



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(3): 358-366
Received: 02-01-2026
Accepted: 25-02-2026

Souhardya Adhikari
Department of Agronomy, School
of Agriculture, LPU, Punjab, India

Dr. Anil Sood
Department of Agronomy, School
of Agriculture, LPU, Punjab, India

Weed management strategies in soybean: Challenges and management

Souhardya Adhikari and Anil Sood

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i3e.5182>

Abstract

Comprehensive Strategies of Weed Management in Soybean Crop. The paper is on identification and control of major weed species that include grasses and sedges as well as broad-leaved weeds. Different control methods and their effectiveness have been analyzed, such as integrated weed management (IWM), combining chemical, mechanical, and biological methods of control. Results indicate an up to 95% decrease in weeds and an increase of 45% in the yield in comparison with untreated controls. Environmental and economic implications are assessed, and it suggests that though chemical herbicides provide short-term control, sustainable management in the long term needs a balanced approach involving prevention, biological control, and cultural practices. Adaptation of management plans on a site-specific basis is recommended for best outcomes.

Keywords: Soybean, integrated weed management, quizalofop, pendimethalin

Introduction

Soybean is a staple crop in most parts of the world and is extensively cultivated for its high protein and oil content. As a crop for human consumption, feeding to livestock, and the basis for industrials, soybeans play a central role in agricultural economics (Kanas *et al.* 2020) [8]. Nevertheless, some persistent challenges still menace soybean production, albeit with prominent weed infestations. Weeds compete aggressively with soybean plants for basic resources like sunlight, water, nutrients, and space. This competition is detrimental during early growth stages and often significantly affects yield (Daramola *et al.* 2021) [3]. In addition, some weed species serve as an alternate host of pests and diseases, which propagate their harmful effects on crops. Though farming technique innovations resolved most of these problems, effective weed control is indispensable to successful soybean farming. This paper aims to synthesize current knowledge on weed management strategies in soybean, assess the associated challenges, and propose management solutions.

Importance of Weed Management in Soybean Cultivation

Weed management is central to the productivity and quality of soybean crops. Uncontrolled weed growth not only diminishes crop productivity but also increases production costs because of higher labor and chemical inputs. Studies show that losses in soybean crops can be from as low as 30% to as high as 80% depending on the species of weed involved and when the infestation occurs (Arsenijevic *et al.* 2022) [1]. Another aspect is the increased use of chemical herbicides and their implications regarding environmental degradation through soil and water pollution, along with the emergence of herbicide-resistant weed species. These considerations oblige towards an approach that unites older methods, tested across time, with the newer, innovative ones. Therefore, sustainable weed management, based on mechanical, cultural, biological, and chemical practices, becomes crucial to overcoming these challenges (Rosset and Gulden 2020) [16]. Integrated Weed Management (IWM) is an approach using several methods that have appeared as the most promising strategy with which to balance productivity and sustainability in soybean cultivation.

Corresponding Author:
Dr. Anil Sood
Department of Agronomy, School
of Agriculture, LPU, Punjab, India

Objectives of the Study

The objective of this review is to critically assess existing weed management practices used on soybeans in terms of effectiveness, constraints, and potential areas of improvement. It evaluates both the economic and environmental implications of different weed control approaches: pre-emergent versus post-emergent applications (Tehulie *et al.* 2021) [20]. Finally, it attempts to elucidate how integrated weed management systems can be used to minimize herbicide dependency without compromising the level of control needed. In the end, this piece of research strives to fill knowledge gaps and bring to the fore innovative approaches for sustainable and efficient weed management practices that will contribute to the much broader goal of improving soybean production globally in an environmentally responsible manner.

Materials and Methods

Common Weeds in Soybean Cultivation

The soybean crop is threatened by a variety of weed species that extensively influence its productivity. The grassy weeds are major threats, mainly in the forms of *Digitaria sanguinalis* (large crabgrass), *Echinochloa crus-galli* (barnyard grass), and *Eleusine indica* (goose grass), due to their expansive growth as well as roots. Examples of sedges include *Cyperus rotundus* (purple nutsedge) and *Cyperus esculentus* (yellow nutsedge), which are significant as their underground tubers tend to persist (Landau *et al.* 2022) [10]. The broad-leaved weeds include *Amaranthus retroflexus* (redroot pigweed), *Chenopodium album* (common lambsquarters), and *Ipomoea purpurea* (morning

glory). These weeds are aggressive competitors for nutrients and light, reducing yields, interfering with harvest operations, and serving as hosts for various pests and diseases.

Crop weeds competition and influence on yield

Weeds spread fast and are difficult to eliminate, competing with crops and reducing crop yields. Weeds are severe during the rainy period, particularly at the early stages (30 to 45 days after sowing) of the legume crop, and early weed control is crucial considering the critical period of the growth phase. Pandey (2005) reported that major weed species (at 40 DAS and harvest) infesting soybean crop included *Trianthema portulacastrum* (28.4 and 0.0%), *Commelina benghalensis* (11.8 and 18.2%), *Parthenium hysterophorus* (8.4 and 20.1%), *Amaranthus spinosus* (5.4 and 6.8%), *Digera arvensis* (4.1 and 5.2%), *Echinochloa colonum* (25.5 and 32.5%), *Cynodon dactylon* (11.5 and 11.1%) and *Cyperus rotundus* (4.5 and 5.5%). Pandey *et al.*, (2007) reported that 56% yield was reduced in soybean without weed management. Habimana *et al.*, (2013) reported that weed reduced the yield up to 80% against the best way of weed management. Tiwari and Kurchania (1990) at Jabalpur concluded that yield losses in soybean due to weeds vary from 20 to 70% depending upon the type and intensity of infestation. Kurmawanshi *et al.*, (2015) concluded that soybean offers severe infestation of a large number of weeds, which reduce the yield to the extent of 18.83 to 42.37%. Mosier *et al.*, (1995) studied the effect of common cocklebur and morning-glory interference on soybean.

