International Journal of Economic Plants
https://ojs.pphouse.org/index.php/IJEP
Crossref
IJEP July 2025, 12(4): 01-07
Article IJEP6295a
Full Research
Natural Resource Management
Doi: HTTPS://DOI.ORG/10.23910/2/2025.6295a

Weed Management Strategies in Soybean: Assessing the Influence of Integrated Nutrient and Weed Management on Weed Dynamics and Dry Weight

Rathod Sridhar[1*], L. T. Longkumer[1], A. P. Singh[2], T. Gohain[1], G. Zion[1], N. Kikon[1] and Ao I.[3]

[1]Dept. of Agronomy, School of Agricultural Sciences, Nagaland University, Nagaland (797 106), India
[2]Dept. of Agriculture, School of Agriculture and Development, Central University of South Bihar, Gaya, Bihar (824 236), India
[3]Dept. of Horticulture, School of Agricultural Sciences, Nagaland University, Nagaland (797 106), India

Corresponding Author

Rathod Sridhar
e-mail: sridharrathod27@gmail.com

Article History

Received on 15th April, 2025
Received in revised form on 03rd July, 2025
Accepted in final form on 20th July, 2025
Published on 31st July, 2025

Abstract

A field investigation was conducted during the *kharif* seasons (July to October) of 2023 and 2024 at the Agronomy Farm, School of Agricultural Sciences, Nagaland University, Medziphema campus, Nagaland, India, to evaluate the effect of integrated nutrient and weed management on weed dynamics and weed dry matter in soybean (*Glycine max* L.). The experiment was laid out in a randomized block design (RBD) with three replications comprising four nutrient management treatments and four weed management practices. The pooled results revealed that 50% RDF+FYM @ 6 t ha^{-1}+PSB @ 20 g kg^{-1} seed (N_3) recorded reduced total weed density (79.0 plants m^{-2}) and dry matter accumulation (6.70 g m^{-2}) at 30 DAS. The sequential application of Pendimethalin @ 750 g ha^{-1} (PE) followed by Imazethapyr @ 75 g ha^{-1} (PoE) (W_4) significantly lowered weed density and dry weight at all crop stages, with weed control efficiency (WCE) of 69.7%, 94.6%, and 95.6% at 15, 30, and 45 DAS, respectively. It was followed by Imazethapyr @ 75 g ha^{-1} (PE)+ one hand weeding at 25 DAS (W_2), which also showed effective control and high WCE values (up to 93.8%). Nutrient treatments had non-significant effects on weed parameters but contributed indirectly to weed suppression via enhanced crop growth. Interaction effects (N×W) were statistically non-significant. The study confirms that sequential herbicide applications along with partial organic nutrient sources offer a sustainable approach to weed control and soil fertility improvement in rainfed soybean.

Keywords: Soybean, integrated weed management, nutrient, pendimethalin, imazethapyr, weed

