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Effect of post-emergence herbicides in pigeonpea (*Cajanus cajan* L.) + Soybean (*Glycine max* L.) Intercropping system

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Abstract
A field experiment was conducted during *Kharif* 2024 at ZARS, Kalaburagi, to evaluate the efficacy of post-emergence herbicides in a pigeonpea + soybean intercropping system. The experiment was laid out in a randomized complete block design (RCBD) with ten treatments, replicated thrice. The results revealed that application of Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} as a pre-emergence *fb* Imazethapyr 35% + Imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS as a post-emergence recorded the significantly higher growth parameters of both pigeonpea and soybean, including plant height, leaf area index, dry matter production, and its accumulation in plant parts. Yield parameters *viz*., seed yield and haulm yield of pigeonpea and soybean also resulted in higher B:C. However, it was statistically on par with pendimethalin with treatment 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + Imazethapyr 3.75% ME @ 125 g *a.i.* ha^{-1} (20-25 DAS, POE), Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Quizalofop ethyl 7.5% + Imazethapyr 15% EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20-25 DAS (POE) and Hand weeding at 15 DAS *fb* IC at 30 DAS.

Keywords: Weed management, pre-emergence, post-emergence

Introduction
Pulses play a vital role in Indian agriculture and diet, serving as an affordable source of protein (21%) and carbohydrates (57.6%), especially for the vegetarian population. Besides their nutritional value, they enhance soil fertility through biological nitrogen fixation and are well adapted to low-input, rainfed systems (Kumar *et al*., 2021) [12]. Among pulses, pigeonpea and chickpea together occupy over 60% of the total pulse area (Saxena, 2008) [22]. Pigeonpea's deep root system and compatibility with shallow-rooted crops make it suitable for intercropping, improving resource use efficiency and soil health (Sarkar *et al*., 2020) [21]. In India, pigeonpea covers 4.13 million ha with a production of 3.41 million tonnes and productivity of 827 kg ha^{-1}, with Karnataka ranking first (Anon., 2024) [2]. Soybean (*Glycine max* L.), known as the "golden bean," is a major *Kharif* oilseed crop containing 40-42% protein and 20% oil, grown over 13.2 million ha with 13.06 million tonnes production and 985 kg ha^{-1} productivity, mainly in Madhya Pradesh (Anon., 2024) [3].

Weed competition is a major yield-limiting factor, causing 40-70% yield loss in soybean and 20-77% in pigeonpea (Kurchania *et al*., 2001) [13]. In pigeonpea + soybean intercropping, early weed competition is severe due to pigeonpea's slow initial growth (Kaur *et al*., 2015), though complementary growth habits improve resource utilization and weed suppression (Reddy *et al*., 2022) [19]. Intercropping can reduce weed growth by up to 25% (Liebman & Dyck, 1993) [15], but manual weeding is labour-intensive, highlighting the need for effective herbicides. The success of herbicide use depends on selectivity and crop safety, pre- and post-emergence herbicides like pendimethalin, imazethapyr, imazamox, propaquizafop, and quizalofop-ethyl have shown promise (Kushwaha and Mehta, 2023; Noraliya *et al*., 2024) [14,]. Therefore, the present investigation entitled "Evaluation of post-emergence herbicides in pigeonpea (*Cajanus cajan* L.) + soybean (*Glycine max* L.) intercropping system" was conducted during *Kharif* 2024 at ZARS,

Kalaburagi, to assess herbicide efficacy for effective weed control and enhanced productivity under rainfed conditions.

Materials and Methods

The field experiment was conducted during *Kharif*, 2024 at ZARS, Kalaburagi entitled with "Evaluation of post-emergence herbicides in pigeonpea (*Cajanus cajan* L.) + soybean (*Glycine max* L.) intercropping system". Raichur during growing season of *Kharif*, 2024. The experimental site belongs to North-Eastern Dry Zone of Karnataka (Zone 2) located between 17.32^0 N and 76.54^0 E longitude at an elevation of 443m mean sea level.

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications and ten treatments comprising of pre-emergent and post-emergent herbicides along with cultural practices like hand weeding and intercultivation. The treatments are Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 35% + Imazamox 35%WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) (T_1), Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + Imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE) (T_2), Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Quizalofop ethyl 7.5% + Imazethapyr 15% w/w EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20-25 DAS (POE) (T_3), Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fomesafen 12% + Quizalofop ethyl 13% w/w SE @ 180 + 45g *a.i.* ha^{-1} at 20-25 DAS (POE) (T_4), Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fluazifop-p-butyl 11.1% w/w + Fomasafen 11.1% w/w SL @ 250 g *a.i.* ha^{-1} at 20-25 DAS (POE) (T_5), Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 10% SL 100 g *a.i.* ha^{-1} at 20-25 DAS (POE) (T_6), Pendimethalin 38.7% CS @ 678 g *a.i.*ha^{-1} (PE) *fb* IC at 30 DAS (T_7), Hand weeding at 15 DAS *fb* IC at 30 DAS (T_8), Weed free check (T_9) and Weedy check(T_{10}).

The pigeonpea variety GRG-152 was used in this experiment. It is a medium-duration and bold-seeded variety that matures in 160 to 165 days. It is moderately resistant to wilt and sterility mosaic disease (SMD) and for soybean DSB-21 variety was used in this experiment. It is the first rust resistant variety in the country developed by UAS, Dharwad and released or notified during 2015 and suitable for *Kharif* season with a spacing of 90 cm x 30 cm (Pigeonpea), 30 cm x 10 cm (Soybean).

During the course of investigation, in order to know the effect of different herbicides on growth parameters of pigeonpea and soybean intercropping system, the observations were recorded at different stages of the crop growth.

Results and Discussion

Growth parameters of pigeonpea

Plant height

At 30 DAS, differences among treatments were non-significant. However, weed free check had significantly higher plant height at 60, 90, 120 DAS and at harvest (70.94, 116.40, 180.20 and 192.96 cm, respectively). While shorter plants were observed in pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* fluazifop-p-butyl 11.1% w/w + fomesafen 11.1% w/w SL @ 250 g *a.i.* ha^{-1} at 20-25 DAS (POE) (49.86 cm). Among the herbicide treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20–25 DAS (POE) recorded taller plant height (64.01, 107.46 164.12 and177.91 cm, respectively). Which was statistically on par with pendimethalin 38.7% CS *fb* propaquizafop 2.5% + imazethapyr 3.75% ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS, hand weeding at 15 DAS *fb* intercultivation at 30 DAS (63.98, 106.78, 163.93 and 176.68 cm, respectively). and (63.01, 106.14, 163.11 and 170.97 cm, respectively).

