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RESEARCH ARTICLE

Optimizing soybean yield, weed dynamics and profitability using herbicides in custard apple-based agri-horti system of the Vindhyan region of Uttar Pradesh, India

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Abstract

A field experiment was conducted during the *Kharif* seasons of 2021 and 2022 to evaluate the weed management effect on weed suppression, crop growth, yield and economics of soybean within a custard apple-based system. The experiment was laid out in a randomized block design comprising seven treatments with three replications. The treatments included pre-emergence (PRE) of pyroxasulfone 85 % w/w WG (GSP sample) 120.0 mL ha^{-1} (T_1), pyroxasulfone 85 % w/w WG (GSP sample) 150.0 mL ha^{-1} (T_2), pyroxasulfone 85 % w/w WG (GSP sample) 187.5 mL ha^{-1} (T_3), pyroxasulfone 85 % w/w WG (Market sample) 150.0 mL ha^{-1} (T_4); early post-emergence (PoE), imazethapyr 10 % SL WC 1000.0 mL ha^{-1} (T_5), hand weeding at 20 and 40 days after sowing (T_6) and untreated control (T_7). The hand-weeded plots (T_6) recorded significantly the lowest weed density (WD) and weed dry weight (WDW) along with the highest weed control efficiency. Among herbicidal treatments, T_3 showed significantly better weed suppression, physiological growth indices, biomass accumulation and grain yield of soybean, followed closely by T_2. This treatment also delivered superior net returns and benefit-cost ratio compared to other herbicidal options. The combination of effective weed management using pyroxasulfone 85 % WG (GSP sample) at 150 mL ha^{-1} (T_2) and the agri-horti system proved to be a sustainable and profitable approach for soybean production under the given agro-climatic conditions.

Keywords: agroforestry; economics; soybean; weed control efficiency; weed management

Introduction

Soybean (*Glycine max* L. Merrill), popularly known as the poor man's meat, is one of the most important crops grown worldwide due to its high economic value and adaptability to varied agro-climatic conditions. It contains 45 % protein, 18 % oil and a high proportion of unsaturated fatty acids (1). Its role in global food security is substantial, as it serves as a vital source of protein and oil for both human consumption and animal nutrition. Approximately 98 % of the soybean meal is utilized as feed in livestock and aquaculture industries (2). However, soybean productivity is severely constrained by weed competition, which remains a major challenge for farmers. The crop's vulnerability arises from its wider spacing and delayed canopy closure, which favour weed emergence and growth. These weeds compete for light, water and nutrients, significantly lowering yield and quality. Globally, about 37 % of the potential soybean crop is lost due to weed infestation (3). Consequently, effective weed management is essential to ensure optimal crop performance (4).

Traditional weed management methods, while effective, are increasingly viewed as labour-intensive and time-consuming (5). In response, herbicide-based weed management has become a widely adopted strategy due to its efficiency. Among herbicides, pyroxasulfone has emerged as a selective and promising option. It controls annual grasses, sedges and broadleaf weeds when applied pre-emergence (PRE) or early post-emergence (POE). It has been approved by the U.S. Environmental Protection Agency (EPA) for use in soybeans since February 2013 and is already used in crops like corn (6, 7). At the same time, the world's population is projected to reach nine billion by 2050 (8), increasing the demand for food and placing unprecedented pressure on agricultural systems (9). This pressure is compounded by climate change, shrinking arable land, dwindling water resources and increasing threats from weeds, which threaten agricultural sustainability and global food security (10).

To address these challenges, agroforestry systems, particularly agri-horticultural systems, are gaining attention as sustainable models. These systems integrate trees and shrubs with crops and/or livestock, providing benefits such as improved soil fertility, enhanced biodiversity, better water conservation and increased overall productivity (11). Among these, alley cropping and agri-horticultural practices-especially those involving fruit trees like custard apple-are preferred for their adaptability, high returns and ecological benefits (12-14). Recent studies indicate that interactions between perennial trees and annual crops can influence weed dynamics, often through allelopathic effects. Such interactions can either suppress or enhance weed flora, depending on species compatibility (15). While the role of trees in modulating weed flora is acknowledged, there is limited research on how herbicide application interacts with these agri-horticultural systems, particularly in semi-arid regions like the Vindhyan plateau. Thus, a clear research gap exists in understanding how selective herbicides like pyroxasulfone perform within agri-horticultural systems, specifically regarding their effectiveness in weed management, crop productivity and ecological compatibility in semi-arid ecosystems. This study, therefore, aims to investigate the weed dynamics, crop performance and herbicide compatibility in soybean-based agri-horticultural systems involving custard apple. By addressing this gap, the research contributes to sustainable weed management strategies and integrated land-use systems that align with environmental and productivity goals (10).