1. Introduction

Soybean (*Glycine max* L.) is a globally significant oilseed and pulse crop, widely cultivated for its high protein (40%) and oil (20%) content, as well as its pivotal role in sustainable agriculture due to its nitrogen-fixing capability. In India, soybean occupies over 12 m ha and contributes significantly to oilseed production and soil fertility in rainfed agroecosystems (Anonymous, 2024). However, weed infestation remains one of the most critical constraints affecting soybean productivity, especially during the early vegetative growth stages when the crop canopy is underdeveloped and less competitive. Uncontrolled weed growth in soybean can lead to yield losses of 30–80 %, depending on the weed species, intensity, and duration of competition (Gharde et al., 2018). Dominant weed flora in soybean include both monocotyledonous (e.g., *Cynodon dactylon*, *Dactyloctenium aegyptium*) and dicotyledonous species (e.g., *Amaranthus viridis*, *Trianthema portulacastrum*), which proliferate quickly under favorable moisture and temperature conditions (Caldas et al., 2023). Traditional weed control methods such as manual weeding are labor-intensive, expensive, and inefficient under peak weed emergence (Dubey et al., 2022). The overdependence on herbicides has provided effective short-term control but has also led to herbicide resistance, weed flora shifts, and increasing concern over residual toxicity and soil microbial imbalance (Ikioukenigha et al., 2024; Anonymous, 2025). In India and other soybean-growing regions, the misuse of ALS-inhibiting herbicides such as Imazethapyr has contributed to the evolution of resistant biotypes in weeds like *Echinochloa colona* and *Amaranthus* spp. (Anonymous, 2023). To address these challenges, Integrated Weed Management (IWM) has emerged as a holistic and sustainable strategy. IWM involves the judicious combination of cultural, mechanical, biological, and chemical methods tailored to cropping systems, environmental conditions, and weed ecology (Balihar and Dahiya, 2024). Sequential herbicide applications using Pendimethalin (pre-emergence) followed by Imazethapyr (post-emergence) have been found effective in managing diverse weed flora with minimal ecological disruption (Naik et al., 2025). In parallel, Integrated Nutrient Management (INM) enhances crop vigor and competitiveness against weeds by improving root architecture, canopy closure, and microbial balance. The application of organic amendments (FYM, compost) and biofertilizers such as Phosphate Solubilizing Bacteria (PSB) along with balanced chemical fertilizers improves nutrient use efficiency, soil health, and indirectly suppresses weed establishment (Singh et al., 2024). Recent studies have shown that INM practices enhance weed suppression by modifying soil nutrient dynamics, thereby favoring the crop over weeds (Saini et al., 2025). Despite advancements in individual weed and nutrient management components, have explored the interactive effects of INM and IWM on weed dynamics and weed control efficiency (WCE%) in soybean. One of the principal factors that constrains the yield in soybean cultivation is the prevalence of weed infestation. Manual weeding and hoeing are commonly utilized strategies for the management of weeds in soybean crops. The predominant technique employed for weed control is hand weeding. However, this approach becomes increasingly ineffective due to the scarcity of labor, particularly during the peak period of competition between crops and weeds, as well as being economically unfeasible due to elevated labor costs (Kumar and Rana, 2022). Particularly throughout the *Kharif* season, the tools and implements available for the removal of weeds are significantly restricted due to persistent and heavy rainfall. Manual weeding, alongside mechanical methods for weed control, may prove to be neither effective nor cost-efficient, as these methods elevate the costs of cultivation and deplete the available resource base. In light of these circumstances, various herbicides both pre-emergence and post-emergence may be applied to effectively manage annual grass and broadleaf weeds in soybean cultivation. The application of appropriate herbicides is essential to alleviate weed-related issues (Kumar and Rana, 2022; Apon and Nongmaithem, 2022). Due to the constrained time frame for sowing soybean during the *kharif* season, farmers typically favor the use of post-emergence herbicides in lieu of pre-emergence options for weed management. Consequently, an integrated weed management strategy is imperative for sustaining weed populations below the economically detrimental threshold level. Therefore, in consideration of the aforementioned factors, the present study was undertaken to assess the weed dynamics and weed dry weight in soybean as influenced by integrated nutrient and weed management practices.

2. Materials and Methods

2. 1. Experimental site and soil characteristics

The field trial was conducted during the *kharif* seasons (July to October) 2023 and 2024*,* at the Agronomy Farm, School of Agricultural Sciences, Nagaland University, located at 25.757083° N latitude, 95.858054° E longitude, and an altitude of 310 meters above sea level. The experimental soil was sandy loam in texture, with a pH of 4.63 and organic carbon content of 1.07%. The soil contained 328.65 kg ha^{-1} of available nitrogen, 13.44 kg ha^{-1} of available phosphorus, and 165.87 kg ha^{-1} of available potassium.

2.*2. Crop and agronomic details*

The soybean variety JS 97–52 was used, with a seed rate of 60 kg ha^{-1}, and spacing of 45×10 cm^2 was maintained between rows and plants, respectively. The full dose of fertilizers was applied as a basal application prior to sowing. Herbicide treatments were applied using a knapsack sprayer.

2.3. Observation recording and sampling

For the assessment of growth parameters, five healthy plants were randomly selected from each plot. Weed samples were collected at different intervals, shade-dried, and then oven-dried to determine dry matter accumulation. For weed dynamics, weed samples were collected using a 0.5 m^2 quadrat, and counts were extrapolated to m^2 basis.

2.4. Statistical analysis

The experimental data were analyzed using pooled data from two years, applying factorial analysis and analysis of variance (ANOVA) as per the methods outlined by Gomez and Gomez (1984). The significance of treatment effects was tested using the F-test at a p=0.05 level of probability.

