weedcontrol journal

RESEARCH ARTICLE

Pre emergent herbicides for volunteer *Acacia mangium* control in plantations in indonesia

Herbicidas pré-emergentes para o controle de *Acacia mangium* voluntária em plantações na Indonésia

Ratih H. Putri[a]*, Syahanda R. Siregar[a], Brilliant G. Subekti[a], Rian A. Sumarto[a], Vinicius de M. Santos[a], Caio A. Carbonari[b]

[a]Fiber Research and Development, Department of Weed Science, APRIL (Asia Pacific Resources International Holdings Limited), Riau, Indonesia.
[b]São Paulo State University, Faculty of Agronomic Sciences, Botucatu, São Paulo, Brazil.

Abstract: **Background**: Volunteer *Acacia mangium* represent a major challenge in Eucalyptus plantations due to the large seedbank remaining in the soil. The use of pre-emergent herbicides with residual effects is essential for achieving effective control of these weeds.
Objective: To identify effective pre-emergent herbicides, with residual effects for controlling volunteer *A. mangium* in Eucalyptus plantations.
Methods: Completely randomized design (CRD) was used with 4 replications. Trays (50 × 33 cm) were filled with a loamy topsoil from commercial plantations. Each tray was sown with 100 *A. mangium* seeds after dormancy-breaking treatment. Thirteen herbicide active ingredients were tested, with a control treatment (no herbicide). Active ingredients tested were Imazapyr, Metsulfuron-methyl, Triclopyr, Isoxaflutole, Indaziflam, Flumioxazine, Sulfentrazone, Oxyfluorfen, Pendimethalin, Metribuzin, Ametryn, Diuron and Saflufenacil. Herbicides were applied 1 day after seeds sowing and emerged seedlings were counted weekly until day 35 (first period assessment). After the first period was finished, all *A. mangium* emerged seedlings and remaining seeds were removed and 100 new *A. mangium* seeds were sown to each tray to test the residual effect. No additional herbicide was applied for the second period, which was assessed weekly until 35 days after second sowing.
Results: Indaziflam, metribuzin, saflufenacil, sulfentrazone, and isoxaflutole were effective in controlling *A. mangium*, with <7.0% seedling emergence at 35 DAS, compared to 92.3% in the control.
Conclusions: Indaziflam provided the best residual control, with 0.0% seedling emergence at the end of the second evaluation period, demonstrating high efficacy for volunteer *A. mangium* control in Eucalyptus plantations.

Keywords: weed Control, forestry, residual effect.

Resumo: **Introdução**: As plantas voluntárias de *Acacia mangium* representam um desafio significativo nas plantações de eucalipto, devido ao grande banco de sementes remanescente no solo. O uso de herbicidas pré-emergentes com efeito residual é essencial para um controle eficaz dessas plantas.
Objetivo: Identificar herbicidas pré-emergentes eficazes, com efeito residual, para o controle de *A. mangium* voluntária em plantações de eucalipto.
Métodos: O experimento foi conduzido em delineamento inteiramente casualizado (DIC) com quatro repetições. Bandejas de 50 cm × 33 cm foram preenchidas com solo argiloso superficial proveniente de plantações comerciais. Cada bandeja recebeu 100 sementes de *A. mangium*, previamente tratadas para superação de dormência. Treze ingredientes ativos foram testados, além da testemunha: imazapyr, metsulfuron-methyl, triclopyr, isoxaflutole, indaziflam, flumioxazin, sulfentrazone, oxyfluorfen, pendimethalin, metribuzin, ametryn, diuron e saflufenacil. Os herbicidas foram aplicados um dia após a semeadura, e as plântulas emergidas foram contadas semanalmente até 35 dias após a semeadura. Após esse período, as plântulas foram removidas e novas sementes foram semeadas para avaliar o efeito residual.
Resultados: Indaziflam, metribuzin, saflufenacil, sulfentrazone e isoxaflutole foram eficazes no controle de A. mangium, com menos de 7,0% de emergência em comparação com 92,3% na testemunha.
Conclusões: O herbicida indaziflam apresentou o melhor controle residual, com 0,0% de emergência no final do segundo período de avaliação, demonstrando alta eficácia para o controle de *A. mangium* voluntária.

