WEED SCIENCE RESEARCH IN MALAYSIA: ACHIEVEMENTS, CHALLENGES, RESEARCH GAPS AND FUTURE DIRECTIONS

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Abstract

Weeds are a severe impediment to agricultural output in Malaysia, notably for rice and plantation crops like oil palm and rubber. This review examines Malaysian weed science's achievements, difficulties, research gaps, and future directions. Weed flora documentation, herbicide-based systems, integrated weed management (IWM), and technologies like Clearfield® rice and UAV spraying have all made significant advances. However, issues like as herbicide resistance, invasive weeds, labor shortages, and herbicide overuse remain. Seed bank ecology, biological control, molecular resistance mechanisms, climate change consequences, and artificial intelligence-based weed identification all have research gaps. Future priorities include ecological weed control, precision agriculture, resistance monitoring, and improved extension services. Sustainable weed management is crucial for long-term agricultural output.

Keywords: Weed management, Herbicide resistance, Precision agriculture, Malaysia, IWM

INTRODUCTION

Agriculture is vital to Malaysia's economy, contributing significantly to national income, employment, and food security. The sector is dominated by rice-based systems and large-scale plantation crops like oil palm and rubber, both of which are particularly vulnerable to weed competition. Weeds grow quickly and actively compete with crops for nutrients, water, light, and space in tropical climates with high temperatures, copious rainfall, and humidity, resulting in significant production losses. Effective weed management is so critical to agricultural productivity. Weed control strategies in Malaysia rely largely on chemical herbicides, accounting for around 83% of overall pesticide usage (Dilipkumar *et al.,* 2020), indicating a strong reliance on chemical approaches. Despite decades of research into improved weed control tactics, such as integrated weed management and precision agricultural equipment, some new obstacles remain. These include the emergence of herbicide-resistant weed biotypes, the spread of invasive weed species, environmental contamination, and concerns about human and ecosystem health. Furthermore, climate change may exacerbate weed problems by changing weed ecology and crop-weed interactions. As a result, there is an urgent need to create sustainable weed management systems that combine ecological approaches like biological control and crop diversity with cutting-edge technologies like artificial intelligence and remote sensing.

This paper summarizes existing knowledge on weed science in Malaysia and identifies major problems and research gaps influencing long-term agricultural production. The goal is to analyse previous accomplishments and propose future research areas that integrate ecological and technological techniques for effective and sustainable weed management.

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MATERIALS AND METHODS

This analysis relies on secondary data from published publications, reports, and Malaysian databases. The data were analysed using descriptive and comparative techniques. The accomplishments, obstacles, research gaps, and so on were illustrated through narrative discussion, tables, and graphical depiction. ChatGPT was used to collect a large amount of information about Malaysian weed science research. The figure was likewise created with the AI tool.

RESULTS AND DISCUSSION

Major achievements in weed science

Table 1 summarises Malaysia's key achievements in weed science research. The achievements in a given field have been briefly reviewed under various subheadings.

Weed flora and ecology

In Malaysia, researchers have discovered prominent weeds such as *Eleusine indica, Clidemia hirta,* and *Asystasia gangetica* in important agroecosystems, including oil palm and rice fields. According to survey data from 14 states, 43% and 28% of planters reported *E. indica* and *C. hirta*, indicating its widespread presence (Ofosu *et al.,* 2023). Understanding weed population dynamics, seasonal emergence patterns, and competitive behavior has resulted in crop-specific management strategies that improve the timing, efficiency, and targeting of control actions in plantation and rice production systems.

Herbicide-based weed control

Due to labor shortages and the requirement for quick, cost-effective management, herbicides remain the most used weed control tool in Malaysian agriculture. According to studies, herbicides represent for 80-83% of total pesticide use in Malaysia, highlighting their importance in agricultural production systems (Dilipkumar *et al.,* 2020). Herbicide efficacy has been considerably enhanced through research by optimizing treatment rates, mixes, and selectivity, ensuring excellent weed suppression while minimizing crop damage. However, chronic and repeated use of identical herbicide modes of action imposes considerable selection pressure, leading to the development of resistant weed biotypes and decreased long-term effectiveness (Roma-Burgos *et al.,* 2018, Das *et al.,* 2024).