2.*5. Treatments details*

The experiment was laid out to evaluate the effect of Integrated Nutrient Management (INM) and Integrated Weed Management (IWM) practices on weed dynamics, weed dry matter, and crop performance in soybean (*Glycine max* L.). The treatments comprised various combinations of nutrient sources and weed control strategies to assess their individual and interactive effects. A randomized block design (RBD) was adopted with three replications. The treatment details are as follows (Table 1).

3. Results and Discussion

3.1. Weed dynamics

A pooled data mean analysis of 2023 and 2024 data revealed significant differences in monocot, dicot, and total weed density across different treatments at 15, 30, and 45 days after sowing (DAS). These variations highlight the influence of Integrated Nutrient Management (INM) and Integrated Weed Management (IWM) on weed suppression in soybean (Table 2).

3.1.1. Integrated nutrient management (INM)

The effect of nutrient management on weed density was statistically non-significant at all stages. At 15 DAS, total weed density ranged from 92.1 to 96.2 plants m^{-2}, with slightly lower weed populations in treatments involving

Table 1: Details of treatments used in the experiment

Integrated nutrient management (N)	
N_1	100% RDF
N_2	50% RDF+FYM (6 t ha^{-1})
N_3	50% RDF+FYM (6 t ha^{-1})+PSB (20 g kg^{-1} seed)
N_4	50% RDF+FYM (6 t ha^{-1})+PSB (20 g kg^{-1} seed)+S (20 kg ha^{-1})
Integrated weed management (W)	
W_1	Weedy check
W_2	Imazethapyr at 75 g ha^{-1} (PE)+1 HW at 25 DAS
W_3	Imazethapyr at 100 g ha^{-1} (PoE) at 15 DAS
W_4	Pendimethalin at 750 g ha^{-1} (PE) fb Imazethapyr at 75 g ha^{-1} (PoE)

*RDF: 20 N- 60 P_2O_5 - 40 K_2O; *PE:Pre emergence; *PoE: Post emergence; *DAS: Days after sowing; *HW: Hand weeding

organic amendments (N_2, N_3, N_4). At 30 DAS, the lowest total weed density (79 plants m^{-2}) was observed under N3 (50% RDF+FYM+PSB), likely due to improved crop vigor and competitiveness. At 45 DAS, total weed density ranged from 82.3 to 86.7 plants m^{-2}, with no significant differences among nutrient treatments. Monocot and dicot weed densities were moderately affected by nutrient management practices. At 15 DAS, monocot weed population ranged from 52.2 to 53.6 plants m^{-2}, while dicot weed density varied between 40 to 43.8 plants m^{-2}. The addition of organic amendments such as FYM (Farm Yard Manure) and PSB (Phosphate Solubilizing Bacteria) in treatments N_2, N_3, and N_4 appeared to slightly reduce weed populations compared to the 100% RDF treatment (N_1), although the differences were statistically non-significant (NS).

At 30 DAS, N_3 (50% RDF+FYM+PSB) recorded the lowest monocot density (6.10 plants m^{-2}) and N_2 the lowest dicot population (5.42 plants m^{-2}), possibly due to better crop competitiveness achieved through enhanced nutrient

Table 2: Effect of integrated nutrient and weed management on total weed density at different stages of soybean crop