Palavras-chave: Controle de plantas daninhas, silvicultura, efeito residual.

Journal Information:
ISSN: 2763-8332
Website: https://www.weedcontroljournal.org/
Jornal da Sociedade Brasileira da Ciência das Plantas Daninhas

How to cite: Putri RH, Siregar SR, Subekti BG, Sumarto RA, Santos VM, Carbonari CA. Pre emergent herbicides for volunteer *Acacia mangium* control in plantations in indonesia. Weed Control J. 2025;24:e202500879.
https://doi.org/10.7824/wcj.2025;24:00879

Approved by:
Editor in Chief: Cristiano Piasecki

Conflicts of interest: The authors declare no conflicts of interest regarding the publication of this manuscript.

Received: February 26, 2025
Approved: June 30, 2025

*** Corresponding author:**
<ratihhartonoputri@gmail.com>

1. Introduction

Eucalyptus plantation management faces ongoing challenges, including substantial yield limitations and increased operational costs due to significant weed competition. This competition is recognized as one of the major limiting factors in eucalyptus production (Osiecka and Minogue, 2013). Studies have shown that weed competition can lead to significant yield losses in eucalyptus plantations, with reported losses reaching up to 91% under unmanaged conditions (Vargas et al., 2018). Weeds compete with eucalyptus for essential resources such as light, water, and nutrients, which limits the resources available to the main crop (Silva et al., 2022). Chhokar et al. (2012) similarly noted that weeds deprive plants of vital inputs by competing for moisture, nutrients, light, and space. Weed competition thus remains one of the most critical constraints in plant production, influenced by factors such as the weed seed bank, emergence patterns, crop growth stage, weed density, competitiveness, and periodicity of emergence (Hoverstad et al., 2004).

In field environments, weeds exhibit high reproductive potential, contributing to the soil seed bank, and rapid growth rates (Silva et al., 2022). In eucalyptus plantations, the weed seed bank often includes *A. mangium*, a species that frequently emerges as a volunteer species, particularly in regions managed by companies like APRIL in Sumatera, Indonesia. Volunteer *A. mangium* (unwanted volunteer plants) are fast-growing, light-demanding pioneer species renowned for their robustness and adaptability (Orwa et al., 2009). Although *A. mangium* thrives in full light, it can also grow successfully under partial shade within eucalyptus understories, which makes managing it more challenging. If not controlled at young stages, volunteer *A. mangium*, can grow up to 25–35 meters in height and can cause operational issues throughout the entire eucalyptus rotation period, potentially impacting production quality and significantly increasing management costs.

Following three previous *A. mangium* rotations, seed-load within top 10 cm of plantation soil was ranging from 0.75 to 5.8 million seeds/ha. They are potential weeds and difficult to control because they do not germinate simultaneously (Siregar et al., 2020). In the field, volunteer *A. mangium* display dynamic growth behaviors, often germinating from persistent soil seed banks and demonstrating rapid establishment and growth, especially after soil disturbance. This invasive growth dynamic requires effective control strategies early in the plantation cycle to prevent subsequent issues. However, almost no literature or very limited studies exist on the specific dynamics of volunteer *A. mangium*, particularly regarding their competition within eucalyptus plantations. This gap in the literature highlights the need for targeted research into effective management practices for these volunteer species, as their behavior poses unique challenges.

One effective approach for weed control in eucalyptus plantations is application of pre-emergent herbicides, particularly those with long residual effects. Pre-emergent herbicides are applied to the soil either before or directly after planting and before weed emergence (Haskins, 2012). They help reduce the weed seed bank and prevent the establishment of volunteer *A. mangium*, thus supporting a more manageable growth environment for eucalyptus.

The objectives of this study are to identify the most effective herbicides for controlling volunteer *A. mangium* and to evaluate the residual effect of pre-emergent herbicides to optimize their use in eucalyptus plantations. This study seeks to address the limited knowledge available regarding volunteer *A. mangium* by providing insights into effective herbicide management strategies.

