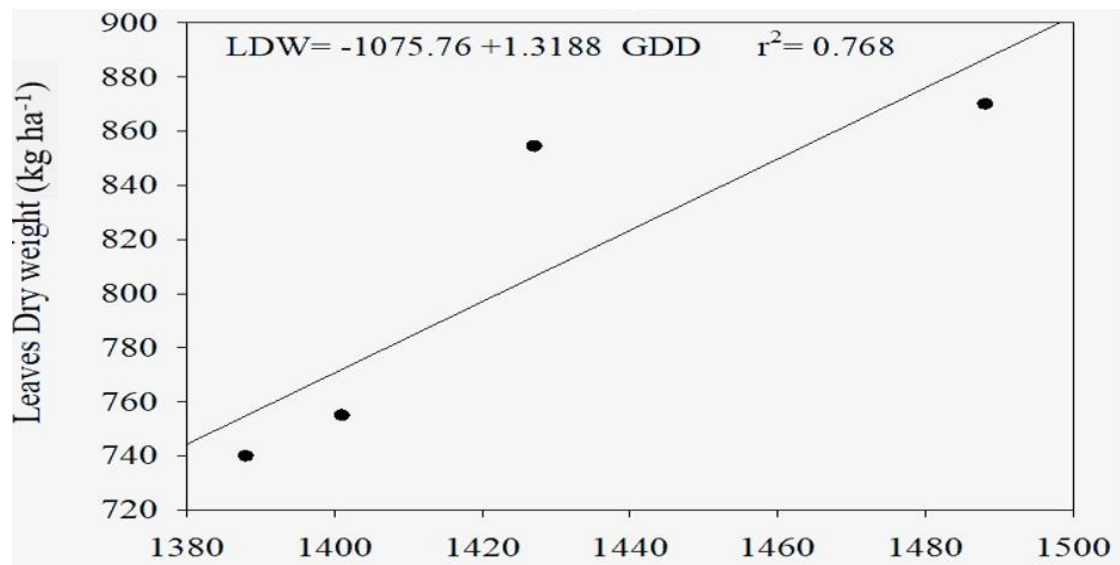


Fig. 7: Leaf dry weight of senna as influenced by Growing Degree days (°D)



Fig. 8: Treatment -S₁D₂ – September II fortnight + 45 cm × 30 cm Fig. 9: Treatment S₅D₃ – November II fortnight + 60 cm × 30 cm

Note: Figures 8 and 9 Represents the photographs of senna plants, showing the phenotypic variation between the best-performing (S₁ and D₂) and least-performing (S₅ and D₃) treatments at harvest.

Dry matter production in leaf, stem and total plant (g plant⁻¹)

Dry matter production in leaves, stems, and total plant biomass was significantly influenced by sowing windows, planting density, and their interaction (Tables 3 and 3a). Among sowing windows, S₁ recorded the highest pooled dry matter accumulation in leaves (11.68 g plant⁻¹), stem (29.40 g plant⁻¹) and total plant (61.60 g plant⁻¹), remaining statistically at par with S₂ (11.47, 28.90 and 60.50 g plant⁻¹, respectively), whereas S₅ recorded the lowest values (7.53, 22.60 and 44.30 g plant⁻¹). Among planting densities, D₃ (60 × 30 cm) recorded the maximum dry matter accumulation in leaves (13.45 g plant⁻¹), stem (32.33 g plant⁻¹) and total plant (68.72 g plant⁻¹), followed by D₂, while D₁ (30 × 30 cm) recorded the lowest values. The interaction effect revealed that S₁D₃ recorded the highest dry matter accumulation (15.40 g leaves, 36.05 g stem and 76.90 g total plant), whereas S₅D₁ recorded the lowest (4.86, 18.00 and 31.96 g plant⁻¹, respectively).

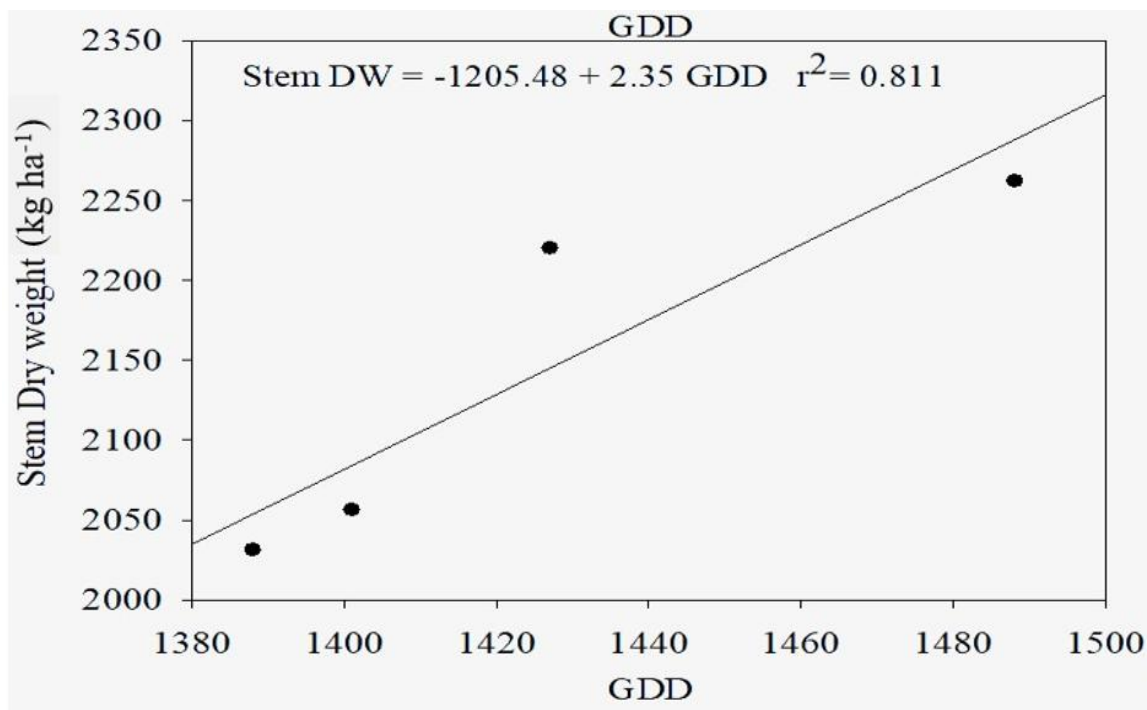


Fig 10: Stem dry weight of senna as influenced by Growing Degree days (°D)

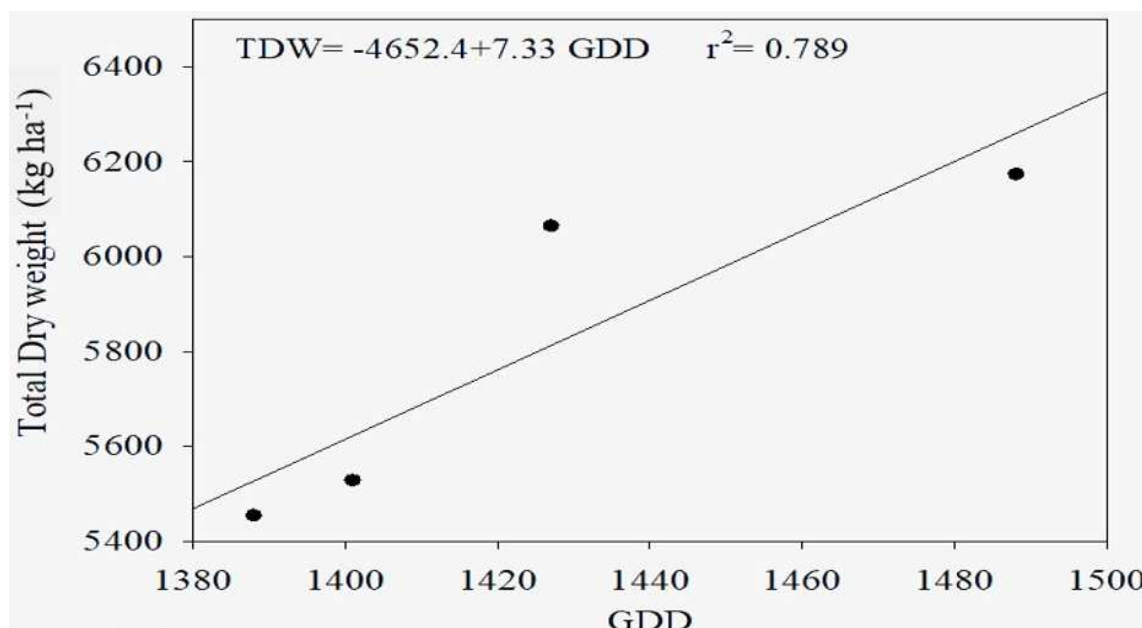


Fig 11: Total dry weight of senna as influenced by Growing Degree days (°D)

Note - Fig 10 and 11 shows the relationship between Growing Degree Days (GDD) and total dry weight (TDW) of senna. TDW increased linearly with accumulated GDD ($TDW = -4652.4 + 7.33 \text{ GDD}$, $R^2 = 0.789$), indicating that higher heat unit accumulation strongly favours biomass production.