The gradual increase in plant height with advancing crop age under effective weed management reflects improved vegetative growth and uninterrupted resource capture. The weed free check consistently produced the tallest plants by minimizing early competition for nutrients, moisture and light. Among herbicide-treated plots, sequential application of pendimethalin as a pre-emergence followed by post-emergence application of imazethapyr + imazamox or propaquizafop + imazethapyr, as well as manual hand weeding followed by intercultivation, effectively suppressed weeds and allowed the crop to allocate assimilates toward stem elongation and biomass accumulation. Conversely, the pendimethalin followed by fluazifop-p-butyl + fomesafen treatment resulted in reduced plant height, likely due to partial phytotoxicity combined with inadequate weed control that restricted nutrient uptake and photosynthetic efficiency. Similar results were reported by Deshmukh (2016) [8] and Rupareliya *et al*. (2020) [20] in pigeonpea based intercropping system and soybean.

Leaf area per plant

At 30 DAS, differences among treatments were non-significant. However, weed free check registered significantly higher leaf area at 60, 90, 120 DAS and at harvest (449.71, 697.44, 1669.70 and 968.95 cm^2 $plant^{-1}$, respectively). While lower leaf area was observed in pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* fluazifop-p-butyl 11.1% w/w + fomesafen 11.1% w/w SL @ 250 g *a.i.* ha^{-1} at 20-25 DAS (POE) (338.88, 545.76, 1116.12 and 752.95 cm^2 $plant^{-1}$). Among the herbicide treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) recorded higher leaf area (420.60, 661.53, 1509.52 and 911.96 cm^2 $plant^{-1}$, respectively). Which was statistically on par with pendimethalin 38.7% CS *fb* propaquizafop 2.5% + imazethapyr 3.75% ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS and hand weeding at 15 DAS *fb* intercultivation at 30 DAS (417.59, 656.99, 1498.14 and 904.92 cm^2 $plant^{-1}$, respectively) and (413.60, 651.02, 1477.09 and 897.92 cm^2 $plant^{-1}$, respectively).

Leaf Area Index (LAI)

At 30 DAS, differences among treatments were non-significant. However, at 60, 90, 120 DAS and at harvest, weed-free check recorded the higher LAI (0.166, 0.258, 0.617 and 0.359). While, the lower LAI was recorded in pendimethalin 38.7% CS *fb* fluazifop-p-butyl 11.1% + fomesafen 11.1% SL @ 250 g *a.i.* ha^{-1} at 20–25 DAS (POE) (0.125, 0.202, 0.413 and 0.279). Among herbicide-treated plots, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (0.156, 0.245, 0.599 and 0.338) was observed higher LAI which was statistically on par with pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* propaquizafop 2.5% + imazethapyr 3.75% w/w ME @ 125 g *a.i.* ha^{-1} (POE) (0.155, 0.243, 0.0.555 and 0.335) and hand weeding 15 DAS *fb* IC 30 DAS (0.153, 0.241, 0.547 and 0.333).

The results clearly demonstrate that weed free conditions and effective herbicide combinations significantly enhance leaf area and LAI throughout the crop growth cycle. weed free check consistently produced the maximum leaf area and LAI, which facilitated greater light interception and higher photosynthetic activity. Among herbicidal treatments, sequential application of pendimethalin as pre-emergence followed by post-emergence mixtures of imazethapyr + imazamox or propaquizafop + imazethapyr and the manual weeding plus intercultivation schedule, recorded significantly higher leaf area and LAI. In contrast, fluazifop-p-butyl + fomesafen, consistently reduced

leaf area and LAI, likely due to residual weed pressure and mild phytotoxicity observed on pigeonpea in this treatment. These findings are in agreement with Jadhav and Bhagyasree *et al*. in pigeonpea based intercropping system.

Dry matter production and its accumulation in different plant parts

Dry matter accumulation in leaves

The differences among treatments were non-significant at 30 DAS. However, at 60, 90, 120 DAS and at harvest, weed free check registered the higher dry matter accumulation in leaves (11.42, 29.35, 33.71 and15.45 g plant^{-1}, respectively). While, the lower dry matter accumulation in leaves was observed in pendimethalin 38.7% CS *fb* fluazifop-p-butyl 11.1% + fomesafen 11.1% SL @ 250 g *a.i.* ha^{-1} at 20–25 DAS (POE) (6.89, 18.03, 20.72 and 9.43 g plant^{-1}, respectively). Among herbicide treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (10.01, 26.54, 30.34 and 13.99 g plant^{-1}, respectively) registered significantly higher the dry matter accumulation in leaves, which was statistically on par with, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* propaquizafop 2.5% + imazethapyr 3.75% w/w ME @ 125 g *a.i.* ha^{-1} (POE) (9.92, 26.00, 30.11 and 13.76 g) and hand weeding 15 DAS *fb* IC 30 DAS (9.86, 25.87, 29.87 and 13.48 g plant^{-1}, respectively).

Dry matter accumulation in stem

At 30 DAS, differences among treatments were non-significant. However, at 60, 90, 120 DAS and at harvest, the higher dry matter accumulation in stem was recorded in the weed free check (15.64, 24.42, 80.65 and 126.88 g plant^{-1}, respectively). While the lower was observed in pendimethalin 38.7% CS *fb* fluazifop-p-butyl 11.1% + fomesafen 11.1% SL @ 250 g *a.i.* ha^{-1} at 20-25 DAS (POE) (9.19, 15.01, 49.83 and 78.47 g plant^{-1}, respectively). Among the herbicide treatments, pendimethalin 38.7% CS @ 678g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35%WG @ 75g *a.i.* ha^{-1} at 20-25 DAS (POE) (14.12, 22.02, 73.43 and 113.49 g plant^{-1}, respectively) recorded higher dry matter accumulation in stem, which was statistically on par with pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* propaquizafop 2.5% + imazethapyr 3.75% w/w ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS (POE) (14.02, 21.93, 71.98 and 113.02 g plant^{-1}, respectively) and hand weeding at 15 DAS *fb* IC at 30 DAS (13.86, 21.06, 72.69 and 112.76 g plant^{-1}, respectively).