2. Material and Methods

This study was a screening trial conducted to evaluate the efficacy of pre-emergent herbicides under controlled conditions. The research was conducted from June to September 2022 at APRIL's rooting house KRN (Kerinci Research Nursery) in Riau, Indonesia, under controlled conditions of temperature, humidity, and irrigation. The materials used in this experiment were mineral topsoil, herbicides, and *A. mangium* seeds. Equipment included nursery trays with dimensions of 50 cm x 33 cm (0.165 m^2), a hand sprayer, used sacks, and an irrigation microsprinkler system.

The selected pre-emergent herbicides for this study were those readily available in Indonesia for weed management, chosen based on their common use and accessibility in local plantation operations. The dosages applied in the trials followed the maximum recommended rates provided by the manufacturers on their product labels, ensuring consistency with practical field application standards.

Treatments tested consisted of 13 herbicides of different mechanism of action and one control with no chemical application. The active ingredients, commercial products and dosage used are described in Table 1.

Table 1. Active ingredients, commercial brand and dosage of the treatments.

	Active Ingredients (AI)	Comercial brand	Dosage AI g / ha
1	Control	-	-
2	Imazapyr	Basf 693 28 H*	2079
3	Metil Metsulfuron	Metsul 24 WP	36
4	Triclopyr	Garlon 670 EC	1005
5	Isoxaflutole	Fordor 75 WG	150
6	Indaziflam + iodosulfuron	Esplanade 22 WG	82.5
7	Flumioxazine	Sumimax 50 WP	150
8	Sulfentrazone	Boral 480 SC	960
9	Oxyfluorfen	Goal 240 EC	960
10	Pendimethalin	Prowl 330 EC	990
11	Metribuzin	Unicor-M 70 WG	2450
12	Ametryn	Amexon 500 SC	1500
13	Diuron	Daimex 80 WP	2400
14	Saflufenacil	Kixor 70 WG	140

*Sample code from manufacturer, as product is not commercially available in Indonesia.

This study used a herbicide formulation containing indaziflam and 2% iodosulfuron. However simplicity, we will refer to this product as "indaziflam" throughout the paper, unless otherwise specified.

A completely randomized design (CRD) was used with four replications. Every tray contained 100 seeds. The seeds were treated before sowing, to break dormancy and ensure they are in good potential to germinate. For seed treatment, the seeds were immersed in hot water (approximately 80°C) and soaked for 24 hours. This techniques are effective for species with hard seed coats, like *A. mangium*. The treated seeds were planted in the topsoil with spacing 2 cm x 5 cm and a depth of 5 cm. Chemical application was performed one day after sowing the seeds in the trays and was done only once.

Each herbicide was applied using a hand sprayer, where each tray with seeds was individually sprayed. Different sprayers were used for each treatment to ensure accuracy and prevent cross-contamination. During application, each tray was moved away from other treatments to avoid drift and contamination. The spray volume per tray was set at 50 mL, which is equivalent to 300 L/ha. Irrigation was applied three times daily morning, midday, and afternoon using an automatic sprinkler system. Each watering cycle lasted for 15 seconds to ensure consistent moisture levels with volume misting 0.29 L/m^2/hour.

The number of emerged *A. mangium* seedlings was recorded in each tray at 14, 21, 28, and 35 days after spraying (DAS) during the first assessment period. Following the 35 DAS evaluation, all emerged seedlings were removed, and new *A. mangium* seeds were sown in the same trays to evaluate the residual effect of the pre-emergent herbicides. This initiated the second assessment period, during which the same parameters as in the first period (number of emerged *A. mangium* seedlings) were recorded at 14, 21, 28, and 35 DAS in the second period.