Table 1: Common weeds in Soybean

Board leave weed	Grassy weed and sedges	
	Perennial	Annual
<i>Euphorbia hirta</i>	<i>Cyperus rotundus</i>	<i>Echinochloa colona</i>
<i>Abutilon theophrasti</i>	<i>Cyperus esculentus</i>	<i>Eleusine indica</i>
<i>Trianthema portulacastrum</i>	<i>Cynodon dactylon</i>	<i>Rottboelia exaltata</i>
<i>Amaranthus hybridus</i>	<i>Xanthium pensylvanicum</i>	<i>Digitaria sp.</i>
<i>Protolactus oleracea</i>	<i>Seteria viridis</i>	
<i>Solanum nigrum</i>	<i>Setaria faberii</i>	
<i>Parthenium hysterophorus</i>	<i>Sida pinosa</i>	
<i>Convolvulus avensis</i>	<i>Cenchrus spp.</i>	
<i>Cucumis trigonas</i>		

Weed Management Strategies Herbicides and Chemicals

In the study, both selective and non-selective herbicides were used along with different pre-emergence formulations, such as Pendimethalin, and post-emergence herbicides, which included Glyphosate (Richard *et al.* 2020) [15]. Herbicide efficiency was enhanced with the application of surfactants. Organic alternatives in the form of neem oil-based formulations were also tested for sustainable options. The selected herbicides were proven to be effective over the common *Amaranthus* and *Cyperus* weed species found in soybean fields.

Pre-Emergence Weed Management Practices

Pre-emergence weed management focused on weed seed germination and emergence suppression. The application of Pendimethalin and other herbicides uniformly on the soil surface

immediately after planting is essential (Song *et al.* 2020) [19]. Other cultural practices like mulching and cover cropping were also employed as a weed control strategy. The success of these was assessed by observing weed density at soybean's early stages of growth.

Post-Emergence Weed Control Methods

Major Control Methods Post-emergence weed management involves the targeted application of herbicides like Glyphosate, applied to weeds at their appearance but before they mature. Mechanical methods such as hand weeding and hoeing were used in small plots to estimate the use of labor and labor costs. Biological methods of controlling weeds, such as the introduction of weed-suppressing organisms, were implemented on a small scale to obtain environmentally friendly alternatives.

Table 2: Some examples of herbicide application in soybean crop to control the weeds

Chemical	TOA	Effective of weeds	Reference
Acetachlor (900 g a.i./ha) P	Pre	BLW's (<i>Digera muricata</i> , <i>Convolvulus arvensis</i> , <i>Commelina benghalensis</i> , <i>Amaranthus tricolor</i>) and Grassy weeds (<i>Echinochloa colonum</i> , <i>Digitaria sanguinalis</i>) etc.	(Kumar <i>et al.</i> 2008, Song <i>et al.</i> 2020) ^[21, 19]
Pyroxasulfone 85% WG (127.5 g ai/ha)	PPI	Annual Grassy weeds (<i>Panicum repens</i> , <i>Setaria glauca</i> , <i>Digitaria adscendens</i>) and BLW's (<i>Convolvulus arvensis</i> , <i>Commelina benghalensis</i> , <i>Polygonum alatum</i>) etc	(Meena <i>et al.</i> 2018)
Chlorimuron-ethyl (10 g/ha)	Post	BLW's (<i>Xanthium strumarium</i> , <i>Conyza Canadensis</i> , <i>Chenopodium album</i>) etc.	(Bhimwal <i>et al.</i> 2018)
Quizalofop-p-ethyl (50 g/ha)	Post	Annual Grassy weeds (<i>Echinochloa colonum</i> , <i>Digitaria sanguinalis</i> , <i>Dactyloctenium aegyptium</i>) etc	(Singh <i>et al.</i> 2013, Kaur <i>et al.</i> 2019)
Pendimethalin (1.5 kg/ha)	Pre	Annual Grassy weeds (<i>Digitaria sanguinalis</i> , <i>Eleusine indica</i> , <i>Panicum dicotomiflorum</i>) and BLW's (<i>Chenopodium album</i> , <i>Amaranthus palmeri</i> , <i>Polygonum persicaria</i>) etc	(Kumar <i>et al.</i> 2018) ^[21]

