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Performance of pre-emergent herbicide weed management practices on productivity and weed control efficiency in soybean (*Glycine max* L.)

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Abstract
A field experiment was conducted to assess the effect of pre-emergent herbicides on yield and yield attributes of soybean at Agriculture College Farm, UAS Raichur, during kharif, 2023. The experiment was laid out in RCBD with three replications. The experiment consisted of 10 treatments consisting of 4 pre-emergence herbicides (Fomesafen + S-Metolachlor, Fomesafen + Quizalofop ethyl, Pendimethalin and Diclosulum) and they were compared with weedy check and weed free check. The results revealed that among all the treatments weed free check recorded significantly a greater number of pods (51.67 $plant^{-1}$), higher seed weight per plant (11.07 g), seed yield (2325 kg ha^{-1}), haulm yield (3802 kg ha^{-1}), net returns (₹ 77,463 ha^{-1}) and benefit cost ratio (3.27). Conversely, weedy check recorded significantly lesser number of pods (13.83 $plant^{-1}$), lower seed weight per plant (2.77 g), seed yield (914 kg ha^{-1}), haulm yield (1838 kg ha^{-1}), net returns (₹ 15735 ha^{-1}) and benefit cost ratio (1.56). Among herbicide treatments, application of Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 3790 g *a.i.* ha^{-1} recorded significantly a greater number of pods (48.83 $plant^{-1}$) higher seed weight per plant (10.00 g), seed yield (914 kg ha^{-1}), haulm yield (1838 kg ha^{-1}), net returns (₹ 70,304 ha^{-1}) and benefit cost ratio (1.56). The lower number of pods (33.07 $plant^{-1}$), seed weight per plant (6.10 g), seed yield (1151 kg ha^{-1}), haulm yield (2497 kg ha^{-1}), net returns (₹ 26,721 ha^{-1}) and benefit cost ratio (1.94) were recorded with the application of Fomesafen 11.385% + Quizalofop ethyl 3% SC @ 225 g *a.i.* ha^{-1}.

Keywords: Pre-emergent herbicides, weed management, soybean yield

Introduction

Soybean (*Glycine max* [L.] Merrill), often termed the "Golden Bean" or "Miracle Crop," is a globally significant oilseed and pulse crop due to its dual role as a source of edible oil and high-quality protein (Sharma *et al*., 2018) [28]. Its nutritional profile, comprising 40-42% protein, 20% oil, essential amino acids, vitamins (A, B, D), minerals and dietary fibre, makes it an important food for addressing malnutrition (Bhumika *et al*., 2015) [4]. Soy protein is comparable in quality to animal protein and the crop provides additional health benefits by lowering the risk of diabetes, cancer and cardiovascular diseases (Mahajan *et al*., 2020) [18]. Agronomically, soybean is recognized for its soil-improving ability, contributing 30-40 kg ha^{-1} of residual nitrogen through biological nitrogen fixation, which benefits succeeding crops in rotation (Singh & Bhattacharya, 2017) [29]. Globally, soybean is cultivated on 175.1 million hectares with an annual production of 395 million tonnes, making it the fourth most widely grown crop after maize, wheat and rice (FAO, 2023) [10]. In India, soybean is primarily grown in Madhya Pradesh, Maharashtra, Rajasthan and Karnataka, covering 12.85 million hectares with a production of 13.2 million tonnes (DES, 2023). However, its productivity (1,275 kg ha^{-1}) remains lower than the world average (1,960 kg ha^{-1}) and in Karnataka, the yield is even lower (937 kg ha^{-1}) (Indiastat, 2023) [12]. One of the major constraints contributing to this yield gap is poor weed management, as weeds compete vigorously with soybean for water, nutrients, light and space, often causing yield reductions ranging between 30% and 77% (Kumari *et al*., 2020) [17].