Soil samples were collected from the trial site before herbicide application to analyze the soil's physical and chemical properties. Sampling was conducted at a depth of 0-10 cm, representing the root zone where herbicide interactions typically occur. These soil characteristics are critical for assessing herbicide performance, as they influence the mobility and efficacy of the applied products. The soil parameters analyzed in this study showed a pH (H_2O) of 4.46, indicating strongly acidic soil conditions. Electrical conductivity (EC) was measured at 0.0348 dS/m, reflecting very low soil salinity. Organic carbon (Org. C) content was 0.10%, indicating minimal organic matter in the soil. The soil texture analysis revealed a composition of 10.10% clay, 6.06% silt, and 83.84% sand/fine sand, classifying it as predominantly sandy. Additionally, available phosphorus (P-Bray) was 1.85 mg/kg, measured using the Bray method, indicating low levels of phosphorus accessible to plants.

The count of emerged plants was transformed into an emergence percentage (% emergence) calculated as follows: % emergence = ((N emerged plants/N observation) * 100). Data were subjected to analysis of variance (ANOVA), and mean comparisons were conducted using Tukey's Honest Significant Difference (HSD) test at a 5% level of significance. Previously, mean separation was also performed using the Duncan's Multiple Range Test (DMRT) at the same significance level.

3. Result and Discussion

The pre-emergent herbicides tested were significantly effective in reducing *A. mangium* seedling emergence compared to the control treatment. Table 2 presents the germination percentages at 14, 21, 28, and 35 days after sowing (DAS) is provided to show the emergence dynamics over time. Among the treatments, metribuzin consistently suppressed emergence and showed the best result at 35 DAS with 0% seedling emergence. In contrast, the control treatment recorded 92.5% emergence at the same assessment time. A graph is provided to illustrate the emergence percentage of *A. mangium* in the first evaluation period (Figure 1).

Table 2. Germination percentage (%) of *A. mangium* at 14, 21, 28, and 35 DAS 1st period.

Treat	14 DAS	21 DAS	28 DAS	35 DAS
Control	83.3 g	93.3 f	94.7 i	92.3 h
Imazapyr	56.7 ef	78.7 ef	67.3 fg	66.3 f
Metil Metsulfuron	87.0 g	84.0 ef	77.7 gh	75.0 g
Triclopyr	20.7 abcd	27.0 c	19.0 c	17.7 c
Isoxaflutole	25.0 bcd	6.3 a	1.3 a	0.7 a
Indaziflam	3.3 a	1.0 a	0.7 a	0.3 a
Flumioxazine	23.0 abcd	10.7 ab	9.7 abc	13.3 bc
Sulfentrazone	16.3 abc	10.0 ab	4.7 ab	6.3 ab
Oxyfluorfen	17.7 abc	43.3 d	33.3 d	29.3 d
Pendimethalin	40.0 de	72.7 e	54.0 e	49.3 e
Metribuzin	39.7 de	17.0 abc	0.3 a	0.0 a
Ametryn	56.3 ef	87.0 ef	84.7 hi	81.7 g
Diuron	56.3 ef	22.7 bc	15.0 bc	11.7 bc
Saflufenacil	6.0 ab	4.0 a	5.3 ab	5.7 ab

Table 2 provides a summary of *A. mangium* germination trends during the first evaluation period (14–35 DAS), with statistical comparison performed using Duncan's Multiple Range Test. The table highlights the consistent effectiveness of several herbicide treatments, namely indaziflam, saflufenacil, isoxaflutole, sulfentrazone, flumioxazine, and metribuzin in maintaining low germination percentages throughout the period. These results are further supported by Figure 1, which summarizes the germination percentages during the same period and presents statistical groupings based on Tukey's Honest Significant Difference (HSD) test.