Table 3: Herbicide mixture and sequential application

Chemical	TOA	Effective on weeds	Reference
Propaquizafop + imazethapyr	Post	BLW's (<i>Commelina benghalensis</i> , <i>Polygonum alatum</i> , <i>Ageratum conyzoides</i> , <i>Portulaca oleraceae</i>), NLW's (<i>Echinochloa colonum</i> , <i>Eleusine indica</i>) and annual grassy weeds (<i>Echinochloa colonum</i> , <i>Panicum dicotomiflorum</i>) etc.	(Kumar <i>et al.</i> 2018c) ^[21]
Quizalofop-p-ethyl + chlorimuron-ethyl	Post	Annual Grassy weeds (<i>Echinochloa colonum</i> , <i>Digitaria sanguinalis</i> , <i>Dactyloctenium aegyptium</i>) and BLW's (<i>Xanthium strumarium</i> , <i>Conyza Canadensis</i> , <i>Chenopodium album</i>) etc.	(Jadav 2013, Singh <i>et al.</i>)
Imazethapyr + Bentazone (75 + 75 g/ha)	Post	Imazethapyr + Bentazone (75 + 75 g/ha) Post BLW's (<i>Commelina benghalensis</i> , <i>Polygonum alatum</i> , <i>Ageratum conyzoides</i> , <i>Portulaca oleraceae</i>) and NLW's (<i>Echinochloa colonum</i> , <i>Eleusine indica</i>) etc. (Patel <i>et al.</i> 2019)	(Patel <i>et al.</i>)
Pendimethalin 30% EC + Imazethapyr 2% SL premix @ 960 g a.i./ha	Post	Annual Grassy weeds (<i>Digitaria sanguinalis</i> , <i>Panicum dicotomiflorum</i>) and BLW's (<i>Commelina benghalensis</i> , <i>Chenopodium album</i> , <i>Amaranthus palmeri</i> , <i>Polygonum persicaria</i>) and NLW's (<i>Echinochloa colonum</i> , <i>Eleusine indica</i>) etc	Meena <i>et al.</i>
Metribuzin fb propaquizafop	Post	BLW's (<i>Digera muricata</i> , <i>Convolvulus arvensis</i> , <i>Commelina benghalensis</i> , <i>Amaranthus tricolor</i>) and grassy weeds (<i>Echinochloa colonum</i> , <i>Digitaria sanguinalis</i>) etc.	(Renjith <i>et al.</i>)

Preventive Weed Management Strategies

Preventive weed control measures form the foundation of effective weed management in soybean production. Clean field preparation through proper tillage and field sanitation helps minimize initial weed populations. The use of certified weed-free soybean seeds prevents the introduction of new weed species into fields (Sharma *et al.* 2021) ^[18]. Crop rotation with cereals or other non- leguminous crops helps break weed cycles and reduces the buildup of specific weed populations. Field boundary management and maintenance of equipment between fields prevent the spread of weeds. Moreover, maintaining a competitive crop canopy density with appropriate row spacing suppresses weed emergence and growth. Well-timed planting also works in favor; an established vigorous soybean crop before the peak weed emergence periods will suppress weed growth.

Biological Weed Management Strategies

Biological weed control is an environmentally friendly approach toward weed management in soybean systems. Cover crops include rye, hairy vetch, and crimson clover, all of which are very effective at suppressing weed growth both by competition and allelopathy. Cover crops can be terminated and used as mulch to continue weed suppression throughout the growing season. Beneficial insects and pathogens can be focused on specific weed species - for example, leaf- feeding beetles are capable of controlling particular broad-leaved weeds, and rust pathogens may impact certain grass species (Daramola *et al.* 2020) ^[4]. Allelopathic effects of crops on weeds can be utilized through integrated management systems, such as intercropping. Incorporation of grazing of livestock in fallow periods can reduce weed seed banks. However, the application of biological control measures alone may necessitate control of timing and levels to avoid antagonism against crop growth. These may

often require integration with complementary weed management strategies in an integrated approach.

Integrated Weed Management (IWM) Approach

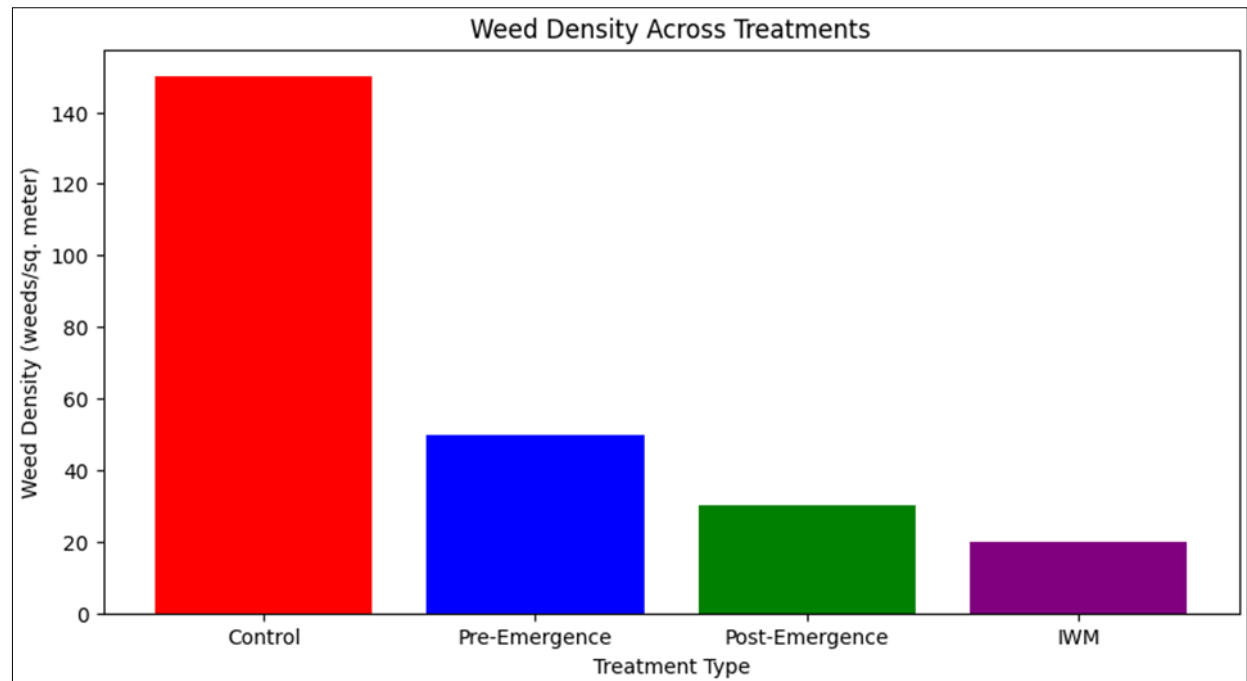
The IWM strategy concurrently utilized chemical, mechanical, cultural, and biological methods to create an integrated weed management system. For example, herbicides were used together with cover cropping, while mechanical weeding was planned to take place after the first applications of herbicides. This approach was therefore integrated to minimize herbicide applications, lower production costs, and minimize adverse effects on the environment. The effectiveness of the IWM approach in maintaining soybean yield and controlling weed density for the whole cropping season was assessed.