Dry matter accumulation in reproductive parts

At 120 DAS and at harvest, the weed free check observed the maximum dry matter accumulation in reproductive parts (48.34 and 56.02 g plant^{-1}, respectively). The lower reproductive dry matter was observed in pendimethalin 38.7% CS *fb* fluazifop-p-butyl 11.1% + fomesafen 11.1% SL @ 250 g *a.i.* ha^{-1} at 20–25 DAS (POE) (31.89 and 32.42 g plant^{-1}, respectively). Among the herbicide-treated plots, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) (43.86 and 50.94 g plant^{-1}, respectively) was observed significantly higher dry matter accumulation in reproductive parts, which was statistically on par with pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* propaquizafop 2.5% + imazethapyr 3.75% w/w ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS (POE) (43.61 and 49.77 g plant^{-1}, respectively) and hand weeding at 15 DAS *fb* intercultivation at 30 DAS (43.50 and 49.50 g plant^{-1}, respectively).

Total dry matter production

At 30 DAS, differences among treatments were non-significant. However, at 60, 90, 120 DAS and at harvest, the weed free check (27.06, 53.77, 162.70 and 198.35 g plant^{-1}, respectively) recorded the higher total dry matter production. The minimum dry matter production was recorded in pendimethalin 38.7% CS *fb* fluazifop-p-butyl 11.1% + fomesafen 11.1% SL @ 250 g *a.i.* ha^{-1} at 20-25 DAS (POE) (16.08, 33.04, 102.44 and 120.32 g plant^{-1}, respectively). Among herbicidal treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} 20-25 DAS, (POE) (24.13, 48.56, 147.63 and 178.42 g plant^{-1}, respectively) was recorded significantly higher total dry matter production and which was statistically on par with pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* propaquizafop 2.5% + imazethapyr 3.75% w/w ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS (POE) (23.95, 47.93, 145.70 and 176.55 g plant^{-1}, respectively) and hand weeding at 15 DAS *fb* intercultivation at 30 DAS (23.72, 46.93, 146.06 and 175.74 g plant^{-1}, respectively).

Dry matter accumulation in pigeonpea + soybean intercropping was significantly influenced by weed management practices beyond 30 DAS. The weed-free check consistently recorded the highest dry matter accumulation in leaves, stems and reproductive parts across all stages, owing to the absence of crop-weed competition, which ensured efficient utilization of nutrients, moisture and light. Among herbicidal treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} (POE) recorded significantly higher dry matter accumulation in all plant parts, which was statistically comparable with pendimethalin *fb* propaquizafop + imazethapyr and hand weeding *fb* intercultivation. These treatments provided effective control of both narrow- and broad-leaved weeds, promoting uninterrupted photosynthetic activity and assimilate translocation. Conversely, pendimethalin *fb* fluazifop-p-butyl + fomesafen recorded the lowest dry matter accumulation throughout the crop growth period due to phytotoxic stress and incomplete weed control, which restricted nutrient uptake and biomass production. These results align with findings of Bhagyasree *et al.* (2018) and Khazi *et al*. (2018) [11].

Effect on crop growth and yield of pigeonpea

Seed yield (kg ha^{-1})

The data related to seed yield as influenced by different weed management practices differed significantly and presented in Table 08.

Different weed management practices showed significant difference seed yield. Significantly higher seed yield was observed with Weed free check (1128 kg ha^{-1}). Among herbicide treatments, treatment receiving pendimethalin 38.7% CS @ 678g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35%WG @ 75g *a.i.* ha^{-1} at 20-25 DAS (POE) (1095 kg ha^{-1}) recorded significantly higher seed yield which was on par with pendimethalin 38.7% CS @ 678g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE) (1046 kg ha^{-1}) and hand weeding at 15 DAS *fb* IC at 30 DAS (1023 kg ha^{-1}). While the seed yield was significantly lower in the pendimethalin 38.7% CS @ 678g *a.i.* ha^{-1} (PE) *fb* fluazifop-p-butyl 11.1% w/w + Fomasafen 11.1% w/w SL @ 250g *a.i.* ha^{-1} at 20-25 DAS (POE) (619 kg ha^{-1}) than in the other treatments.

Haulm yield (kg ha^{-1})

The data related to haulm yield as influenced by different weed

management practices differed significantly and presented in Table 08.

Different weed management practices showed significantly different haulm yield. Significantly higher haulm yield was observed with Weed free check (3491 kg ha^{-1}). Among herbicide treatments, treatment receiving pendimethalin 38.7% CS @ 678g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35%WG @ 75g *a.i.* ha^{-1} at 20-25 DAS (POE) (3165 kg ha^{-1}) recorded significantly higher haulm yield which was on par with pendimethalin 38.7% CS @ 678g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE) (3012 kg ha^{-1}) and hand weeding at 15 DAS *fb* IC at 30 DAS (2979 kg ha^{-1}). While the haulm yield was significantly lower in pendimethalin 38.7% CS @ 678g *a.i.* ha^{-1} (PE) *fb* fluazifop-p-butyl 11.1% w/w + Fomasafen 11.1% w/w SL @ 250g *a.i.* ha^{-1} at 20-25 DAS (POE) (1914 kg ha^{-1}) than in the other treatments.

Seed and haulm yield of pigeonpea + soybean intercropping were significantly influenced by weed management practices. The weed-free check recorded the higher seed and haulm yield due to complete elimination of weed competition, which enhanced crop growth, dry matter accumulation and assimilate partitioning towards reproductive structures. Among herbicide treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} (POE) produced significantly higher seed and haulm yield, comparable with pendimethalin *fb* propaquizafop + imazethapyr and hand weeding *fb* intercultivation. These treatments ensured effective and prolonged weed control during the critical crop-weed competition period, leading to improved resource utilization and biomass production. Conversely, pendimethalin *fb* fluazifop-p-butyl + fomesafen recorded the lower seed and haulm yield due to phytotoxic effects and incomplete weed suppression, which restricted nutrient uptake and assimilate translocation. These findings corroborate the results of Mangaraj *et al.* (2021) [16].