Treatments	Weed density (no m^{-2}) at 15 DAS		Total weed density (no. m^{-2}) at 15 DAS	Weed density (no. m^{-2}) at 30 DAS		Total weed density (no. m^{-2}) at 30 DAS	Weed density (no. m^{-2}) at 45 DAS		Total weed density (no. m^{-2}) at 45 DAS
	Monocot	Dicot		Monocot	Dicot		Monocot	Dicot	
Integrated Nutrient management (N)									
N_1:100% RDF	7.11 (53.4)	6.42 (42.2)	13.53 (95.6)	6.64 (52.1)	5.69 (37.1)	12.33 (89.2)	6.55 (52.2)	5.15 (33.5)	11.70 (85.6)
N_2: 50% RDF+FYM (6 t ha^{-1})	7.06 (52.2)	6.23 (40)	13.29 (92.1)	6.44 (51)	5.42 (33.7)	11.86 (84.7)	6.44 (50)	5.24 (35)	11.68 (84.6)
N_3: 50% RDF+FYM (6 t ha^{-1})+PSB (20 g kg^{-1} seed)	7.07 (52.5)	6.60 (43.8)	13.67 (96.2)	6.10 (45.3)	5.51 (33.7)	11.61 (79)	6.46 (50)	5.41 (37)	11.87 (86.7)
N_4: 50% RDF+FYM (6 t ha^{-1})+PSB (20 g kg^{-1} seed)+S (20 kg ha^{-1})	7.15 (53.6)	6.37 (40.9)	13.52 (94.5)	6.34 (48.5)	5.55 (35.8)	11.90 (84.2)	6.35 (49.2)	5.17 (33.1)	11.52 (82.3)
SEm±	0.19	0.12	0.23	0.04	0.08	0.10	0.09	0.11	0.15
CD (p=0.05)	NS	NS	NS	0.12	NS	0.28	NS	NS	NS
Integrated weed management (W)									
W_1: Weedy check	8.67 (75.3)	7.53 (56.4)	16.20 (131.7)	11.44 (131)	9.28 (85.8)	20.72 (216.3)	11.39 (129.5)	9.88 (97.1)	21.27 (227)
W_2: Imazethapyr at 75 g ha^{-1} (PE)+1 HW at 25 DAS	6.71 (44.6)	4.99 (24.6)	11.70 (69.2)	4.77 (22.3)	4.42 (19)	9.19 (41.4)	4.17 (17)	3.66 (14)	7.83 (30)
W_3: Imazethapyr at 100 g ha^{-1} (PoE) at 15 DAS	8.45 (71.3)	7.07 (47.8)	15.53 (121.1)	5.53 (30.1)	3.87 (14.6)	9.40 (44.6)	6.42 (41)	4.34 (18.6)	10.76 (59.4)
W_4: Pendimethalin at 750 g ha^{-1} (PE) fb Imazethapyr at 75 g ha^{-1} (PoE)	4.57 (20.4)	6.02 (36)	10.59 (56.4)	3.78 (14)	4.62 (21)	8.40 (34.8)	3.81 (14)	3.10 (9.2)	6.9 (23.2)

Table 2: Continue...

Treatments	Weed density (no. m^{-2}) at 15 DAS		Total weed density (no. m^{-2}) at 15 DAS	Weed density (no. m^{-2}) at 30 DAS		Total weed density (no. m^{-2}) at 30 DAS	Weed density (no. m^{-2}) at 45 DAS		Total weed density (no. m^{-2}) at 45 DAS
	Monocot	Dicot		Monocot	Dicot		Monocot	Dicot	
SEm±	0.19	0.12	0.23	0.04	0.08	0.10	0.09	0.11	0.15
CD (*p*=0.05)	0.54	0.34	0.65	0.12	0.24	0.28	0.25	0.31	0.43
N×W									
SEm±	0.38	0.23	0.45	0.09	0.17	0.20	0.17	0.21	0.30
CD (*p*=0.05)	NS	0.67	NS	0.25	0.48	0.57	NS	NS	NS

Note: The figures within parentheses indicate original value and data were subjected to the square root transformation (√x+0.5)

uptake, microbial activity, and root growth. However, the trend was again statistically non-significant. By 45 DAS, the differences in monocot and dicot weed populations across nutrient management treatments remained minimal, suggesting that nutrient regimes alone were insufficient for effective weed suppression.These observations aligned with the findings of Bommireddy et al. (2024), who reported that organic amendments like FYM improve crop vigor and canopy development, which could indirectly suppress weed emergence by enhancing the crop's competitive ability.

3.*1. 2. Integrated weed management (IWM)*

Weed management treatments significantly influenced monocot, dicot, and total weed populations across all crop growth stages. The weedy check (W1) consistently recorded the highest total weed density at all intervals: 131.7 plants m^{-2} at 15 DAS, 216.3 plants m^{-2} at 30 DAS, and 227 plants m^{-2} at 45 DAS, indicating rapid and unchecked weed proliferation in the absence of control measures.