Materials and Methods

To assess the effect of herbicides on weed dynamics, growth and yield of the soybean crop, this experiment was conducted at the Agricultural Farm of Rajiv Gandhi South Campus, BHU, Barkachha, Mirzapur, Uttar Pradesh, during *Kharif* season of 2021 and 2022 under a custard apple-based agri-horticultural system.

Study Area

The experimental field is located at 25° 30' N latitudes and 82° 35' E longitudes in the sub-tropical zone at an altitude of 168 m above mean sea level. This region comes under the semi-arid eastern plain zone (Zone-III A), which is mostly rainfed. The monsoon season here typically begins in the last week of June and extends until late September or occasionally the first week of October, contributing the majority of the annual rainfall. The winters, spanning from December to mid-February, bring occasional showers and are generally cool, while summers are hot and dry. During crop growth, the weekly temperatures ranged between 5.5 °C to 21.6 °C (minimum) and 22.2 °C to 40.5 °C (maximum). The lowest temperatures were observed in January, gradually rising toward the end of the cropping season. Rainfall during this period was limited to 103.5 mm. Relative humidity varied significantly, ranging from 54 % to 98 % in the morning and decreasing to 7 % to 57 % in the evening. Sunshine duration ranged from 1.6 to 9.7 hr per day and evaporation rates fluctuated between 0.6 to 6.2 mm per day. Moreover, the soil in the experimental field was sandy clay loam with a slightly acidic pH of 6.2.

Experimental Details

The field experiment was performed under a custard-apple-based agri-horti system (planting distance 4.0 × 4.0 m^2) in a randomised block design (RBD) for convenience and efficient agricultural operations. There were seven treatments with three replications. The treatments included a company sample of pre-emergence herbicide at three different doses *viz.*, T_1-Pyroxasulfone 85 % w/w WG (GSP sample) 120.0 mL ha^{-1}, T_2-Pyroxasulfone 85 % w/w WG (GSP sample) 150.0 mL ha^{-1}, T_3-Pyroxasulfone 85 % w/w WG (GSP sample) 187.5 mL ha^{-1}, one market sample of same pre-emergence herbicide i.e., T_4-Pyroxasulfone 85 % w/w WG (Market sample) 150.0 mL ha^{-1}, one early post emergence herbicide i.e. T_5-Imazethapyr 10 % SL WC 1000.0 mL ha^{-1} early post emergence (PoE), T_6-Hand weeding at 20 and 40 days after sowing and T_7-Untreated control.

Agronomic Practices

During the *Kharif* season, the field was ploughed with a disc plough and planking was done to evenly level the field. Thereafter, the recommended dose of fertilizer (N, P and K- 25, 60 and 40 kg ha^{-1}) was applied through Urea, single super phosphate (SSP) and muriate of potash (MOP) and incorporated into the soil to fulfil the nutritional demand of the crop. Soybean (*Glycine max* cv. NRC-86) seeds treated with mancozeb to avoid fungal attack were sown at a spacing of 40 × 40 cm at a depth of 2-3 cm and adjusted to 70-75 kg seed ha^{-1}. To each 2.5 m × 2.0 m plot, the PRE herbicides were applied immediately after sowing soybean and the early PoE herbicides were applied between 7-14 days after sowing (DAS). The herbicides were applied using a knapsack sprayer fitted with a hollow cone nozzle that was adjusted to deliver 500 L ha^{-1}. The crop was visually observed for its maturity and then harvested manually.