Table 1: Plant height of pigeonpea as influenced by weed management practices in pigeonpea + soybean intercropping system

Treatments		Plant height (cm)				
		30 DAS	60 DAS	90 DAS	120 DAS	At harvest
T_1:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 35% + Imazamox 35%WG @ 75g *a.i.* ha^{-1} at 20-25 DAS (POE)	36.00	64.01	107.46	164.12	177.91
T_2:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + Imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE)	35.62	63.98	106.78	163.93	176.68
T_3:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Quizalofop ethyl 7.5% + Imazethapyr 15% w/w EC @ 32.81 + 65.62g *a.i.* ha^{-1} at 20-25 DAS (POE)	34.86	55.81	99.03	153.85	162.85
T_4:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fomesafen 12% + Quizalofop ethyl 13% w/w SE @ 180 + 45g *a.i.* ha^{-1} at 20-25 DAS (POE)	36.38	54.33	97.50	152.29	161.29
T_5:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fluazifop-p-butyl 11.1% w/w + Fomasafen 11.1% w/w SL @ 250g *a.i.* ha^{-1} at 20-25 DAS (POE)	33.34	49.86	76.40	126.28	130.71
T_6:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 10% SL 100g *a.i.* ha^{-1} at 20-25 DAS (POE)	34.48	53.89	95.00	151.80	159.34
T_7:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1}(PE) *fb* IC at 30 DAS	34.10	53.62	91.50	150.31	158.01
T_8:	Hand weeding at 15 DAS *fb* IC at 30 DAS	35.24	63.01	106.14	163.11	170.97
T_9:	Weed free check	36.76	70.94	116.40	180.20	192.96
T_{10}:	Weedy check	33.35	51.40	86.80	119.00	140.19
S. Em. ±		1.05	1.76	2.99	4.62	4.94
CD @ 5%		NS	5.23	8.88	13.72	14.69

Table 2: Leaf area of pigeonpea at various growth stages as influenced by weed management practices in pigeonpea + soybean intercropping system

Treatments		Leaf area (cm^2 plant^{-1})				
		30 DAS	60 DAS	90 DAS	120 DAS	At harvest
T_1:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 35% + Imazamox 35%WG @ 75g *a.i.* ha^{-1} at 20-25 DAS (POE)	331.97	420.46	661.53	1509.52	911.96
T_2:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + Imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE)	331.95	417.29	656.99	1498.14	904.92
T_3:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Quizalofop ethyl 7.5% + Imazethapyr 15% w/w EC @ 32.81 + 65.62g *a.i.* ha^{-1} at 20-25 DAS (POE)	329.81	400.68	638.58	1368.39	863.97
T_4:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fomesafen 12% + Quizalofop ethyl 13% w/w SE @ 180 + 45g *a.i.* ha^{-1} at 20-25 DAS (POE)	328.58	384.47	614.21	1320.76	839.94
T_5:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fluazifop-p-butyl 11.1% w/w + Fomasafen 11.1% w/w SL @ 250g *a.i.* ha^{-1} at 20-25 DAS (POE)	325.05	338.81	545.76	1116.21	752.98
T_6:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 10% SL 100g *a.i.* ha^{-1} at 20-25 DAS (POE)	327.90	379.50	605.25	1301.73	832.94
T_7:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1}(PE) *fb* IC at 30 DAS	327.00	356.82	595.67	1292.33	823.97
T_8:	Hand weeding at 15 DAS *fb* IC at 30 DAS	330.90	413.31	651.02	1477.09	897.92
T_9:	Weed free check	332.14	449.54	697.44	1664.70	968.95
T_{10}:	Weedy check	326.80	347.64	558.45	1138.47	766.96
S. Em. ±		9.89	9.12	11.01	41.52	25.84
CD @ 5%		NS	27.10	33.01	123.36	76.77

Note: DAS = Days after sowing IC = Intercultivation HW = Hand weeding
PE = Pre-emergence POE = Post-emergence *a.i.* = Active ingredient *fb* = Followed by

Table 3: Leaf area index of pigeonpea at various growth stages as influenced by weed management practices in pigeonpea and soybean intercropping system

Treatments		LAI				
		30 DAS	60 DAS	90 DAS	120 DAS	At harvest
T_1:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 35% + Imazamox 35%WG @ 75g *a.i.* ha^{-1} at 20-25 DAS (POE)	0.123	0.156	0.245	0.559	0.338
T_2:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + Imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE)	0.123	0.155	0.243	0.555	0.335
T_3:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Quizalofop ethyl 7.5% + Imazethapyr 15% w/w EC @ 32.81 + 65.62g *a.i.* ha^{-1} at 20-25 DAS (POE)	0.122	0.148	0.237	0.507	0.320
T_4:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fomesafen 12% + Quizalofop ethyl 13% w/w SE @ 180 + 45g *a.i.* ha^{-1} at 20-25 DAS (POE)	0.122	0.142	0.227	0.489	0.311
T_5:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fluazifop-p-butyl 11.1% w/w + Fomasafen 11.1% w/w SL @ 250g *a.i.* ha^{-1} at 20-25 DAS (POE)	0.120	0.125	0.202	0.413	0.279
T_6:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 10% SL 100g *a.i.* ha^{-1} at 20-25 DAS (POE)	0.121	0.141	0.224	0.482	0.308
T_7:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1}(PE) *fb* IC at 30 DAS	0.121	0.125	0.221	0.479	0.305
T_8:	Hand weeding at 15 DAS *fb* IC at 30 DAS	0.123	0.153	0.241	0.547	0.333
T_9:	Weed free check	0.123	0.166	0.258	0.617	0.359
T_{10}:	Weedy check	0.121	0.129	0.207	0.422	0.284
S. Em. ±		0.004	0.003	0.004	0.015	0.010
CD @ 5%		NS	0.010	0.012	0.046	0.028

Table 4: Total dry matter production in pigeonpea as influenced by weed management practices in pigeonpea + soybean intercropping system

Treatments		Total dry matter production (g plant^{-1})				
		30 DAS	60 DAS	90 DAS	120 DAS	At harvest
T_1:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 35% + Imazamox 35%WG @ 75g *a.i.* ha^{-1} at 20-25 DAS (POE)	10.73	24.13	48.56	147.63	178.42
T_2:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + Imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE)	10.67	23.95	47.93	145.70	176.55
T_3:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Quizalofop ethyl 7.5% + Imazethapyr 15% w/w EC @ 32.81 + 65.62g *a.i.* ha^{-1} at 20-25 DAS (POE)	10.39	21.44	43.34	133.03	159.94
T_4:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fomesafen 12% + Quizalofop ethyl 13% w/w SE @ 180 + 45g *a.i.* ha^{-1} at 20-25 DAS (POE)	10.05	21.18	42.59	131.53	156.81
T_5:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fluazifop-p-butyl 11.1% w/w + Fomasafen 11.1% w/w SL @ 250g *a.i.* ha^{-1} at 20-25 DAS (POE)	8.73	16.08	33.04	102.44	120.32
T_6:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 10% SL 100g *a.i.* ha^{-1} at 20-25 DAS (POE)	9.77	20.63	41.86	128.33	151.89
T_7:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1}(PE) *fb* IC at 30 DAS	9.61	20.47	41.29	126.97	145.23
T_8:	Hand weeding at 15 DAS *fb* IC at 30 DAS	10.50	23.72	46.93	146.06	175.74
T_9:	Weed free check	10.79	27.06	53.77	162.70	198.35
T_{10}:	Weedy check	8.90	18.69	38.16	120.65	138.30
S. Em. ±		0.30	0.66	1.33	4.09	4.88
CD @ 5%		NS	1.97	3.95	12.15	14.51