Integrated weed management (IWM)

Integrated Weed Management (IWM) combines chemical, cultural, and mechanical measures to keep weed populations under economic control while increasing sustainability. Cover cropping, mulching, crop rotation, and timely mechanical weeding reduce pesticide use while increasing system resilience (Muniswamy, 2023). Field studies demonstrate that combining herbicides with manual or mechanical weeding can increase weed control efficiency by up to 82-93% while also considerably improving crop yield and profitability when compared to single techniques (Padhan *et al.,* 2026). In rice systems, IWM has decreased weeding costs by 50-61%, increased net returns, and maintained output. Extension activities have been crucial in increasing IWM acceptance, notably in Asian rice systems (Adhikarya, 1995).

Weed management technologies

The Clearfield® rice system has been widely implemented in Malaysia as an effective weed-control method, resulting in yield gains of up to 15% in direct-seeded systems. However, repeated use and poor management standards have expedited the development of imidazolinone-resistant weedy rice populations, lowering long-term effectiveness (Mahmod *et al.,* 2024). In contrast, UAV-based herbicide spraying has showed significant operational benefits, including reductions of roughly 91% in water use, 81% in labor expenses, and 37% in working time, consequently increasing efficiency and scalability in plantation agriculture (Ruzlan *et al.,* 2024).

Table 1. Major Achievements in Malaysian Weed Science

Area	Key Contributions	Impact
Weed ecology	Species identification	Targeted control
Herbicides	Optimized use	Increased efficiency
IWM	Integrated practices	Reduced chemical reliance
Technology	UAV, Clearfield®	Improved productivity

Current challenges

The challenges remaining have been discussed with appropriate data under a few headings as below -

Herbicide resistance

Herbicide resistance has become common in Malaysian agroecosystems, owing to the repetitive use of herbicides with similar modes of action, which places a strong selection pressure on weed populations. As a result, Eleusine indica and other species have evolved resistant biotypes in a variety of environments. Studies have found resistance levels ranging from 2-fold to over 150-fold when compared to susceptible populations, as well as resistance to at least eight herbicide modes of action (Bzour *et al.,* 2020; Josep *et al.,* 2024). Resistance raises production costs by necessitating greater doses or alternative herbicides, threatening the long-term viability of weed management systems.

Invasive weeds

Invasive weeds, such as *Parthenium hysterophorus,* have swiftly spread throughout Malaysia and other tropical regions, posing major challenges to agriculture and biodiversity. *P. hysterophorus* can withstand a wide range of environmental conditions and emerge from varied soil levels, allowing it to colonize a variety of ecosystems and compete aggressively with crops for light, nutrients, and water. Its high allelopathic qualities, mediated by compounds such as parthenin, restrict the growth of surrounding plants and reduce native species richness, lowering ecological variety and crop yield. These biological characteristics, along with high seed production and persistence, make *P. hysterophorus* particularly challenging to handle using standard management strategies (Ruzmi, 2021; Shabbir, 2024).

Overdependence on herbicides

Heavy and repetitive herbicide use not only kills weeds, but also leaves residues in soil and water systems, raising environmental problems. Pesticide contamination has been reported in agricultural soils and surrounding rivers in Malaysia, demonstrating that chemical inputs from farming persist in the environment and may have an impact on ecosystem health and water quality (Zainol *et al.,* 2024). Herbicides and their metabolites can pass through soil profiles or wash off into surface waters, potentially affecting non-target creatures and biodiversity. Such environmental exposure also increases selection pressure for herbicide-resistant weed populations, compromising long-term management tactics (Dilipkumar *et al.,* 2020).

Labor shortage

Malaysia's agricultural sector is strongly reliant on foreign labor, particularly for manual and seasonal duties that local workers increasingly reject. Historically, foreign laborers made up a considerable proportion of agricultural labor, with some plantation industries employing more than two-thirds of the workforce. This reliance contributes to structural labor shortages when migrant availability varies owing to policy changes or global movement trends, lowering productivity and driving higher use of mechanization and automation in farming operations. To maintain productivity increases, it is critical to increase local worker involvement and upskilling. (Ismail, 2013; Crowley, 2020).