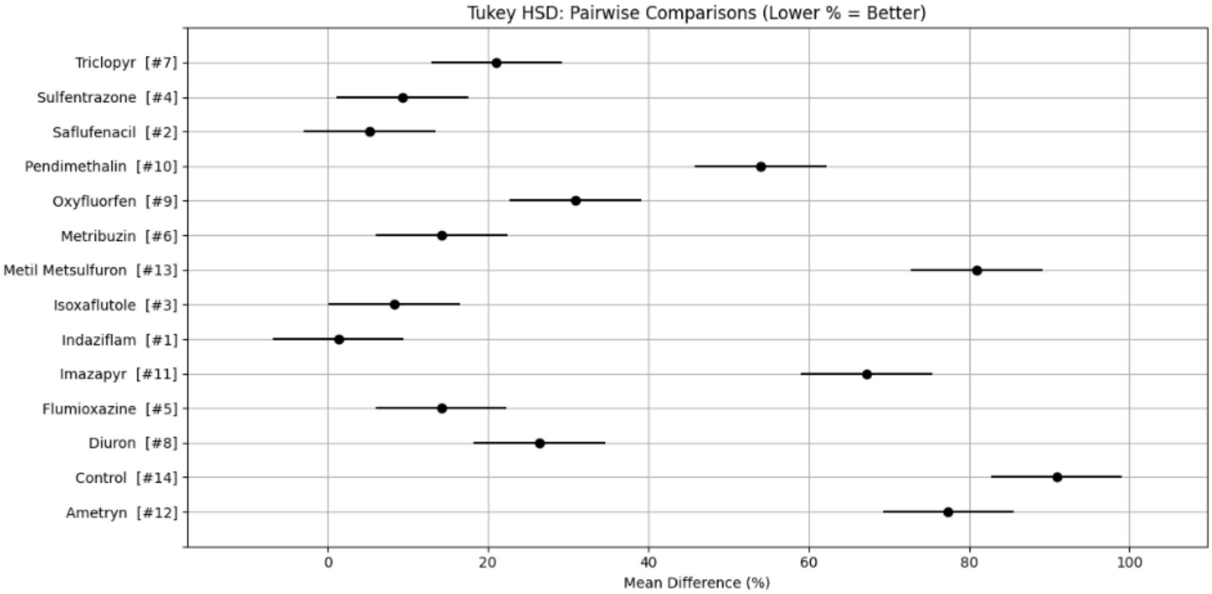

Figure 1. Emergence percentage of *A. mangium* in the first evaluation period.

The figure presents the results of a Tukey Honest Significant Difference (HSD) test assessing the efficacy of various pre-emergent herbicide treatments in reducing *A. mangium* seed germination. The x-axis represents the mean difference in germination percentage (%), where lower values correspond to greater suppression. Herbicides are ranked along the y-axis from most to least effective based on their comparative performance.

Among the treatments evaluated, Indaziflam exhibited the highest efficacy in suppressing *A. mangium* germination, followed by Saflufenacil, Isoxaflutole, Sulfentrazone, Flumioxazine, and Metribuzin. These herbicides formed a cluster of high-performing treatments, characterized by low mean differences and overlapping confidence intervals, suggesting comparable levels of pre-emergent activity. In contrast, the Control, Metil Metsulfuron, Ametryn, Imazapyr and Pendimethalin consistently showed the highest germination percentages, indicating minimal suppression and significantly lower effectiveness compared to the other treatments.

These results provide a statistically robust basis for selecting effective pre-emergent herbicides for managing volunteer *A. mangium* in plantation. In particular, the consistent performance of Indaziflam, Saflufenacil, Isoxaflutole, and Sulfentrazone highlights their potential suitability for operational use where seedbank suppression is critical. These findings are consistent with prior studies that highlighted the efficacy of these herbicides against a broad spectrum of weed species (Volova et al., 2020). Metribuzin, a systemic selective herbicide belonging to the 1,2,4-triazine class, exhibited broad-spectrum activity and can be applied both pre-emergence and early post-emergence (Volova et al., 2020). Its mode of action involves inhibiting the Hill reaction (water photolysis) and disrupting photosynthetic electron transport between the primary and secondary electron acceptors in photosystem II. This disruption leads to physiological and morphological changes in the leaf structures, resulting in chlorosis, necrosis, and eventual leaf abscission (Kostopoulou et al., 2020).