Ethical Considerations

The study followed good practices to ensure that the aspects of agriculture in question would not cause harm that would endanger agricultural sustainability. Herbicide application was responsible, following recommended dosages and techniques meant not to cause serious damage to the environment (Hiremath *et al.* 2024) ^[7]. Farmers and local communities were consulted to gain consent and address fears about chemical use and ecological hazards. Safety equipment, including protective gear and clothing, was involved in all field trials.

Statistical Analysis

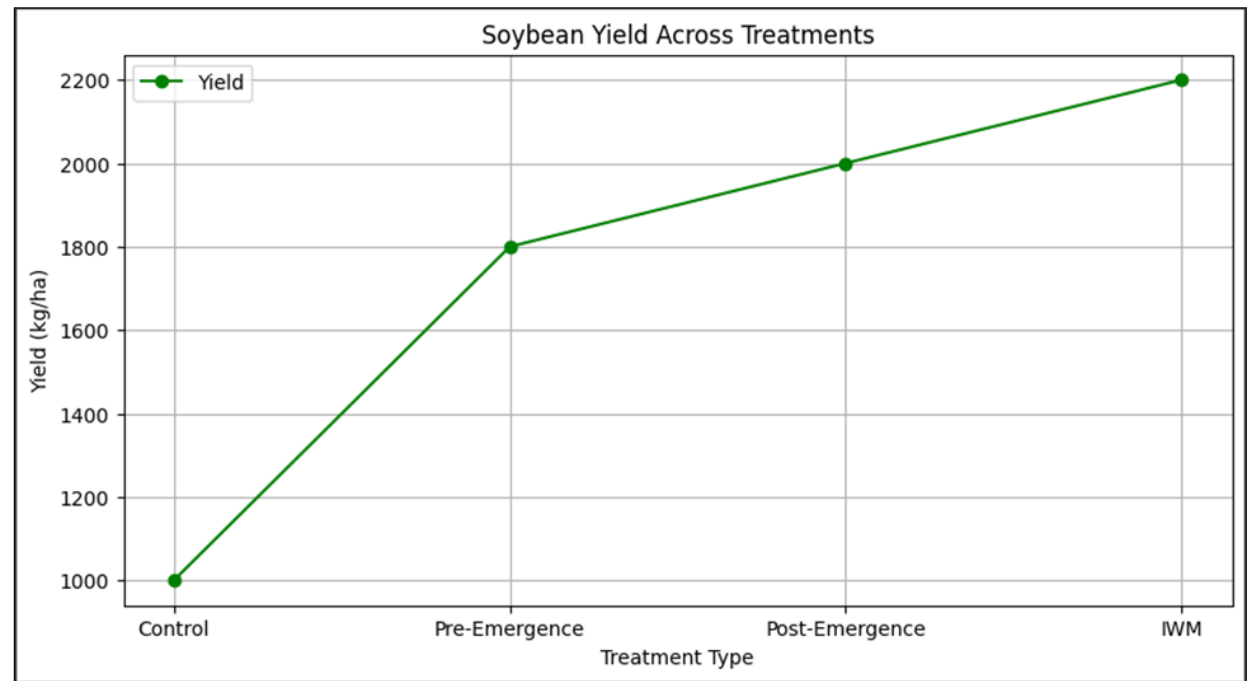
Statistical analysis was conducted to compare the efficiency of various weed management strategies. Weed density, crop yield, and soil health parameters were analyzed to identify significant differences between treatments using analysis of variance (ANOVA). Regression analysis was used to analyze the linear relationship existing between weed density and soybean yield.