Weed management is therefore crucial to realizing the yield potential of soybean. Integrated approaches involving cultural, mechanical, chemical and biological methods have been advocated, but reliance on manual weeding is declining due to labour shortages, high costs and untimely rains that restrict field operations (Choudhary *et al*., 2017) [8]. Among the available methods, chemical weed control using herbicides has emerged as the most efficient, reliable and cost-effective option (Meena, 2020) [19]. The use of pre-emergent herbicides, applied before weed seed germination, has proven particularly effective in minimizing early crop-weed competition and ensuring vigorous soybean establishment (Jha & Soni, 2013) [13]. Such practices not only reduce dependency on manual labour but also improve canopy development, resource use efficiency and ultimately crop yield (Gore *et al*., 2014) [11]. With herbicide use in India projected to rise by nearly 10% annually, adoption of appropriate chemical weed management practices can significantly enhance soybean productivity and profitability under diverse agro-ecological conditions (Patel *et al*., 2019) [26].

2. Material and Methods

A field experiment was conducted during the *Kharif* season of 2023 at the Agricultural College Farm, Raichur, located at 16°11′47.6″ N latitude, 77°19′23.3″ E longitude and an altitude of 389 meters above mean sea level. The site falls within the North Eastern Dry Zone (Zone II) of Karnataka. The study aimed to evaluate the effect of pre-emergent herbicides on the yield and yield-attributing characters of soybean. The crop was sown in deep black soils under irrigated conditions, maintaining a spacing of 30 cm × 10 cm. The experiment comprised ten treatments, including pre-emergent herbicides Fomesafen 11.385% + S-Metolachlor 51.783% EC at five concentrations (1,265; 1,580; 1,895; 2,370; and 3,790 g a.i. ha⁻¹), Fomesafen 12% + Quizalofop-ethyl 3% SC at 225 g a.i. ha⁻¹, Pendimethalin 38.7% CS at 677.25 g a.i. ha⁻¹ and Diclosulam 84% WDG at 26 g a.i. ha⁻¹ along with weedy and weed-free checks. Treatments were arranged in a Randomized Complete Block Design (RCBD) with three replications. Each plot measured 4.8 m × 3.6 m. The recommended dose of nitrogen, phosphorus and potassium was applied uniformly to all plots in the form of urea, diammonium phosphate (DAP) and muriate of potash (MOP), respectively. Biofertilizers *Rhizobium*, *Trichoderma* and phosphate-solubilizing bacteria (PSB) at 1,250 g ha⁻¹ each were applied at sowing. Herbicides were sprayed using a knapsack sprayer fitted with a flat-fan nozzle, delivering 500 l ha⁻¹ of water.

3. Result and Discussion

3.1 Effect of weed management practices on yield parameters of soybean

3.1.1 Number of pods (plant^{-1})

The number of pods per plant was significantly affected by weed management practices (Table 1). The weed-free check recorded the maximum pod number (51.67 plant⁻¹), demonstrating the benefits of eliminating crop-weed competition, whereas the weedy check produced the minimum (13.83 plant⁻¹), indicating severe yield losses due to unchecked weed growth (Billore *et al*., 2009) [6]. Among herbicidal treatments, Fomesafen 11.385% + S-Metolachlor 51.783% EC at 3790 g a.i. ha⁻¹ registered the highest pod number (48.83 plant⁻¹), followed by its application at 2370 (46.53 plant⁻¹) and 1895 g a.i. ha⁻¹ (45.57 plant⁻¹). These were statistically at par, showing the effectiveness of this pre-emergent herbicide combination across doses (Mahajan *et al*., 2020) [18]. The lowest pod number among herbicides (33.07 plant⁻¹) was recorded with Fomesafen 12% + Quizalofop-ethyl 3% SC at 225 g a.i. ha⁻¹, reflecting weaker control of weed flora (Patel *et al*., 2014) [27]. Higher pod formation in weed-free and effective herbicide treatments may be attributed to reduced weed pressure, which enhanced resource use efficiency, canopy growth and photosynthate partitioning to reproductive structures. In contrast, ineffective weed suppression during the critical crop-weed competition period restricted nutrient supply and assimilate flow, reducing pod formation (Billore *et al*., 2009) [6].