Note: DAS = Days after sowing IC = Intercultivation HW = Hand weeding
PE = Pre-emergence POE = Post-emergence *a.i.* = Active ingredient *fb* = Followed by

Growth parameters of soybean

Plant height

At 30 DAS, differences among treatments were non-significant. However, at 60, 90 DAS and at harvest, weed free check recorded the tallest plant height (43.14, 55.12, and 55.65 cm). Among herbicidal treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) (39.01, 50.12 and 51.09 cm) recorded taller plant height, which was on par with, pendimethalin 38.7% CS *fb* propaquizafop 2.5% + imazethapyr 3.75% ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS (POE) (38.28, 49.98 and 50.30 cm), hand weeding at 15 DAS *fb* intercultivation at 30 DAS (37.66, 48.32 and 49.42 cm) and pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* quizalofop-ethyl 7.5% + imazethapyr 15% w/w EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20-25 DAS (POE) (36.84, 47.13 and 48.50 cm). While the shortest plant height was again recorded in weedy check (22.34, 27.72 and 29.34 cm), due to poor weed control and slight competition for resources.

The progressive increase in plant height across growth stages demonstrates that effective weed management enhances light interception, nutrient availability and overall canopy development. Among herbicidal treatments pre-emergence application of pendimethalin followed by post-emergence herbicide application as well as manual hand weeding resulted in better plant height, stem elongation and biomass accumulation. Conversely, poor weed control in the weedy check restricted vegetative growth due to competition. These results are consistent with findings reported by Thakare *et al*. (2015) [24] and Rupareliya *et al*. (2020) [20] in soybean.

Number of branches per plant

Number of branches per plant was found non-significant among the treatments at 30 DAS. However, at 60, 90 DAS and at harvest, the weed free check produced the highest number of branches per plant (5.92, 7.04 and 7.54 plant^{-1}). Among herbicide treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1}

(PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) (5.41, 6.40 and 6.92 plant^{-1}) produced a significantly higher number of branches per plant, which was statistically on par with pendimethalin *fb* propaquizafop 2.5% + imazethapyr 3.75% ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS (POE) (5.35, 6.23 and 6.84 plant^{-1}) and hand weeding at 15 DAS *fb* intercultivation at 30 DAS (5.26, 6.02 and 6.72 plant^{-1}) and pendimethalin *fb* quizalofop ethyl 7.5% + imazethapyr 15% EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20-25 DAS (POE) (5.16, 5.90 and 6.54 plant^{-1}). The lowest number of branches was observed in weedy check (3.08, 3.32 and 4.15 plant^{-1}).

The weed free check consistently recorded the highest number of branches at all growth stages, indicating that the absence of weed competition favoured better nutrient, water and light availability, which promoted axillary bud development. Among herbicidal treatments, sequential application of pendimethalin followed by post-emergence application such as imazethapyr + imazamox, propaquizafop + imazethapyr, or quizalofop-ethyl + imazethapyr supported higher branching, comparable to manual weeding. In contrast, the weedy check showed the lowest number of branches due to intense competition with weeds for essential resources, which limited vegetative growth. These results suggest that effective weed management enhances canopy development and branch formation, thereby contributing to overall crop growth and potential yield. Similar trends were reported by Thakare *et al*. (2015) [24] and Rupareliya *et al*. (2020) [20] in soybean.

Leaf area per plant

Differences among treatments were non-significant at 30 DAS. However, at 60 and 90 DAS, the weed free check recorded the significantly highest leaf area (922.00 and 827.00 cm² plant^{-1}). Among herbicide treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) (852.35 and 753.80 cm² plant^{-1}) observed significantly higher leaf area, which was statistically on par with pendimethalin 38.7% CS *fb* propaquizafop 2.5% + imazethapyr 3.75% ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS (POE) (849.62 and 728.70 cm² plant^{-1}), hand weeding at 15 DAS *fb* intercultivation at 30 DAS (846.38 and 705.55 cm² plant^{-1}) and pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* quizalofop-ethyl 7.5% + imazethapyr 15% w/w EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20-25 DAS (POE) (842.08 and 697.33 cm² plant^{-1}). The minimum leaf area was again associated with weedy check (620.05 and 390.92 cm² plant^{-1}).

Leaf area index (LAI)

At 30 DAS, differences among treatments were non-significant. However, at 60 and 90 DAS, the weed free check recorded the highest LAI (3.07 and 2.76). Among herbicide treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) (2.84 and 2.51) observed higher LAI, which was closely on par with, pendimethalin 38.7% CS *fb* propaquizafop 2.5% + imazethapyr 3.75% ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS (POE) (2.83 and 2.43), hand weeding at 15 DAS *fb* intercultivation at 30 DAS (2.82 and 2.35) and pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* quizalofop-ethyl 7.5% + imazethapyr 15% w/w EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20-25 DAS (POE) (2.81 and 2.32). While the lowest LAI occurred in weedy check (2.07 and 1.30), was associated with less effective weed suppression and which limited the leaf expansion.

Leaf area and LAI increased progressively up to the peak vegetative stage, reflecting active leaf expansion and declined thereafter as the crop approached maturity and lower leaves senesced. The weed free check consistently maintained the higher leaf area and LAI at all stages, indicating that absence of weed competition facilitated better canopy development, efficient light interception and greater assimilate production. Among the weed management practices, sequential application of pendimethalin as pre-emergence followed by post-emergence mixtures such as imazethapyr + imazamox, propaquizafop + imazethapyr, quizalofop-ethyl + imazethapyr and hand weeding with intercultivation produced higher leaf area and LAI, comparable to the weed free check. These treatments effectively suppressed weeds, ensuring better resource availability and enhanced leaf expansion. In contrast, the weedy check recorded the lower leaf area and LAI throughout the crop growth period, reflecting restricted canopy development and reduced photosynthetic efficiency under weeds competition stress. Similar results were reported by Bhagyasree *et al.* (2018) and Rupareliya *et al*. (2020) [20] in soybean and in pigeonpea based intercropping system.