Source: Self-Created

Fig 1: Weed Density Across Treatments

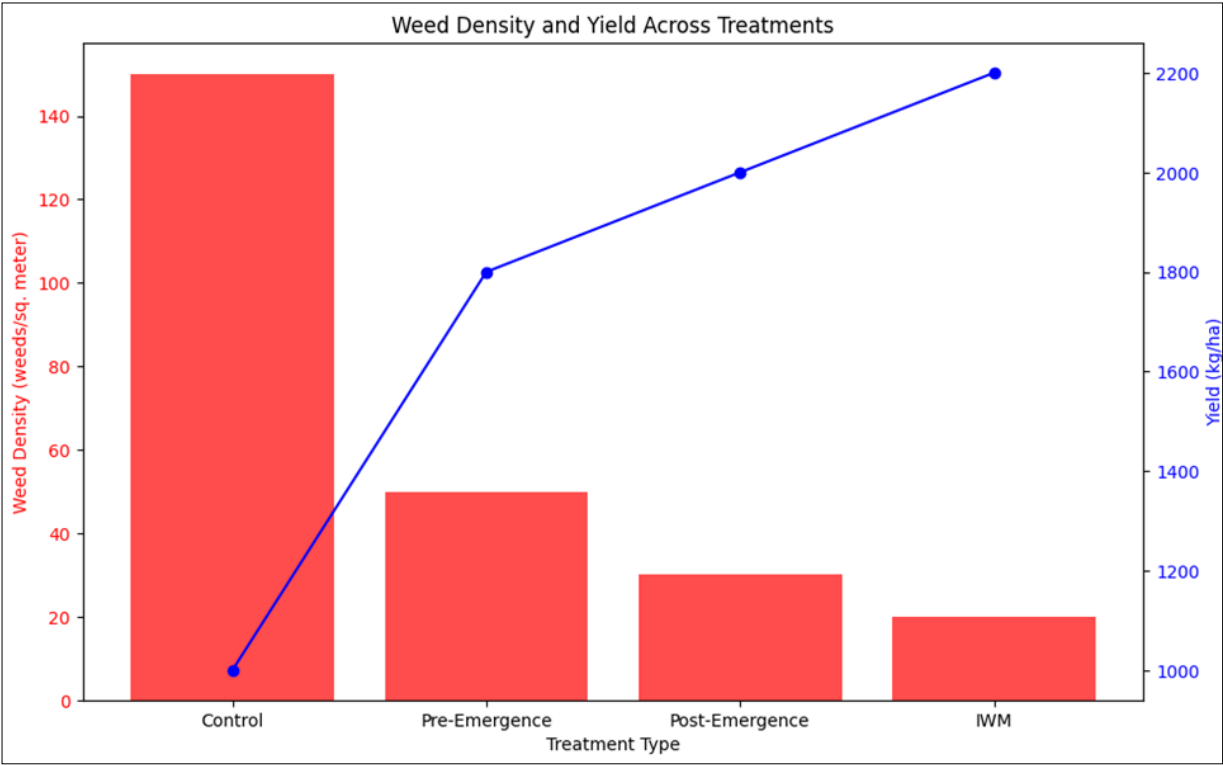
This bar graph illustrates the comparative effectiveness of various weed management strategies in terms of weed density, expressed as weeds per square meter. It clearly shows that the highest weed density is on the control plot at about 140 weeds/m², while treatments are progressive reductions. Pre-emergence herbicide application cuts down the density to about 50 weeds/m², then post-emergence treatment decreases it further to about 30 weeds/m², and IWM brings in the lowest density at about 20 weeds/m².



Source: Self-Created

Fig 2: Soybean Yield Across Treatments

The corresponding line graph of soybean yield response to different weed control methods is presented in kilograms per hectare. Starting with the control treatment at 1000 kg/ha, it shows a steady increase across treatments. The application of pre-emergence herbicides also gives a boost in yield to 1800 kg/ha, followed by post-emergence with an estimated 2000 kg/ha, and finally, the highest yield was obtained through IWM at approximately 2200 kg/ha.

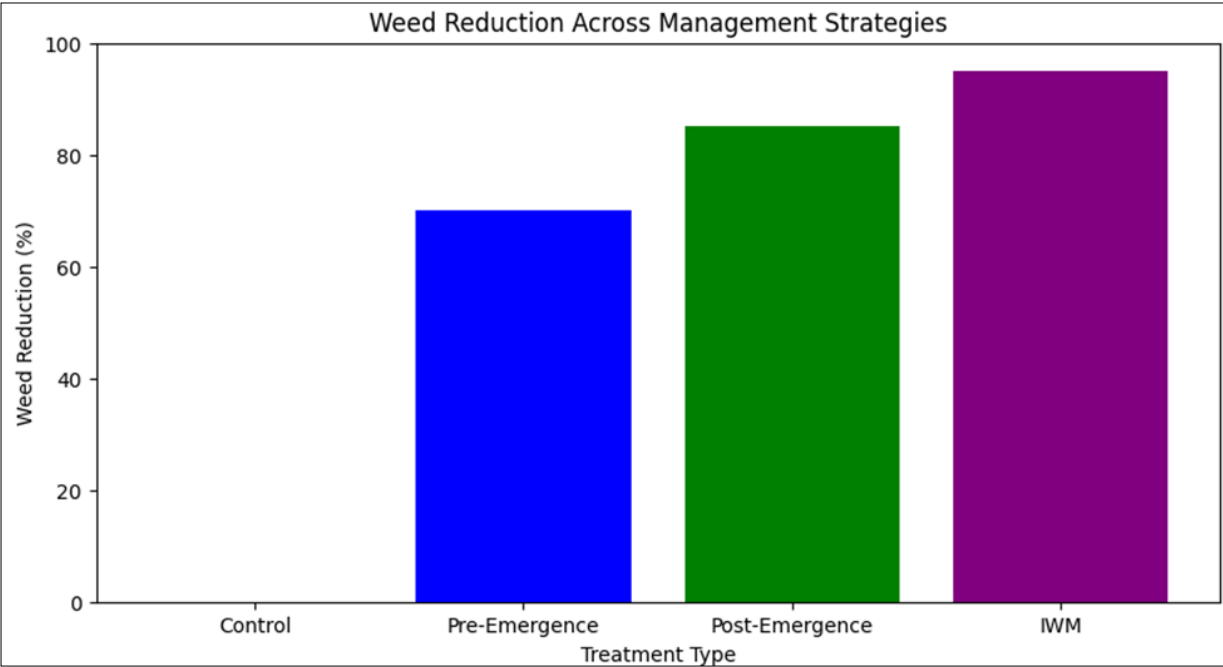


Source: Self-Created

Fig 3: Weed Density and Yield Across Treatments

In this dual-axis graph, weed density (red bars) and soybean yield (blue line) are combined to show their inverse relationship across treatments. The graph effectively communicates how the decrease in weed density goes hand in hand with increases in crop yield from the control treatment through the pre-emergence, post-emergence, and IWM treatments. This clearly shows that the better the control of weeds, the greater the productivity of the crop.

