OPEN ACCESS

Haya: The Saudi Journal of Life Sciences
Abbreviated Key Title: Haya Saudi J Life Sci
ISSN 2415-623X (Print) | ISSN 2415-6221 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Review Article

Herbicide Strategies for Weed Control in Rice Cultivation: Current Practices and Future Directions

Rida Pervaiz[1], Rania Baloch[1], Muhammad Awais Arshad[2], Rana Nadeem Abbas[2*], Nimra Shahzad[1], Muhammad Hamid[3], Zahra Batool[3], Muhammad Salman Maqbool[3], Adeel Masih[3], Abdul Salam[3], Mohammad Munir Akbar[3]

[1]Department of Botany, Faculty of Sciences, University of Agriculture Faisalabad, Pakistan
[2]Department of Agronomy, Faculty of Agriculture, University of Agriculture Faisalabad, Pakistan
[3]Department of Chemistry, Faculty of Sciences, University of Agriculture Faisalabad, Pakistan

DOI: 10.36348/sjls.2024.v09i04.004 | **Received:** 11.03.2024 | **Accepted:** 15.04.2024 | **Published:** 23.04.2024

***Corresponding author:** Rana Nadeem Abbas
Department of Agronomy, Faculty of Agriculture, University of Agriculture Faisalabad, Pakistan

Abstract

Rice, as a staple food for more than half of the world's population, plays a crucial role in global food security. However, weed competition poses a significant challenge to rice cultivation, affecting yield and quality. To address this challenge, rice farmers have increasingly turned to chemical herbicides as a cost-effective alternative to labor-intensive manual weeding. This review paper explores the current practices and future directions in herbicide strategies for weed control in rice cultivation, with a specific focus on diverse approaches adopted in various agro-ecological regions, particularly in Pakistan. The paper begins by highlighting the importance of rice cultivation in global agriculture and the economic significance of the crop, emphasizing the need for effective weed management to ensure sustainable production. It discusses the impact of labor shortages and rising labor costs on weed control practices, driving the adoption of chemical herbicides, especially in direct-seeded rice cultivation. Additionally, the review underscores the importance of integrated weed management systems, which combine cultural practices, targeted herbicide applications, and legislative measures to optimize crop productivity while minimizing environmental impact. Furthermore, the paper evaluates the efficacy of different herbicides and their timing of application in managing weeds and maximizing rice yield. It synthesizes findings from recent studies to provide insights into the effectiveness of pre-emergence and post-emergence herbicides, as well as their impact on weed-crop competition and overall crop health. By analyzing the strengths and limitations of existing herbicide strategies, the review identifies opportunities for innovation and improvement in weed management practices. Overall, this review paper offers a comprehensive overview of herbicide strategies for weed control in rice cultivation, highlighting the need for sustainable and integrated approaches to address weed challenges while ensuring food security and environmental sustainability in rice-producing regions.

Keywords: Rice Cultivation, Weed Management, Herbicide Strategies, Integrated Weed Management, Herbicide Efficacy, Weed-Crop Competition, Sustainable Agriculture, Pre-Emergence Herbicides, Post-Emergence Herbicides, Herbicide Timing.

Copyright © 2024 The Author(s): This is an open-access article distributed under the terms of the Creative Commons Attribution **4.0 International License (CC BY-NC 4.0)** which permits unrestricted use, distribution, and reproduction in any medium for non-commercial use provided the original author and source are credited.

INTRODUCTION

Rice constitutes the reproductive structure of the *Oryza sativa* grass species, commonly known as Asian rice, or to a lesser extent, *Oryza glaberrima*, referred to as African rice. This crop holds considerable importance as a primary cereal crop and serves as a fundamental dietary component for approximately 50% of the global populace (Liu *et al.*, 2014). Cultivated across roughly 114 nations, the majority of which belong to developing regions in Asia and Africa. Consequently, any factor posing a threat to yield levels exerts a substantial influence on these economies. In the international rice market, the production for the 2022-23 period experienced a reduction of 2.3 million tonnes, resulting in a total of 512.4 million tonnes (milled basis). Despite the decline, this production level still ranked second only to the record set in the previous year. The primary contributors to this downward revision in production are India, Bangladesh, and the European Union. On the other hand, the projected global consumption and residual use for 2022-23 have undergone a slight increase, reaching a record high of 518.7 million tonnes. As for global ending stocks, it is anticipated that they will amount to 178.5 million tonnes in 2022-23, which is 4.2 million tonnes lower than the previous forecast. This marks the third consecutive year of decline in global ending stocks (USDA, United States Department of Agriculture, 2022-23). Rice holds significant economic value as a cash crop, following wheat. Its production is composed 34% fine or basmati types and 66% coarse types. Rice contributes approximately in the agricultural sector to the country's GDP. In the 2021-22 period, rice cultivation spanned across 3,537 thousand hectares, reflecting a 6.1 percent increase compared to the previous year's 3,335 thousand hectares. Notably, the production of rice reached a record high marking increase from the previous year's production. Over the past few years, the area allocated to rice cultivation has shown a consistent upward trend (Government of Pakistan, 2022).

As a consequence of labor shortages and escalating labor costs, rice farmers have been compelled to adopt alternative methods of weed control, moving away from labour-intensive manual weeding. One such alternative is the utilization of chemical herbicides. In the context of direct-seeded rice (DSR) cultivation, efficient herbicide measures assume critical importance, with chemical herbicides being deemed essential for this purpose (Farooq *et al.*, 2011). The increasing popularity of DSR has led to a rise in the use of weedicides (Naylor, 1994). However, the application of weedicides can vary within the same area, influenced by factors such as weed species, population, soil composition, and prevailing climatic conditions (Williams *et al*., 2005). The acceptance of herbicides is contingent upon their compatibility with the surrounding environment. While hand weeding represents an effective method of herbicide application, the diminishing rural labour force poses challenges to its widespread implementation.

In various agro-ecological regions of Pakistan, diverse strategies for weed management are implemented to address the challenges posed by weeds and enhance crop productivity and profitability (Khaliq *et al.*, 2013; Siddiqi *et al.*, 2014). The adoption of improved cultural practices plays a significant role in conventional weed management. These practices include tight, higher crop densities, utilization of cover crops, intercropping, along with their integration (Hanif *et al.*, 2017). In Pakistan, effectively managing weeds requires the adoption of advanced weed control techniques. These approaches may include targeted and site-specific weed management, variable rate application of herbicides based on soil conditions and weed distribution, harvesting of weed seeds, utilizing predation and microbial decay to destroy weed seeds, integrating nano-herbicides, and deploying optical spraying technologies. Furthermore, implementing quarantine measures and enacting legislation can play a crucial role in preventing the introduction of invasive plant species and enhancing the effectiveness of existing weed management strategies (Bajwa *et al*., 2016).

An essential component of a successful weed management program is the identification and comprehension of the key period of weed-crop competition (Swanton and Weise, 1991). The time of weed emergence, weed species, weed density, environmental conditions, and management techniques are some of the variables that affect this important phase in different crops (Shehzad *et al.,* 2011). The duration during which the crop must be kept free of weeds in order to keep production losses from rising above a particular threshold level is referred to as the crucial period for weed control (Weaver and Tan, 1983). For efficient weed management planning and a knowledge of the dynamics of interactions between weeds and crops, it is essential to identify the important period of weed-crop competition (Weaver and Tan, 1987; Mubeen *et al.,* 2009). Determining the critical period of weed-crop competition and identifying weed thresholds are essential elements of a comprehensive integrated weed management system (Jones and Medd, 2000). These elements help farmers decide whether or not to apply herbicides (Fleck *et al.*, 2002; Portugal and Vidal, 2009). Manual, mechanical, or chemical techniques are the main means of weed control. The first alternative, hand weeding, involves a lot of labor. Depending on the frequency of weeding treatments, it has been estimated that manual weeding in rice systems requires 173 to 376 person-hours per hectare. Despite the farmers underlying interest, mechanical weeding tools whether powered by people, animals, or engines are not generally available in African rice systems (Ogwuike *et al*., 2014).

Physical (manual and mechanical), cultural, biological, and chemical strategies are among the many used to control weeds. In agricultural systems that are less developed, physical approaches are frequently used. Chemical control is currently the main weed management strategy used in rice farms. Chemical weed management is regarded as the most successful, time-efficient, and cost-effective strategy when compared to other weed control techniques, despite some environmental and crop quality concerns. The main chemical agents, known as herbicides, usually target numerous weed species, each of which has varied degrees of efficiency (Vangessel *et al*., 2000). In agriculturally advanced nations, herbicides are extensively used to effectively manage weed populations and maintain sustainable agricultural practices. However, the rise of herbicide-resistant weed species (Torra *et al*., 2010), rising costs, and environmental concerns (Sanyal and Shrestha, 2009) have prompted producers to seek ways to minimize herbicide usage. Consequently, integrated weed management strategies are being devised to improve the effectiveness of herbicides.

© 2024 | Published by Scholars Middle East Publishers, Dubai, United Arab Emirates

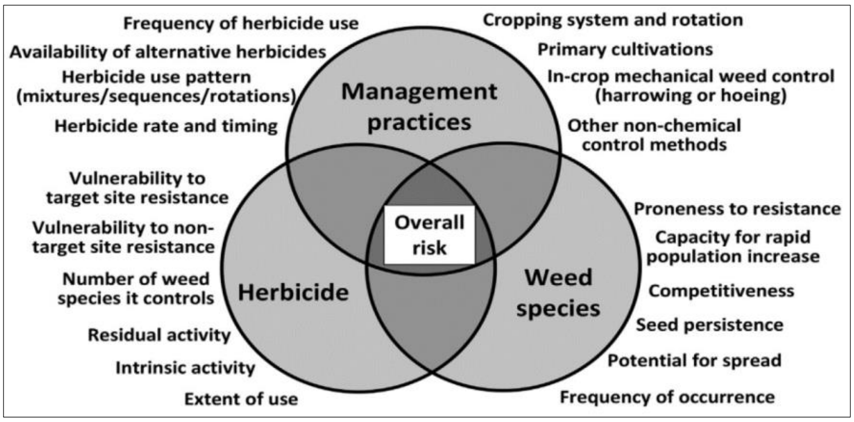

Figure 1: The assessment of resistance risk to the main weeds of rice crops (Calha *et al*., 2022).