Sennoside content (%)

Sennoside content of senna leaves was not significantly influenced by sowing windows, planting density, or their interaction at 75 and 90 DAS during both years and in pooled analysis (Table 4 and fig. 12). However, a consistent numerical trend was observed. At 90 DAS, S_1 recorded the highest sennoside content (3.32%), which was followed by S_2 (3.30%), whereas S_5 recorded the lowest (3.17%). Among planting densities, D_3 (60×30 cm) recorded the highest sennoside content (3.33%), while D_1 (30×30 cm) recorded the lowest (3.23%). The interaction effect showed maximum sennoside content in S_1D_3 (3.39%) and minimum in S_5D_1 (3.17%).

Carotenoid content (mg kg⁻¹)

Carotenoid content of senna leaves was significantly influenced by sowing windows, planting density, and their interaction at 75 and 90 DAS (Table 5 and fig. 12). At 75 DAS, S_1 recorded the highest carotenoid content (112.60 mg kg⁻¹), remaining statistically at par with S_2 (111.87 mg kg⁻¹), whereas S_5 recorded the lowest (100.47 mg kg⁻¹). Among planting densities,

D₃ (60 × 30 cm) recorded the maximum carotenoid content (118.74 mg kg⁻¹), followed by D₂ (111.87 mg kg⁻¹), while D₁ (30 × 30 cm) recorded the minimum (94.77 mg kg⁻¹). The interaction effect showed the highest carotenoid content in S₁D₃ (123.10 mg kg⁻¹) and the lowest in S₅D₁ (90.00 mg kg⁻¹).

At 90 DAS, a similar trend was observed, with S₁ (104.05 mg kg⁻¹) and S₂ (103.15 mg kg⁻¹) recording higher carotenoid content, whereas S₅ recorded the lowest (90.83 mg kg⁻¹). Among planting densities, D₃ recorded the highest carotenoid content (111.23 mg kg⁻¹), while D₁ recorded the lowest (86.56 mg kg⁻¹). The interaction effect revealed maximum carotenoid accumulation in S₁D₃ (116.50 mg kg⁻¹) and minimum in S₅D₁ (81.35 mg kg⁻¹).

Crude protein content (g)

Crude protein content of senna leaves was significantly influenced by sowing window, planting density, and their interaction at 75 and 90 DAS (Table 6 and fig. 12). At 75 DAS, S₁ recorded the highest pooled protein content (6.26 g 100 g⁻¹), followed by S₂ (5.89 g 100 g⁻¹), whereas S₅ recorded the lowest (4.87 g 100 g⁻¹). Among planting densities, D₂ (45 × 30 cm) recorded the maximum protein content (6.16 g 100 g⁻¹), followed by D₃, while D₁ (30 × 30 cm) recorded the lowest (4.99 g 100 g⁻¹). The interaction effect showed the highest protein content in S₁D₂ (7.07 g 100 g⁻¹) and the lowest in S₅D₁ (4.02 g 100 g⁻¹).

At 90 DAS, a similar trend was observed, with S₁ recording the highest protein content (5.41 g 100 g⁻¹) and S₅ the lowest (4.21 g 100 g⁻¹). Among planting densities, D₂ recorded the maximum value (5.32 g 100 g⁻¹), whereas D₁ recorded the minimum (4.34 g 100 g⁻¹). The interaction effect revealed maximum protein content in S₁D₂ (6.13 g 100 g⁻¹) and minimum in S₅D₁ (3.47 g 100 g⁻¹).

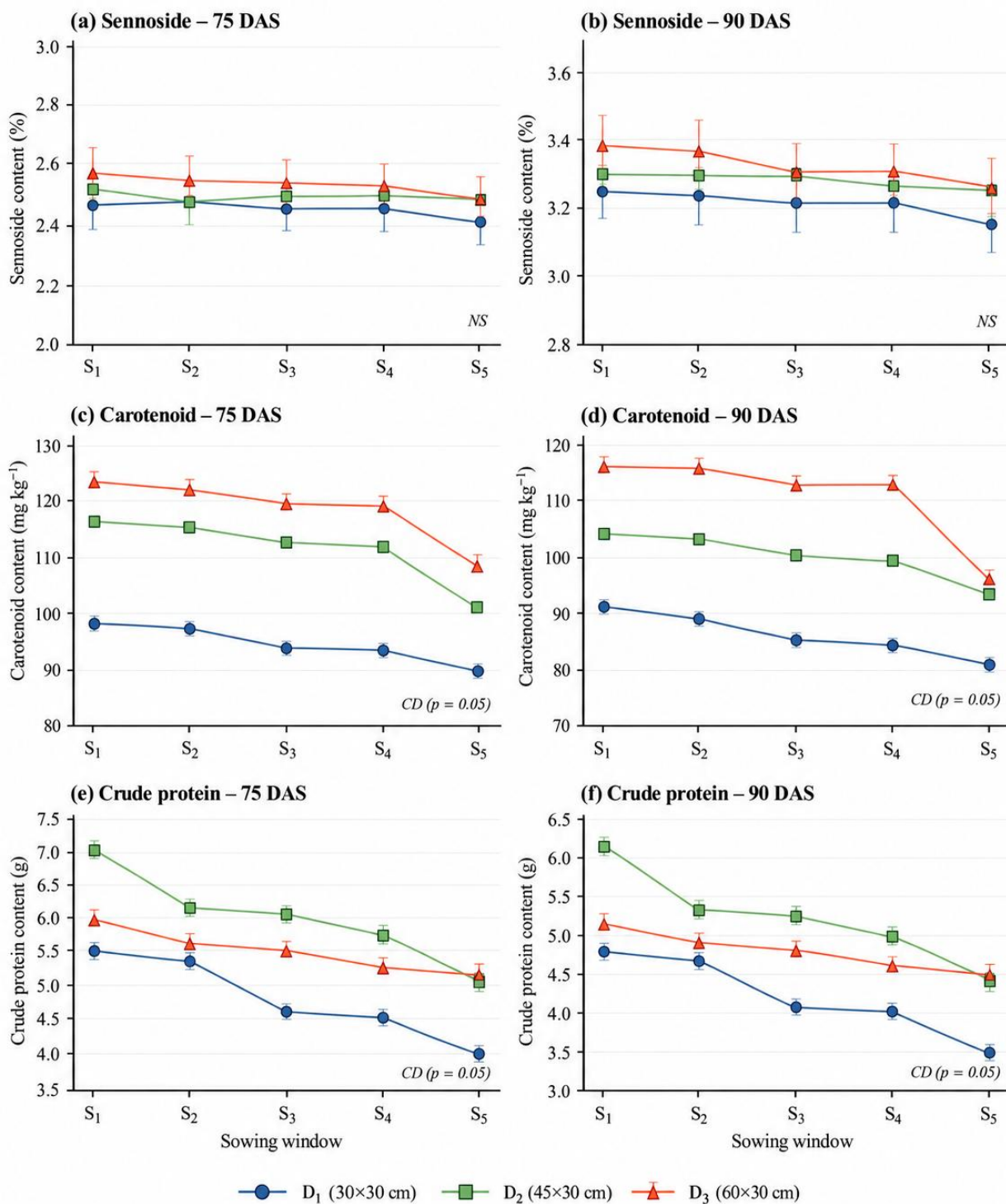


Fig. 12- Sennoside, carotenoid and crude protein content of senna leaves as influenced by sowing window and planting density at 75 and 90 DAS

Available nutrients and plant nutrient uptake

1. Available Nitrogen (N), Phosphorus (P) and Potassium (K) (kg/ha)

Residual soil N, P, and K availability after harvest was significantly influenced by sowing window and planting density, while their interaction effect was non-significant (Table 7 and 7a). Among sowing windows, the highest pooled available N ($352.00 \text{ kg ha}^{-1}$), P (59.05 kg ha^{-1}) and K ($289.48 \text{ kg ha}^{-1}$) were recorded in S_5 , followed by S_4 , whereas S_1 recorded the lowest values (342.00 , 51.00 and $281.18 \text{ kg ha}^{-1}$, respectively). Among planting densities, D_3 ($60 \times 30 \text{ cm}$) recorded the highest residual N, P, and K (364.00 , 70.11 and $301.08 \text{ kg ha}^{-1}$, respectively), while D_1 ($30 \times 30 \text{ cm}$) recorded the lowest (331.40 , 38.69 and $269.29 \text{ kg ha}^{-1}$, respectively).