3.1.2 100 seed weight (g)

There were no significant differences were observed among treatments in terms of hundred-seed weight of soybean at harvest (Table 1). However, numerically higher values were recorded in the weed-free check (14.77 g) and with the application of Fomesafen 11.385% + S-Metolachlor 51.783% EC at 3,790 g a.i. ha⁻¹ (14.58 g), whereas the weedy check had the lowest (12.14 g). In contrast, significant variation was observed for pods per plant and seed yield plant^{-1}. The weed-free check produced the highest values, which were statistically comparable with Fomesafen 11.385% + S-Metolachlor 51.783% EC at 3,790 g a.i. ha⁻¹, followed by 2,370 and 1,895 g a.i. ha⁻¹. Superior performance under these treatments was attributed to favourable growth parameters such as greater leaf number, leaf area and branching that enhanced reproductive development and pod filling (Jha & Soni, 2013; Meshram, 2013) [13, 20]. Effective weed suppression from early growth stages likely facilitated better resource utilization (Gore *et al*., 2014; Bhumika *et al*., 2015) [11, 14], leading to improved pod formation and yield, which aligns with previous findings (Mahajan *et al*., 2020; Meena, 2020) [18, 19].

3.1.3 Seed yield (kg ha^{-1})

The seed yield of soybean varied significantly under different weed management practices (Table 1). The weed-free check produced the maximum yield (2325 kg ha⁻¹), clearly demonstrating the advantage of maintaining a weed-free environment, whereas the weedy check recorded the lowest yield (861 kg ha⁻¹), confirming the drastic yield reduction due to unchecked weed competition). (Billore *et al*., 2009) [6] Among herbicidal treatments, Fomesafen 11.385% + S-Metolachlor 51.783% EC at 3790 g a.i. ha⁻¹ produced the highest yield (2176 kg ha⁻¹), followed by 2370 (2094 kg ha⁻¹) and 1895 g a.i. ha⁻¹ (2032 kg ha⁻¹). These treatments were statistically at par, indicating the strong efficacy of this pre-emergent herbicide combination even at moderate doses (Channappagoudar *et al*., 2007) [7]. Conversely, Fomesafen 12% + Quizalofop-ethyl 3% SC at 225 g a.i. ha⁻¹ recorded the lowest yield among herbicides (1151 kg ha⁻¹), reflecting its weaker suppression of broad-leaved weeds (Patel *et al*., 2014) [27]. The higher yields under effective treatments can be attributed to improved weed control, which reduced competition and ensured greater resource availability. Enhanced vegetative growth (plant height, leaf area index, branch number) and yield traits (pods plant⁻¹, seeds pod⁻¹ and 100-seed weight) under these conditions supported superior productivity. In contrast, unchecked weed growth restricted photosynthate accumulation and assimilate partitioning, thereby lowering yield (Billore *et al*., 2009) [6].

3.1.4 Haulm yield (kg ha^{-1})

The haulm yield of soybean showed significant variation under different weed management practices (Table 1). The weed-free check recorded the highest haulm yield (3802 kg ha⁻¹), markedly superior to all treatments, while the weedy check registered the lowest (1838 kg ha⁻¹), highlighting the adverse effect of unchecked crop-weed competition on vegetative biomass accumulation (Bhowmick & Singh, 2004) [3]. Among herbicidal treatments, Fomesafen 11.385% + S-Metolachlor 51.783% EC at 3790 g a.i. ha⁻¹ produced the maximum haulm yield (3604 kg ha⁻¹), followed by 2370 (3488 kg ha⁻¹) and 1895 g a.i. ha⁻¹ (3409 kg ha⁻¹). These were statistically comparable, demonstrating the sustained effectiveness of this combination in suppressing weeds and promoting vigorous crop growth (Channappagoudar *et al.*, 2007) [7]. In contrast, Fomesafen 12% + Quizalofop-ethyl 3% SC @ 225 g a.i. ha⁻¹ recorded the lowest haulm yield (2497 kg ha⁻¹) among herbicides, reflecting its weaker broad-spectrum control (Kumar *et al.*, 2018) [16]. Higher haulm yield under weed-free and effective herbicidal regimes was attributed to reduced competition, ensuring better availability of nutrients, moisture and light to soybean. Enhanced vegetative traits such as plant height and leaf area index favoured greater photosynthetic efficiency, ultimately contributing to increased haulm production.