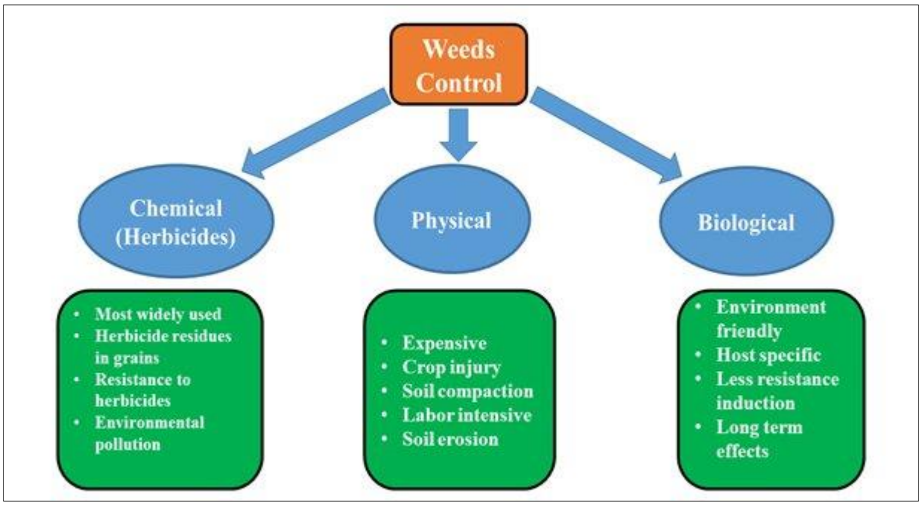

Figure 2: Flow sheet diagram of various weed control approaches, this figure was uploaded by Muhammad Tauseef Jaffar (Rehman *et al*., 2023)

In the context using post-emergence herbicides, it is imperative that the herbicides employed in the treatment of crops to establish, subsequently translocate to specific, thereby inducing. However, the waxy cuticle found on numerous weed species tends to repel spherical water droplets due to their high surface tension. Consequently, the inclusion of adjuvants in the application process has emerged as a crucial practice for enhancing herbicide efficiency. Adjuvants possess the capacity. This perennial adjuvant belongs to the family Amaranthaceae and exhibits adaptability to diverse soil types. It primarily spreads through adventitious rooting from stem nodes and roots, as its seed production is limited and the seeds produced are typically non-viable.

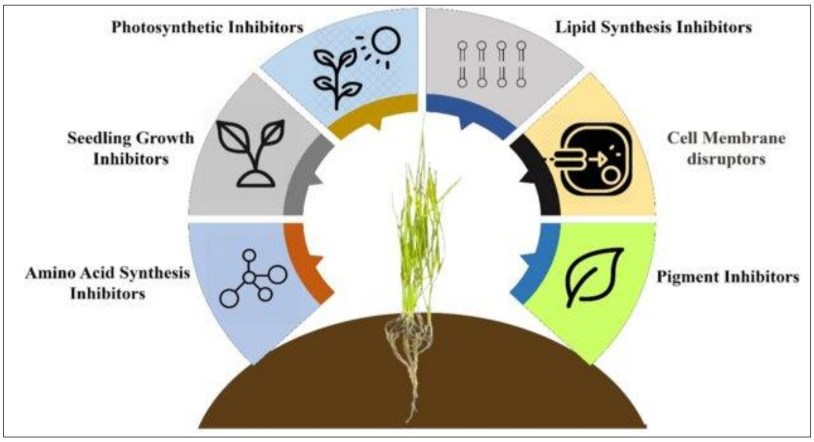

Figure 3: Possible mechanisms of chemical herbicide, this figure was uploaded by Muhammad Tauseef Jaffar (Rehman *et al.*, 2023).

A diverse range is recommended for weed control in rice cultivation. Among the recently introduced and registered herbicides are bispyribac sodium (sold as Clover) and ethoxy sulfuron ethyl (marketed as Sunstar gold). herbicides belong to the pyrimidinyl (thio) benzoate and sulfonylurea chemical groups, respectively. They exhibit effectiveness the recommended dosage mentioned on the product label. The foliage and roots of plants absorb the selective and systemic herbicide bispyribac sodium. It functions by preventing the acetolactate synthase (ALS) enzyme system from functioning. Ethoxy sulfuron ethyl, on the other hand, is an ALS inhibitor that also hampers the activity of acetohydroxyacid synthase. Upon absorption and translocation within the plants, both herbicides disrupt amino acid synthesis, resulting in the rapid inhibition of stem, leaf, and root growth. Consequently, affected weeds experience complete death within approximately seven days after herbicide application. *Alternanthera philoxeroides,* native to northeastern Argentina, has thrived in various climates worldwide, including tropical, subtropical, and temperate regions, adapting to both aquatic and terrestrial environments. Despite its origin, it has become an invasive weed in neighboring Brazil (Barreto and Torres, 1999). This plant presents significant challenges in around 30 countries, including Australia, the United Kingdom (Arthington and Mitchell, 1986), the United States (Rhodes, 1983), and numerous Asian countries like China (Gunasekera and Bonilla, 2001).

In Pakistan, as in many Asian countries, the traditional method of rice plantation involves transplanting. In this conventional approach to rice establishment, a nursery is initially prepared on raised beds. After reaching an age of around 30 to 35 days, the seedlings from the nursery are transplanted into a puddled and flooded field (Ehsanullah *et al.*, 2007). The nursery can be established using different techniques such as the wet bed method, dry bed method, or daab method. The transplanting method of rice cultivation offers several advantages. It creates a favorable environment for crop growth and effectively suppresses weed growth by submerging them under standing water, thus preventing light from reaching the weeds (Rao *et al.*, 2007; Farooq *et al.*, 2011). However, it is important to note that the transplanting method is labor-intensive, time-consuming, and requires a significant amount of water for the establishment of rice plants (Bouman *et al.*, 2007).

In later-emerging weeds become a significant issue during a crucial period of weed-crop competition. To address this issue effectively, it is crucial to utilize pre-emergence or post-emergence herbicides, or a combination of both, to reduce weed interference with the crop. In transplanted rice necessitates this approach helps in suppressing the growth and development of weeds throughout the rice cultivation cycle, thereby reducing competition for resources and optimizing crop yield. Glyphosate, a non-selective herbicide, possesses broad-spectrum capabilities and is commonly employed in non-agricultural settings to manage the growth of newly emerging weeds, its herbicidal properties were initially discovered. Glyphosate is also utilized for weed suppression in transplanted rice by means of pre-planting spray application.

Since glufosinate ammonium functions as a contact herbicide, its effects are confined to the specific areas of plants that have been exposed to the spray. This herbicide has been utilized in non-agricultural settings to manag, and broadleaf weeds), glufosinate ammonium to degradation by microorganisms and does not exhibit residual activity. As a non-volatile salt containing a phosphorus-based amino acid, there is limited information available regarding its application as a pre-plant treatment in transplanted rice. Halosulfuron methyl, an herbicide employed after the emergence of plants, is utilized for the purpose of managing sedges and various other types of weeds. This particular herbicide falls under the category of sulfonyl urea herbicides. It effectively inhibits the growth of Cyperus and reduces the viability of its tubers. Additionally, halosulfuron has been found to effectively control purple nutsedge and other challenging-to-manage weed species. The utilization has demonstrated efficacy in weed control for rice cultivation, without causing any loss in crop yield. Simultaneously, combination of herbicides has the potential to mitigate herbicide resistance. However, as the crop progresses, particularly under UPTR (upland rice) conditions, there is an increase.

Effective weed management strategies are crucial for optimizing rice cultivation, given its significant economic and nutritional importance globally. The adoption of alternative weed control methods, such as chemical herbicides, has become increasingly prevalent, particularly in response to labor shortages and escalating labor costs. However, the application of herbicides must be carefully managed to minimize environmental impacts and ensure sustainable agricultural practices. Additionally, integrated weed management approaches, incorporating physical, cultural, biological, and chemical strategies, are essential for enhancing herbicide efficacy and minimizing herbicide resistance. The identification of the critical period of weed-crop competition and the implementation of targeted weed control measures are vital components of successful weed management programs. Further research is needed to explore innovative weed control techniques and enhance our understanding of weed-crop interactions, ultimately contributing to the development of more efficient and sustainable rice cultivation practices.

Weed Competition Challenges in Rice Cultivation

More than half of the global population primarily depends on rice as a staple food source. However, the crop faces various challenges from both

© 2024 | Published by Scholars Middle East Publishers, Dubai, United Arab Emirates

living organisms (biotic) and environmental factors (abiotic). Among these challenges, weed competition poses a significant obstacle to achieving high yields in rice cultivation. Rice plants and weeds struggle for limited resources including water, light, nutrients, and space. To address this issue, there are several weed control methods available, since they function quickly and are inexpensive, herbicides are becoming more and more prevalent in modern rice production. Herbicides offer beginning, allowing the crop to establish a strong start and outcompete the weeds. A diverse array of herbicides is accessible in the market, emphasizing the significance of assessing their efficacy through testing various dosages and application timings. However, existing research in this area is not sufficient and conclusive. The goal of this chapter is to present an overview of noteworthy and educational studies and study findings about the quantity and time of herbicide use in rice farming, both nationally and internationally. Nutrient absorption was notably higher in directly seeded rice crops in contrast to weeds, particularly when employing manual weeding and applying pendimethalin at 1.0 kg/ha alongside anilophos at 0.4 kg/ha.