2. Plant nutrient uptake (kg/ha)

Nutrient uptake of N, P, and K by senna was significantly influenced by sowing window, planting density, and their interaction during both years and in pooled analysis (Tables 7 and 7a). Among sowing windows, S_1 recorded the highest pooled uptake of N (57.40 kg ha^{-1}), P (32.90 kg ha^{-1}) and K (9.66 kg ha^{-1}), followed by S_2 , whereas S_5 recorded the lowest values (39.45 , 18.57 and 7.04 kg ha^{-1} , respectively). Among planting densities, D_2 ($45 \times 30 \text{ cm}$) recorded the maximum uptake of N (56.27 kg ha^{-1}), P (33.50 kg ha^{-1}) and K (9.62 kg ha^{-1}), while D_1 ($30 \times 30 \text{ cm}$) recorded the lowest values. The interaction effect showed the highest nutrient uptake in S_1D_2 and the lowest in S_5D_1 .

Profitability of senna as influenced by sowing window and planting density

Economics of senna cultivation was significantly influenced by sowing windows and planting densities (Table 8 and fig. 13). Among the treatments, S_1D_2 (September II fortnight sowing with $45 \times 30 \text{ cm}$ spacing) recorded the highest gross returns ($\text{₹}66,256 \text{ ha}^{-1}$), net returns ($\text{₹}22,282 \text{ ha}^{-1}$) and B:C ratio (1.51), followed by S_2D_2 ($\text{₹}64,797 \text{ ha}^{-1}$, $\text{₹}20,827 \text{ ha}^{-1}$ and 1.47, respectively). The lowest economic performance was observed in S_5D_3 (November II fortnight sowing with $60 \times 30 \text{ cm}$ spacing), recording gross returns of $\text{₹}44,100 \text{ ha}^{-1}$, net returns of $\text{₹}208 \text{ ha}^{-1}$ and a B:C ratio of 1.005.

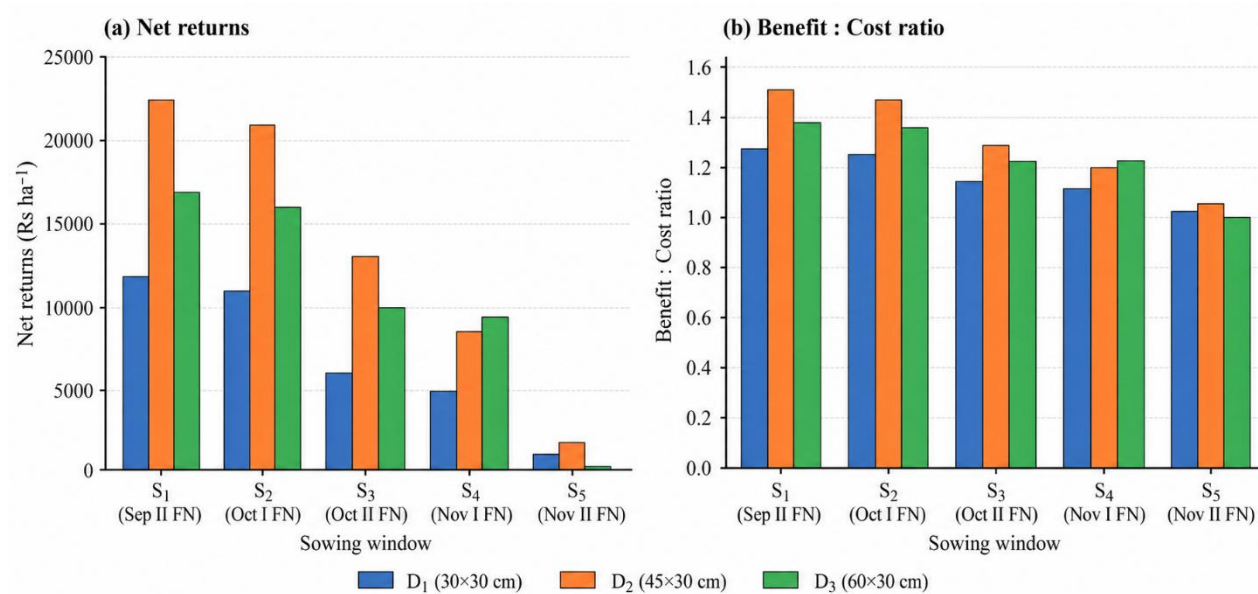


Fig. 13- Profitability of senna as influenced by sowing window and planting density

Discussion

Plant height

The greater plant height under earlier sowing and wider spacing at later growth stages is consistent with greater opportunity for vegetative development and lower inter-plant competition. In the present experiment, the response became significant only after 30 DAS, indicating that treatment effects developed as the canopy expanded. The direction of the spacing response agrees with recent work showing that plant-to-plant and row spacing can alter individual-plant growth in *C. angustifolia*, although the spacing that maximizes individual plant size need not maximize biomass yield per hectare (Constantinescu et al. 2025).

These findings are consistent with previous reports in senna (Sirajul *et. al.*, 2008; Ilangovan *et. al.*, 1990; Jithendra Kumar 2015) and other medicinal crops (Vasanthi *et. al.*, 2011; Ayub *et. al.*, 2008).

Plant spread

Early sowing and wider spacing increased canopy spread at later stages. Earlier establishment likely allowed a longer period for leaf and branch expansion before the later-season environmental conditions constrained growth, while wider spacing reduced physical and resource competition around individual plants. This interpretation is consistent with the

broader senna literature, in which sowing time and plant geometry have been associated with differences in growth and biomass accumulation (Sirajul Islam et al. 2008; Constantinescu et al. 2025).

Number of branches per plant

The increase in branches plant⁻¹ under S₁ and D₃ is compatible with reduced intra-specific competition and greater availability of space for lateral growth. The present data also illustrate an important distinction between individual-plant responses and area-based yield: D₃ produced more branches and greater individual-plant biomass, but D₂ produced greater dry leaf yield per hectare. Recent spacing research in senna similarly reported that plant development and biomass yield per unit area can respond differently to plant density (Constantinescu *et al.* 2025). Similar findings have been reported in senna and other medicinal crops (Sirajul *et. al.*, 2008; Ilangovan *et. al.*, 1990; Jitendra Kumar, 2015)

Number of compound leaves per plant

The greater number of compound leaves under early sowing and wider spacing contributed to the larger individual-plant photosynthetic surface observed in the present study. These responses are biologically consistent with reduced competition for light, water and nutrients during canopy establishment. However, because leaf number was measured per plant, the result should not be equated directly with leaf yield per hectare; the latter also depends on plant population. This distinction is supported by recent senna work emphasizing that individual plant performance and area-based biomass can diverge as spacing changes (Constantinescu *et al.* 2025). These findings are consistent with previous reports in senna and other medicinal crops (Sirajul *et. al.*, 2008; Ilangovan *et. al.*, 1990; Jitendra Kumar, 2015; Vasanthi *et. al.*, 2011).

Leaf Area (cm²)

The increase in leaf area under earlier sowing and wider spacing is consistent with greater canopy expansion under less intense competition. Larger leaf area can increase the potential for light interception and carbon assimilation, but the present experiment measured leaf area per plant, whereas dry leaf yield was expressed per hectare. Thus, the higher individual-plant leaf area at D₃ did not translate into the highest area-based dry leaf yield, which occurred at D₂. These findings are consistent with previous reports in senna and other medicinal

crops (Sirajul *et. al.*, 2008; Ilangovan *et. al.*, 1990; Jitendra Kumar, 2015; Vasanthi *et. al.*, 2011; Ayub *et. al.*, 2008).