W_4 (Pendimethalin 750 g ha^{-1} PE fb Imazethapyr 75 g ha^{-1} PoE) was the most effective treatment, reducing total weed density to 56.4, 34.8, and 23.2 plants m^{-2} at 15, 30, and 45 DAS, respectively over 70–80% lower than the weedy check. This strong control was due to Pendimethalin's residual activity suppressing early weed flushes and Imazethapyr's systemic effect on later-emerging weeds (Naik et al., 2025; Choudhary et al., 2025). Weed management treatments significantly influenced monocot and dicot populations. The weedy check (W_1) recorded the highest densities, increasing from 8.67 and 7.53 plants m^{-2} at 15 DAS to 11.39 and 9.88 plants m^{-2} by 45 DAS, respectively, highlighting yield loss potential without control (Gharde et al., 2018). W_4 consistently showed the lowest monocot (3.81 plants m^{-2}) and dicot (3.10 plants m^{-2}) counts at 45 DAS (>70% reduction), confirming its broad-spectrum efficacy (Singh and Singh, 2021). W_2 (Imazethapyr PE+1 hand weeding) also provided strong suppression, reducing dicot density to 3.66 plants m^{-2} at 45 DAS. Integrating mechanical weeding with chemical treatments enhances sustainability and reduces herbicide use by 24–60% while maintaining effective control (Gerhards and Husgen, 2024). W_3 (Imazethapyr PoE alone) was less effective early on (8.45 monocot and 7.07 dicot plants m^{-2} at 15 DAS) but improved later, underscoring the need for timely application to avoid early weed establishment (Imran and Al Tawaha, 2021).

3.1.3. Interaction effect (N×W)

The interaction between nutrient and weed management practices showed no significant influence on monocot or dicot weed populations at 15 and 45 DAS (Nongmaithem et al., 2024). However, at 30 DAS, a significant interaction was observed in monocot weed populations, indicating that the effectiveness of weed control could be influenced by the nutrient environment under certain growth stages. This observation was supported by studies emphasizing that nutrient availability modulates crop-weed competition, although the dominant factor remained the weed management strategy itself (Rao, 2000).

3.2. *Weed dry weight*

3.2.1. Effect of integrated nutrient management (INM)

The data revealed that integrated nutrient treatments had a measurable impact on weed dry weight (Table 3) at all stages of crop growth, although differences were statistically non-significant at 45 DAS. At 15 DAS, N_2 (50% RDF+FYM at 6 t ha^{-1}) recorded the lowest weed dry weight (4.81 g m^{-2}), while N_1 (100% RDF) showed the highest value (5.09 g m^{-2}). The use of organic manure (FYM) likely enhanced microbial activity and improved soil structure, contributing to better crop vigor and thus indirectly suppressed weed growth through increased competition (Bommireddy et al., 2024).

At 30 DAS, weed dry weight ranged from 6.70 g m^{-2} (N_3) to 7.17 g m^{-2} (N_1). Addition of Phosphate Solubilizing Bacteria (PSB) in N_3 might have supported better root proliferation and crop competitiveness. At 45 DAS, although N_1 had a relatively lower dry weight (7.26 g m^{-2}) compared to N_3 (7.79 g m^{-2}), the differences were not statistically significant, indicating that nutrient supplementation beyond a threshold does not necessarily reduced weed biomass, aligned with findings by Saini et al., 2025.

3.2.2. Effect of integrated weed management (IWM)

Weed management treatments significantly influenced weed dry weight at 15, 30, and 45 Days After Sowing (DAS). The weedy check (W_1) consistently recorded the highest weed dry

Table 3: Effect of integrated nutrient and weed management on weed dry weight (g m^{-2}) at different stages of soybean crop