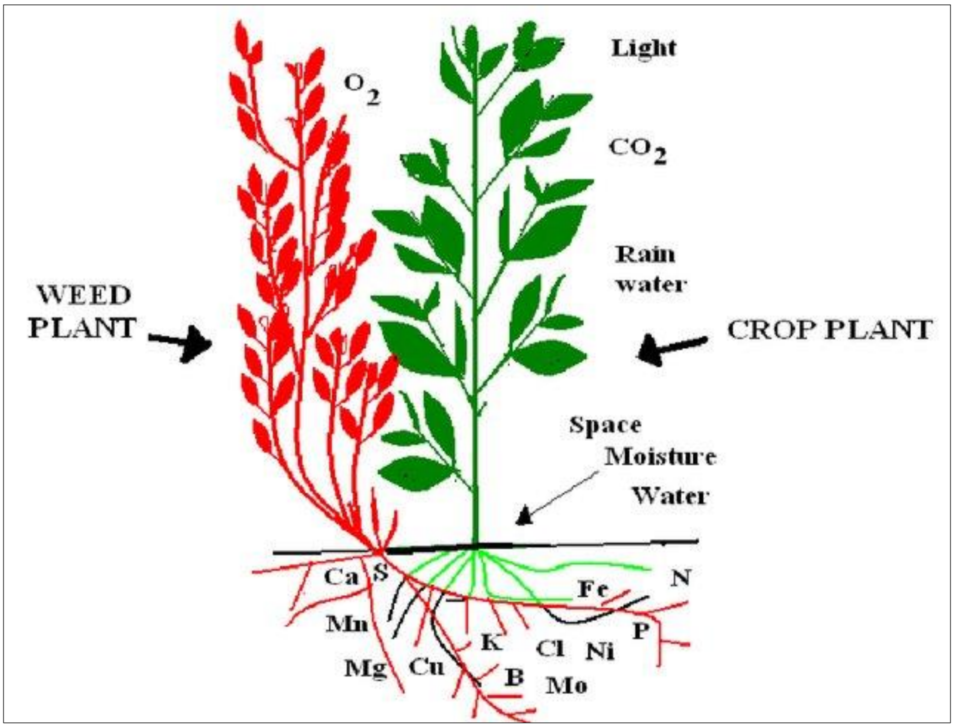

Figure 4: Weed plant giving tough time to the main crop plant for growth in different ways for different resources. This figure was uploaded by Shah Jahan Leghari (Leghari *et al*., 2015)

Impact of Herbicides on Germination, Seedling Growth, and Yield of Rice

The application of herbicide before the emergence of rice had a detrimental impact on its germination. Specifically, the herbicide pendimethalin caused a 45% decrease in rice germination compared to the control group. On the other hand, pretilachlor had the least inhibitory effect, with only a 30% reduction in rice germination. Regardless of when they were applied, all herbicides also hindered the growth of rice seedlings. They resulted in a reduction in root length and a decrease in leaf score by 18-36% compared to the control group. Rice plants treated with oxyfluorfen experienced a notable decrease in plant height compared to those treated with metamifop, irrespective of the dosage applied. This reduction can be attributed to oxyfluorfen's phytotoxic effects on rice plants during their early vegetative stage. The application of acetochlor as a pre-emergence herbicide, and ethoxsulfuron ethyl and bispyribac sodium as post-emergence herbicides, had a milder adverse impact on young rice seedlings. Among the herbicides evaluated, penoxsulam exhibited the lowest seedling mortality rate around 4%, followed by oxadarigyl, bispyribac sodium, and ethoxysulfuron ethyl, suggesting their relatively lower phytotoxicity to rice seedlings. Throughout the study period, there were no significant signs of rice injury observed in any herbicide treatment. It was found that bispyribac sodium was safe to use in rice cultivation. At 7 days after treatment (DAT), bispyribac sodium caused less than 10% foliar injury compared to the untreated control. However, by 21 DAT, the injury had fully recovered and was comparable to the non-treated control, with no adverse effect on kernel yield. Bispyribac-sodium demonstrated comparable efficacy to higher doses and twice hand weeding in promoting tiller and panicle production, surpassing the application of butachlor. Weed-free plots exhibited the highest number of panicles per square meter.

Comparative Analysis of Herbicidal Treatments for Weed Control in Aerobic Rice Cultivation

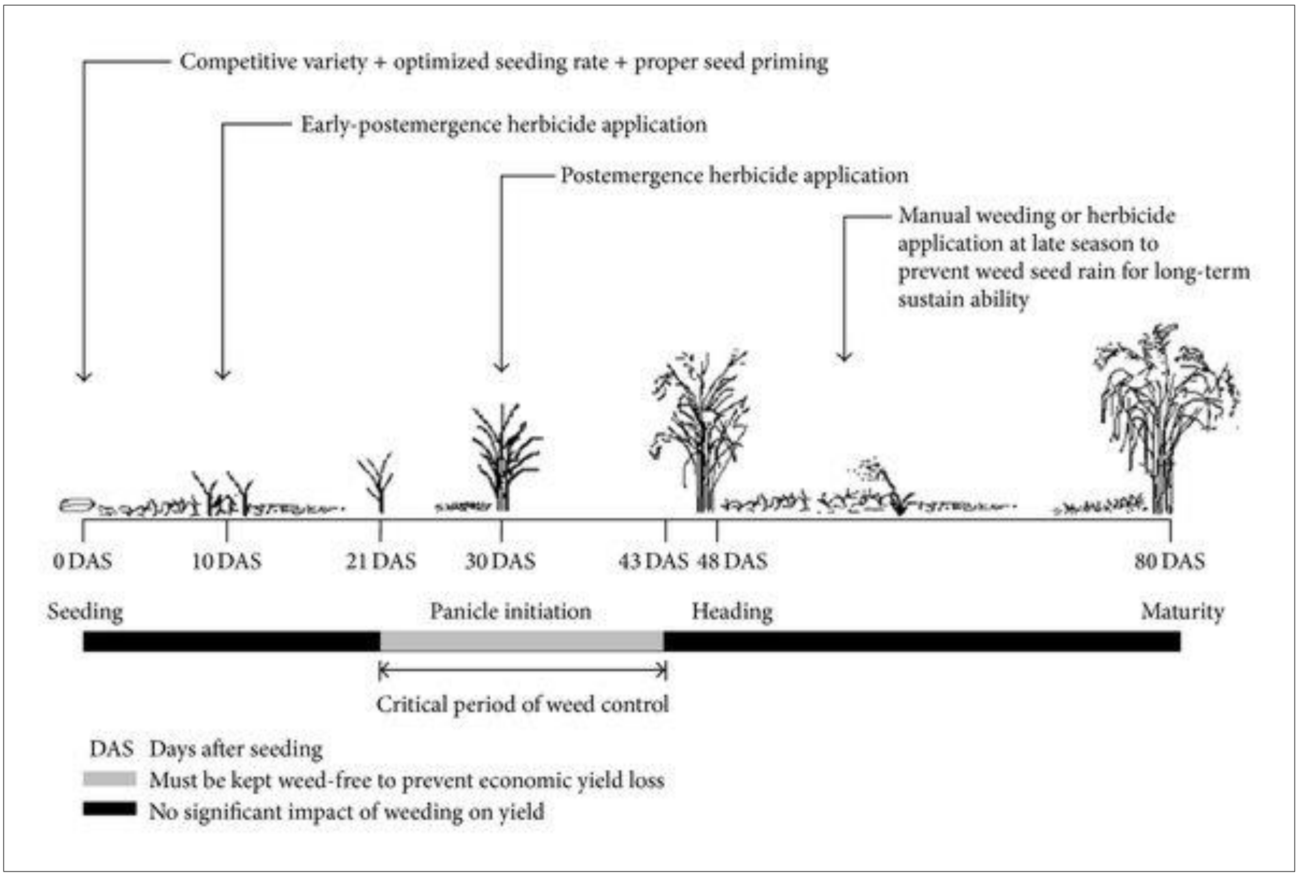

Figure 5: Integrated weed management schedule for aerobic rice production. Content available from The Scientific World Journal (Anwar *et al*., 2013)

In a recent study conducted by Kumar *et al.*, (2020), various herbicidal treatments were evaluated for their effectiveness in controlling weeds and their impact on grain yield in aerobic rice cultivation. Notably, plots maintained free of weeds exhibited the lowest weed population and weed dry weight, outperforming other herbicidal treatments significantly. The most successful weed control method was observed in the weed-free conditions, with a control rate of 100%. Following closely were treatments involving Pyrazosulfuron combined with manual weeding and Bispyribac, both achieving high control rates exceeding 80%. Regarding grain output, the weed-free plots recorded the highest average yield of aerobic rice, followed by plots treated with Pyrazosulfuron in conjunction with manual weeding. Conversely, plots with unrestricted weed growth demonstrated the lowest average grain yield, highlighting the critical importance of effective weed management practices in maximizing crop productivity. Ravikiran *et al.,* (2019) found that effective control of weeds was achieved through the application of penoxsulam at varying rates of 20, 25, and 30 g ha^{-1}, along with manual weeding or metsulfuron methyl + chlorimuron ethyl. By the 60th day after sowing (DAS), these treatments resulted in reduced total weed dry weight and improved weed control efficiency. The highest grain yield, reaching 3.23 tons per hectare (t ha^{-1}), was attained by applying penoxsulam at a rate of 25 g ha^{-1} between 10-15 DAS, followed by manual weeding between 35-40 DAS. Similarly, Kalaisudarson and Srinivasaperumal (2019) proposed a practical approach for rice farmers, suggesting the application of a preemergence herbicide, specifically bensulfuron methyl + pretilachlor at a rate of 0.66 kg ha^{-1} on the third day after transplanting (DAT), followed by a post-emergence herbicide, bispyribac sodium at a rate of 0.02 kg ha^{-1} on the thirty-first DAT. This recommendation takes into account the challenges associated with labor scarcity and the high costs of manual weeding in transplanted rice cultivation.

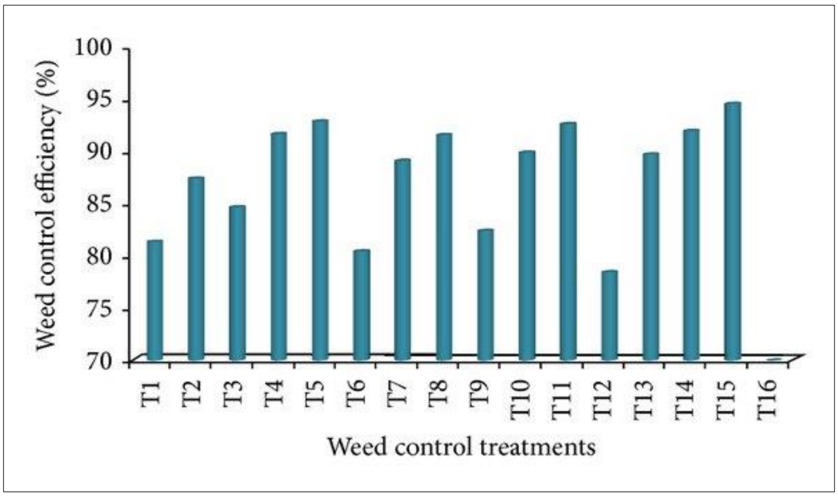

Figure 6: Weed control efficiency of different weed control treatments in aerobic rice variety AERON 1 (averaged over seasons). T1: pretilachlor/safener fb bentazon/MCPA; T2: pretilachlor/safener fb manual weeding; T3: pretilachlor/safener fb propanil/thiobencarb; T4: pretilachlor/safener fb propanil/thiobencarb fb bentazon/MCPA; T5: pretilachlor/safener fb propanil/thiobencarb fb manual weeding; T6: propanil/thiobencarb; T7: propanil/thiobencarb fb bentazon/MCPA; T8: propanil/thiobencarb fb manual weeding; T9: cyhalofop-butyl + bensulfuron; T10: cyhalofop-butyl + bensulfuron fb bentazon/MCPA; T11: cyhalofop-butyl + bensulfuron fb manual weeding; T12: bispyribac-sodium; T13: bispyribac-sodium fb bentazon/MCPA; T14: bispyribac-sodium fb manual weeding; T15: season long weed-free by manual weeding; T16: season long weedy (Anwar *et al*., 2013).