Observations

To evaluate the effectiveness of herbicidal practices in soybean, data were recorded on weed density (number m^{-2}), weed dry weight (g $plant^{-1}$) and weed control efficiency (%) at 30, 45 and 60 DAS. Weed density (number m^{-2}) was assessed by counting weeds within randomly placed 25 × 25 cm quadrats at 30, 45 and 60 DAS and the average value was recorded. To normalize the variation, the recorded weeds data were square root transformed before analysis. The sampled weeds were uprooted and first sun-dried, then oven-dried at 24 °C for 48 hr until a constant $\sqrt{(x+0.5)}$ weight was achieved to determine weed dry weight (g $plant^{-1}$). Some other weed indices like absolute density (AD), weed index (WI), herbicide efficiency index (HEI), weed persistence index (WPI), crop resistance index (CRI) and weed effectiveness (WE %) were also calculated using the following formula:

Weed control efficiency (%)

$$\mathrm{WCE}(\%) = \frac{\mathrm{D.M.C.} - \mathrm{D.M.T.}}{\mathrm{D.M.C.}} \times 100 \qquad \text{(Eqn. 1)}$$

Where D.M.C. is dry matter production of weeds per unit area in the weedy check and D.M.T. is dry matter production of weeds per unit area in the treatment to be compared.

Weed index (WI)

$$\mathrm{WI} = \frac{\mathrm{X} - \mathrm{Y}}{\mathrm{Y}} \times 100 \qquad \text{(Eqn. 2)}$$

Where, X is the grain yield of the weed-free (twice hand-weeded) plot and Y is the grain yield of the treated plot.

Crop resistance index (CRI)

$$\mathrm{CRI} = \frac{\begin{array}{c}\text{Dry matter production by}\\ \text{the crop in treated plot}\end{array}}{\begin{array}{c}\text{dry matter production}\\ \text{by the crop in control plot}\end{array}} \times \frac{\begin{array}{c}\text{Dry matter production of}\\ \text{weed in control plot}\end{array}}{\begin{array}{c}\text{Dry matter production of}\\ \text{weed in treated plot}\end{array}}$$

(Eqn. 3)

(16)

Herbicidal efficiency index (HEI)

$$HEI = \frac{\text{Yield from treated plot} - \text{Yield from control plot/Yield from control plot}}{\text{Dry weight of weeds in treated plot / Dry weight of weeds in control plot}} \times 100$$

(Eqn. 4)

Weed persistence index (WPI)

$$WPI = \frac{\text{Dry weightof weeds in treated plot}}{\text{Dry weight of weeds in control plot}} \times \frac{\text{Weed density in control plot}}{\text{Weed density in treated plot}}$$

(Eqn. 5)

(16)

Weed effectiveness (%)

$$WE\ (\%) = \frac{\text{Number of weed in treatment plot}}{\text{number of weeds on control plot}}$$

(Eqn. 6)

Absolute density (AD) =

$$\frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats employed}}$$

(Eqn. 7)

(17)

In addition, growth and yield parameters like plant height, dry matter accumulation, branches plant^{-1}, functional root nodules, pods plant^{-1}, grains pod^{-1}, 100-grains weight, grain yield and straw yield were evaluated at 30, 60 DAS and at harvest to estimate the effect of various treatments applied to the soybean crop. At harvest, yield attributes including the total number of pods per plant, the average number of grains per pod (from five randomly selected pods) and the 100-grain weight were recorded. Grain yield per plot was determined after threshing and yield data were converted to kg ha^{-1} based on the net plot area. Stem and chaff weights were also recorded and converted to kg ha^{-1}. Harvest index (%) was calculated as the ratio of economic yield (grain weight) to biological yield (grain + stover weight).

To estimate the economics, the cost of cultivation, gross and net returns under different treatments were worked out on the basis of prevailing cost of different enterprises, as well as per the rate prevalent at the research farm Rajiv Gandhi South Campus, B.H.U., Mirzapur. The cost of cultivation was taken into account for calculating the economics of treatments and expressed as net returns (₹/ha) and benefit-cost ratio. The yield of the experimental crop was converted into gross returns in ₹/hectare based on the current price of the produce. The average fruit yield of custard apple was also recorded in t ha^{-1} to assess its contribution to enhancing the economic return.

Statistical Analysis

The data collected were tabulated and statistically analysed as per the standard statistical analysis using analysis of variance (ANOVA) to draw a valid conclusion (18). Data about weed density (WD) and weed dry weight (WDW) were first transformed using the square-root transformation $\sqrt{(x+0.5)}$ and then analyzed. The significant differences between the treatments were determined by the F-test statistical analysis. The standard error of mean (SEm±) and critical difference (CD) were calculated, if the variance ratio (F test) was found significant at a probability $p < 0.05$ level of significance for further comparison.