Treatments	Weed dry weight (g m^{-2}) 15 DAS	Weed dry weight (g m^{-2}) 30 DAS	Weed dry weight (g m^{-2}) 45 DAS
Integrated nutrient management (N)			
N_1: 100% RDF	5.09 (27.1)	7.17 (73.1)	7.26 (82.4)
N_2: 50% RDF+FYM (6 t ha^{-1})	4.81 (24.7)	6.82 (68.8)	7.70 (98.8)
N_3: 50% RDF+FYM (6 t ha^{-1})+PSB (20 g kg^{-1} seed)	5.08 (27.2)	6.70 (61.3)	7.79 (103.4)
N_4: 50% RDF+FYM (6 t ha^{-1})+PSB (20 g kg^{-1} seed)+S (20 kg ha^{-1})	4.85 (25)	6.96 (69.4)	7.66 (93.6)
SEm±	0.08	0.15	0.28
CD (*p*=0.05)	0.24	NS	NS
Integrated Weed management (W)			
W_1: Weedy check	6.50 (41.9)	14.72 (217.2)	18.02 (327)
W_2: Imazethapyr at 75 g ha^{-1} (PE)+1 HW at 25 DAS	3.62 (12.7)	4.81 (22.8)	4.47 (20.1)
W_3: Imazethapyr at 100 g ha^{-1} (PoE) at 15 DAS	6.09 (37)	4.65 (21.1)	4.06 (16.8)
W_4: Pendimethalin at 750 g ha^{-1} (PE) fb Imazethapyr at 75 g ha^{-1} (PoE)	3.63 (12.7)	3.48 (11.7)	3.86 (14.4)
SEm±	0.08	0.15	0.28
CD (*p*=0.05)	0.24	0.43	0.81
N×W			
SEm±	0.16	0.30	0.56
CD (*p*=0.05)	NS	NS	NS

The figures within parentheses indicate original value and data were subjected to the square root transformation (√x+0.5)

weights 6.50, 14.72, and 18.02 g m^{-2}, respectively highlighting the need for effective weed control to avoid excessive weed competition and yield loss (Gharde et al., 2018).

Among the treatments, W_4 (Pendimethalin 750 g ha^{-1} PE fb Imazethapyr 75 g ha^{-1} PoE) was most effective, reducing weed dry weights to 3.63, 3.48, and 3.86 g m^{-2} at 15, 30, and 45 DAS, respectively. This superior control was due to the residual action of Pendimethalin and systemic effect of Imazethapyr, ensuring broad and prolonged weed suppression, consistent with Gerhards and Husgen (2024). W_2 (Imazethapyr 75 g ha^{-1} PE+hand weeding) also performed well (4.47 g m^{-2} at 45 DAS), as integrating manual and chemical control eliminated escaped weeds, aligning with findings by Amini et al. (2023).

W_3 (Imazethapyr 100 g ha^{-1} PoE) was less effective initially but improved by 45 DAS (4.06 g m^{-2}), indicating that post-emergence herbicides are timing-dependent and may miss early flushes (da Silva et al., 2023). These results emphasize the need to maintain weed-free conditions during the critical 15–45 DAS window, when soybean is least competitive. Treatments like W_4 and W_2 effectively minimized weed pressure, improved resource use efficiency, and supported sustainable weed management (Das et al., 2019; Kumar and Rana, 2022; Imran and Al Tawaha, 2021).

3.2.3. *Interaction effect (N×W)*

The interaction between nutrient and weed management practices was found to be non-significant at all growth stages. This suggested that the efficacy of weed control strategies remained consistent regardless of the nutrient regime applied. Similar observations were reported by Rao (2000), who highlighted that while nutrient management improved crop competitiveness, weed control efficiency largely depended on the timely and appropriate selection of herbicides.

3.3. *Weed control efficiency (WCE%)*

Weed Control Efficiency (WCE) was a critical indicator of the effectiveness of herbicide-based and integrated weed management treatments in suppressing weed growth over the crop cycle. The results from Figure 1 showed clear temporal trends and differences among the treatments evaluated (W_2, W_3 and W_4).

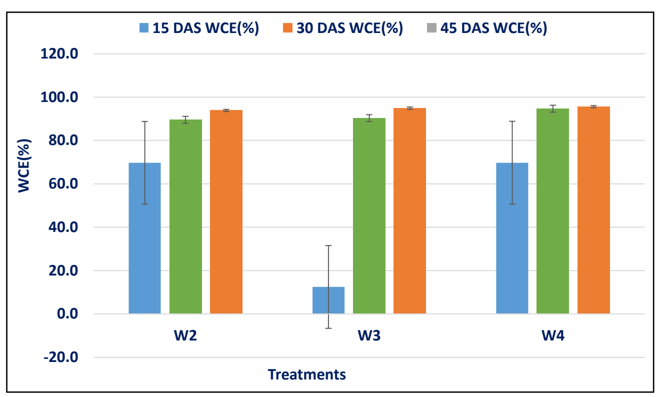

Figure 1: Effect of weed management practices on Weed Control Efficiency (WCE%) at different intervals 15, 30, and 45 Days After Sowing (DAS) (Pooled mean data of 2023 and 2024)