Evaluation of Herbicides for Weed Management in Transplanted Rice

According to a study by Singh *et al.*, (2018), the herbicidal treatment combining pendimethalin 38.7% CS followed by bispyribac-sodium demonstrated superior results, yield, and weed population control in transplanted. This particular treatment resulted in the highest plant height, measuring 101.82 cm, as well as tons per hectare. These results imply that the pendimethalin and bispyribac-sodium combination was more successful than the other herbicides tested in the study. According to Mahbub *et al*., (2017), their study examines the effectiveness of various herbicides, including Pyrazosulfuran ethyl, Metsulfuron methyl + Chlorimuron ethyl WP. Additionally, they compared the results with a weed-free plot and an unweeded control. The investigation focused on weed populations during both the Aman and Boro seasons of 2014-15, revealing the presence of two grasses, two sedges, and three broadleaves during the Aman season, and two grasses, two sedges, and two broadleaves during the Boro season. Notably, Cyperus difformis, Echinochloa crus-galli, Scirpus maritimus, and Monochoria vaginalis emerged as the predominant weeds in both growing seasons. Among the herbicide treatments, the application of Metsulfuron methyl + Chlorimuron ethyl 2% WP showed promising results.

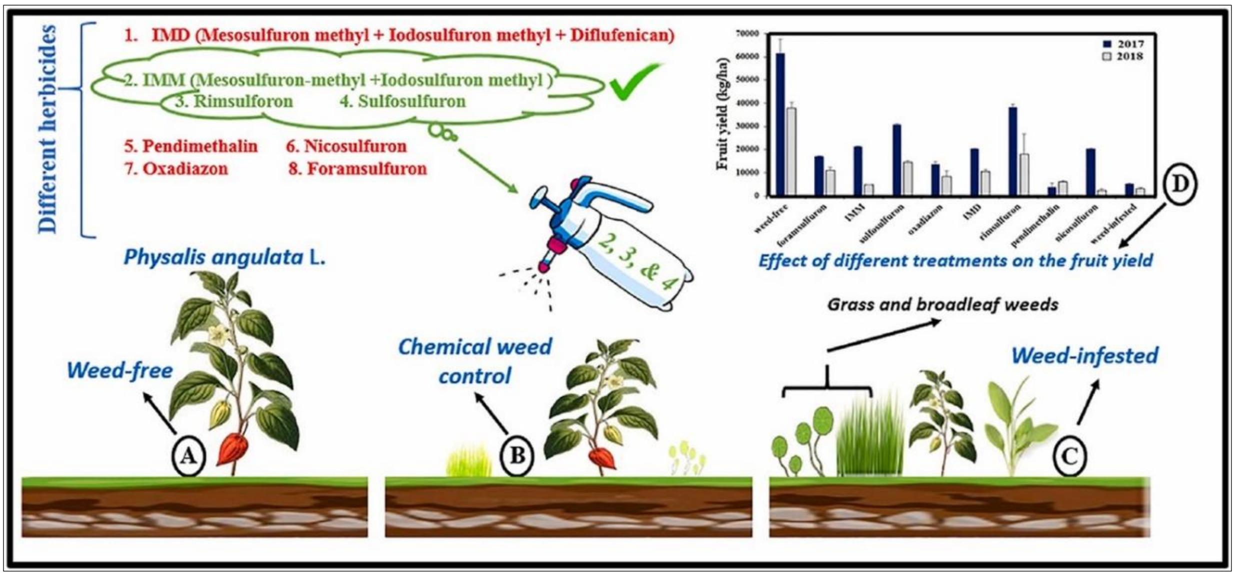

Figure 7: Evaluation of herbicides for selective weed control (Khodadadi *et al*., 2023).

According to Kishore *et al.,* (2016), in contrast to the weedy check (no weed control), chemical and mechanical weed control approaches produced outcomes that were superior). The lowest weed density, dry weight, and highest weed control efficiency (WCE) were achieved with these treatments. Furthermore, these interventions resulted in the highest panicle length, the greatest number of panicles per square meter, grain yields ranging from 30.40 to 32.60 quintals per hectare (q ha^{-1}), and 1000-grain weights. Among the treatments, the combination of two hand weedings (HW) showed comparable results of one hand weeding is done after applying butachlor. These treatments outperformed other weed control techniques used in weed management and agronomic parameters, resulting in the highest grain yield. Antralinaa *et al*., (2015) conducted a study, in order to determine the effects of various weed control techniques on rice yield, according to the findings, manual weed management produced similar effects. A separate study by Kashid *et al.,* (2015), they observed that applying oxyfluorfen at a rate of 0.150 and metsulfuron-methyl + chlorimuronethyl a rate of 0.004 kg/ha, enhanced weed control efficiency (91.08%) in rice. Additionally, this weed control measure resulted in improved yield-contributing characteristics and overall rice yield. According to Chowdhury *et al*., (2015), the pre-emergence herbicide Sunrice® 150WG demonstrated successful weed control and performed well. The maximum grain yield was obtained by using Sunrice® 150WG, which was 50.73% greater than the control 32.07% higher than one hand weeding (HW), 11.95% higher than two HW, and 5.25% higher than Topstar® 400SC-treated plots. In a research conducted various doses of the pre-emergence herbicide Pretilachlor were applied to Boro rice under different water management conditions. Their investigation revealed that the treatment receiving Pretilachlor at 125% of the recommended dose, while continuously flooded, exhibited the highest weed control efficacy of 65.75% at 60 days after treatment (DAT). Conversely, in Boro rice, the treatment receiving 75% of the recommended dose under field capacity demonstrated the lowest weed control efficacy at 54.76%.

Effectiveness of Herbicides and Manual Weeding on Weed Control and Rice Yield

According to Menon *et al.,* (2014), their observations revealed that the herbicide treatments control effective weeds by significantly reducing weed biomass. These treatments also resulted in high grain yield and favorable benefit-to-cost (B:C) ratios. The hand-weeded plots had the best weed control efficiency (97.1%), followed by the bispyribac-sodium treatment (93.6%). The hand-weeded plot also recorded a higher grain yield by applying different herbicides. According to Mamun *et al.,* (2012), Metsulfuron-methyl 20% WDG was examinedfor its efficacy in weed suppression. They discovered that using 80 g ha^{-1} of metsulfuron-methyl 20% WDG produced a weed control efficiency of above 80%. In addition, this treatment minimizes the quantity and dry weight of weeds, which ultimately increased rice production characteristics and grain output. According to a study by Pasha *et al.,* (2012), the most effective method of weed management involved using a herbicide followed by one round of manual weeding. This treatment also resulted in the maximum grain yield. In contrast, the control treatment, which did not receive any weed control measures, exhibited a high number of unfilled grain panicles and a lower panicle number per square meter, resulting in a 2505 kg /ha^{-1} grain output, which is the lowest.

Integrated Weed Management Strategies for Enhancing Rice Productivity

Affective weed control in direct-seeded rice (DSR) can be achieved through a combination of pre-emergence pendimethalin application with post-emergence seedling applications of bispyribac or azimsulfuron, Sole application of pendimethalin was found ineffective in suppressing the diverse weed species commonly found in DSR. Combining the pre-emergence pendimethalin application with either bispyribac or azimsulfuron post-emergence treatments resulted in significantly higher yields. Compared to sole application of Pendimethalin, the combination with bispyribac increased yield by 61.7%, while the combination with azimsulfuron increased yield by 8.42%. (Walia *et al.,* 2011). Herbicidal treatments proved significantly superior to the weedy check, where plots without weed control experienced over a 44% decrease in rice grain yield due to weed competition. The weed-free check plot yielded the highest grain output at 4.96 tons per hectare (t ha^{-1}) and exhibited an N-use efficiency of 62.0. Among the tested herbicides, metsulfuron methyl demonstrated the most effective suppression of prevalent weeds when applied at a rate of 8 g ha^{-1}, ten days after transplantation. This treatment showed an impressive 87.9% weed control efficiency and increased yield by 72%, similar to the check plot with no weeds. Tank-mix application of metsulfuron methyl + chlorimuron ethyl at rates of 4 + 6 g ha^{-1} (57.9) and chlorimuron ethyl at a rate of 8 g ha^{-1} (55.8), followed by metsulfuron methyl treatment (8 g ha^{-1}), exhibited the highest N-use efficiency (Saha and Rao, 2010).