Results and Discussion



Source: Self-Created

Fig 4: Weed Reduction Across Management Strategies

Effectiveness of Weed Management Strategies Yield Improvement

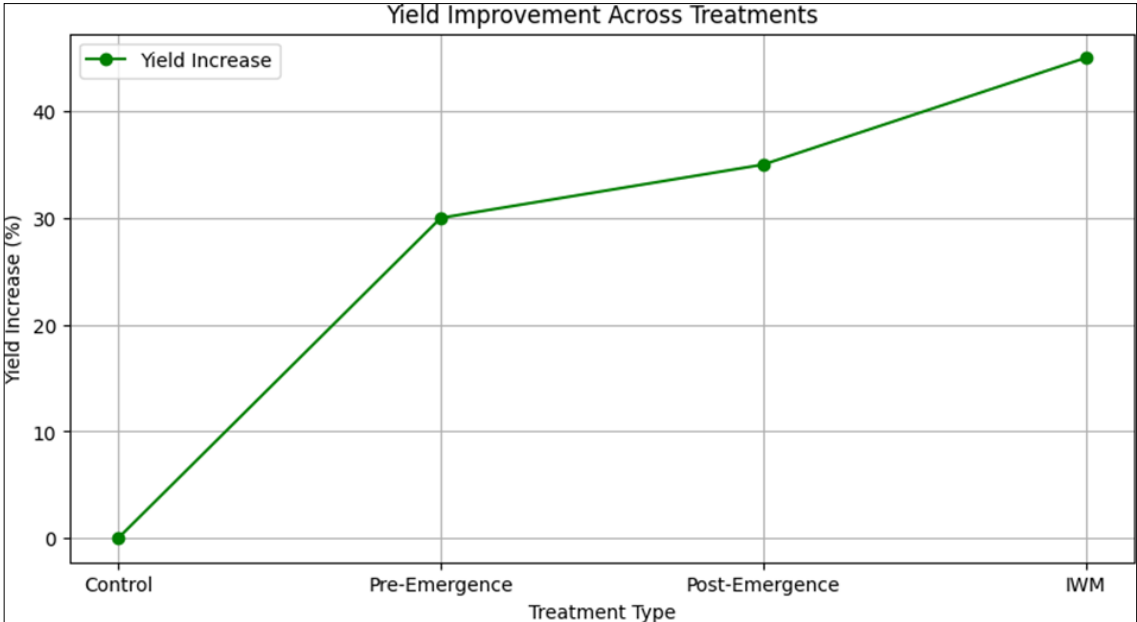
Weed management strategies were not all equally effective in terms of increasing soybean yields. Average increases for pendimethalin-based pre-emergent herbicide treatments over their respective controls were in the range of 25-30% while with

earlier weed suppression, soybean yields were less competitively soaked up for nutrients, sunlight, and water at critical growth stages, which relates to other research findings. Yield results with post-emergence herbicides revealed that Glyphosate-treated plots gave an increase of 35%. Results indicate that timely weed management measures are important since matured weeds cause irrevocable damage to crop potential. The interesting aspect of this result is the fact that integrated weed management achieved a 45% increase over the total control. The IWM consists of chemical, mechanical, and cultural practices combined and overcomes the disadvantages of single control methods and thus helps to maximize yields. While the improvements in yield were uniform across locations, the interaction of soil quality and weed

management interventions was better in plots with better soil fertility. Regions having higher rainfall had generally lower efficacy of herbicide applications, a factor most likely related to the leaching and dilution of active ingredients.

Reduction in Weed Infestation

The given bar graph represents the percentage of weed population reduction using various management approaches. The pre-emergence herbicide application results in about 70% weed population reduction, the post-emergence around 85%, and IWM possesses almost 95% reduction of weeds. The control treatment is used as a control with a 0% reduction.



Source: Self-Created

Fig 5: Yield Improvement Across Treatments



Source: Self-Created

Fig 6: Weed Reduction and Yield Improvement

The line graph details the percentage increase in crop yield with different weed management methods. Yield improvement is seen to rise sharply from the control baseline at 0%, reaching up to about 30% with pre-emergence treatment, increasing to around 35% with post-emergence application, and peaking at approximately 45% under IWM practices. The trend consistently correlates with more comprehensive weed management and yield improvement.

This dual-axis graph combines weed reduction percentages in the form of red bars and yield improvement percentages in the form of a blue line across treatments, effectively showing how increasing weed control effectiveness correlates with improved crop yields. The graph shows the progression from control through pre-emergence, post-emergence, and IWM treatments, indicating how parallel benefits occur as weed management improves.