3.2 Effect of weed management practices on weed control efficiency (%)

3.2.1 Weed control efficiency (%) for broad-leaved weeds

The data on weed control efficiency (WCE) for broad-leaved weeds revealed clear differences among treatments (Table 2). The weed-free check consistently achieved 100% WCE, while the weedy check recorded 0%, emphasizing the importance of effective weed management (Patel *et al.*, 2015). At 14 DAHA, all herbicidal treatments maintained 100% WCE due to the absence of weed emergence. From 21 DAHA onward, Fomesafen 11.385% + S-Metolachlor 51.783% EC at all doses (3790, 2370, 1895, 1580 and 1265 g a.i. ha⁻¹) achieved complete control of broad-leaved weeds (100%), confirming its strong pre-emergence residual activity (Nagre *et al.*, 2017) [21]. In contrast, Fomesafen 12% + Quizalofop-ethyl 3% SC @ 225 g a.i. ha⁻¹ showed lower efficiency (64.61%), reflecting its limited control spectrum (Vyas & Kushwah, 2008) [32]. At later stages (28-56 DAHA), Fomesafen + S-Metolachlor continued to record superior WCE (96-100%), whereas Quizalofop-ethyl declined sharply (34.86-11.82%), indicating poor persistence (Nainwal *et al.*, 2010) [22]. At harvest, maximum WCE (97.87%) was obtained with the highest dose of Fomesafen + S-Metolachlor, statistically similar to its medium doses. Overall, its broad-spectrum efficacy ensured prolonged weed suppression, while the weaker performance of Quizalofop-ethyl was due to its grass-selective action (Yadav *et al.*, 2019) [33].

3.2.2 Weed control efficiency (%) for grassy weeds

The data on weed control efficiency (WCE) for grassy weeds at successive crop growth stages showed clear differences among weed management practices (Table 3). The weed-free check consistently achieved 100% WCE, whereas the weedy check remained at 0%, confirming severe competition in the absence of control measures (Patel *et al.*, 2015). At 14 DAHA, all herbicidal treatments recorded 100% WCE due to the absence of weed dry matter. From 21 DAHA onwards, herbicide performance diverged. Application of Fomesafen 11.385% + S-Metolachlor 51.783% EC at all tested doses (3790, 2370, 1895, 1580 and 1265 g a.i. ha⁻¹) consistently maintained 100% WCE, reflecting its strong pre-emergence and residual efficacy (Nagre *et al.*, 2017) [21]. Similarly, Fomesafen + Quizalofop-ethyl @ 225 g a.i. ha⁻¹ sustained complete control, indicating high selectivity and post-emergence activity against grassy weeds (Vyas & Kushwah, 2008) [32]. In contrast, Pendimethalin 38.7% CS @ 677.25 g a.i. ha⁻¹ showed significantly lower WCE (85.96-30.89%) across stages, suggesting weaker residual persistence under field conditions (Pandya, 2005; Nainwal *et al.*, 2010) [24, 22]. Overall, the superior efficacy of PPO inhibitor-chloroacetamide and PPO-ACCase premixes in maintaining grassy weed suppression aligns with earlier findings in soybean and other legume systems (Yadav *et al.*, 2019) [33].