© 2024 | Published by Scholars Middle East Publishers, Dubai, United Arab Emirates

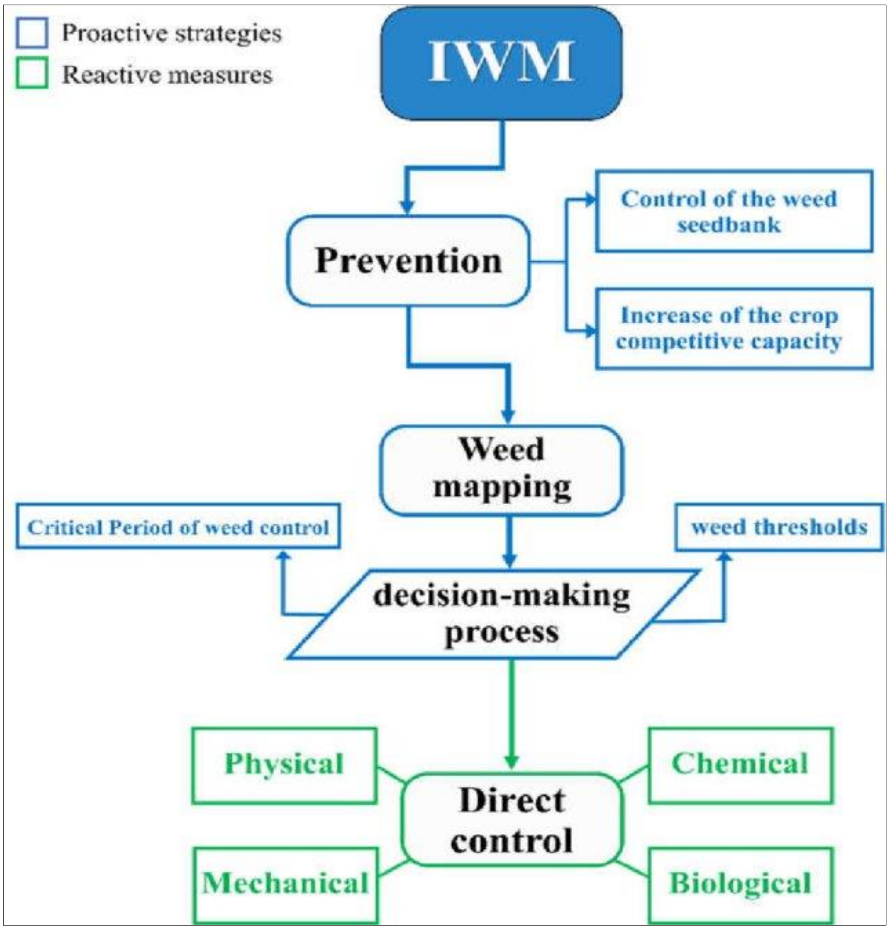

Figure 8: Proactive and reactive tactics of an Integrated Weed Management (IWM) strategy. At the base there is prevention, which should be combined with direct control (integration both intrapreventive methods and inter-preventive/direct ones) after an appropriate decision-making process closely linked to the specific weed flora (Scavo and Mauromicale, 2020)

Significant variations in grain yield were observed among different herbicidal treatments in transplanted wetland rice during the Aman growing season. The highest grain yield, reaching 4.08 tons per hectare (t ha^{-1}), was recorded in plots treated with butachlor, while the lowest yield was observed in plots treated with MCPA at recommended rate. This highlights the impact of herbicide choice on rice productivity in wetland cultivation. Additionally, effective weed management strategy involved applying bispyribac sodium at a rate after pre-emergence treatment with pendimethalin. Similarly, Bhagat *et al*., (2008) reported that a combination of pendimethalin as a pre-emergence treatment, followed by manual weeding at 30 days after sowing (DAS) and the use of Sesbania aculeate 2,4-D, led to a significant reduction in weed dry weight. These findings underscore the importance of tailored weed control practices for optimizing crop yield and quality (Bari *et al.*, 2010; Mahajan *et al*., 2009; Bhagat *et al*., 2008). The effectiveness of various herbicides, including butachlor, oxadiargyl, pyrazosulfuron ethyl, pretilachlor, Chlorimuron + Metsulfuron Methyl, and fenoxaprop-p-ethyl, was evaluated for weed control in transplanted summer rice. The results revealed a significant increase in rice grain yield under all weed management strategies compared to unweeded plots. These treatments also led to a substantial reduction in weed population and dry weight. Notably, uncontrolled weed growth resulted in a 49% reduction in crop yield. Among the herbicide treatments, the combination of pretilachlor as a pre-emergence treatment followed by paddy weeding, demonstrated the highest grain yield and weed control efficiency of 88%. The application of butachlor at a rate of 1 kg ha^{-1} three days after transplanting (DAT) and almix 20 WP at a rate of 4 g ha-1 twenty days after transplanting (DAT) resulted in enhanced weed control efficacy and grain production. The achieved grain yield of 3.17 and 3.5 tons per hectare (t ha^{-1}) was comparable to weed-free conditions when consistent weed management was maintained throughout the growing season. These findings underscore the importance of effective weed control strategies in optimizing rice productivity and minimizing yield losses (Rajkhowa *et al*., 2007; Mukherjee *et al*., 2007).

© 2024 | Published by Scholars Middle East Publishers, Dubai, United Arab Emirates

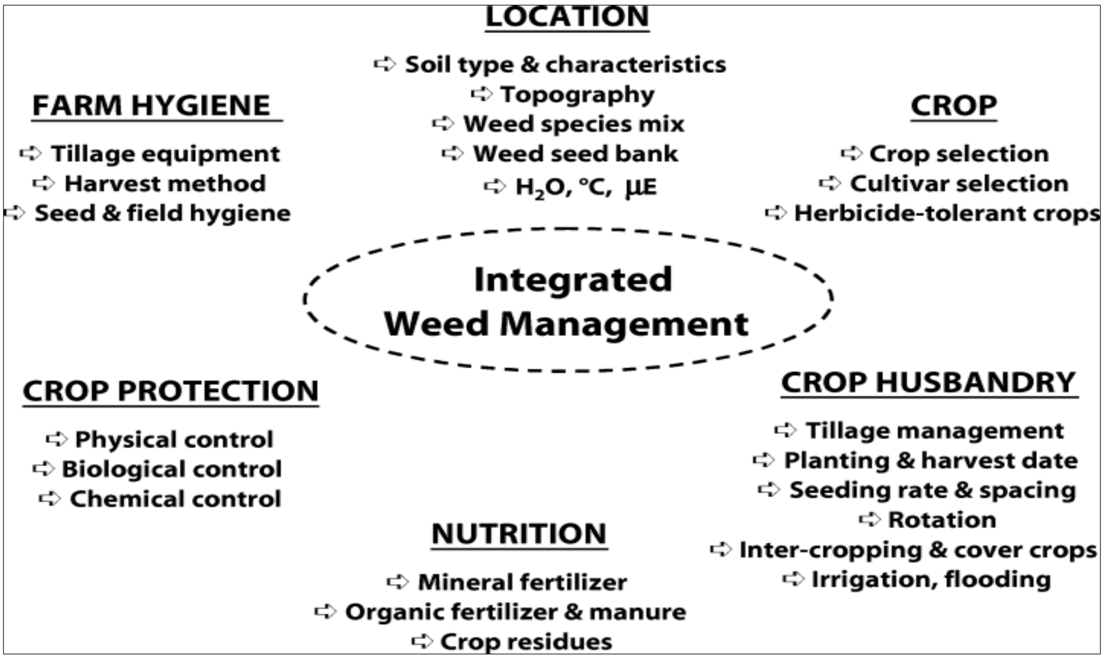

Figure 9: Integrated weed management (Zoschke and Quadranti, 2002)

Various levels of herbicide application and hand weeding techniques were assessed for their effectiveness in controlling weeds in transplanted Aman rice. The study revealed that the highest grain yield was achieved with the application of Rifit 500 EC at a rate of 1-liter ha-1, which was comparable to the yield obtained from manual weeding. Moreover, applying Rifit 500 EC at a slightly higher rate resulted in maximum profit, with a benefit-cost ratio of 1.55, the highest among all treatments. This suggests that utilizing Rifit 500 EC at the specified rate not only led to a significant increase in grain yield but also proved to be economically advantageous, offering a favorable return on investment (Rahman *et al*., 2007).

The effectiveness of specific pesticides in weed management in rice fields. Post-emergence herbicides such as azimsulfuron, penoxsulam, cyhalofop-butyl, and ethoxysulfuron were found to be more successful in controlling weeds compared to pre-emergence herbicides like pyrazosulfuron and oxadiargyl (Rao *et al*., 2007). Another investigation by evaluated three treatments—Ronstar, Machete, and Saturn to assess their impact on weed control and rice yield. The study reported that Ronstar treatment resulted in the highest grain yield compared to the weedy plot. Furthermore, in a separate experiment conducted in Nigeria, two treatments involving two hand weedings and the application of butachlor combined with cinosulfuron were compared to evaluate their effectiveness in weed management. The treatments were found to enhance plant vigor, height, dry matter, and rice grain production. In an experiment by Bali *et al.*, (2006), various herbicide combinations were assessed, including Anilophos + Ethoxy Sulfuron (0.312 + 0.015 kg ha^{-1}) applied 10 days after transplanting (DAT), and Metsulfuron-Methyl + Chlonimuron Ethyl + Butachlor applied 3 DAT followed by 21 DAT. These treatments yielded an average of 48.1 quintals per hectare (q ha^{-1}), respectively, which was comparable to the yield from two hand weedings performed at 20 and 40 DAT. Despite significantly increasing grain production by 67.6%, 54.4%, and 58.9%, respectively, compared to the control, these herbicide combinations also notably improved weed-control efficiency. In a study by Subramanian *et al.*, (2006), the impact of integrated weed management practices on weed control and yield in wet-seeded rice was examined. Their findings revealed that employing pre-emergence herbicides followed by one hand weeding at 125 days after transplanting (DAT) led to reduced weed density and dry weight. This integrated approach demonstrated higher weed control efficiency and yielded the highest yield attributes, resulting in a grain yield of 58.73 tons per hectare (t ha^{-1}).

According to Singh *et al.,* (2005), their study revealed that applying herbicides treatment, along with additional weedings after 4 and 8 weeks after sowing, resulted in the highest reduction in weed dry matter. Additionally, this weed control strategy led to the maximum yield per hectare. The specific treatment that achieved these results involved the application of butachlor, along with two hand weedings in the rice crop. According to the findings of Ranjit and Suwanketnikom (2005), both Anilofos and Bispyribacsodium were effective in reducing the expansion of rice weeds with narrow and broad leaves in comparison to the unweeded control. The study suggests that achieving a promising grain yield in rice can be accomplished by combining the use of Anilofos or Bispyribac-sodium in conjunction with additional mechanical or physical restraint techniques, such as manual weeding or other mechanical weed control techniques. Amarjit *et al.*, (2005) conducted a study revealing that manual weeding resulted in the lowest weed count and dry weight while also yielding the highest panicle weight, panicle weight per panicle, panicle yield, and panicle per panicle numbers. The most favorable yield and associated characteristics were achieved through the application of Anilophos + Ethoxysulfuron at a rate of 0.312 + 0.015 kg ha^{-1}, administered 10 days after transplanting (DAT). Compared to the weedy check, this treatment exhibited a remarkable 67.3% increase in yield, with yields comparable to those obtained through manual weeding practices.