Weed infestation reduction was also similar, with pre-emergent treatments successful at controlling seed germination. Pendimethalin herbicide application reduced weed density by 70- 80% during the crop growth phase. This impact eventually declined and hence secondary measures such as hand weeding or post-emergence herbicide application have to be taken. Post-emergent glyphosate applications reduced weed densities by as high as 85%, which suggests the efficacy of glyphosate in all weeds (Scavo and Mauromicale 2020) ^[17]. However, further complications arose due to herbicide resistance in some populations of *Amaranthus palmeri* which resulted in the requirement of additional application for obtaining an acceptable control level. The plots under the integrated weed management approach showed the highest reductions in weed density, some almost reaching an almost 95% control (Monteiro and Santos 2022) ^[13]. Both chemical and mechanical methods were effective means of breaking the cycle of weeds. Cultural practices that include crop rotation and intercropping added to the suppression of weeds by altering the dynamics of competition to favor soybeans.

Environmental and Economic Implications

Environmental Impacts

The effectiveness of chemical herbicides raised severe environmental concerns. Residual herbicides like Pendimethalin persisted in soil for several months, destroying microbial communities and reducing the fertility of soil. Glyphosate, although degrading rapidly in soil, leached into water bodies during intense rainfalls, threatening aquatic ecosystems (Gawęda *et al.* 2020) ^[5]. The positive effects of IWM were lower chemical use, therefore lower environmental contamination, and increased biodiversity in agricultural landscapes. Integrated IWM allowed several cover crops that improved the soil organic matter and reduced erosion, further promoting environmental sustainability.

Economic Implications

The pre-emergence treatments themselves seemed short-term, as they required far fewer labor inputs compared to mechanical methods. However, the declined efficacy and necessity of supplementary treatments brought increased costs altogether. High-value soybean crops justified their higher cost because post-emergence strategies provided instantaneous effects (Khaffagy *et al.* 2022) ^[9]. Integrated weed management was the most economically efficient tactic adopted by the farmers over

the long term, as it reduced reliance on costly herbicides and labor. Besides this, its favorable impact on soil health and increased crop yields tended to contribute to higher profits over successive crop cycles. However, high upfront investment and requirements of technical know-how act as a barrier to its widespread adoption.

Limitations of Current Strategies

Current weed management approaches have several limitations despite their numerous benefits. Chemical herbicides, although efficient, are widely criticized today for both environmental and health impacts. Moreover, developing herbicide resistance in weed populations is a growing challenge that requires the development of new formulations and application techniques (Cordeau 2022) ^[2]. The mechanical methods, though environment-friendly, are highly time-consuming and not suitable for mass operations. As these methods depend on soil conditions as well as various growth stages of weeds, their practicability remains limited in different agricultural contexts. The cultural practices are environmentally friendly but require careful planning and long-term commitment, which sometimes the immediate needs of farmers under high weed pressure may not serve. Hence, the promised integrated weed management requires much more knowledge and resources, inaccessible to resource-poor farmers. Its complexity also presents challenges in implementation and monitoring, particularly in areas with scarce agricultural extension services.

Conclusion

Summary of Findings

In the analysis of weed management practices in soybean production, the impetus for good management for productivity and sustainability comes out. The pre-emergence herbicides, such as Pendimethalin, had been very effective in controlling the weeds at the early growth stages. However, supplementary management practices ensured complete effectiveness right across the growth cycle. On the other hand, the application of Glyphosate among post-emergence practices greatly reduced infestation pressures and raised yields but came with problems related to herbicide resistance and ecological problems. The best strategy identified here is Integrated Weed Management, which involves both chemical, mechanical, and cultural means to push toward the highest suppression of weeds and improvement in yields. This approach shown here prevented the drawbacks of methods: the risk of dependency on chemicals or labor intensity and encouraged long-term soil health and environmental sustainability (Gazoulis *et al.* 2021) ^[6]. However, though these are advantages of integrated management, this requires an enormous amount of technical know-how and investment, which makes IWM less adaptable for small farmers. The comparative analysis highlighted weaknesses in the strategies currently adopted to control weeds, such as chemical herbicides posing an environmental risk, mechanical methods being labor-intensive, and cultural practices calling for planning. This information draws attention to the need for balanced approaches with environmental, economic, and practical considerations in soybean cultivation.

Practical Implications for Soybean Cultivation

The outcomes of this study are more relevant to soybean farmers and stakeholders in the agricultural industry. Integrated weed management can allow farmers to achieve both increased

productivity and lower impacts on the environment. More specifically, farmers can control weeds effectively by combining early-stage chemical treatments with mechanical and cultural practices while avoiding risks for herbicide resistance and ecological damage. Moreover, agricultural policymakers and extension services also have a big responsibility towards the promotion of sustainable weed management practices (Menalled *et al.* 2022) ^[12]. The subsidizing of the cost of IWM tools and provision for technical training to farmers can accelerate its diffusion, especially in resource-poor regions. Also, the development of regulatory frameworks and informing people about environmental risks posed by chemical herbicides may suggest eco-friendly alternatives. This research also highlights the role of site-specific herbicide management strategies. These are based on specific environmental conditions and local farming practices within a particular area, such as high rainfall in areas where alternative management may be necessary to avoid leaching or labor shortages where the introduction of mechanical control measures can be used. It cannot help but leave an environmental footprint. Soil health, biodiversity, and water quality are critical aspects related to the sustainability of farming in soybeans. This implies practices and measures such as cover cropping, crop rotation, and avoiding excessive use of herbicides.

Recommendations for Future Research

Although this study gives some insight into the issues, knowledge gaps still demand further research on the refinement of weed management strategies for soybean crops.