At 15 DAS, W_2 (Imazethapyr 75 g ha^{-1} PE+1 hand weeding) and W_4 (Pendimethalin 750 g ha^{-1} PE fb Imazethapyr 75 g ha^{-1} PoE) showed higher weed control efficiency (69.7%), while W_3 (Imazethapyr 100 g ha^{-1} PoE) recorded only 12.5%. This indicates that pre-emergence herbicides combined with early weed removal (W_2, W_4) were more effective in managing early weed flushes compared to post-emergence application alone (Imran and Al Tawaha, 2021). At 30 DAS, WCE improved significantly across treatments. W_3 increased to 90.3%, while W_2 and W_4 recorded 89.5% and 94.6%, respectively, showing sustained weed suppression. Similar findings were reported by Gerhards and Husgen (2024), who demonstrated that combining pre-emergence herbicides with follow-up weed management ensured prolonged control. By 45 DAS, all treatments achieved high efficiency (W_3: 94.9%, W_2: 93.8%, W_4: 95.6%), with W_4 consistently superior due to the residual effect of Pendimethalin and the systemic action of Imazethapyr, providing broad-spectrum and season-long weed control (Naik et al., 2025).

3.4. General implications

Overall, W_4 (Pendimethalin at 750 g ha^{-1} PE followed by Imazethapyr at 75 g ha^{-1} PoE) emerged as the most consistent and effective treatment across all stages, confirming earlier reports by Naik et al. (2025) that sequential herbicide applications significantly reduced weed dry matter and improved control efficiency in field crops. Meanwhile, W_2 also performed exceptionally well, showcasing the benefits of combining pre-emergence herbicides with physical weeding to tackle escaped or tolerant weed species (Amini et al., 2023). In contrast, W_3's efficacy improved over time, emphasizing the importance of timing in post-emergence herbicide application.

4. Conclusion

Integrated weed management (IWM) practices significantly reduced weed density, weed dry weight, and improved weed control efficiency in soybean. The sequential use of W_4 (Pendimethalin at 750 g ha^{-1} PE followed by Imazethapyr at 75 g ha^{-1} PoE) proved most effective across all growth stages. W_2 (Imazethapyr combined with hand weeding) also provided substantial control. Nutrient management had a moderate effect, mainly enhancing crop vigor and competitiveness. The interaction effects were statistically non-significant, indicating that herbicide-based strategies primarily governed effective weed suppression.

5. References

Amini, R., Behgam, M., Mohammadi Nasab, A.D., 2023. Using non-chemical options in integration with reduced rates of imazethapyr in weed management of pinto bean (*Phaseolus vulgaris* L.). Weed Research 63(6), 361–370. Available from: https://doi.org/10.1111/wre.12599.

Anonymous, 2024. Agricultural Statistics at a Glance. Ministry of Agriculture & Farmers Welfare, Government of India. Accessed on 24th December, 2024. Available from: https://desagri.gov.in/en/document-report-category/agriculturestatisticsataglance/

Anonymous, 2025. The International Herbicide-Resistant Weed Database. Available from: http://www.weedscience.org. Accessed on 15th March, 2025.

Apon, M., Nongmaithem, D., 2022. Influence of integrated nutrient and weed management on growth, yield and quality of soybean. International Journal of Bio-resource and Stress Management 13(6), 654–660. Available from: https://doi.org/10.23910/1.2022.2675.

Balihar, R., Dahiya, S., 2024. Enhancing agricultural sustainability through integrated weed management. International Journal of Research in Agronomy 7(5), 87–92. Available from: https://doi.org/10.33545/2618060x.2024.v7.i5sb.717.

Bommireddy, M., Mudigiri, C., Ramesh, G.P., Saidulu, P., Meenakshi, N., Prasanna, C.L., 2024. Enhancing soil health and fertility management for sustainable agriculture: a review. Asian Journal of Soil Science and Plant Nutrition 10(3), 182–190. Available from: https://doi.org/10.9734/ajsspn/2024/v10i3330.

Caldas, J.V.D.S., Silva da, A.G., Braz, G.B.P., Procopio, S.D.O., Teixeira, I.R., Souza, M.D.F., Reginaldo, L.T.R.T., 2023. Weed competition on soybean varieties from different relative maturity groups. Agriculture 13(3), 725. Available from: https://doi.org/10.3390/agriculture13030725.