Knowledge gaps among farmers

Farmers in Malaysia generally rely on informal sources for weed management assistance, such as agrochemical shops, neighbors, and social networks, rather than scientific advice from extension organizations. A survey of vegetable growers found that social networking and agrochemical companies were the main information sources on weed control methods, with limited input from agricultural agencies, contributing to inconsistent practices and misunderstanding of herbicide rotation principles (80.6% of respondents relied on these informal sources) and resistance management (Dewi *et al.,* 2022). Such gaps impede efficient decision-making and hasten the evolution of herbicide-resistant weeds, emphasizing the need for expanded extension and focused education efforts.

Taking all these issues into account, we have graphically represented the weed problems in Malaysia as below (Figure 1).

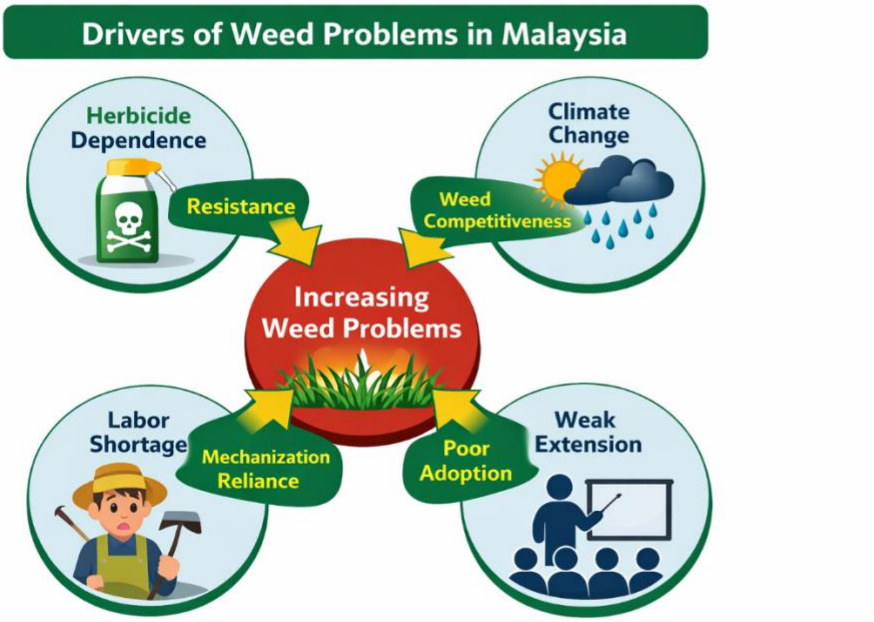

Figure 1. Conceptual diagram showing major drivers of weed problems in Malaysia

Research gaps

Research gaps are areas that require additional effort. The following are a few areas where weed scientists could conduct more intensive research:

Weed seed bank ecology

Limited study on weed seed banks in Malaysian agroecosystems other than rice systems limits the effectiveness of long-term weed management plans. Soil weed seed banks are the primary source of future weed populations in annual and perennial species. In tropical cropping systems, densities can exceed thousands to tens of thousands of seeds per m², reflecting past weed management practices and tillage regimes (Hossain and Begum, 2016; Schnee *et al.,* 2023). The lifespan of seeds in the soil is highly variable, with some species remaining viable for years to decades. Understanding seed dormancy and persistence is critical for creating sustainable management measures that limit seed bank replenishment and future infestations.

Biological weed control

Despite increased interest in sustainable alternatives to chemical herbicides, research into bioherbicides and microbial/insect-based weed control agents is restricted in Malaysia and around the world. In controlled trials, bioherbicides made from phytotoxic plant extracts and microbes (bacteria or fungus) demonstrated promise in inhibiting weed germination and growth, and certain treatments based on microbial metabolites are being investigated for broader application. However, uneven performance, limited weed target ranges, formulation problems, and a lack of large-scale field validation all impede wider usage in commercial agriculture. Recent studies stress the need for enhanced formulation stability, field trials, and integration with other management measures to make bioherbicides practicable and successful in a variety of cropping systems (Hasan *et al.,* 2021; Babu & Ramesh, 2025).