Results and Discussion

Effect on weeds

The experimental field was infested mainly with six *Kharif* season weeds, namely, *Amaranthus viridis*, *Digera arvensis*, *Trianthema portulacastrum*, *Celosia argentia*, *Physalis minima* and *Cyprus rotundus*. These diverse weeds were present because to field had been previously used for soybean cultivation and kept fallow afterwards for two growing seasons. The weeds found were similar to the findings on soybean (19, 20). The various weed management practices included in this study significantly influenced the density and dry weight of these weeds. Significantly ($p < 0.05$) lowest weed density (0.71 m^{-2}), dry weight (0.71 gm^{-2}) and maximum weed control efficiency (100 %) were recorded under two-hand weeding, which was superior over all the treatments at all the growth stages. Among herbicidal treatments, at 30 DAS the treatment T_3 recorded significantly ($p < 0.05$) lowest density (6.42, 7.28 m^{-2}), dry weight (3.51, 3.57 gm^{-2}), weed index (4.11, 7.60 %) and significantly ($p < 0.05$) highest weed control efficiency (76.4, 69.8 %) for all the predominant weeds and it was statistically at par with T_2 treatment, respectively. Similar trends were observed at all the growth stages (Table 1). These findings are in close agreement with those reported by previous studies (21). This was due to the high efficacy of pyroxasulfone, as it can control a large number of annual weeds, particularly grasses. It suppresses the growth of weeds that are just starting to germinate, interfering with the elongation of very long-chain fatty acids at several stages and inhibiting the development of both roots and shoots (22). Moreover, pyroxasulfone requires lower application rates as compared to other commercial herbicides (23). Among all treatments, the untreated control showed the least performance due to heavy weed infestation.

Furthermore, various weed indices like WPI, HEI, CRI, WE and AD were calculated to understand the efficacy of these herbicidal treatments resulting in the success or failure of these weed management practices (Table 2). Among the herbicidal treatments, except hand weeding, T_3 exhibited significantly ($p < 0.05$) the highest persistence index (1.032) while T_4 showed the lowest (1.006), indicating optimal herbicide concentration for effective weed suppression without significant phytotoxic effects on the soybean crop. A similar trend was noted in the HEI assessment with T_3 achieving the significantly ($p < 0.05$) highest herbicide efficiency index (102.04) which were at par with T_2 (82.13) and T_4 treatment found significantly ($p < 0.05$) lowest herbicide efficiency index (31.00), indicating the weed killing potential of these herbicidal treatments and their phytotoxicity effect on the soybean crop. Significantly ($p < 0.05$) highest CRI was recorded in T_6, followed by T_3 and T_2, with 17.97, 3.44 and 2.94, respectively. Consistent results were found in WE and AD, where T_6 demonstrated significantly (< 0.5 %) lower weed effectiveness, while T_3 significantly ($p < 0.05$) outperformed with other herbicidal treatments by recording the least weed effectiveness (45.9 %). The treatments T_3 and T_2 were found to be non-significant ($p < 0.05$) with each other. These PRE herbicides controlled weeds better than PoE herbicides as they kill the weeds at the early stages of growth. Moreover, the dose-dependent response observed between T_1, T_2 and T_3, respectively, demonstrates the importance of appropriate dosage calibration for pyroxasulfone applications. Previous research indicates that pyroxasulfone increased the efficacy with dosage until reaching an optimal concentration, beyond which phytotoxicity concerns may arise (24).

Table 1. Effect of weed management on weed density, weed dry weight and weed control efficiency (pooled data of two years)

Treatments	Total weed density (No. m^{-2})			Total weed dry weight (g m^{-2})			Weed control efficiency (%)			Weed Index (%)
	30DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	
T_1	8.00 (63.6)*	8.83 (77.6)	8.58 (73.3)	3.96 (15.2)	4.33 (18.3)	4.20 (17.2)	62.7	66.1	67.3	24.03
T_2	7.28 (52.6)	8.22 (67.3)	7.87 (61.6)	3.57 (12.3)	4.02 (15.7)	3.86 (14.4)	69.8	70.9	72.6	7.60
T_3	6.42 (40.8)	7.25 (52.3)	6.89 (47.0)	3.51 (9.6)	3.57 (12.3)	3.45 (11.4)	76.4	77.2	78.3	4.11
T_4	9.04 (81.3)	9.76 (95.0)	9.48 (89.6)	4.47 (19.5)	4.78 (22.4)	4.63 (21.0)	52.1	58.5	60.1	29.02
T_5	8.51 (72.0)	9.26 (85.3)	9.02 (81.0)	4.25 (17.6)	4.62 (20.9)	4.50 (19.8)	56.8	61.3	62.4	31.21
T_6	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	100.0	100.0	100.0	0.00
T_7	13.0 (169.6)	15.2 (230.3)	15.0 (225.0)	6.41 (40.7)	7.38 (54.0)	7.28 (52.6)	-	-	-	54.46
SEm±	2.59	2.98	2.93	1.31	1.66	1.47				
CD (p=0.05)	0.87	0.99	0.98	0.43	0.56	0.48	-	-	-	-