Optimizing Weed Management Strategies in Direct-Seeded Rice: Impact of Herbicide Application Timing

Herbicides can be applied either before or after the emergence of weeds. A multitude of pre and post-emergence herbicides have undergone thorough testing and assessment to gauge their effectiveness in managing weeds in direct-seeded rice. In the context of Southeast Asia, Fentrazamide and a combination of fentraramide and propunil have proven to be effective in managing grasses and annual sedges in direct-seeded rice. These herbicides exhibited a broad spectrum of action, effectively controlling various weed grasses such as L. *chinensis* and E. *crus-galli,* sedges like C. *difformis* and F. *miliacea,* and broad-leaved weeds such as Monochoria vaginalis and *Ludwigia* sp. To optimize weed control, it is recommended to include herbicides in combination or mixture formulations in weed management programs. The concurrent use of pre-emergence herbicides has been identified as an effective method for controlling various weed types, ultimately boosting productivity in rainfed rice cultivation. In terms of efficacy, early post-emergence herbicide treatments have shown a substantial reduction in total weed density by 85-100% and biomass by 80-100%. However, late post-emergence treatments have comparatively lower effectiveness, resulting in a reduction of weed density by 32-50% and biomass by 40-62%.

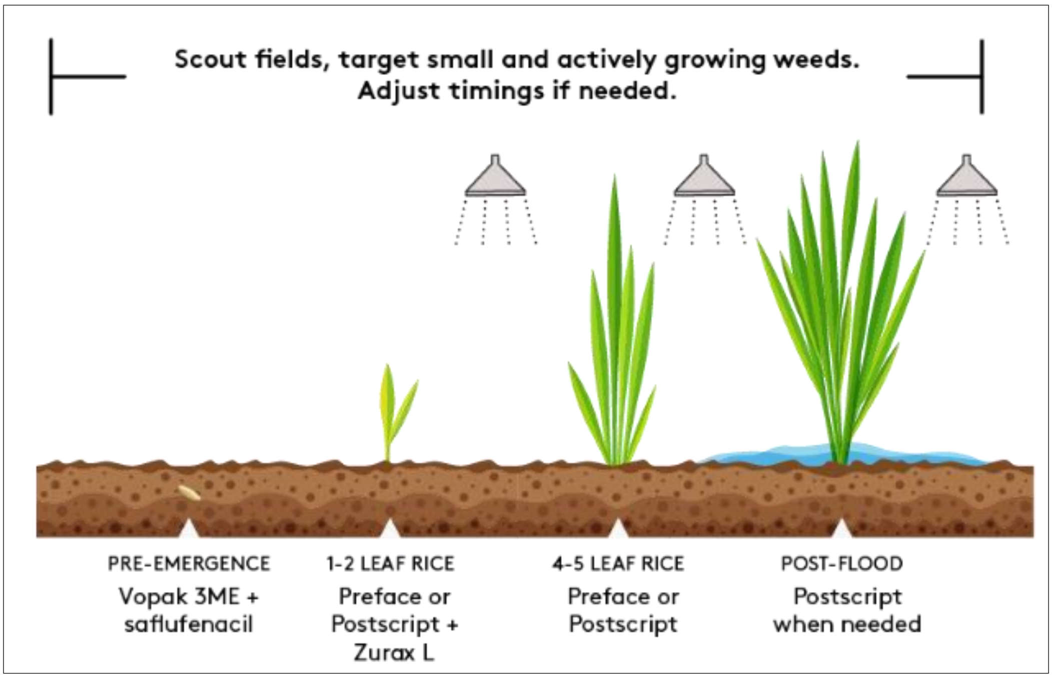

Figure 10: Herbicide application timing at different stages.

When the weed has one to two leaves, can serve as an effective alternative for weed control in transplanted rice. This option helps reduce weed infestation. Metamifop and Oxyflurofen demonstrated effective suppression of most grassy weeds, excluding L. *chinensis*. However, some sedges (C. *difformis*) and broad-leaved weeds (S. *zeylanica*) were observed in the plots at this stage. When Metamifop was applied at a relatively lower dose of 150 g ha^{-1}, it also exhibited good suppression of grassy weeds, except L. *chinensis*. At 45 DAS, there were no significant occurrences of grassy weeds in plots treated with Metamifop at ha^{1}, except for L. *chinensis*, a few sedges (C. difformis).

Optimizing Weed Control in Transplanted Rice: Insights from Recent Studies

According to Rahman *et al.*, (2019), they found that the least quantity of weeds and dry stuff in transplanted rice were observed when the rice at a depth of five seeds were sowed in cm, and Pendimethalin was applied at 1 day after sowing (DAS). One hand weeding at 20 DAS was done after that, and then Pendimethalin was applied once more right away. This combination of methods produced the least amount of dry matter and weeds,as well as the highest rice yield among the treatment combinations studied. Based on their findings, the researchers suggested that sowing the rice seeds at a depth of 5 cm, pendimethalin pre-emergence application, hand weeding after 3 weeks, and a further application of

© 2024 | Published by Scholars Middle East Publishers, Dubai, United Arab Emirates

Pendimethalin could be considered the best approach for effective weed control in transplanted rice. According to Naik *et al.*, (2018), their research showed that two hand weedings reduced weed dry weight and density. Additionally, this treatment demonstrated greater weed control effectiveness, yield characteristics, and a maximum grain yield of 5637 kg ha. Additionally, it resulted in a harvest index of 46.60% and a higher straw output of 6599.00 kg ha. Additionally, the two hand weeding treatment and the post-emergence application of conjunction with hand weeding at 40 days after transplanting (DAT) produced outcomes in terms of weed control, yield attributes, and grain yield that were comparable. Pendimethalin + Pyrazosulfuron Ethyl at a dosage of 920 g/ha as a pre-emergence treatment within 1 to 2 days after sowing (DAS), coupled with manual weeding at 20 DAS, followed by the application of halosulfuron at a rate of 35 g/ha as a post-emergence treatment at 35 DAS, proved effective in weed suppression and enhancing weed control efficiency. This treatment regimen notably enhanced the developmental traits and yield of directly seeded rice. Significant improvements were observed in variables such as productive panicles per square meter, grains per panicle, 1000-grain weight, and overall grain yield. It's noteworthy that this weed control approach did not cause any harm to the crops (Mishra *et al*., 2018). The effectiveness of different herbicide combinations in weed control and rice yield enhancement was investigated. It was found that pre-emergence applications of pendimethalin at a rate of 0.75 kg a.i ha-1 at 3 to 5 days after sowing (DAS), followed by a post-emergence application of Metsulfuron Methyl + Chlorimuron Ethyl, yielded results equivalent to the weed-free check. This herbicide combination led to the highest grain yield, net profits, and other relevant economic parameters, highlighting its effectiveness in weed control and its ability to enhance profitability in rice production (Hemalatha *et al*., 2018). According to Rangaraju study conducted in India in 2002, in dry-seeded rainfed rice, the impact of herbicide treatment and timing on weed flora and dynamics was examined. The outcomes demonstrated that weeds could be efficiently controlled by using either butachlor or thiobencarb. Additionally, it was discovered that these herbicides encouraged rice grain yield and the traits that contributed the most to yield. Nair *et al.* (2002) observed that the combination of one-hand weeding at 40 days after transplanting (DAT) with the application of Butachlor herbicide led to a considerably higher weed control efficiency. Additionally, this treatment produced plants that were longer, had the most effective tillers per hill, produced the most panicles per square meter, had the most grains per panicle, and had the highest grain weight per 1000 grains. A higher grain yield of rice was ultimately a result of these beneficial modifications. In the experiment conducted by Pathak *et al*., (2001), they compared different practices in rice cultivation, incorporating weed prevention techniques, water management, and seed treatment. They experimented with two seed treatment techniques: the standard method, which does not involve seed soaking, and the modified method, which involves applying 49.8 kg of potassium per hectare while seed is soaked in a solution of 40% KCl. Additionally, they assessed various water management techniques, such as intermittent irrigation and rainfed circumstances at 3 and 6 days. A comparison was made between weed control achieved with a dosage of 2 kg ha-1 butachlor and an alternative method. Interestingly, no significant variance in yield was observed between these two treatments. However, notable enhancements were noted in various growth parameters with the modified seed treatment, particularly in terms of the number of useful tillers and root volume, surpassing the standard approach. Notably, the application of butachlor significantly augmented the number of productive tillers, grain panicles per plant, and overall grain yield when contrasted with the untreated weedy control. Specifically, the butachlor spray led to a remarkable 23% increase in yield compared to the weedy control condition.

In their investigation involving transplanted rice variety P-33, both manual weeding and the use of Anilofos at a rate of 0.04 kg ha-1 significantly mitigated weed competition compared to the unmanaged control. Their findings revealed that manual weeding resulted in rice plants exhibiting the longest panicle, the highest number of tillers per hill, the tallest stature, the greatest dry matter content, and ultimately, the highest rice yield. Conversely, manual weeding demonstrated superior performance across these metrics compared to the application of Anilofos. (Laxminaryan and Mishra, 2001. The pre-emergence treatment of bensulfuron methyl at 3 days after transplanting (DAT) produced various favorable effects in transplanted rice, according to Samant's (2017) observations. When compared to the farmer's one-handed weeding technique, the use of this upgraded technology resulted in decreased weed dry weight at various stages of growth (20, 30, and 40 DAT). The upgraded technology also increased the effectiveness of weed control. A greater grain output of 48.63 quintals per hectare was also a result of the enhanced technique. Other yield-related metrics like the harvest index, the efficiency of the tillers, and the fertility of the spikelets all demonstrated promising outcomes. The enhanced method, featuring a pre-emergence application of pretilachlor and bensulfuron methyl at 3 days after transplanting (DAT), demonstrated significant advantages over the conventional practice. With a benefit-cost ratio and a net return increase of compared to the local check, this approach yielded superior gross returns. The findings underscored the effectiveness of the pre-emergence treatment in reducing weed biomass in transplanted rice, leading to enhanced grain yield and favorable economic outcomes.