Molecular herbicide resistance

Most weed resistance studies in Malaysia and other tropical systems have concentrated on field surveys and phenotypic responses to herbicide treatments, with little molecular-level research into the underlying genetic origins of resistance. Herbicide resistance, on the other hand, is driven by target-site mutations (TSR) that alter the herbicide binding site, as well as non-target-site mechanisms (NTSR) such as increased detoxification pathways, both of which have been extensively reported globally but remain understudied locally. Understanding these pathways at the molecular and biochemical levels is crucial for creating diagnostic tools and resistance management methods (Mishra *et al.,* 2025; Torra and Cruz, 2025).

Climate change impacts

Rising CO_2 concentrations and temperatures are expected to impact crop-weed interactions, increasing weed growth, physiological activity, and competitiveness compared to other crops. Elevated CO_2 boosts photosynthesis and biomass accumulation in weeds, while higher temperatures can accelerate phenology, enhance seed production, and modify weed distribution patterns, putting more pressure on crops globally. These climate-induced changes complicate weed management, but empirical research unique to Malaysian agroecosystems is sparse, emphasizing the necessity for localized climate-weed interaction studies to inform adaptive methods (Kaur *et al.,* 2024; Mou *et al.,* 2025).

Digital weed detection

AI and machine learning (ML) applications for weed detection and control have improved significantly, particularly because to deep learning models that accurately classify and localise weeds in crop photos. Recent reviews highlight the effectiveness of ML and deep learning for distinguishing weeds from crops, but most studies use controlled datasets or small plots rather than full field conditions (for example, deep learning object detection achieves high mean average precision in research settings) (Zhao and Wang, 2026). Scaling these technologies to field-level systems presents significant problems due to variations in illumination, soil backdrop, plant morphology, and computer needs for real-time processing, which limit on-farm usage. More research is needed on robust, low-cost sensors, edge computing, and interaction with autonomous platforms to make AI-driven weed management practicable in a variety of agricultural situations (Ahmad *et al.,* 2025).

Future research directions

In the final chapter, the directions in which weed researchers in Malaysia should focus their investigations to make crop production sustainable are discussed (Table 2).

Ecological weed management

Cover crops, such as *Mucuna bracteata*, produce dense ground cover that reduces weed emergence by shading the soil and competing for light and nutrients, lowering the requirement for pesticides in tropical settings (Fernando & Shrestha, 2023). *M. bracteata* not only suppresses weeds but also enhances soil fertility through nitrogen fixation and increased soil organic matter, resulting in better soil structure and nutrient cycling. Studies have shown that leguminous cover crops can significantly enhance soil health indicators and reduce erosion, contributing to more sustainable cropping systems (Chemiseed, 2025).

Allelopathy and bioherbicides

Plant-derived bioherbicides, which are manufactured from natural allelochemicals and plant extracts, are gaining popularity as long-term alternatives to synthetic herbicides due to their environmentally beneficial mode of action and low risk. Recent studies highlight their ability to selectively reduce weed growth by targeting key physiological processes in weeds while causing minimal harm to crop and non-target creatures (Arora, 2025; Raza *et al.,* 2025). The global bioherbicide market is quickly rising, with valuations reaching several billion USD and double-digit growth expected over the next decade, reflecting increased acceptance of biological weed management technologies (Juyal, 2025). However, hurdles remain in enhancing formulation stability, field efficacy, regulatory approval, and scalable production, all of which are necessary for greater commercial uptake and consistent performance under a variety of field settings (Islam *et al.,* 2024; Arora, 2025).

Crop diversification

Diversified cropping systems help to manage weeds more effectively by disturbing their life cycles and lowering their ecological dominance. Crop rotation changes planting dates, resource availability, and disturbance patterns, producing an unstable environment for weed adaption. A global meta-analysis found that diverse rotations can lower weed density by 49%, suggesting their substantial suppressive effect (Weisberger *et al.,* 2019; Gu *et al.,* 2021). Similarly, intercropping improves crop competition by optimizing resource utilization and canopy coverage, resulting in significant weed suppression. According to studies, intercrops can reduce weed biomass by about 58% when compared to solo crops (Li *et al.,* 2021; Weisberger *et al.,* 2019). These systems also promote soil health, nutrient cycling, and microbial activity, which reduces weed growth.