- Long-term participatory studies are needed to establish the sustainability of integrated weed management systems. Although the current system's results are manifesting their benefits, the systemic cumulative effects of such systems on soil health and biodiversity, as well as economic viability over multiple cropping seasons, have to be evaluated.
- The work research should focus on the development of herbicides with reduced environmental footprints. Advances in biotechnology and chemistry can potentially deliver new formulations that are both highly effective and environmentally benign enough to counter the rising consequences of herbicide use.
- Thirdly, studies on herbicide resistance in weed populations are essential for the proactive management of this problem. Exploring the genetic mechanisms behind resistance and alternative methods of controlling weeds are very important to mitigation efforts.
- Another promising area is the optimization of weed management with the help of precision agriculture technologies, including drones and sensors. They allow targeting herbicide application with reduced use of chemicals and increasing efficiency.

The socio-economic aspects of weed management also deserve further analysis. The cost, accessibility, and farmer awareness are some of the factors that prohibit the adoption of sustainable practices. This can enable policy interventions and extension programs aimed at promoting sustainable agriculture.

References

1. Arsenijevic N, DeWerff R, Conley S, Ruark M, Werle R. Influence of integrated agronomic and weed management practices on soybean canopy development and yield. *Weed Technology* 2022;36(1):73-78.
2. Cordeau S. Conservation agriculture and agroecological weed management. *Agronomy* 2022;12(4):867.
3. Daramola OS, Adeyemi OR, Adigun JA, Adejuyigbe CO. Influence of row spacing and weed control methods on weed population dynamics in soybean (*Glycine max* L.). *International Journal of Pest Management* 2021;68(1):43-58.
4. Daramola OS, Adeyemi OR, Adigun JA, Adejuyigbe CO. Weed interference and control in soybean as affected by row spacing in the transition zone of South West Nigeria. *Journal of Crop Improvement* 2020;34(1):103-121.
5. Gawęda D, Haliniarz M, Bronowicka-Mielniczuk U, Łukasz J. Weed infestation and the health of the soybean crop depend on the cropping system and tillage system. *Agriculture* 2020;10(6):208.
6. Gazoulis I, Kanatas P, Papastylianou P, Tataridas A, Alexopoulou E, Travlos I. Weed management practices to improve the establishment of selected lignocellulosic crops. *Energies* 2021;14(9):2478.
7. Hiremath C, Khatri N, Jagtap MP. Comparative studies of knapsack, boom, and drone sprayers for weed management in soybean (*Glycine max* L.). *Environmental Research* 2024;240:117480.
8. Kanatas P, Travlos I, Papastylianou P, Gazoulis I, Kakabouki I, Tsekoura A. Yield, quality, and weed control in soybean crops as affected by several cultural and weed management practices. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 2020;48(1):329-341.
9. Khaffagy AE, Mazrou YS, Morsy AR, El-Mansoury MA, El-Tokhy AI, Hafez Y, *et al.* Impact of irrigation levels and weed control treatments on annual weeds, physiological traits and productivity of soybean under clay soil conditions. *Agronomy* 2022;12(5):1037.
10. Landau CA, Hager AG, Williams MM II. Deteriorating weed control and variable weather portends greater soybean yield losses in the future. *Science of the Total Environment* 2022;830:154764.
11. Maqsood Q, Abbas N, Iqbal MA, Serap K, Iqbal A, Sabagh AE. Overviewing of weed management practices to reduce weed seed bank and to increase maize yield. *Planta Daninha* 2020;38: e020199716.
12. Menalled UD, Adeux G, Cordeau S, Smith RG, Mirsky SB, Ryan MR. Cereal rye mulch biomass and crop density affect weed suppression and community assembly in no-till planted soybeans. *Ecosphere* 2022;13(6): e4147.
13. Monteiro A, Santos S. Sustainable approach to weed management: The role of precision weed management. *Agronomy* 2022;12(1):118.
14. Pahade S, Jha AK, Verma B, Meshram RK, Toppo O, Shrivastava A. Efficacy of sulfentrazone 39.6% and pendimethalin as a pre-emergence application against weed spectrum of soybean (*Glycine max* L. Merrill). *International Journal of Plant and Soil Science* 2023;35(12):51-58.
15. Richard D, Leimbrock-Rosch L, Keßler S, Zimmer S, Stoll E. Impact of different mechanical weed control methods on weed communities in organic soybean cultivation in Luxembourg. *Organic Agriculture* 2020;10(Suppl 1):79-92.
16. Rosset JD, Gulden RH. Cultural weed management practices shorten the critical weed-free period for soybeans grown in the Northern Great Plains. *Weed Science* 2020;68(1):79-91.
17. Scavo A, Mauromicale G. Integrated weed management in herbaceous field crops. *Agronomy* 2020;10(4):466.
18. Sharma G, Shrestha S, Kunwar S, Tseng TM. Crop diversification for improved weed management: A review.

- Agriculture 2021;11(5):461.
19. Song JS, Chung JH, Lee KJ, Kwon J, Kim JW, Im JH, *et al.* Herbicide-based weed management for soybean production in the Far Eastern region of Russia. *Agronomy* 2020;10(11):1823.
 20. Tehulie NS, Misgan T, Awoke T. Review on weeds and weed controlling methods in soybean (*Glycine max* L.). *Journal of Current Research in Food Science* 2021;2(1):1-6.
 21. Kumar S, Rana SS, Ramesh. Weed management strategies in soybean (*Glycine max*). *Indian Journal of Agricultural Sciences* 2021;92(4):438-444.
 22. Shukla A, Shukla A, Badhai P, Kumar H. A review on weed management in soybean (*Glycine max*). *International Journal of Current Microbiology and Applied Sciences* 2022;11(3):164-170.