Leaf Area Index (LAI)

LAI increased with crop development and was greater under earlier sowing and wider spacing in the present study. Because LAI integrates leaf area with ground area, its interpretation should consider the spacing denominator carefully. The observed treatment differences are compatible with changes in canopy establishment and leaf expansion under contrasting sowing environments, but the relatively low absolute LAI values reported here should be retained as measured rather than interpreted beyond the experimental conditions. These findings are consistent with earlier reports in senna and other medicinal crops (Sirajul *et. al.*, 2008; Ilangovan *et. al.*, 1990; Vasanthi *et. al.*, 2011)

Chlorophyll content (SPAD values)

Higher SPAD values under S₁ and D₃ indicate differences in relative leaf chlorophyll status at 60 and 90 DAS. Earlier establishment may have maintained more favourable conditions for leaf development, while wider spacing can reduce shading within the canopy. SPAD measurements are an indirect indicator of leaf chlorophyll status; therefore, the present results support differences in physiological status but do not by themselves establish differences in photosynthetic rate. Nutrient-management studies in senna also show that improved crop nutrition can alter growth and leaf physiological characteristics. These findings are in agreement with earlier reports in senna and other medicinal crops (Muruganandam *et. al.*, 2022; Rani and Usha, 2013; Basak *et. al.* 2022)

Dry weight of leaves (kg /ha)

Higher dry leaf yield under early sowing may be attributed to favourable growing conditions (Fig. 7) that enhanced leaf development, photosynthate accumulation, and dry matter partitioning. The superior performance of D₂ (45 × 30 cm) suggests an optimum balance between plant population and resource availability, resulting in efficient biomass production. In contrast, closer spacing increased competition, while wider spacing reduced yield per unit area due to lower plant population. The significant interaction further indicated that early sowing combined with optimum spacing provided favourable conditions for maximizing dry biomass accumulation in senna. These findings are in agreement with earlier reports in senna

and other medicinal crops (Sirajul *et. al.*, 2008; Ilangovan *et. al.*, 1990; Jitendra Kumar, 2015; Vasanthi *et. al.*, 2011; Ayub *et. al.*, 2008).

Dry matter production in leaf, stem and total plant (g plant⁻¹)

Higher dry matter production under early sowing and wider spacing may be attributed to favourable growing conditions (Fig. 10), improved light interception and reduced intra-specific competition, which enhanced photosynthetic activity and assimilate partitioning. Wider spacing allowed better resource availability for individual plants, resulting in greater biomass accumulation, while delayed sowing and closer spacing restricted vegetative growth due to adverse environmental conditions and increased competition. Since dry matter accumulation reflects overall crop growth and assimilate production, improved biomass under favourable sowing and spacing combinations contributes directly to higher productivity and secondary metabolite accumulation in senna. These findings are consistent with earlier reports in senna and other medicinal crops (Sirajul *et. al.*, 2008; Ilangovan *et. al.*, 1990; Jitendra Kumar, 2015; Muruganandam *et. al.*, 2022; Vasanthi *et. al.*, 2011; Ayub *et. al.*, 2008).

Sennoside content (%)

The non-significant variation indicates that sennoside accumulation was relatively stable across sowing windows and planting densities, suggesting a strong genetic regulation of this quality trait. Similar observations regarding the influence of crop management practices on sennoside accumulation in senna have been reported by Ilangovan *et. al.*, (1990), Muruganandam *et. al.*, (2022), Rani and Usha (2013), and Saikhom *et. al.*, (2012).

Carotenoid content (mg kg⁻¹)

Higher carotenoid content under early sowing and wider spacing may be attributed to improved light availability, reduced competition, and enhanced chloroplast activity, favouring pigment synthesis. The decline at 90 DAS may be due to leaf ageing and pigment degradation. These results highlight the role of optimum sowing time and plant geometry in maintaining physiological efficiency and quality traits in senna, in agreement with earlier reports (Sirajul *et. al.*, 2008; Muruganandam *et. al.*, 2022; Rani and Usha, 2013).

Crude protein content (g)

Higher crude protein content under early sowing and optimum spacing may be attributed to favourable growing conditions and improved nitrogen uptake and assimilation, enhancing protein synthesis. The superior performance of D₂ (45 × 30 cm) suggests a balanced plant geometry that optimized resource availability and nitrogen utilization. These results indicate that timely sowing and appropriate spacing improve the physiological quality of senna leaves and are consistent with earlier reports (Sirajul *et. al.*, 2008; Muruganandam *et. al.*, 2022; Rani and Usha, 2013).

Available nutrients and plant nutrient uptake

1. Available Nitrogen (N), Phosphorus (P) and Potassium (K) (kg/ha)

Higher residual nutrient availability under late sowing and wider spacing may be attributed to reduced crop growth and nutrient uptake, resulting in lower nutrient removal from the soil. In contrast, early sowing and closer spacing promoted vigorous growth and greater biomass production, leading to higher nutrient extraction and comparatively lower residual fertility. The non-significant interaction indicated that individual effects of sowing window and planting density predominantly influenced post-harvest soil nutrient status.

These findings suggest that residual soil fertility is closely associated with crop nutrient uptake and biomass production. Similar observations regarding the influence of agronomic practices on soil nutrient dynamics in senna and medicinal crops have been reported by Muruganandam *et. al.* (2022), Ilangoan *et. al.* (1990), and Saikhom *et. al.* (2012).

2. Plant nutrient uptake (kg/ha)

Higher nutrient uptake under early sowing and optimum spacing may be attributed to enhanced root growth, prolonged vegetative growth, and greater biomass accumulation under favourable environmental conditions. The superior performance of D₂ (45 × 30 cm) indicates an optimum balance between plant population and resource availability, resulting in efficient nutrient acquisition and utilization. In contrast, delayed sowing and suboptimal spacing reduced crop growth and nutrient demand, leading to lower uptake.

Efficient nutrient uptake is closely associated with higher leaf biomass production and overall crop productivity in senna. These findings highlight the importance of timely sowing

and suitable plant geometry for improving nutrient-use efficiency and yield potential, and are consistent with earlier reports in senna and other medicinal crops (Sirajul *et. al.*, 2008; Muruganandam *et. al.*, 2022; Rani and Usha, 2013; Vasanthi *et. al.*, 2011; Ayub *et. al.*, 2008).

Profitability of senna as influenced by sowing window and planting density

The treatment S₁D₂ recorded 50.3% higher gross returns and 50.2% higher B:C ratio compared with S₅D₃, indicating the economic advantage of early sowing combined with optimum plant density. The higher profitability under early sowing was attributed to improved crop growth, leaf biomass accumulation, and yield enhancement under favourable environmental conditions. In contrast, delayed sowing reduced economic returns due to restricted growth duration and suboptimal climatic conditions.

Among planting densities, D₂ (45 × 30 cm) exhibited superior economic performance by maintaining an optimum balance between plant population and individual plant growth. Wider spacing enhanced per-plant biomass but reduced yield per unit area, whereas closer spacing increased competition and limited productivity.

Overall, September II fortnight sowing with 45 × 30 cm spacing (S₁D₂) was identified as the most profitable production strategy for senna under dryland conditions. Similar findings have been reported by Sirajul *et. al.*, (2008), Jitendra Kumar (2015), and Constantinescu *et. al.*, (2025), emphasizing the importance of optimum sowing time and planting density for improving productivity and profitability in medicinal crops.



Fig. 14: Treatment S₁D₂ – September II fortnight + 45 cm × 30 cm



Fig. 15: Treatment S₅D₃ – November II fortnight + 60 cm × 30 cm

Note: Figures 14 and 15 Illustrates the morphological variation in senna leaves under the best-performing (S₁D₂) and least-performing (S₅D₃) treatment combinations.

Conclusion

The two-year field study clearly demonstrated that crop establishment practices — sowing window and planting density — play a decisive role in determining the growth, productivity, and biochemical quality of *Cassia angustifoli* Vahl. under semi-arid tropical conditions. Early sowing during the September II fortnight (S₁) or October I fortnight (S₂) consistently favoured vegetative growth, canopy development, chlorophyll and carotenoid synthesis, nutrient uptake and leaf yield compared with delayed sowing, primarily due to more favourable thermal and moisture regimes during crop growth. Among planting densities, 45 × 30 cm (D₂) proved optimum for leaf yield, crude protein content, nutrient uptake and economic returns by maintaining a balanced plant population, while wider spacing (60 × 30 cm, D₃) favoured individual plant vigour but not yield per unit area. The interaction of early sowing with 45 × 30 cm spacing (S₁D₂) consistently gave the best combination of biomass production, nutrient-use efficiency, and profitability, recording the highest net returns and benefit–cost ratio. Sennoside content, being under strong genetic control, remained statistically unaffected by these agronomic treatments.

Overall, sowing senna during the September II fortnight or October I fortnight at a planting density of 45 × 30 cm can be recommended as an effective, resource-efficient agronomic strategy for enhancing growth, leaf yield and profitability of *C. angustifolia* under semi-arid tropical conditions. These findings provide a practical basis for standardizing senna cultivation and can guide growers, researchers, and policymakers in developing sustainable production strategies for this economically important medicinal crop.