Precision agriculture

Artificial intelligence (AI) unmanned aerial vehicles (UAVs), and robotics are changing weed management by allowing for highly precise, site-specific solutions. AI-driven picture analysis enables real-time weed detection and mapping, whereas UAVs and robotic sprayers target affected areas rather than administering herbicides uniformly. According to studies, precision weed control systems can cut pesticide consumption by 70-90% using selective spraying technologies like "see-and-spray" systems while still providing efficient weed control (Vijayakumar *et al.,* 2025). Furthermore, robotic spot-spraying can minimize herbicide consumption by 35-65%, depending on weed density, considerably reducing environmental damage and expenses (Rahimi *et al.,* 2025). These technologies help boost operational efficiency by lowering labor requirements and optimizing resource utilization.

Herbicide resistance monitoring

A countrywide monitoring system that incorporates GIS and molecular diagnostic technologies is critical for early discovery and successful management of herbicide-resistant weeds. Geographic Information Systems (GIS) provide geographical mapping of resistance hotspots and tracking of weed spread across regions, thereby facilitating targeted treatments and policy decisions. For example, web-based mapping platforms have been used to visualize the spread of resistant weed populations and assist management techniques (Panozzo *et al.,* 2015). A national monitoring system that combines GIS and molecular diagnostic technologies is critical for detecting herbicide-resistant weeds early and managing them effectively. Geographic Information Systems (GIS) allow for the spatial mapping of resistance hotspots as well as the tracking of weed spread throughout regions, hence facilitating targeted treatments and policy decisions. Web-based mapping technologies, for example, have been used to visualize the spread of resistant weed populations and inform management tactics (Panozzo *et al.,* 2015).

Extension and farmer training

Improving extension services and farmer education is critical to increasing the adoption of sustainable agriculture techniques. Participatory initiatives, such as Farmer Field Schools (FFS), have been particularly beneficial in improving farmers' knowledge, skills, and decision-making abilities. Farmers participating in FFS are 45-48% more likely to adopt sustainable practices than non-participants, indicating considerable increases in technology adoption (Jabbar *et al.,* 2022). Similarly, studies show that adoption rates for certain practices after FFS instruction surpass 70-90% (Nyayiera *et al.,* 2025). FFS initiatives have touched 10-15 million farmers worldwide, indicating their significant impact on agricultural innovation (FAO, 2026). As a result, boosting extension services through FFS can significantly expedite the adoption of sustainable weed control practices.

Table 2. Key Research Gaps and Future Priorities

Research Gap	Future Priority
Seed bank ecology	Long-term studies
Biological control	Bioherbicide development
Resistance mechanisms	Molecular research
Climate change	Predictive modeling
Digital tools	AI-based systems

CONCLUSION

Weed science research in Malaysia has made significant progress, particularly in understanding weed ecology and devising herbicide-based and integrated control plans. However, the overwhelming reliance on herbicides, which account for around 83% of total pesticide use, has expedited the evolution of resistant weeds such as Eleusine indica and weedy rice, raising serious sustainability concerns. Invasive species and chemical residues provide additional threats to agroecosystems. Future research should focus on ecological weed management, precision technology that can minimize herbicide use by up to 35–65%, and stronger extension systems to increase farmer uptake. Sustainable weed control is consequently critical for long-term productivity and environmental resilience.

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REFERENCES

Adhikarya, R. 1995. Strategic extension campaign: a participatory-oriented method of agricultural extension. p. 209. Available at: https://www.cabidigitallibrary.org/doi/full/10.5555/19951812466

Ahmad, S.N.I.S.S., Juraimi, A.S., Che'ya, N.N., Su, A.S.M., Roslim, M.H.M., Noor, N.M. and Motmainna, M. 2025. Application of hyperspectral imaging to identify spectral signatures of grass weeds in rice at early stages: a review. *Front. Agric. Sci. Eng.* 12(4):763-778.

Arora, K. 2025. Plant-based bioherbicides in weed management: a review of efficacy, challenges, and future prospects. *J. Adv. Fut. Res.* 3(6):101-103.

Babu, C.V. and Ramesh, B. 2025. Microbial-based herbicides for sustainable agriculture: a review. SSRN 5087053. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5087053

Bzour, M.I.Y. 2020. Investigation of imidazolinone herbicide towards weedy rice (*Oryza sativa* L.) and effects of its residual concentration in soil. Ph.D. diss., Univ. Malaya, Malaysia.