Dry matter production and its distribution in various plant parts

Dry matter accumulation in leaves

At 30 DAS, differences among treatments were non-significant. However, at 60, 90 DAS and at harvest, maximum dry matter accumulation in leaves per plant was recorded in the weed free check (6.45, 7.55 and 5.60 g plant^{-1}). Among herbicide treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) (5.93, 6.96 and 5.16 g plant^{-1}), which was statistically comparable with pendimethalin 38.7% CS *fb* propaquizafop 2.5% + imazethapyr 3.75% ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS (POE) (5.53, 6.63 and 5.01 g plant^{-1}), hand weeding at 15 DAS *fb* intercultivation at 30 DAS (5.49, 6.45 and 4.86 g plant^{-1}) and pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* quizalofop-ethyl 7.5% + imazethapyr 15% w/w EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20-25 DAS (POE) (5.48, 6.41 and 4.76 g plant^{-1}). Lowest dry matter accumulation in leaves was observed in weedy check (3.21, 3.61 and 2.78 g plant^{-1}).

Dry matter accumulation in stem

At 30 DAS, differences among treatments were non-significant. However, at 60, 90 DAS and at harvest, stem dry matter increased sharply, with weed free check (13.20, 14.50 and 16.30 g plant^{-1}) being significantly superior. Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) (12.04, 13.21 and 14.81 g plant^{-1}), pendimethalin 38.7% CS *fb* propaquizafop 2.5% + imazethapyr 3.75% ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS (POE) (11.21, 12.88 and 13.98 g plant^{-1}), hand weeding at 15 DAS *fb* intercultivation at 30 DAS (11.16, 12.74 and 13.84 g plant^{-1}) and pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* quizalofop-ethyl 7.5% + imazethapyr 15% w/w EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20-25 DAS (POE) (11.10, 12.54 and 13.74 g plant^{-1}) were comparable and statistically similar. Weedy check (6.73, 6.52 and 7.84 g plant^{-1}) remained significantly lower than all other treatments, reflecting suppressed stem growth under less effective weed control.

Dry matter accumulation in pod

At 60, 90 DAS and at harvest, weed-free check observed the highest pod dry matter of (5.12, 18.58 and 27.54 g plant^{-1}). Among herbicide-treated plots, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75

g *a.i.* ha^{-1} at 20-25 DAS (POE) (4.65, 17.05 and 25.21 g plant^{-1}) observed significantly higher pod biomass, which was statistically on par with pendimethalin 38.7% CS *fb* propaquizafop 2.5% + imazethapyr 3.75% ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS (POE) (4.51, 16.13 and 24.34 g plant^{-1}), hand weeding at 15 DAS *fb* intercultivation at 30 DAS (4.40, 15.90 and 23.96 g plant^{-1}) and pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* quizalofop-ethyl 7.5% + imazethapyr 15% w/w EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20-25 DAS (POE) (4.32, 15.73 and 23.02 g plant^{-1}). While the dry matter accumulation in pods was significantly lower in the weedy check (2.38, 10.12 and 12.25 g plant^{-1}).

Total dry matter production

At 30 DAS, differences among treatments were non-significant. However, at 60, 90 DAS and at harvest, total dry matter production increased significantly with weed free check (24.77, 40.63 and 49.44 g plant^{-1}) maintaining its superiority. Among herbicide sequences pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (22.62, 37.22 and 45.18 g plant^{-1}), pendimethalin 38.7% CS *fb* propaquizafop 2.5% + imazethapyr 3.75% ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS (POE) (21.25, 35.64 and 43.33 g plant^{-1}) and hand weeding at 15 DAS *fb* intercultivation at 30 DAS (21.05, 35.09 and 42.66 g plant^{-1}) and pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* quizalofop-ethyl 7.5% + imazethapyr 15% w/w EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20-25 DAS (POE) (20.90, 34.68 and 41.52 g plant^{-1}) were statistically similar, reflecting effective weed suppression during vegetative growth. Weedy check (12.32, 20.25 and 22.87 g plant^{-1}) again observed significantly lower, showing the negative impact of weed interference on biomass accumulation.

Dry matter accumulation in soybean was significantly influenced by weed management practices beyond 30 DAS. The weed-free check consistently recorded the higher dry matter accumulation in leaves, stems, pods and total biomass at all stages due to complete elimination of weed competition, which enhanced light interception, nutrient uptake and photosynthetic efficiency. Among herbicidal treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} (POE) recorded significantly higher dry matter in all plant parts, comparable with pendimethalin *fb* propaquizafop + imazethapyr, pendimethalin *fb* quizalofop-ethyl + imazethapyr and hand weeding *fb* intercultivation. These treatments effectively suppressed weeds throughout the critical crop-weed competition period, ensuring better vegetative growth and assimilate translocation to reproductive parts. Conversely, the weedy check consistently produced the lower dry matter accumulation across all stages, indicating severe growth suppression due to intense competition for light, nutrients and moisture. Similar results were reported by Bhimwal *et al*. (2018) [5] and Rupareliya *et al*. (2020) [20].

Effect on crop growth and yield of soybean

Seed yield (kg ha^{-1})

The data on soybean seed yield are presented in Table 08 and a significant variation among treatments was observed.

The weed free check recorded the higher seed yield of (1032 kg ha^{-1}), which was significantly superior to all other treatments. Among the herbicide-based weed management treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35%WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) produced higher seed yield (979 kg ha^{-1}) which was on par with, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* propaquizofop 2.5% + imazethapyr 3.75% w/w ME @ 125 g *a.i.* ha^{-1} 20-25 DAS (POE) yielded (943 kg ha^{-1}), hand weeding at 15 DAS *fb* intercultivation at 30 DAS produced (934 kg ha^{-1}) and pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* quizalofop ethyl 7.5% + imazethapyr 15% w/w EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20–25 DAS (POE) yielded (926 kg ha^{-1}). The lower seed yield was observed in weedy check (615 kg ha^{-1}).

Haulm yield (kg ha^{-1})

The results indicated that haulm yield was significantly influenced by the weed management practices.

The weed free check produced the higher haulm yield of (2686 kg ha^{-1}), which was significantly superior to all other treatments. Among the herbicide-based treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35%WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) (2501 kg ha^{-1}), pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + imazethapyr 3.75% w/w ME @ 125 g *a.i.* ha^{-1} 20-25 DAS (POE) (2458 kg ha^{-1}), hand weeding at 15 DAS *fb* intercultivation at 30 DAS (2398 kg ha^{-1}) and pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* quizalofop ethyl 7.5% + imazethapyr 15% w/w EC @ 32.81 + 65.62 g *a.i.* ha^{-1} at 20–25 DAS (POE) (2320 kg ha^{-1}). These treatments were statistically on par with each other, indicating that effective weed suppression during the early critical period leads to better vegetative growth and biomass production. The lower haulm yield was recorded in weedy check (1771 kg ha^{-1}).