Choudhary, R., Verma, A., Tomar, M., Kannoj, R., Patidar, R., Kumawat, L., 2025. Assessment of different weed management practices on weed dynamics, growth and yield of dill (*Anethum graveolens* L.). Plant Science Today 12(2). Available from: https://doi.org/10.14719/pst.7652.

Dubey, R.P., Lal, S., Ghosh, D., Singh, P.K., 2022. System productivity, energetics and economics of soybean (*Glycine max*)–wheat (*Triticum aestivum*) cropping system as influenced by weed management practices. Indian Journal of Agricultural Sciences 92(8). Available from: https://doi.org/10.56093/ijas.v92i8.97969.

Gerhards, R., Husgen, K., 2024. Evaluation of mechanical and combined chemical with mechanical weeding in maize (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.) and winter wheat (*Triticum aestivum* L.). Plant, Soil and Environment 70(12). Available from: https://doi.org/10.2139/ssrn.4844674.

Gharde, Y., Singh, P.K., Dubey, R.P., Gupta, P.K., 2018. Assessment of yield and economic losses in agriculture due to weeds in India. Crop Protection 107, 12–18. Available from: https://doi.org/10.1016/j.cropro.2018.01.007.

Gomez, K.A., Gomez, A.A., 1984. Statistical procedures for agricultural research (2nd Edn.). John Wiley and Sons, New York, USA, pp. 1–680. Available from: https://www.scirp.org/reference/referencespapers?referenceid=2253909.

Ikioukenigha, M., Abamba, E.E., Chikukula, A.A., Dugeri, D.R., Ibeneme, U.J., Olukayode, O.J., Okpro, O., Akpome, A., 2024. Herbicides effects on soil functions: A review. Asian Soil Research Journal 8(4), 34–41. Available from: https://doi.org/10.9734/asrj/2024/v8i4160.

Imran, A., Al Tawaha, A.R., 2021. Efficacy of pre- and post-emergence herbicides alone and in combination for effective weed control without affecting growth and development of maize (*Zea mays* L.). Russian Agricultural Sciences 47(3), 261–269. Available from: https://doi.org/10.3103/S1068367421030083.

Kumar, S., Rana, S., 2022. Weed management strategies in soybean (*Glycine max*)-A review. Indian Journal of Agricultural Sciences 92(4), 438–444. Available from: https://doi.org/10.56093/ijas.v92i4.123868.

Naik, A., Naik, T.B., Nagaraj, R., Madhu, G., Goudra, S., 2025. Efficacy of pre- and post-emergence herbicides for weed management in groundnut. Legume Research 48(4), 658–663. Available from: https://doi.org/10.18805/lr-4924.

Nongmaithem, D., Dolie, S., Jamir, M., Gohain, T., Longkumer, T., Singh, A.P., Tzudir, L., Yadav, R., Dutta, M., 2024. Influence of transplanting date and integrated weed management in system of rice intensification of aromatic black rice (*Oryza sativa*). Indian Journal of Agricultural Sciences 94(5), 472–477. Available from: https://doi.org/10.56093/ijas.v94i5.143355.

Rao, V.S., 2000. Principles of weed science. Oxford & IBH Publishing Co., 497–498p. Available from: https://www.scirp.org/reference/referencespapers?referenceid=777298.

Singh, R., Singh, G., 2021. Influence of herbicides on symbiotic parameters, growth, yield and nutrient uptake in mungbean [*Vigna radiata* (L.) Wilczek]. Archives of Agronomy and Soil Science 67(3), 410–425. Available from: https://doi.org/10.1080/03650340.2020.1734574.

Singh, S., Devi, N.B., Divakaran, D., Kumar, A., Singh, S., Tyagi, G., Nath, A., Kumar, A., 2024. Soil fertility management: Role of organic amendments and bio-fertilizers-a review. International Journal of Research in Agronomy 7(12), 766–772. Available from: https://doi.org/10.33545/2618060x.2024.v7.i12j.2253.

Saini, N., Yadav, H.S., Saini, S., Sharma, A.C., Saini, N., 2025. Advances in integrated nutrient management practices for cereal crops: A comprehensive review. International Journal of Plant and Soil Science 37(1), 375–383. Available from: https://doi.org/10.9734/ijpss/2025/v37i15279.