Chemiseed. 2025. The role of leguminous plants: nature's powerful soil fertility boosters for Malaysian farms. Chemiseed Blog. Available at: https://chemiseed.com/blogs/soil-health-sustainability-1?srsltid=AfmBOoo7vYSs0o3ak8mHfUxoXcYQgKzJRKF50FDLCLkluEkz0ToNmJ3y

Crowley, M.Z. 2020. Foreign labor shortages in the Malaysian palm oil industry: impacts and recommendations. *Asian J. Agric. Dev.* 17(2):1–18.

Das, T.K., Behera, B., Nath, C.P., Ghosh, S., Sen, S., Raj, R., Ghosh, S., Sharma, A.R., Yaduraju, N.T., Nalia, A. and Dutta, A. 2024. Herbicides use in crop production: an analysis of cost-benefit, non-target toxicities and environmental risks. *Crop Prot.* 181:106691.

Dewi, Y.A., Yulianti, A., Hanifah, V.W., Jamal, E., Sarwani, M., Mardiharini, M., Anugrah, I.S., Darwis, V., Suib, E., Herteddy, D. and Sutriadi, M.T. 2022. Farmers' knowledge and practice regarding good agricultural practices (GAP) on safe pesticide usage in Indonesia. *Heliyon* 8(1).

Dilipkumar, M., Chuah, T.S., Goh, S.S. and Sahid, I. 2020. Weed management practices in Malaysia. *Crop Prot.* 134:104–112. https://doi.org/10.1016/j.cropro.2017.08.027

FAO. 2026. Global Farmer Field Schools Platform. Food Agric. Organ. United Nations. Available at: https://www.fao.org/farmer-field-schools/overview/en/

Fernando, M. and Shrestha, A. 2023. The potential of cover crops for weeds management. *Plants* 12(4):752.

Goh, Y.K., La, C.H., Mahamooth, T.N., Gan, H.H., Goh, Y.K. and Goh, K.J. 2014. Chemical control of Mucuna bracteata DC. ex Kurz. *Oil Palm Bull.* 68:16–24.

Gu, C., Bastiaans, L., Anten, N.P., Makowski, D. and Van der Werf, W. 2021. Annual intercropping suppresses weeds: a meta-analysis. *Agric. Ecosyst. Environ.* 322:107658. https://doi.org/10.1016/j.agee.2021.107658

Hasan, M., Ahmad-Hamdani, M.S., Rosli, A.M. and Hamdan, H. 2021. Bioherbicides: an eco-friendly tool for sustainable weed management. *Plants* 10(6):1212.

Hossain, M. and Begum, M. 2016. Soil weed seed bank: importance and management for sustainable crop production – a review. *J. Bangladesh Agric. Univ.* 13(2):221–228.

Islam, A.K.M.M., Karim, S.M.R., Kheya, S.A. and Yeasmin, S. 2024. Unlocking the potential of bioherbicides for sustainable and environment friendly weed management. *Heliyon* 10(16):e36088.

Ismail, A. 2013. The effect of labor shortage in the supply and demand of palm oil in Malaysia. *Oil Palm Ind. Econ. J.* 13(2):15–26.

Jabbar, M.A., Rahman, M.M. and Hossain, M.S. 2022. Impact of farmer field schools on adoption of sustainable agricultural practices in developing countries. *J. Agric. Ext.* 26(3):45–58.

Jones, E.A.L., Austin, R., Dunne, J.C., Cahoon, C.W., Jennings, K.M., Leon, R.G. and Everman, W.J. 2023. Utilization of image-based spectral reflectance to detect herbicide resistance. *Weed Sci.* 71(1):11–21. doi:10.1017/wsc.2022.68

Joseph, D.D., Marshall, M.W. and Cutulle, M. 2024. The international herbicide-resistant weed database. *Agric. Sci.* 15(8). Available at: https://www.scirp.org/reference/referencespapers?referenceid=3790862

Juyal, V. 2025. Global bioherbicides market size, share, and trends analysis report. Available at: https://www.databridgemarketresearch.com/reports/global-bioherbicides-market