Weed management practices significantly influenced both seed and haulm yield of soybean. The weed-free check recorded the highest seed and haulm yield due to complete elimination of crop-weed competition, resulting in enhanced nutrient uptake, canopy development and assimilate partitioning towards pods. Among the herbicidal treatments, sequential application of pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) followed by imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} (POE) recorded superior yields of seed and haulm, which were on par with other effective combinations and manual weeding. The effectiveness of these treatments can be attributed to season-long control of both grassy and broad-leaved weeds, where pendimethalin controlled early flushes and imidazolinone or ACCase-inhibiting herbicides managed later-emerging weeds. Conversely, the lower yields in the weedy check were due to severe crop-weed competition reducing growth and pod formation. Similar yield enhancement through integrated herbicidal approaches was reported by Singh and Abraham *et al*. (2017) [23], Vijay *et al*. (2018) [25], and Aher *et al*. (2023) [1].

Pigeonpea Equivalent Yield (PEY) (kg ha^{-1})

The pigeonpea equivalent yield, which reflects the overall productivity of the pigeonpea and soybean intercropping system, differed significantly among the weed management treatments. The data on the pigeonpea equivalent yield are presented in Table 08.

The higher PEY was recorded with the weed free check (1709 kg ha^{-1}), which was significantly superior to all other treatments. Among herbicide-based treatments, pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) recorded the maximum PEY (1646 kg ha^{-1}), followed by pendimethalin 38.7% CS @ 678g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE) (1576 kg ha^{-1}) and hand weeding at 15 DAS *fb* intercultivation at 30 DAS also maintained a relatively higher PEY (1548 kg ha^{-1}). The lower PEY was observed in pendimethalin 38.7% CS @ 678g *a.i.* ha^{-1} (PE) *fb* fluazifop-p-butyl 11.1% w/w + fomasafen 11.1% w/w

SL @ 250 g *a.i.* ha^{-1} at 20-25 DAS (POE) (1026 kg ha^{-1}), which was even inferior to the weedy check (1073 kg ha^{-1}).

The superior PEY in the weed-free check was due to the complete absence of crop-weed competition, which ensured better nutrient uptake, light interception and assimilate partitioning in both pigeonpea and soybean. Among herbicidal treatments, sequential application of pendimethalin (microtubule inhibitor) as pre-emergence followed by imazethapyr + imazamox (ALS inhibitors) provided broad-spectrum and season-long weed control, enhancing crop vigour and yield. Propaquizofop and quizalofop-ethyl (ACCase inhibitors) effectively managed grassy weeds. While imazethapyr controlled broad-leaved weeds. Hand weeding followed by intercultivation also improved yield but was labour-intensive and less practical. Fluazifop-p-butyl + fomesafen caused severe phytotoxicity to pigeonpea, leading to reduced PEY, emphasizing the importance of herbicide selectivity in intercropping. Overall, sequential use of pendimethalin fb imazethapyr + imazamox proved most effective for broad-spectrum weed control and yield improvement in pigeonpea + soybean intercropping, corroborating findings of Deshmukh (2016) [8] and Singh and Abraham (2017) [23].

Economics

Benefit cost ratio (B:C)

There was a significant difference observed with respect to benefit cost ratio due to different weed management practices.

Higher B:C was recorded with application of pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) (3.26) followed by pendimethalin 38.7% CS @ 678g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE)(3.13) and hand weeding at 15 DAS *fb* intercultivation at 30 DAS (3.06). Whereas, significantly lower B:C was recorded in pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* fluazifop-p-butyl 11.1% w/w + fomasafen 11.1% w/w SL @ 250 g *a.i.* ha^{-1} at 20-25 DAS (POE) (2.04).

The higher B:C with application of pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS (POE) and pendimethalin 38.7% CS @ 678g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE) was due to higher seed yield with lesser cost of weeding with herbicide application. Similar findings observed by Chouhan and Verma (2023) [7] soybean + pigeonpea intercropping system.

Table 5: Plant height of soybean as influenced by weed management practices in pigeonpea + soybean intercropping system

	Treatments	Plant height (cm)			
		30 DAS	60 DAS	90 DAS	At harvest
T_1:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 35% + Imazamox 35%WG @ 75g *a.i.* ha^{-1} at 20-25 DAS (POE)	20.01	39.01	50.12	51.09
T_2:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + Imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE)	19.93	38.28	49.98	50.30
T_3:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Quizalofop ethyl 7.5% + Imazethapyr 15% w/w EC @ 32.81 + 65.62g *a.i.* ha^{-1} at 20-25 DAS (POE)	18.91	36.84	47.13	48.50
T_4:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fomesafen 12% + Quizalofop ethyl 13% w/w SE @ 180 + 45g *a.i.* ha^{-1} at 20-25 DAS (POE)	18.92	32.70	42.18	43.41
T_5:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fluazifop-p-butyl 11.1% w/w + Fomasafen 11.1% w/w SL @ 250g *a.i.* ha^{-1} at 20-25 DAS (POE)	18.58	26.32	34.15	35.45
T_6:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 10% SL 100g *a.i.* ha^{-1} at 20-25 DAS (POE)	18.71	30.54	39.21	40.50
T_7:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1}(PE) *fb* IC at 30 DAS	18.32	26.45	32.18	34.23
T_8:	Hand weeding at 15 DAS *fb* IC at 30 DAS	19.01	37.66	48.32	49.42
T_9:	Weed free check	21.52	43.14	55.12	55.65
T_{10}:	Weedy check	18.10	22.34	27.72	29.34
	S. Em. ±	1.13	1.02	1.31	1.35
	CD @ 5%	NS	3.04	3.91	4.00

Table 6: Leaf area and Leaf area index of soybean as influenced by weed management practices in pigeonpea + soybean intercropping system.