According to Maheswari *et al*., (2015), employing orthosulfamuron at a dose of 120 g ha^{-1} through a pre-emergence sand mix application (SMA) 3-

5 days after transplanting (DAT), followed by a subsequent post-emergence application of orthosulfamuron at the same rate at, emerged as a proficient and cost-effective strategy for weed management in transplanted rice. This approach not only effectively curbed weed growth but also proved to be a viable alternative to labor-intensive hand weeding, without causing any harm to the cultivated crops. These included the pre-emergence application of pyrazosulfuron ethyl, followed by manual weeding, supplemented by an additional hand weeding session. Another effective treatment involved the pre-emergence application of pretilachlor, followed by a post-emergence application of Metsulfuron Methyl + Chlorimuron Ethyl. These treatments led to substantial increases in grain yields, demonstrating their efficacy in weed management and enhancing crop productivity. According to Mahajan and Chauhan's (2008) research, the following outcomes were seen in terms of grain yield and weed control effectiveness. With the application of penoxsulam at a rate of 25 gha^{-1} at 12 days after transplanting (DAT), a maximum weed control efficacy of 90% was attained. The manual weeding method had a76% weed control effectiveness. With a yield of 7.95 tonnes ha^{-1}, the penoxsulam-treated plots that were applied at 12 DAT had the highest grain production. In comparison to the weedy check, this treatment increased yield by roughly 104%, and also increased yield by 13% when compared to the butachlor treatment at a rate of 1500 g/ha. Penoxsulam was found to be superior when given at 12 DAT for improving grain production and decreasing weed dry. The following observations were observed in relation to weed population, weed control effectiveness, and grain production in rice farming. According to Gopinath and Kundu (2008) the weed population in the check plots with weeds was estimated to be 272 plants per square meter. The application of Metsulfuron-Methyl + Mhlorimuron-Ethyl Compared to previous treatments, these ones produced a noticeably decreased density of grass weeds. The manual weeding that was done twice had the highest weed control efficacy, 90.6%. Hand weeding, also resulted in weed control efficiencies ranging from 88.7% to 89.8%. Season-long weed-crop competition caused a decrease in grain yield by 79.7%. The maximum grain yield was achieved by hand weeding at 20 and 40 days after sowing and was 2439 kg ha^{-1}. Except for the sequential applications of butachlor at a rate of 2000 gha-1, metsulfuron-methyl + chlorimuron-ethyl administered 21 days after sowing, and Metsulfuron-Methyl + Chlorimuron-Ethyl applied 7 days after sowing, followed by hand weeding, this particular treatment outperformed the others. These results underscore the efficacy of hand weeding, whether conducted independently or in combination with herbicide applications, in mitigating weed proliferation and enhancing rice yield.

The post-emergence application herbicide was statistically as effective as hand weeding in weed control in transplanted rice. The grain yields obtained from these treatments were also comparable. Promising herbicides identified in the study included Butachlor. The study noted that weedy plots exhibited the highest weed density, emphasizing the efficacy of various herbicides and hand weeding (Bhowmick *et al.,* 2000). While Singh (2005) revealed that combining Beushening, a mechanical weed management approach, with one hand weeding at 40 days after sowing (DAS) proved more effective in weed control compared to other chemical treatments with or without one hand weeding. The grain yield obtained from Beushening combined with one hand weeding was similar to that from two hand weedings. Additionally, Kumar and Uthayakumar (2005) found that applying butachlor significantly reduced weed population and enhanced rice yield-contributing traits and grain yield. In transplanted rice, Bhowmick *et al.*, (2002) discovered that two hand weedings days after transplanting (DAT) exhibited the best weed control efficacy, comparable to the herbicide combination of Ethoxysulfuron + Anilophos applied. These studies collectively suggest that mechanical weed control methods like Beushening and hand weeding, coupled with appropriate herbicide applications, can effectively manage weeds and boost grain yields in rice cultivation.

CONCLUSION

Effective weed management is essential for optimizing rice cultivation and ensuring global food security. The escalating challenges posed by weed competition demand innovative approaches, with chemical herbicides emerging as a prevalent solution, particularly in response to labor shortages and rising labor costs. However, the use of herbicides must be balanced with environmental concerns and the need for sustainable agricultural practices. Integrated weed management systems that incorporate physical, cultural, biological, and chemical strategies are crucial for enhancing herbicide efficacy and minimizing herbicide resistance. The identification of the critical period of weed-crop competition and the implementation of targeted weed control measures are vital components of successful weed management programs. Further research is warranted to explore innovative weed control techniques and deepen our understanding of weed-crop interactions. By fostering collaboration between researchers, farmers, and policymakers, we can develop more efficient and sustainable rice cultivation practices to address weed challenges while ensuring food security and environmental sustainability in rice-producing regions globally.

Acknowledgement

The authors would like to express their sincere gratitude to Haroon Ur Rasheed, Institute of Horticultural Sciences, University of Agriculture Faisalabad, for his valuable contribution in reviewing this paper. His insightful comments and constructive feedback greatly enhanced the quality and clarity of the manuscript. We are deeply thankful for his time, expertise, and commitment to scholarly excellence.

REFERENCES

- Amarjit, S., Singh, B. M., Kachroo, D., Sharma, B. C., & Shivran, D. R. (2005). Efficacy of herbicides in transplanted, medium-duration rice under subtropical conditions of Jammu. *Indian Journal of Agronomy*, 5.
- Antralinaa, M., Istina, I. N., Yuwariah, Y., & Simarmata, T. (2015). Effect of different weed control methods on the yield of lowland rice in the SOBARI. *Journal of Food Science, 3*, 323-329.
- Anwar, M. P., Juraimi, A. S., Mohamed, M. T. M., Uddin, M. K., Samedani, B., Puteh, A., & Man, A. (2013). Integration of agronomic practices with herbicides for sustainable weed management in aerobic rice. *The Scientific World Journal*, 2013.
- Arthington, A. H., & Mitchell, D. S. (1986). Aquatic invading species. In Groves, R. H., & Burdon, J. J. (Eds.), Ecological and Biological Invasions.
- Bajwa, A., Chauhan, A., Farooq, B. S., Shabbir, M. A., & Adkins, S. W. (2016). A review of the invasion mechanism of one of the world's worst weeds. *Planta*, 244, 39-57.
- Bali, A., Singh, S., Kachroo, M. D., Sharma, B. C., & Shivran, D. R. (2006). Efficacy of herbicides in transplanted, medium-duration rice (Oryza sativa) under sub-tropical conditions of Jammu. *Indian Journal of Agronomy, 51*, 128-130.
- Bari, M. N. (2010). Effects of herbicides on weed suppression and rice yield in transplanted wetland rice. *Pakistan Journal of Weed Science Research, 16*, 349-361.
- Barreto, R. W., & Torres, A. N. L. (1999). Nimbya alternanthera and Cercospora alternanthera: Two new records of fungal pathogens on Alternanthera philoxeroides (alligator weed). *Australian Plant Pathology Journal, 28*, 103-107.
- Bhagat, S., Malik, R., Ashok, K. Y., & Nandal, D. P. (2008). Suitable methods of sowing and weed management in direct-seeded rice. *Haryana Journal of Agriculture, 24*, 34-36.
- Bhowmick, M., Nayar, N. R. L., & Ray, D. (2002). Herbicide status on weed management, crop phytotoxicity, growth and yield of dry season rice. *Annals of Agricultural Sciences*.
- Bouman, B. A. M., Humphreys, E., Tuong, T. P., & Barker, R. (2007). Rice and water. *Advances in Agronomy, 97*, 187-237.
- Calha, I., Oliveira, M. D. F., & Reis, P. (2022). Weed management challenges in rice cultivation in the context of pesticide use reduction: A survey approach. *Sustainability*, *15*(1), 244.
- Chowdhury, I., Ali, F., Karim, M. H., Masum, M. F., & Rahman, S. M. A. (2015). Weed control strategies affecting yield potential of aromatic rice. *Pakistan Journal of Research in Weed Science*.
- Ehsanullah, N. A., Jabran, K., & Habib, T. (2007). Comparison of different planting methods for optimization of plant population of rice (Oryza sativa L.) in Punjab (Pakistan). *Pakistan Journal of Agricultural Sciences, 44*, 597-599.
- Farooq, M., Siddique, K. H. M., Rehman, H., Aziz, T., Dong, J. L., & Wahid, A. (2011). Rice direct seeding: Experiences, challenges and opportunities. *Soil Tillage Research, 111*, 87-98.
- Fleck, N., Rizzardi, G., & Agostinetto, M. A. D. (2002). Threshold level as a criterion for narrow leaf sida control decision in soybeans. *Planta Daninha, 20*, 421-429.
- Gopinath, K. A., & Kundu, S. (2008). Evaluation of metsulfuron-methyl and chlorimuron-ethyl for weed control in direct-seeded rice (Oryza sativa). *Indian Journal of Agricultural Sciences, 78*, 466-469.
- Government of Pakistan. (2020). Pakistan Economic Survey 2019-20, Finance Division, Economic Advisor's Wing, Islamabad, 5-6.
- Gunasekera, L., & Bonilla, J. (2001). Alligator weed: A tasty vegetable in Australian backyards? *Journal of Aquatic Plant Management, 39*, 17-20.
- Hemalatha, K., Ramana, A. A., Bisen, V. N., & Rani, M. (2018). Effect of weed management practices on yield and economics of semidry rice. *Journal of Pure and Applied Microbiology, 11*, 1027-1032.
- Jones, R., & Medd, E. R. W. (2000). Economic thresholds and the case for longer-term approaches to population management of weeds. *Weed Technology, 14*, 337-350.
- Kashid, N., Barhate, V. K. K., & Bodake, P. S. (2015). Management of weeds in direct-seeded rice. *Indian Journal of Weed Science, 47*, 110-112.
- Khaliq, A., Matloob, A., Ihsan, M. Z., Abbas, R. N., Aslam, Z., & Rasul, F. (2013). Supplementing herbicides with manual weeding improves weed control efficiency, growth, and yield of dry-seeded rice. *International Journal of Agriculture and Biology, 15*, 191-199.
- Khodadadi, V., Yousefi, A. R., Heydari, M., Kanatas, P., Tataridas, A., & Travlos, I. (2023). Evaluation of herbicides for selective weed control in cutleaf groundcherry (Physalis angulata L.). *Crop Protection, 169*, 106243.
- Kishore, R., Dwivedi, A., Singh, R., Naresh, R. K., Kumar, V., Bankoti, P., Sharma, D. K., & Yadav, N. (2016). Integrated effect of population and weed management regimes on weed dynamics, performance, and productivity of basmati rice. *Paddy and Water Environment, 15*, 49-58.
- Kumar, B., Kumar, S., Ranjan, R. D., & Azad, C. S. (2020). Effect of weed management practices on complex weed flora and soil microflora in aerobic rice under rainfed condition of Bihar. *Current Journal of Applied Science and Technology, 39*, 72-79.