3.2.3 Total weed control efficiency (%)

Weed control efficiency (WCE) varied significantly across weed management treatments (Table 4). At 14 DAHA, all herbicidal treatments achieved 100% WCE due to negligible weed dry matter, while the weed-free and weedy checks consistently recorded the highest (100%) and lowest (0%) values, respectively (Patel *et al.*, 2015). At 21 DAHA, the premix of Fomesafen 11.385% + S-Metolachlor 51.783% EC at all tested doses maintained 100% WCE, whereas Fomesafen + Quizalofop-ethyl showed reduced efficacy (71.51%) (Nagre *et al.*, 2017) [21]. With crop advancement, WCE declined in most treatments; however, Fomesafen + S-Metolachlor at higher and moderate doses (3790, 2370 and 1895 g a.i. ha⁻¹) sustained near-complete control (>96%), highlighting their superior residual activity (Vyas and Kushwah, 2008) [32]. In contrast, Fomesafen + Quizalofop-ethyl consistently recorded lower WCE (32.97-52.48%) due to inadequate broadleaf weed suppression (Pandya, 2005). At harvest, the highest WCE (97.87%) was achieved with Fomesafen + S-Metolachlor @ 3790 g a.i. ha⁻¹, statistically on par with its moderate doses, owing to the dual action of PPO inhibition and fatty acid synthesis disruption, which minimized crop-weed competition (Nainwal *et al.*, 2010; Yadav *et al.*, 2019) [22, 33]

Table 1: Yield and yield parameters of soybean as influenced by weed management practices

Tr. No.	Treatment details	Number of pods plant^{-1}	100 Seeds weight (g)	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
T_1	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 1265 g *a.i.*ha^{-1} at 0-3 DAS	40.40	13.98	1430	2998
T_2	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 1580 g *a.i.*ha^{-1} at 0-3 DAS	41.23	14.19	1642	3101
T_3	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 1895 g *a.i.*ha^{-1} at 0-3 DAS	45.57	14.23	2032	3409
T_4	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 2370 g *a.i.*ha^{-1} at 0-3 DAS	46.53	14.45	2094	3488
T_5	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 3790 g *a.i.*ha^{-1} at 0-3 DAS	48.83	14.58	2176	3604
T_6	Fomesafen 12% + Quizalofop ethyl 3% SC @ 225 g *a.i.*ha^{-1} at 0-3 DAS	33.07	12.95	1151	2497
T_7	Pendimethalin 38.7% CS @ 677.25 g *a.i.*ha^{-1} at 0-3 DAS	36.63	13.15	1360	2763
T_8	Diclosulam 84% WDG @ 26 g *a.i.*ha^{-1} at 0-3 DAS	40.10	13.95	1428	2924
T_9	Weedy check	13.83	12.14	914	1838
T_{10}	Weed free check	51.67	14.77	2325	3802
	S.Em. ±	1.33	0.21	74	91
	CD @ 5%	3.96	NS	219	271

A.i.- Active ingredient **DAS**- Days after sowing **EC**- Emulsifiable concentrate
CS- Capsule suspension **SC**- Suspension concentrate **WDG**- Water dispersible granules

Table 2: Weed control efficiency (%) for broadleaved weeds at different growth stages of soybean as influenced by different weed management practices