*Figures in parentheses are the original values. The data was transformed to SQRT √(x+0.5) before analysis, DAS: Days after sowing; T_1-pyroxasulfone 85 %WG (GSP sample) 120 mL ha^{-1}; T_2-pyroxasulfone 85 %WG (GSP sample) 150 mL ha^{-1}; T_3-pyroxasulfone 85 %WG (GSP sample) 187.5 mL ha^{-1}; T_4-pyroxasulfone 85 %WG (Market sample) 150 mL ha^{-1}; T_5-imazethapyr 1000 mL ha^{-1}; T_6-hand weeding at 20 and 40 DAS and T_7-Control

Table 2. Effect of herbicides on weed indices in soybean (pooled data of two years)

Treatment	Weed persistence index	Herbicide efficiency index	Crop resistance index	Weed effectiveness (%)	Absolute density (AD)
T_1	1.009	42.52	2.64	57.2	2.86
T_2	1.011	82.13	2.94	52.5	2.62
T_3	1.032	102.04	3.44	45.9	2.30
T_4	1.006	31.00	2.10	63.2	3.16
T_5	1.028	28.67	2.25	60.1	3.01
T_6	2.060	-	17.97	4.7	0.24
T_7	1.000	0.00	1.00	100.0	5.00
SEm±	0.064	67.6	1.51	19.9	0.97
CD (p=0.05)	0.021	22.6	0.51	6.7	0.33

Effect on soybean

The herbicidal application of pyroxasulfone on the experimental field shows no negative effect on the growth and yield of the soybean crop (25). The growth, yield attributing traits and yield of crop at the harvest stage showed a significant ($p < 0.05$) variation among all the treatments (Table 3). The plant height (47 cm), dry weight (19.8 g plant^{-1}), grain yield (1316 kg ha^{-1}) and straw yield (1962 kg ha^{-1}) were found significantly ($p < 0.05$) maximum in T_6 which were statistically at par with the treatment T_3 in terms of plant height, branches plant^{-1}, grains pod^{-1} and 100-grain weight with 45.2cm, 3.95, 3.0 and 9.87, respectively. The treatments T_3 and T_2 showed on par with each other. However, among all the treatments, the untreated control showed the least significant ($p < 0.05$) the least performance for both growth and yield attributes due to heavy infestation of weed flora. This outcome aligns well with the research conducted by earlier studies (21). It might be due to the lowest weed density manually-weeded plot, resulting in the least crop weed competition. Among herbicides, the reason may be the high pre-emergence activity of pyroxasulfone and good selectivity for soybeans (23). The application of pre-emergence pyroxasulfone delayed the CTWR in soybean, which starts at an early stage of growth, i.e., around 28 DAS (25). Hence, it provided sufficient time for the crop to establish itself at an early stage of growth (24). Pyroxasulfone application at different rates shows a direct relation with weed control. The treatment having the highest dose of pyroxasulfone (187.5 mL ha^{-1}) proved to be significantly ($p < 0.05$) more efficient in weed control (WCE) than the others (Table 1). The reduction in weed growth resulted in better usage of natural resources like water, sunlight, as well as nutrient uptake by the crop, which in turn resulted in good vegetative growth, like plant height and dry weight.