Materials and Methods

Experimental site and plant material

The experiment was conducted during the Rabi seasons of 2023–2024 and 2024–2025 at the Herbal Garden, College of Agriculture, University of Agricultural Sciences, Raichur, India (16°12' N, 77°35' E; 389 m above sea level), in the North-Eastern Dry Zone (Zone II) of Karnataka. The soil was red sandy loam with pH 7.67, electrical conductivity 0.15 dS m⁻¹, organic carbon 0.39% and available N, P₂O₅ and K₂O was 262.34, 39.98 and 268.12 kg ha⁻¹, respectively. The region has a semi-arid tropical climate. The cultivar 'CIM-Sona' was procured from CSIR–Central Institute of Medicinal and Aromatic Plants (CIMAP), Hyderabad. Seeds were soaked in water for 24 h and treated with fungicide before sowing. The crop was raised following the recommended agronomic practices, with supplemental irrigation during prolonged dry spells.

Experimental design and treatments

The experiment was laid out in split-plot design with three replications. Five sowing windows were assigned as main-plot treatments: September II fortnight (S_1), October I fortnight (S_2), October II fortnight (S_3), November I fortnight (S_4) and November II fortnight (S_5). Three planting densities were assigned as sub-plot treatments: 30×30 cm (D_1), 45×30 cm (D_2) and 60×30 cm (D_3), giving 15 treatment combinations. Each plot measured 5.2×4.2 m.

Experimental design and sampling

Treatments were assigned to experimental plots using a random number table. Each plot had a net plot size of 5.2×4.2 m (21.84 m^2). Border plants were excluded from sampling to minimize potential border effects. Five plants per plot were selected as sampling units across all treatments and replications. The selected plants were tagged and the same plants were used for successive observations throughout the experimental period to ensure consistency in repeated measurements. Thus, the sampling area for observations corresponded to the net plot area after exclusion of the designated border plants.

Measurement procedures and calculations

Leaf area

Leaf area per plant was estimated following the method described by Vivekanandan *et. al.* (1972). Twenty representative leaves were sampled from ten randomly selected compound leaves obtained from two plants in each treatment. The sampled leaves were dried to a constant weight and leaf area was estimated using the following equation:

$$\text{Leaf area (cm}^2 \text{ plant}^{-1}) = \text{Leaf length (cm)} \times \text{Leaf breadth (cm)} \times \text{Correction factor}$$

Stage-specific correction factors were used for estimating leaf area at different crop growth stages: 0.69 at 30 DAS, 0.71 at 60 DAS, and 0.74 at 90 DAS based on standard practices in legumes and medicinal plants (Pandey and Singh, 2011). The correction factors were applied according to the respective growth stage. The cumulative leaf area and dry weight of the sampled leaves were used to establish the relationship between leaf area and leaf dry weight. This relationship was subsequently used to estimate the total leaf area per plant based on the total leaf dry weight of the corresponding plant.

Nutrient uptake

Collection and preparation of plant samples

Plant samples used for studying dry matter production were used for estimating nitrogen, phosphorus and potassium content. The plant samples were dried at 60 ± 5 °C in a hot air oven and powdered using a grinder fitted with stainless steel blades and preserved in polythene bags for further analysis.

Estimation of nitrogen in plant samples

Total nitrogen was determined by Kjeldahl's method as described by Jackson (1973). Powdered samples were digested with concentrated sulphuric acid in the presence of digestion mixture (K_2SO_4 : $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$: Se powder in the ratio 100:20:1). The nitrogen content in the aliquot of digested sample was determined by distillation under alkaline medium. The liberated ammonia was trapped in boric acid mixed indicator solution and was titrated against standard acid. The per cent nitrogen was calculated using the following formula.

$$\text{Nitrogen (\%)} = \frac{\text{TV (ml)} \times \text{Normality of H}_2\text{SO}_4 \times 0.014 \times \text{Dilution factor}}{\text{Weight of plant sample taken (g)}}$$

3.10.2.3 Estimation of phosphorous in plant samples

A known quantity of powdered plant sample (0.5 g) was pre-digested with concentrated nitric acid for overnight. Further, digestion was done with 5 ml of di-acid mixture (HNO_3 : HClO_4 , 10:4) until white residue was developed. Then, the residue was dissolved in 6 N HCl and volume was made up to 50 ml using distilled water. Blank was prepared in the same way without plant material. From the solution, 5 ml of aliquot was taken in a 50 ml volumetric flask along with 10 ml vanadomolybdic acid reagent and the volume was made up to 50 ml with distilled water. Yellow colour developed was measured at 490 nm against a reagent blank. The concentration of phosphorus in the sample was obtained by comparing with the phosphorus standard curve and per cent phosphorus was calculated using following formula (Jackson, 1973).

$$\text{Phosphorus (\%)} = \frac{\text{Graph ppm} \times \text{Vol. of extract (ml)} \times \text{Vol. made (ml)}}{10^6 \times \text{Aliquot taken (ml)} \times \text{Weight of plant sample taken (g)}} \times 100$$

3.10.2.4 Estimation of potassium in plant samples

Potassium concentration in the digested plant material was determined by flame photometric method (Jackson, 1973). One ml of an aliquot of di-acid digest was transferred to 50 ml volumetric flask and volume was made up with distilled water. Flame photometer was calibrated using 50 and 100 ppm potassium standards. Diluted solution of plant digest was fed to flame photometer and reading was recorded. The potassium content in the sample was determined using flame photometer and was calculated using the following formula.

$$\text{Potassium (\%)} = \frac{\text{Graph ppm} \times \text{Dilution factor} \times \text{Volume of the digest (ml)}}{10^6 \times \text{Weight of plant sample taken (g)}} \times 100$$

Total sennoside content in leaves (%)

Estimation procedure:

- i. 0.5 grams of senna plant powder (Leaf, Stem, Root, Flower or Pod) was taken into a conical flask and add 20 mL of distilled water and extracted in hot condition and filtered. The residue was re extracted with water furthermore two times. All the mother liquids are taken in to a 100 mL volumetric flask and make up with distilled water.
- ii. Water extract of 20 mL was taken and acidified with 0.1 mL of 2N HCl and extracted with chloroform (2 × 15 mL).
- iii. The aqueous portion was neutralized (pH-7-8) with 5% Sodium carbonate solution.
- iv. Ferric chloride (6.3%) solution was added and heated in a water bath for 20 min.
- v. Without cooling 1 mL of con. HCl was added to above mixture and heated for another 20 min (to dissolve to precipitate).
- vi. The solution was cooled up to RT and extracted with ether (3 × 25 mL). Then the extract was washed with distilled water (2 × 10 mL). The ether portion was made up to 10 mL with ether.
- vii. 10 mL of ether extract was concentrated using rotary evaporator.

- viii. Then 10 mL of 1N KOH solution was added.
- ix. The colour intensity was read at 500 nm using UV-Vis Spectrophotometer. (Sneha *et. al.*, 2022)

$$\text{Percentage of total sennosides (\%)} = \frac{\text{Optical density 500 nm} \times 100 \times 50}{130 \times 4 \times \text{Weight of the sample}}$$

Carotenoid content (mg kg⁻¹)

Procedure:

- i. The weighed leaf tissue (0.05 g or 50 mg) was placed in a clean test tube or 10 mL volumetric flask.
- ii. DMSO was added at the rate of 10 mL per 50 mg fresh tissue (scale proportionally). A common working volume is 10 mL DMSO for 50 mg tissue; you may use 5–10 mL for 50–100 mg depending on spectrophotometer range. (exact extraction volume v in mL was recorded)
- iii. The closed tube/flask was incubated in a water bath at 65 °C for 3–4 hours (or until the tissue becomes colourless), occasionally swirling. (Hiscox & Israelstam, 1979)
- iv. The extract was allowed to cool to room temperature, then brought up to a known final volume v (mL) if necessary (e.g., to 10.0 mL). If particulate matter was present, it was briefly centrifuged (e.g., 3000 rpm for 5 min) and pipetted the clear supernatant.
- v. The DMSO was used as the blank (zero) for the spectrophotometer.

$$\text{Carotenoids (mg kg}^{-1} \text{ FW)} = \frac{(A_{470} \times 2500 \times \text{Final Volume in mL})}{(\text{Sample weight in g} \times 1000)}$$

Crude protein content (g)

Nitrogen content in the leaves was estimated by Kjeldhal's method (Jackson, 1973). The crude protein per cent in leaves was calculated by multiplying the nitrogen content by a factor of 6.25.

Statistical analysis

The data collected on different parameters during the course of investigation were subjected to Fisher's method of analysis of variance and interpretation of data was done as per the procedure described by Panse and Sukhatme (1985). Data on different aspects were subjected to the statistical analysis as per the procedures of Split plot design. The data was analysed using 5 % level of significance for F – test which was employed for data obtained.

Pooled data analysis

Data recorded during two consecutive growing seasons were subjected to pooled analysis to assess the consistency of treatment effects across seasons. For each treatment, the seasonal means obtained from the two growing seasons were averaged to obtain the pooled mean, which was used for subsequent statistical analysis and presentation of the pooled results.

LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation		Expansion
%	:	Per cent
ANOVA	:	Analysis of variance
B:C	:	Benefit Cost ratio
CD	:	Critical Difference
cm	:	Centi meter
cm ²	:	Centi meter square
DAS	:	Days After Sowing
DAP	:	Diammonium phosphate
<i>et al.</i> ,	:	And others
E-W	:	East – West
Fig.	:	Figure
FYM	:	Farm Yard Manure
g	:	Gram
g plant ⁻¹	:	grams per plant
ha	:	Hectare

<i>i.e.</i> ,	:	That is
K	:	Potassium
K ₂ O	:	Potassium oxide
kg	:	Kilo gram
L	:	Litre
LAI	:	Leaf area index
m	:	Meter
m ²	:	Meter square
mL	:	Milli Litre
mg	:	Milli gram
MOP	:	Muriate of Potash
N	:	Nitrogen
NPK	:	Nitrogen: Phosphorus: Potassium
NS	:	Non-significant
N-S	:	North – South
P	:	Phosphorus
ppm	:	Parts Per Million
PSB	:	Phosphate Solubilizing Bacteria
RDF	:	Recommended Dose of Fertilizer
RH	:	Relative Humidity
S	:	Significant
S.Em	:	Standard error of mean
SPAD	:	Soil Plant Analysis Development

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Authors' Contributions

SBM conducted the experiments, collected and analysed the data, interpreted the results, and drafted the manuscript. ARK conceived the study, supervised the research, secured the required facilities, and critically revised the manuscript. SGP provided technical guidance, reviewed the research, and contributed to manuscript revision. RG provided technical support, monitored the progress of the research, and contributed to data interpretation. UKN contributed to the formulation of the research objectives, refinement of the experimental design, and critical revision of the manuscript. UMR contributed to research planning, data analysis, interpretation of results, and graphical presentation of the data. YND identified the research gap, contributed to the conceptualization of the study, provided scientific guidance on data analysis and interpretation, and critically reviewed the manuscript. All authors read and approved the final manuscript.

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Availability of Data and Materials

The datasets analysed during the current study are available from the corresponding author upon reasonable request.

Declaration

This is a declaration that the manuscript titled “EFFECT OF SOWING WINDOW AND PLANTING DENSITY FOR ENHANCED GROWTH, PRODUCTIVITY, AND BIOCHEMICAL QUALITY OF SENNA (*Cassia augustifoli* Vahl.)” is my original work and is not published earlier and I have not submitted this manuscript for publication elsewhere. I have cited the names of the authors whose published materials are used in the manuscript.

Name of the corresponding author: Setty Baliya Mounika

Ethics Approval and Consent to Participate

Not applicable. This study involved field experimentation on plants and did not involve human participants, human data, or animal subjects.

Consent for Publication

Not applicable.

Clinical trial number

Not applicable.

Competing Interests

The authors declare that they have no competing interests.

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Table 1: Physiological growth of senna at different intervals as influenced by different sowing windows and planting density

Treatments	Plant height (cm)			Plant spread (cm²)			Number of branches per plant		
Sowing window (S)	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
S₁	15.06	44.82	51.07	238.61	2648.67	2825.55	3.29	7.52	8.66
S₂	14.59	44.52	50.83	317.31	2612.50	2788.67	2.63	7.32	8.60
S₃	13.06	42.92	48.98	246.80	2480.33	2596.17	2.46	6.57	8.09
S₄	14.40	42.47	48.68	273.07	2430.83	2562.83	3.38	6.38	7.98
S₅	14.88	38.53	43.23	367.62	2099.33	2192.33	3.30	5.01	6.86
S.Em ±	0.98	0.18	0.23	34.18	15.72	18.16	0.22	0.08	0.05
C.D. at 5 %	NS	0.59	0.75	NS	52.26	59.24	NS	0.26	0.17
Planting density (D)									
D₁	14.53	36.59	41.13	285.77	1928.30	1989.30	2.93	4.10	6.40
D₂	14.51	43.86	50.03	273.67	2564.10	2699.70	3.16	7.05	8.44
D₃	14.15	47.50	54.52	306.61	2870.60	3090.33	2.95	8.52	9.27
S.Em ±	0.63	0.18	0.22	17.83	15.79	18.30	0.25	0.07	0.05
C.D. at 5 %	NS	0.53	0.65	NS	46.59	54.00	NS	0.22	0.14

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₂: October I fortnight

S₃: October II fortnight

S₄: November I fortnight

S₅: November II fortnight

D₁: 30 cm × 30 cm

D₂: 45 cm × 30 cm

D₃: 60 cm × 30 cm

Table 1a: Physiological growth of senna at different growth stages as influenced by interaction effect of sowing windows and planting density

Treatments	Plant height (cm)						Plant spread (cm ²)						Number of branches per plant					
S × D Interactions	30 DAS		60 DAS		30 DAS		30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS	
S ₁ D ₁	14.82		38.60		43.25		222.10		2042.00		2141.33		3.46		4.85		7.15	
S ₁ D ₂	16.03		45.65		52.65		267.33		2777.00		2903.33		3.16		7.95		8.82	
S ₁ D ₃	14.25		50.20		57.30		226.40		3127.00		3431.33		3.24		9.75		10.00	
S ₂ D ₁	15.65		38.30		43.05		330.87		2028.00		2120.00		2.23		4.65		7.00	
S ₂ D ₂	13.30		45.51		52.40		279.20		2756.00		2874.00		2.93		7.85		8.92	
S ₂ D ₃	14.75		49.75		57.05		341.87		3053.50		3372.00		2.73		9.45		9.89	
S ₃ D ₁	12.93		36.50		41.25		225.47		1922.00		1974.50		2.56		4.05		6.53	
S ₃ D ₂	13.72		44.26		50.15		214.87		2596.00		2720.00		2.43		7.00		8.44	
S ₃ D ₃	12.45		48.00		55.55		300.07		2923.00		3094.00		2.39		8.65		9.32	
S ₄ D ₁	15.13		36.05		40.90		295.80		1878.50		1944.00		3.20		3.80		6.33	
S ₄ D ₂	14.23		43.90		49.95		241.60		2518.50		2676.33		3.67		6.80		8.37	
S ₄ D ₃	13.77		47.45		55.20		281.80		2895.50		3068.00		3.27		8.55		9.24	
S ₅ D ₁	13.98		33.50		37.20		354.63		1771.00		1766.50		3.20		3.17		5.00	
S ₅ D ₂	15.12		40.00		45.00		365.33		2173.00		2324.50		3.59		5.65		7.68	
S ₁ D ₁	15.49		42.10		47.50		382.89		2354.00		2486.00		3.12		6.20		7.90	
	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %
Factor D at same level of S	1.70	NS	0.40	1.19	0.39	1.50	39.87	NS	35.31	104.17	40.93	120.75	0.38	NS	0.17	0.50	0.09	0.33
Factor S at same level of D	1.51	NS	0.38	1.14	0.46	1.41	47.20	NS	32.84	99.21	38.04	114.91	0.51	NS	0.16	0.48	0.10	0.31

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₂: October I fortnight

S₃: October II fortnight

S₄: November I fortnight

S₅: November II fortnight

D₁: 30 cm × 30 cm

D₂: 45 cm × 30 cm

D₃: 60 cm × 30 cm

Table 2: Physiological growth of senna at different intervals as influenced by different sowing windows and planting density

Treatments	Number of compound leaves per plant			Leaf area (cm ²) per plant			Leaf area index (LAI)			Relative chlorophyll content (SPAD readings)		
Sowing window (S)	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
S ₁	8.90	69.74	89.90	294.16	476.40	586.50	0.236	0.375	0.460	37.90	58.28	77.25
S ₂	8.82	67.01	89.15	295.18	471.50	580.50	0.237	0.371	0.455	37.28	56.77	76.78
S ₃	7.96	60.28	83.63	295.83	457.50	565.00	0.237	0.359	0.443	39.12	53.47	74.28
S ₄	9.32	55.45	82.72	278.17	452.60	554.37	0.224	0.355	0.434	36.85	52.45	73.97
S ₅	8.72	48.28	74.25	297.81	428.00	518.83	0.239	0.338	0.409	38.65	46.63	68.32
S.Em ±	0.45	1.07	1.16	4.27	2.37	3.05	0.0041	0.0017	0.0022	1.80	1.07	0.85
C.D. at 5 %	NS	3.48	3.78	NS	7.74	9.94	NS	0.0054	0.0070	NS	3.25	2.74
Planting density (D)												
D ₁	8.81	41.11	71.36	292.07	415.80	501.80	0.325	0.462	0.558	37.79	42.94	64.44
D ₂	8.72	64.20	85.44	291.87	462.70	571.90	0.216	0.343	0.424	38.35	54.96	76.45
D ₃	8.71	75.15	94.99	292.77	493.10	609.40	0.163	0.274	0.339	37.74	62.66	81.47
S.Em ±	0.23	1.05	0.61	2.88	1.62	2.15	0.0025	0.0029	0.0034	0.92	0.72	0.78
C.D. at 5 %	NS	3.12	1.80	NS	4.78	6.35	NS	0.0087	0.0101	NS	2.18	2.59