	Treatments	Leaf area (cm^2 plant^{-1})			LAI		
		30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T_1:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 35% + Imazamox 35%WG @ 75g *a.i.* ha^{-1} at 20-25 DAS (POE)	579.81	852.35	753.80	1.93	2.84	2.51
T_2:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + Imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE)	576.18	849.62	728.77	1.92	2.83	2.43
T_3:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Quizalofop ethyl 7.5% + Imazethapyr 15% w/w EC @ 32.81 + 65.62g *a.i.* ha^{-1} at 20-25 DAS (POE)	571.02	842.08	697.33	1.90	2.81	2.32
T_4:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fomesafen 12% + Quizalofop ethyl 13% w/w SE @ 180 + 45g *a.i.* ha^{-1} at 20-25 DAS (POE)	566.28	774.52	626.31	1.89	2.58	2.09
T_5:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fluazifop-p-butyl 11.1% w/w + Fomasafen 11.1% w/w SL @ 250g *a.i.* ha^{-1} at 20-25 DAS (POE)	556.24	701.68	507.46	1.85	2.34	1.69
T_6:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 10% SL 100g *a.i.* ha^{-1} at 20-25 DAS (POE)	561.01	770.42	578.39	1.87	2.57	1.93
T_7:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1}(PE) *fb* IC at 30 DAS	551.78	698.96	465.88	1.84	2.33	1.55
T_8:	Hand weeding at 15 DAS *fb* IC at 30 DAS	574.33	846.38	705.55	1.91	2.82	2.35
T_9:	Weed free check	590.01	922.00	827.00	1.97	3.07	2.76
T_{10}:	Weedy check	546.18	620.05	390.92	1.82	2.07	1.30
	S. Em. ±	17.04	23.84	19.42	0.06	0.08	0.06
	CD @ 5%	NS	70.82	57.69	NS	0.24	0.19

Note: DAS = Days after sowing IC = Intercultivation HW = Hand weeding
PE = Pre-emergence POE = Post-emergence *a.i.* = Active ingredient *fb* = Followed by

Table 7: Total dry matter production in soybean as influenced by weed management practices in pigeonpea + soybean intercropping system

Treatments		Total dry matter production (g plant^{-1})			
		30 DAS	60 DAS	90 DAS	At harvest
T_1:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 35% + Imazamox 35%WG @ 75g *a.i.* ha^{-1} at 20-25 DAS (POE)	8.80	22.62	37.22	45.18
T_2:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + Imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE)	8.65	21.25	35.64	43.33
T_3:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Quizalofop ethyl 7.5% + Imazethapyr 15% w/w EC @ 32.81 + 65.62g *a.i.* ha^{-1} at 20-25 DAS (POE)	8.39	20.90	34.68	41.52
T_4:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fomesafen 12% + Quizalofop ethyl 13% w/w SE @ 180 + 45g *a.i.* ha^{-1} at 20-25 DAS (POE)	8.64	18.72	31.29	36.57
T_5:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fluazifop-p-butyl 11.1% w/w + Fomasafen 11.1% w/w SL @ 250g *a.i.* ha^{-1} at 20-25 DAS (POE)	7.90	15.31	25.37	28.73
T_6:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 10% SL 100g *a.i.* ha^{-1} at 20-25 DAS (POE)	8.84	17.43	29.73	34.57
T_7:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1}(PE) *fb* IC at 30 DAS	7.65	14.52	23.74	26.92
T_8:	Hand weeding at 15 DAS *fb* IC at 30 DAS	8.48	21.05	35.09	42.66
T_9:	Weed free check	8.98	24.77	40.63	49.44
T_{10}:	Weedy check	7.47	12.32	20.25	22.87
S. Em. ±		0.35	0.58	0.97	1.16
CD @ 5%		NS	1.73	2.87	3.43

Note: DAS = Days after sowing IC = Intercultivation HW = Hand weeding
PE = Pre-emergence POE = Post-emergence *a.i.* = Active ingredient *fb* = Followed by

Table 8: Grain yield, haulm yield, pigeonpea equivalent yield and B:C ratio as influenced by weed management practices in pigeonpea + soybean intercropping system

Treatments		Seed yield (kg ha^{-1})		Haulm yield (kg ha^{-1})		P pea equivalent yield (kg ha^{-1})	B:C ratio
		P pea	Soy	P pea	Soy		
T_1:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 35% + Imazamox 35%WG @ 75g *a.i.* ha^{-1} at 20-25 DAS (POE)	1095	979	3165	2501	1646	3.26
T_2:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Propaquizofop 2.5% + Imazethapyr 3.75% w/w ME @ 125g *a.i.* ha^{-1} 20-25 DAS (POE)	1046	943	3012	2458	1576	3.13
T_3:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Quizalofop ethyl 7.5% + Imazethapyr 15% w/w EC @ 32.81 + 65.62g *a.i.* ha^{-1} at 20-25 DAS (POE)	952	926	2900	2398	1473	2.92
T_4:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fomesafen 12% + Quizalofop ethyl 13% w/w SE @ 180 + 45g *a.i.* ha^{-1} at 20-25 DAS (POE)	932	854	2876	2218	1412	2.83
T_5:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Fluazifop-p-butyl 11.1% w/w + Fomasafen 11.1% w/w SL @ 250g *a.i.* ha^{-1} at 20-25 DAS (POE)	619	723	1914	2001	1026	2.04
T_6:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} (PE) *fb* Imazethapyr 10% SL 100g *a.i.* ha^{-1} at 20-25 DAS (POE)	901	819	2779	2137	1362	2.72
T_7:	Pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1}(PE) *fb* IC at 30 DAS	892	704	2701	1954	1288	2.60
T_8:	Hand weeding at 15 DAS *fb* IC at 30 DAS	1023	934	2979	2320	1548	3.06
T_9:	Weed free check	1128	1032	3491	2686	1709	2.88
T_{10}:	Weedy check	704	615	2017	1771	1050	2.43
S. Em. ±		28.6	26.0	85.2	67.9	43.19	0.09
CD @ 5%		84.9	77.4	253.0	201.8	128.32	0.25

Note: DAS = Days after sowing IC = Intercultivation HW = Hand weeding
PE = Pre-emergence POE = Post-emergence *a.i.* = Active ingredient *fb* = Followed by

Conclusion

Sequential application of pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} as pre-emergence *fb* post-emergent application of imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS was found effective in controlling weeds by reducing their density and dry weight than other treatments and weedy check in pigeonpea + soybean intercropping system. Sequential application of pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} as pre-emergence *fb* post-emergent application of imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS resulted in significantly higher growth and yield parameters of both pigeonpea + soybean. Sequential application of pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} as pre-emergence *fb* post-emergent application of imazethapyr 35% + imazamox 35% WG @ 75 g *a.i.* ha^{-1} at 20-25 DAS was more effective in achieving maximum gross returns, net returns and benefit-cost ratio in pigeonpea + soybean intercropping system. However, it was on par with sequential application of pendimethalin 38.7% CS @ 678 g *a.i.* ha^{-1} as pre-emergence *fb* post-emergent application of propaquizafop 2.5% + imazethapyr 3.75% w/w ME @ 125 g *a.i.* ha^{-1} at 20-25 DAS.

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