Fig. 1 demonstrated the correlation between WCE (%) and biological yield (kg ha^{-1}) across all the treatments, i.e. T_1 to T_7. Noticeably, the a direct relationship between WCE and biological yield. Due to an increase in WCE, biological yield also increases. The significantly ($p < 0.05$) highest WCE (100 %) and biological yield (3278 kg ha^{-1}) were seen in T_6, followed by T_3 (78.3 % and 3048 kg ha^{-1}) and T_2 (72.6 % and 2946 kg ha^{-1}), respectively. Significantly ($p < 0.05$) the lowest WCE (%) and the lowest biological yield were observed in the control plot (T_7). The highest weed control efficiency and biological yield is due fact of a lesser number of weeds in the plot, providing a sufficient growing environment to the crops. General evidence shows that

Table 3. Effect of weed management on crop growth, yield attributes and yield of soybean (pooled data of two years)

Treatments	Plant height at harvest (cm)	Plant dry weight at harvest (g plant^{-1})	Branch plant^{-1}	Functional root nodule	Pods plant^{-1}	Grains pod^{-1}	100 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
T_1	40.8	17.2	3.69	38.40	37.0	2.3	9.31	1061	1707	38.33
T_2	42.5	17.6	3.72	38.43	38.0	2.4	9.42	1223	1723	41.51
T_3	45.2	18.4	3.95	38.51	41.0	3.0	9.87	1264	1784	41.47
T_4	37.1	15.1	3.68	38.44	35.0	2.0	8.64	1020	1652	38.17
T_5	38.7	15.7	3.42	38.41	34.0	2.0	8.23	1003	1598	38.56
T_6	47.0	19.8	4.12	38.60	45.0	3.0	10.41	1316	1962	40.15
T_7	39.7	11.3	3.04	38.47	30.0	2.0	7.89	852	1174	42.05
SEm±	8.18	2.42	0.70	0.56	9.25	1.87	1.64	164	196	
CD (p=0.05)	2.72	0.81	0.24	NS	3.09	0.62	0.56	54	66	-

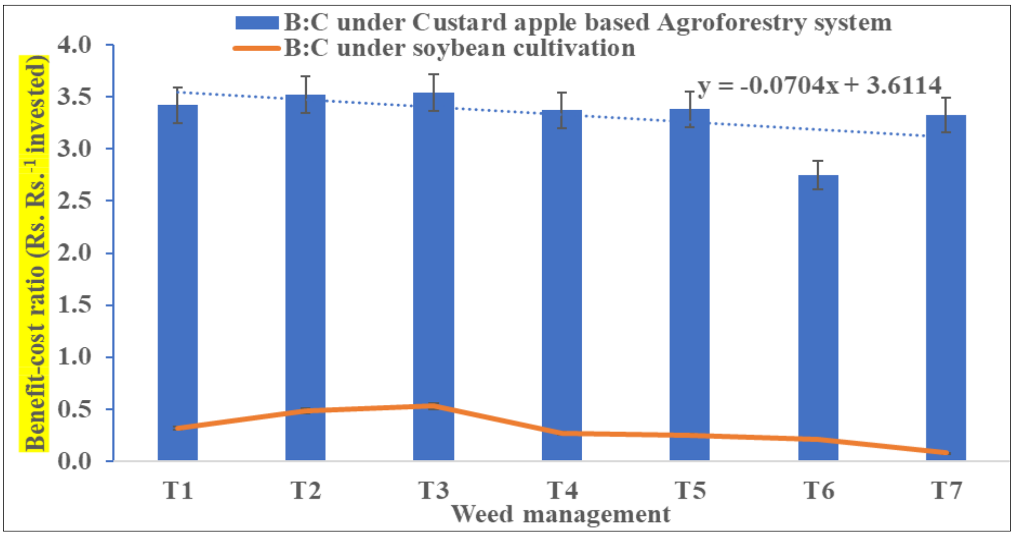

Fig. 1. Correlation between WCE and biological yield.

increased WCE-whether via hand weeding or optimized herbicide use- directly correlated with biomass and yield due to reduced weed competition for resources (26).

Economics

The practical efficiency of weed management practices is typically assessed based on net returns and the benefit-cost (B-C) ratio. Research outcomes are deemed successful when they are both economically and practically viable for farmers. Among the treatments, although T_6 had outperformed the other treatments, it incurred the highest cultivation costs due to labour charges, resulting in higher gross returns (Rs. 59830 ha^{-1}) but lower net returns. In contrast, among the herbicidal treatments, T_3 followed by T_2 was found to be more economically advantageous. Despite lower total returns compared to hand weeding, this treatment yielded the highest net returns (Rs. 19828 ha^{-1}) and B-C ratio (1.53), primarily due to its reduced cost of cultivation (Table 4).