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₂: October I fortnight

S₃: October II fortnight

S₄: November I fortnight

S₅: November II fortnight

D₁: 30 cm × 30 cm

D₂: 45 cm × 30 cm

D₃: 60 cm × 30 cm

Table 2a: Physiological growth of senna at different growth stages as influenced by interaction effect of sowing windows and planting density

Treatments	Number of compound leaves per plant						Leaf area (cm ²) per plant						Leaf area index (LAI)						Relative chlorophyll content (SPAD readings)					
S x D Interactions	30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS	
S ₁ D ₁	9.10		46.93		75.90		290.50		435.50		524.00		0.323		0.484		0.582		37.85		46.95		67.50	
S ₁ D ₂	8.72		74.83		90.10		297.00		477.50		594.50		0.220		0.354		0.440		39.35		58.60		79.35	
S ₁ D ₃	8.88		87.45		103.70		295.00		516.00		641.00		0.164		0.287		0.356		36.50		69.30		84.90	
S ₂ D ₁	9.24		49.57		75.20		295.50		430.50		518.00		0.328		0.478		0.576		39.20		45.85		66.75	
S ₂ D ₂	8.55		68.03		89.70		293.50		473.00		589.00		0.217		0.350		0.436		35.65		57.10		79.10	
S ₂ D ₃	8.66		83.43		102.55		296.50		511.00		634.50		0.165		0.284		0.353		37.00		67.35		84.50	
S ₃ D ₁	8.35		39.08		72.00		294.50		413.00		505.00		0.327		0.459		0.561		38.55		42.20		63.75	
S ₃ D ₂	7.68		65.80		84.75		295.00		462.00		574.00		0.219		0.342		0.425		39.67		54.85		76.65	
S ₃ D ₃	7.86		75.97		94.15		298.00		497.50		616.00		0.166		0.276		0.342		39.15		63.35		82.45	
S ₄ D ₁	8.93		36.40		70.50		283.83		406.50		491.00		0.315		0.452		0.546		35.80		41.50		63.50	
S ₄ D ₂	9.68		59.02		84.35		273.30		458.50		562.00		0.202		0.340		0.416		37.50		53.85		76.15	
S ₄ D ₃	9.35		70.93		93.30		277.33		493.00		610.00		0.154		0.274		0.339		37.25		62.00		82.25	
S ₅ D ₁	8.40		33.55		63.20		296.00		393.50		471.00		0.329		0.437		0.523		37.55		38.20		60.70	
S ₅ D ₂	8.95		53.33		78.30		300.50		442.50		540.00		0.223		0.328		0.400		39.60		50.40		71.00	
S ₅ D ₃	8.80		57.97		81.25		297.00		448.00		545.50		0.165		0.249		0.303		38.80		51.30		73.25	
	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %
Factor D at same level of S	0.77	NS	1.86	5.48	1.36	4.02	4.51	NS	3.63	10.70	4.82	14.21	0.0055	NS	0.0066	0.0194	0.0077	0.0226	2.10	NS	1.52	4.38	1.43	3.64
Factor S at same level of D	0.61	NS	1.75	5.30	1.61	5.03	5.40	NS	3.80	11.66	4.98	15.26	0.0061	NS	0.0056	0.0167	0.0066	0.0198	2.45	NS	1.50	4.67	1.58	3.76

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₂: October I fortnight

S₃: October II fortnight

S₄: November I fortnight

S₅: November II fortnight

D₁: 30 cm × 30 cm

D₂: 45 cm × 30 cm

D₃: 60 cm × 30 cm

Table 3: Yield measures of senna at harvest as influenced by different sowing windows and planting density

Treatments	Dry weight of leaves (kg ha ⁻¹)	Dry matter production of leaves (g plant ⁻¹)	Dry matter production of stem (g plant ⁻¹)	Total dry matter production of plant (g plant ⁻¹)
Sowing window (S)				
S ₁	870.04	11.68	29.43	61.56
S ₂	854.61	11.47	28.90	60.47
S ₃	754.99	10.17	26.73	55.18
S ₄	740.14	10.00	26.42	54.46
S ₅	567.97	7.53	22.58	44.32
S.Em ±	7.42	0.12	0.20	0.51
C.D. at 5 %	24.50	0.41	0.73	1.70
Planting density (D)				
D ₁	693.38	6.15	20.24	38.37
D ₂	820.51	10.90	27.87	58.51
D ₃	758.76	13.45	32.33	68.72
S.Em ±	3.40	0.12	0.20	0.50
C.D. at 5 %	10.21	0.37	0.64	1.49

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₂: October I fortnight

S₃: October II fortnight

S₄: November I fortnight

S₅: November II fortnight

D₁: 30 cm × 30 cm

D₂: 45 cm × 30 cm

D₃: 60 cm × 30 cm

Table 3a: Yield measures of senna at harvest as influenced by different sowing windows and planting density

Treatments	Dry weight of leaves (kg ha ⁻¹)		Dry matter production of leaves (g plant ⁻¹)		Dry matter production of stem (g plant ⁻¹)		Total dry matter production of plant (g plant ⁻¹)	
S ₁ D ₁	794.63		7.05		22.05		43.25	
S ₁ D ₂	946.52		12.58		30.20		64.53	
S ₁ D ₃	868.97		15.40		36.05		76.90	
S ₂ D ₁	783.33		6.95		21.55		42.45	
S ₂ D ₂	925.68		12.30		29.80		63.55	
S ₂ D ₃	854.81		15.15		35.35		75.40	
S ₃ D ₁	682.04		6.05		19.95		37.50	
S ₃ D ₂	812.47		10.80		27.80		58.40	
S ₃ D ₃	770.46		13.65		32.45		69.65	
S ₄ D ₁	659.44		5.85		19.65		36.70	
S ₄ D ₂	797.53		10.60		27.60		57.85	
S ₄ D ₃	763.44		13.53		32.00		68.83	
S ₅ D ₁	547.44		4.86		18.00		31.96	
S ₅ D ₂	620.37		8.25		23.95		48.20	
S ₅ D ₃	536.11		9.50		25.80		52.80	
	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %
Factor D at same level of S	9.70	24.23	0.21	0.84	0.45	1.41	1.13	3.50
Factor S at same level of D	12.81	30.75	0.26	0.78	0.41	1.25	1.04	3.15

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₂: October I fortnight

S₃: October II fortnight

S₄: November I fortnight

S₅: November II fortnight

D₁: 30 cm × 30 cm

D₂: 45 cm × 30 cm

D₃: 60 cm × 30 cm

Table 4: Sennoside content of leaves of senna at different intervals as influenced by different sowing windows and planting density

Sennoside content (%)				
Sowing window (S)	75 Days after sowing		90 Days after sowing	
S ₁	2.53		3.32	
S ₂	2.51		3.31	
S ₃	2.52		3.28	
S ₄	2.51		3.27	
S ₅	2.47		3.24	
S.Em ±	0.04		0.05	
C.D. at 5 %	NS		NS	
Planting density (D)				
D ₁	2.47		3.23	
D ₂	2.51		3.30	
D ₃	2.55		3.33	
S.Em ±	0.02		0.04	
C.D. at 5 %	NS		NS	
S × D Interactions				
S ₁ D ₁	2.48		3.26	
S ₁ D ₂	2.53		3.31	
S ₁ D ₃	2.58		3.39	
S ₂ D ₁	2.49		3.25	
S ₂ D ₂	2.49		3.31	
S ₂ D ₃	2.56		3.38	
S ₃ D ₁	2.47		3.23	
S ₃ D ₂	2.51		3.31	
S ₃ D ₃	2.55		3.32	
S ₄ D ₁	2.47		3.23	
S ₄ D ₂	2.51		3.28	
S ₄ D ₃	2.54		3.32	
S ₅ D ₁	2.43		3.17	
S ₅ D ₂	2.50		3.27	
S ₅ D ₃	2.50		3.28	
	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5%
Factor D at same level of S	0.07	NS	0.08	NS
Factor S at same level of D	0.06	NS	0.09	NS