- Kumar, G. P., & Uthayakumar, B. (2005). Effect of sequential application of pre and post-emergence herbicides in wet-seeded rice. *Crop Research, 29*, 366-370.
- Laxminarayan, P., & Mishra, B. N. (2001). Effect of nutrient and weed management practices on weeds and yield of transplanted rice. *Annals of Agricultural Sciences, 22*, 258-261.
- Leghari, S. J., Leghari, U. A., Laghari, G. M., Buriro, M., & Soomro, F. A. (2015). An overview of various weed control practices affecting crop yield. *Journal of Chemical, Biological and Physical Sciences, 6*(1), 59-69.
- Liu, S., Rao, S. A., & Vinson, S. B. (2014). Biological control in China: Past, present, and future - an introduction to this special issue. *Biological Control, 68*, 1-5.
- Mahajan, G., & Chauhan, B. S. (2008). Performance of penoxsulam for weed control in transplanted rice. *Pest Technology, 2*, 114-116.
- Mahajan, G., Chauhan, B. S., & Son, D. E. A. (2009). Weed management in aerobic rice in North Western Indo-Gangetic Plains. *Crop Improvement, 23*, 366-382.
- Mahbub, M., Bhuiyan, M. M. K. A., & Mir Kabir, M. M. (2017). Performance of Metsulfuron Methyl 10% + Chlorimuron Ethyl 2% WP against annual weed inhibition in transplanted rice. *Haya: Saudi Journal of Life Sciences, 2*, 298-305.
- Maheswari, M., Rao, D., Prasuna, A. S. P. R., & Venkateswarlu, B. (2015). Effect of weed management practices on growth and economics of transplanted rice. *International Journal of Pure and Applied Bioscience, 3*, 113-116.
- Mamun, M., Shultana, A. A. R., Islam, S. A., Bhuiyran, M. K. A., & Mridha, A. J. (2012). Efficacy of Metsulfuron-methyl 20% WDG in controlling weeds in transplanted rice. *Journal of Bangladesh Agronomy, 15*, 17-23.
- Menon, S., Prameela, S. P., & Abraham, C. T. (2014). Weed control in wet-seeded rice by post-emergence herbicides. *Indian Journal of Weed Science, 46*, 169-171.
- Mishra, G., Luther, M. M., & Mishra, G. C. (2018). Efficacy of new generation herbicides in combination and integrated application on weed control efficiency, production potential, and economics in direct-seeded rice (Oryza sativa L.). *International Journal of Chemical Studies, 6*, 1235-1238.
- Mubeen, K., Tanveer, A., Nadeem, M. A., Sarwar, N., & Shahzad, M. (2009). Critical period of weed-crop competition in fennel (Foeniculum vulgare Mill.). *Journal of Weed Science Research, 15*, 171-181.
- Mukherjee, P., Reddy, K. D. S., & Malty, S. K. (2007). Weed control in transplanted and wet-seeded rainy season rice (Oryza sativa). *Indian Journal of Agricultural Sciences, 81*, 134-139.
- Naik, M., Babu, A. P. V. R., Reddy, M. S., & Kavitha, P. (2018). Effect of different herbicide combinations on weed dynamics and production potential of transplanted rice. *International Journal of Pure and Applied Bioscience, 6*, 742-747.
- Nair, A., Pramic, K. S. C., Ravisankar, N., & Dinesh, R. (2002). Effect of varieties and weed control practices on productivity of rice and weed growth in lowland of the South Andamans. *Indian Journal of Agricultural Sciences, 72*, 477-479.
- Naylor, R. (1994). Herbicide use in Asian rice production. *World Development, 22*, 55-70.
- Ogwuike, P., Rodenburg, J., Diagne, A., Agboh-Noameshie, R., & Amovin-Assagba, E. (2014). Weed management in upland rice in sub-Saharan Africa: Impact on labor and crop productivity. *Food Security, 6*, 327-337.
- Pasha, H., Koloor, Y. R. T., & Hashemi, S. J. (2012). Effects of weed control methods on yield and yield components of Iranian rice. *Australian Journal of Crop Science, 3*, 59-64.
- Pathak, K., Kendra, K. V., & Chowdhury, A. K. (2001). Water and weed management studies in direct-seeded upland rice. Assam Agricultural University (AAU), Arunachal 778 025, Cachar, India. *International Rice Research, 26*, 55-57.
- Portugal, J. M., & Vidal, R. A. (2009). Economic levels of weed injury on crops: Concepts, definitions, and calculation models. *Planta Daninha, 27*, 869-877.
- Rahman, M., Ali, H. M. H., Ali, M. M., & Khatun, M. M. (2007). Effect of different levels of nitrogen on growth and yield of transplant aman rice cv. BRRI dhan32. *International Journal of Sustainable Crop Production, 2*, 28-34.
- Rahman, M., Mehedi, M., & Masood, M. M. (2019). Effect of seeding depth and weed management options on weed control and yield performance of dry direct-seeded rice. *Journal of Applied Sciences, 19*, 654-661.
- Rajkhowa, D., Deka, J. N. C., Borah, N. C., & Barua, I. C. (2007). Effect of herbicides with or without paddy weeder on weeds in transplanted summer rice (Oryza sativa). *Indian Journal of Agronomy, 52*, 107-110.
- Ranjit, J. D., & Suwanketnikom, R. (2005). Response of weeds and yield of dry direct-seeded rice to tillage and weed management. *Natural Science, 39*, 165-173.
- Rao, A., Johnson, N. D. E., Sivaprasad, B., Ladha, J. K., & Mortimer, A. M. (2007). Weed management in direct-seeded rice. *Advances in Agronomy, 93*, 153-255.

- Rao, A., Johnson, N. D. E., Sivaprasad, B., Ladha, J. K., & Mortimer, A. M. (2007). Weed management in direct-seeded rice. *Advances in Agronomy, 93*, 153-255.

- Ravikiran, K., Syriac, E., & Raj, S. K. (2019). Integrated weed management in upland rice intercropped in coconut. *Journal of Tropical Agriculture, 57*, 71-77.

- Rehman, A. D., Ayyub, M., & Zahir, Z. A. (2023). The trend towards suppressing most troublesome weeds for sustainable production of wheat. Food and Agriculture on Social, Economic and Environmental Linkages, Iksad Publications: *Ankara, Türkiye*, 74.
- Rhodes, G., Jr., & Demont, D. J. (1983). Aquatic weed management perspectives in North Carolina.
- Saha, S., & Rao, K. S. (2010). Efficacy of metsulfuron methyl for controlling broadleaf weeds in transplanted rice (Oryza sativa) under rainfed shallow lowland. *Indian Journal of Agricultural Sciences, 80*, 522-526.
- Sanyal, D., & Shrestha, A. (2009). Direct effect of herbicides on plant pathogens and disease development in various cropping systems. *Weed Science, 56*, 155-160.
- Scavo, A., & Mauromicale, G. (2020). Integrated weed management in herbaceous field crops. *Agronomy, 10*(4), 466.
- Shehzad, M., Tanveer, A., Ayub, M., Mubeen, K., Sarwar, N., Ibrahim, M., & Qadir, I. (2011). Effect of weed-crop competition on growth and yield of garden cress (Lepidium sativum L.). *Journal of Medicinal Plants Research, 5*, 6169-6172.
- Siddiqi, M., WaLee, H. S., & Khan, A. M. (2014). Weed image classification using wavelet transform, stepwise linear discriminant analysis, and support vector machines for an automatic spray control system. *Journal of Information Science and Engineering, 30*, 1227-1244.
- Singh, G., Roy, D. K., & Yadav, S. (2018). Effect of herbicide combinations and hand weeding on growth, yield, and weed population in transplanted rice (Oryza sativa L.). *International Journal of Chemical Studies, 6*, 154-157.
- Singh, G., Singh, R. G., Singh, O. P., Kumar, T., Mehta, R. K., & Singh, P. P. (2005). Effect of weed management practices on transplanted rice. *Indian Journal of Agronomy, 50*, 25-37.
- Singh, G., Singh, R. G., Singh, O. P., Kumar, T., Mehta, R. K., & Singh, P. P. (2005). Effect of weed management practices on transplanted rice. *Indian Journal of Agronomy, 50*, 25-37.
- Subramanian, E., Martin, G. James, & Balasubramanian, R. (2006). Effect of integrated weed management practices on growth and yield of wet-seeded rice (Oryza sativa) and their residual effect on succeeding pulse crop. *Indian Journal of Agronomy, 51*, 93-96.
- Swanton, C. J., & Weise, S. F. (1991). Integrated weed management: The rationale and approach. *Weed Technology, 5*, 657-663.
- Torra, J., Cirujeda, A., Taberner, A., & Recasens, J. (2010). Evaluation of herbicides to manage herbicide-resistant corn poppy (Papaver rhoeas) in winter cereals. *Crop Protection, 29*, 731-736.
- USDA. (2022). World Agricultural Production [Internet]. 2021. Available from: [Accessed: December 12, 2022].
- Vangessel, M., Monks, D. W., & Johnson, Q. R. (2000). Herbicides for potential use in Lima bean (Phaseolus lunatus) production. *Weed Technology, 14*, 279-286.
- Walia, U., Gill, S. G., Waliam, S. S., & Sidhu, A. S. (2011). Production of direct-seeded rice (Oryza sativa) under differential plant densities and herbicides in the central plains of Punjab. *Journal of Crop and Weed, 7*, 1-5.
- Weaver, S. E., & Tan, C. S. (1983). Critical period of weed interference in transplanted tomatoes (Lycopersicon esculentum): *Growth analysis. Weed Science, 31*, 476-481.
- Weaver, S. E., & Tan, C. S. (1987). Critical period of weed interference in field-seeded tomatoes and its relation to water stress and shading. *Canadian Journal of Plant Science, 67*, 575-583.
- Williams, A.E., Duthie, H.C., Hecky, R.E., 2005. Water hyacinth in LakeVictoria: why did it vanish so quickly and will it return? *Aquat. Bot, 81*, 300–314.
- Zoschke, A., & Quadranti, M. (2002). Integrated weed management: Quo vadis?. *Weed Biology and Management, 2*(1), 1-10.

© 2024 | Published by Scholars Middle East Publishers, Dubai, United Arab Emirates