Moreover, on comparing the benefit-cost ratio of soybean cultivation with and without custard apple-based agri-horti system, it indicates approximately three times more returns under agri-horti systems (Fig. 2). Under custard apple-based agroforestry, the B-C ratio for all treatments (T_1-T_7) remained consistently high, ranging between approximately 3.2 to 3.5. In contrast, considering only soybean crop cultivation, the B-C ratio was significantly lower, ranging between approximately 0.25 to 0.5 across treatments. This can be attributed to the additional income source provided through fruit sales and reducing input costs (e.g., irrigation, fertilizers) by improving the microclimatic conditions.

Table 4. Effect of weed management on the economics of soybean

Treatment	Common cost of cultivation (Rs. ha^{-1})	Treatment cost of cultivation (Rs. ha^{-1})	Cost of custard apple cultivation (Rs. ha^{-1})	Total cost of cultivation (Rs. ha^{-1})	Returns from Custard apple (Rs. ha^{-1})	Returns from Soybean (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	B-C ratio
T_1	35598	1300	17730	54628	192500	48738	186610	3.42
T_2	35598	1450	17730	54778	192500	55201	192923	3.52
T_3	35598	1638	17730	54965	192500	57064	194599	3.54
T_4	35598	1450	17730	54778	192500	46898	184620	3.37
T_5	35598	1100	17730	54428	192500	46011	184083	3.38
T_6	35598	14000	17730	67328	192500	59830	185002	2.75
T_7	35598	-	17730	53328	192500	38350	177522	3.33

*Grain rate - Rs. 39.50 kg^{-1}, straw rate -Rs. 4.00 kg^{-1}

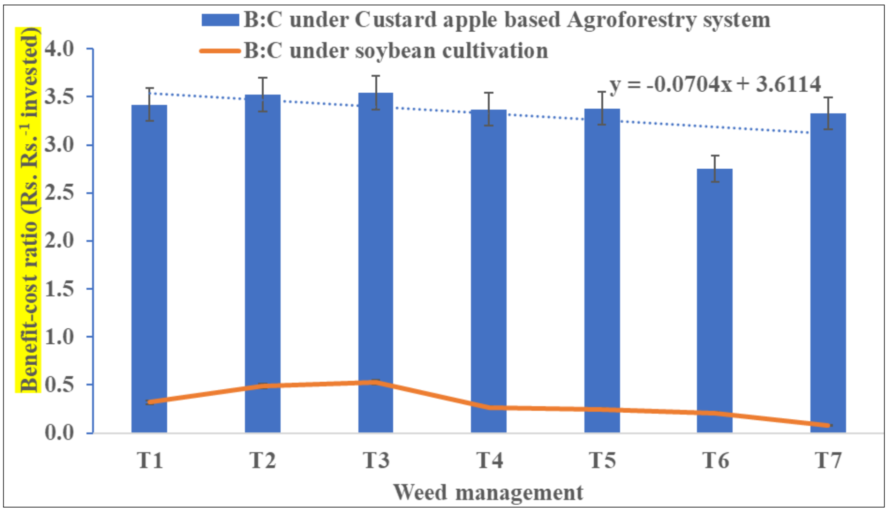

Fig. 2. Correlation between B:C of soybean cultivation with and without agri-horti system.

Conclusion

The study revealed that pyroxasulfone 85 % WG (GSP sample) at 150 mL ha^{-1} (T_2) is an effective pre-emergence herbicide for soybean, providing weed control, crop yield and economic returns comparable to the higher dose (T_3), while using a lower quantity of herbicide. Additionally, integrating soybean cultivation under custard apple-based agri-horti systems significantly improved profitability, with benefit-cost ratios nearly three times higher than sole cropping. Thus, the combination of an optimized herbicide strategy (T_2) and agri-horti integration offers a sustainable and economically viable approach for enhancing soybean productivity and farm income.

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Authors' contributions

HS has performed all the experiments and back calculations. SS, MV, SBS and DK supported in manuscript writing and SKV, SKR and CB helped in designing experiments, analysing all data, calculations and supervising field trials. All authors have read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: All the authors declare no conflict of interest.

Ethical issues: None

AI Declaration : During the preparation of this work, the author(s) used Chat GPT by Open AI to enhance language clarity and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication's content.

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