Tr. No.	Treatment details	7 DAHA	14 DAHA	21 DAHA	28 DAHA	42 DAHA	56 DAHA	At harvest
T_1	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 1265 g *a.i.*ha^{-1} at 0-3 DAS	100.00	100.00	100.00	79.38	76.51	81.47	80.59
T_2	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 1580 g *a.i.*ha^{-1} at 0-3 DAS	100.00	100.00	100.00	79.43	79.58	82.85	81.55
T_3	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 1895 g *a.i.*ha^{-1} at 0-3 DAS	100.00	100.00	100.00	100.00	100.00	100.00	96.82
T_4	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 2370 g *a.i.*ha^{-1} at 0-3 DAS	100.00	100.00	100.00	100.00	100.00	100.00	96.84
T_5	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 3790 g *a.i.*ha^{-1} at 0-3 DAS	100.00	100.00	100.00	100.00	100.00	100.00	97.87
T_6	Fomesafen 12% + Quizalofop ethyl 3% SC @ 225 g *a.i.*ha^{-1} at 0-3 DAS	100.00	100.00	64.61	34.86	18.56	11.82	16.79
T_7	Pendimethalin 38.7% CS @ 677.25 g *a.i.*ha $^{-1}$ at 0-3 DAS	100.00	100.00	74.20	58.76	50.18	42.90	46.27
T_8	Diclosulam 84% WDG @ 26 g *a.i.*ha^{-1} at 0-3 DAS	100.00	100.00	81.44	66.16	61.13	48.89	52.66
T_9	Weedy check	100.00	0.00	0.00	0.00	0.00	0.00	0.00
T_{10}	Weed free check	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	S.Em. ±	-	-	0.25	0.24	0.23	0.51	0.25
	CD @ 5%	-	-	0.75	0.71	0.68	1.50	0.74

A.i.- Active ingredient, **DAS**- Days after sowing, **EC**- Emulsifiable concentrate, **CS**- Capsule suspension, **SC**- Suspension concentrate **WDG**- Water dispersible granules, **DAHA**- Days after herbicide application

Table 3: Weed control efficiency (%) for grassy weeds at different growth stages of soybean as influenced by different weed management practices

Tr. No.	Treatment details	7 DAHA	14 DAHA	21 DAHA	28 DAHA	42 DAHA	56 DAHA	At harvest
T_1	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 1265 g *a.i.*ha^{-1} at 0-3 DAS	0	100.00	100.00	100.00	100.00	100.00	100.00
T_2	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 1580 g *a.i.*ha^{-1} at 0-3 DAS	0	100.00	100.00	100.00	100.00	100.00	100.00
T_3	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 1895 g *a.i.*ha^{-1} at 0-3 DAS	0	100.00	100.00	100.00	100.00	100.00	100.00
T_4	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 2370 g *a.i.*ha^{-1} at 0-3 DAS	0	100.00	100.00	100.00	100.00	100.00	100.00
T_5	Fomesafen 11.385% + S-Metolachlor 51.783% EC @ 3790 g *a.i.*ha^{-1} at 0-3 DAS	0	100.00	100.00	100.00	100.00	100.00	100.00
T_6	Fomesafen 12% + Quizalofop ethyl 3% SC @ 225 g *a.i.*ha^{-1} at 0-3 DAS	0	100.00	100.00	100.00	100.00	100.00	100.00
T_7	Pendimethalin 38.7% CS @ 677.25 g *a.i.*ha $^{-1}$ at 0-3 DAS	0	100.00	85.96	42.57	30.89	37.49	38.53
T_8	Diclosulam 84% WDG @ 26 g *a.i.*ha^{-1} at 0-3 DAS	0	100.00	90.71	44.49	46.39	58.04	59.87
T_9	Weedy check	0	0.00	0.00	0.00	0.00	0.00	0.00
T_{10}	Weed free check	0	100.00	100.00	100.00	100.00	100.00	100.00
	S.Em. ±	-	-	0.27	0.38	0.39	0.27	0.25
	CD @ 5%	-	-	0.81	1.13	1.16	0.79	0.74

4. Conclusion

The weed-free check treatment consistently performed superior in all aspects, including seed yield and yield attributes, owing to the absence of crop-weed competition. Among herbicide treatments, the pre-emergence application of Fomesafen 11.385% + S-Metolachlor 51.783% EC at 3,790, 2,370 and 1,895 g a.i. ha^{-1} (0-3 DAS) proved highly effective in ensuring better crop growth, yield components and ultimately higher productivity. Economic evaluation also demonstrated that these treatments generated higher gross returns, net returns and benefit-cost ratios compared to other weed management options. Overall, the results highlight that effective weed suppression during the early crop growth period through either weed-free management or appropriate pre-emergence herbicides is critical for maximizing both productivity and profitability in soybean cultivation.

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