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₂: October I fortnight

S₃: October II fortnight

S₄: November I fortnight

S₅: November II fortnight

D₁: 30 cm × 30 cm

D₂: 45 cm × 30 cm

D₃: 60 cm × 30 cm

Table 5: Carotenoid content of leaves of senna at different intervals as influenced by different sowing windows and planting density

Carotenoid content (mg kg ⁻¹)				
Sowing window (S)	75 Days after sowing		90 Days after sowing	
S ₁	112.60		104.05	
S ₂	111.87		103.15	
S ₃	109.02		100.00	
S ₄	108.35		99.40	
S ₅	100.47		90.83	
S.Em ±	0.36		0.38	
C.D. at 5 %	1.17		1.23	
Planting density (D)				
D ₁	94.77		86.56	
D ₂	111.87		100.67	
D ₃	118.74		111.23	
S.Em ±	0.40		0.41	
C.D. at 5 %	1.18		1.20	
S × D Interactions				
S ₁ D ₁	98.35		91.15	
S ₁ D ₂	116.35		104.50	
S ₁ D ₃	123.10		116.50	
S ₂ D ₁	97.70		89.45	
S ₂ D ₂	115.65		103.75	
S ₂ D ₃	122.25		116.25	
S ₃ D ₁	94.20		85.90	
S ₃ D ₂	113.20		100.85	
S ₃ D ₃	119.65		113.25	
S ₄ D ₁	93.60		84.95	
S ₄ D ₂	112.25		100.15	
S ₄ D ₃	119.20		113.10	
S ₅ D ₁	90.00		81.35	
S ₅ D ₂	101.90		94.10	
S ₅ D ₃	109.50		97.05	
	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5%
Factor D at same level of S	0.89	2.63	0.91	2.68
Factor S at same level of D	0.81	2.45	0.83	2.51

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₄: November I fortnight

D₁: 30 cm × 30 cm

S₂: October I fortnight

S₅: November II fortnight

D₂: 45 cm × 30 cm

S₃: October II fortnight

D₃: 60 cm × 30 cm

Table 6: Crude protein content of leaves of senna at different intervals as influenced by different sowing windows and planting density

Crude protein content (g)				
Sowing window (S)	75 Days after sowing		90 Days after sowing	
S ₁	6.26		5.41	
S ₂	5.89		5.08	
S ₃	5.61		4.87	
S ₄	5.41		4.70	
S ₅	4.87		4.21	
S.Em ±	0.04		0.03	
C.D. at 5 %	0.13		0.12	
Planting density (D)				
D ₁	4.99		4.34	
D ₂	6.16		5.32	
D ₃	5.68		4.90	
S.Em ±	0.04		0.03	
C.D. at 5 %	0.08		0.05	
S × D Interactions				
S ₁ D ₁	5.66		4.89	
S ₁ D ₂	7.07		6.13	
S ₁ D ₃	6.07		5.23	
S ₂ D ₁	5.56		4.80	
S ₂ D ₂	6.32		5.45	
S ₂ D ₃	5.80		5.00	
S ₃ D ₁	4.90		4.31	
S ₃ D ₂	6.23		5.37	
S ₃ D ₃	5.72		4.93	
S ₄ D ₁	4.83		4.25	
S ₄ D ₂	5.94		5.14	
S ₄ D ₃	5.46		4.73	
S ₅ D ₁	4.02		3.47	
S ₅ D ₂	5.25		4.54	
S ₅ D ₃	5.36		4.62	
	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5%
Factor D at same level of S	0.07	0.14	0.05	0.19
Factor S at same level of D	0.06	0.18	0.10	0.28

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₂: October I fortnight

S₃: October II fortnight

S₄: November I fortnight

S₅: November II fortnight

D₁: 30 cm × 30 cm

D₂: 45 cm × 30 cm

D₃: 60 cm × 30 cm

Table 7: Available NPK content of soil as influenced by different sowing windows and planting densities of senna after harvest

Treatments	Available NPK content of soil			Nutrient uptake of senna		
Sowing window (S)	N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)
S ₁	342.00	51.00	281.18	57.40	32.90	9.66
S ₂	345.87	52.95	283.48	54.75	30.86	9.20
S ₃	347.93	54.93	285.17	50.78	27.40	8.42
S ₄	350.31	56.92	287.43	47.18	24.42	7.87
S ₅	352.00	59.05	289.48	39.45	18.57	7.04
S.Em ±	1.53	1.21	1.58	0.53	0.41	0.08
C.D. at 5 %	5.10	3.95	5.24	2.54	1.33	0.25
Planting density (D)						
D ₁	331.40	38.69	269.29	42.04	19.83	7.37
D ₂	347.70	56.11	285.68	56.27	33.50	9.62
D ₃	364.00	70.11	301.08	51.43	27.16	8.32
S.Em ±	1.32	1.02	1.34	0.52	0.23	0.04
C.D. at 5 %	3.88	2.90	3.56	1.62	0.71	0.11

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₂: October I fortnight

S₃: October II fortnight

S₄: November I fortnight

S₅: November II fortnight

D₁: 30 cm × 30 cm

D₂: 45 cm × 30 cm

D₃: 60 cm × 30 cm

Table 7a: Available NPK content of soil as influenced by interaction effect of different sowing windows and planting densities of senna

Treatments	Available NPK content of soil						Nutrient uptake of senna					
S ×D Interactions	N (kg ha ⁻¹)		P (kg ha ⁻¹)		K (kg ha ⁻¹)		N (kg ha ⁻¹)		P (kg ha ⁻¹)		K (kg ha ⁻¹)	
S ₁ D ₁	325.00		34.70		265.20		52.00		24.80		8.20	
S ₁ D ₂	342.50		52.10		281.15		62.50		39.21		11.26	
S ₁ D ₃	360.00		66.20		297.20		57.70		34.70		9.52	
S ₂ D ₁	330.00		36.65		267.00		50.45		24.50		7.98	
S ₂ D ₂	345.50		54.05		284.05		60.15		38.24		10.92	
S ₂ D ₃	362.00		68.15		299.40		53.65		29.85		8.71	
S ₃ D ₁	332.00		38.50		269.35		40.75		17.80		7.13	
S ₃ D ₂	347.50		56.20		285.55		59.35		36.70		9.75	
S ₃ D ₃	364.00		70.10		300.60		52.25		27.70		8.37	
S ₄ D ₁	334.00		40.60		271.40		35.25		17.55		7.05	
S ₄ D ₂	350.50		58.05		287.75		56.30		32.87		8.90	
S ₄ D ₃	366.00		72.10		303.15		50.00		22.85		7.66	
S ₅ D ₁	336.00		43.00		273.49		31.75		14.50		6.50	
S ₅ D ₂	352.50		60.15		289.90		43.05		20.50		7.28	
S ₅ D ₃	368.00		74.00		305.05		43.55		20.70		7.35	
	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %	S.Em ±	C.D. at 5 %
Factor D at same level of S	2.94	NS	2.19	NS	2.43	NS	1.53	3.68	0.65	2.19	0.13	0.28
Factor S at same level of D	2.85	NS	2.16	NS	2.31	NS	1.27	3.85	0.59	1.90	0.11	0.33

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₂: October I fortnight

S₃: October II fortnight

S₄: November I fortnight

S₅: November II fortnight

D₁: 30 cm × 30 cm

D₂: 45 cm × 30 cm

D₃: 60 cm × 30 cm

Table 8: Profitability of senna as influenced by different sowing windows and planting densities

Treatments	Cost of cultivation (Rs ha⁻¹)	Gross returns (Rs ha⁻¹)	Net returns (Rs ha⁻¹)	Benefit Cost ratio (Rs ha⁻¹)
S₁D₁	43944	55624	11680	1.27
S₁D₂	43974	66256	22282	1.51
S₁D₃	43959	60828	16869	1.38
S₂D₁	43942	54833	10892	1.25
S₂D₂	43970	64797	20827	1.47
S₂D₃	43956	59836	15880	1.36
S₃D₁	43921	49894	5973	1.14
S₃D₂	43947	56873	12925	1.29
S₃D₃	43939	53932	9993	1.23
S₄D₁	43917	48767	4850	1.11
S₄D₂	43945	52487	8543	1.19
S₄D₃	43938	53441	9503	1.22
S₅D₁	43894	44917	1022	1.02
S₅D₂	43909	45733	1824	1.04
S₅D₃	43892	44100	208	1.005

DAS- Days after sowing, NS- Non-significant

S₁: September II fortnight

S₂: October I fortnight

S₃: October II fortnight

S₄: November I fortnight

S₅: November II fortnight

D₁: 30 cm × 30 cm

D₂: 45 cm × 30 cm

D₃: 60 cm × 30 cm

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