Indaziflam, another herbicide evaluated in this study, is commonly used in turf, perennial crops, and non-agricultural settings for pre-emergent control of grasses and broadleaf weeds (Brabham et al., 2014). As a cellulose biosynthesis inhibitor, indaziflam represents a unique site of action, with no reported cases of resistance in the field (Brabham et al., 2014; Clark et al., 2019). It inhibits cellulose biosynthesis and controls annual weeds as their seeds germinate. This soil-active herbicide provides an opportunity for effective control of annual broadleaf weeds (Seedorf, 2020). Additionally, indaziflam has a longer soil residual compared to other herbicides, providing up to three years of control (Sebastian et al., 2016; Clark et al., 2019).

Isoxaflutole, known for its potential to broaden the spectrum of controlled weeds, can extend the length of residual weed control and reduce the likelihood of resistance development, particularly against *Amaranthus* species, which have shown resistance to other HPPD inhibitors (Foster et al., 2021). Isoxaflutole works as a diketonitrile derivative, formed rapidly after uptake by roots and shoots. The herbicide's activity in susceptible species is characterized by a distinct bleaching of the foliar tissue (Zhao et al., 2017).

Saflufenacil, a broad-spectrum herbicide, inhibits protoporphyrinogen oxidase (PPO), leading to rapid chlorophyll loss in broadleaf weeds, causing leaf desiccation and plant death. It is highly effective against common broadleaf weeds, such as *Conyza canadensis* (horseweed), making it a valuable tool in broadleaf weed management (Grossmann et al., 2017).

Sulfentrazone, another herbicide evaluated in this study, functions as a pre-emergence herbicide by inhibiting protoporphyrinogen oxidase (Protox), a key enzyme in chlorophyll synthesis. Sulfentrazone is absorbed by the roots and translocated through the xylem to the leaves, where it disrupts chloroplast function under light exposure, resulting in visible symptoms. Sulfentrazone is highly effective in controlling yellow and purple nutsedge, as well as most broadleaf weeds (Gehrke et al., 2019).

A. mangium seeds exhibit tegument dormancy, allowing them to remain viable in the soil for extended period. This dormancy contributes to a continuous emergence of volunteer *A. mangium*, complicating weed management efforts. Furthermore, these volunteers grow into sizeable trees, causing operational difficulties during harvesting. To mitigate this, costly under-brushing activities are often required, not only increasing management expenses but also reducing the efficiency and safety of harvesting operations.

Current weed management strategies have been insufficient in controlling volunteer *A. mangium* effectively. Post-emergence herbicides alone have shown limited success in addressing the persistent seedbank and the ongoing emergence of wildlings. This highlights the need for a more comprehensive approach that includes the use of pre-emergent herbicides with residual effects to target *A. mangium* seedlings before they establish.

Pre-emergent herbicides have the potential to offer a viable solution for managing volunteer *A. mangium* populations in eucalyptus plantations. Their ability to provide residual control can prevent the germination and establishment of volunteer *A. mangium*, reducing the reliance on labor-intensive and expensive mechanical methods.

The herbicides performed differently during the 35 days of first evaluation period analyzed, as observed in Table 2. All the other treatments with herbicides had some emergence of *A. mangium* seedlings during the 35 days of first period. In most treatments, a variable number of seedlings survived until 35 DAS, except in metribuzin treatment that reached 100% control in the end of the first period.

As a general behavior for all herbicides, seedlings emerged until a peak percentage varying from 6.0% until 87.0%, frequently with signs of intoxication. After this peak, a variable response of the plants to the different herbicides present in the soil was observed. This indicates that few active ingredients, among the tested ones, are quickly absorbed and effective to control the seedlings, even before emergence, whilst most of them need more time to perform the maximum efficacy in controlling *A. mangium* seedlings. This delayed response could be due to the varying modes of action and chemical properties of the herbicides, such as their solubility, adsorption to soil particles, and mobility in the soil. Some herbicides, like pre-emergent herbicides that target root and shoot systems before emergence, show faster control, while others may have slower systemic absorption or require longer soil persistence to inhibit seedling growth.

Treatments ametryn, imazapyr, metsulfuron-methyl and pendimethalin had peaks of emergence, reaching at the end of the first period percentage of emerged seedlings of 49.3% until 81.7%. It is important to mention that plants that survived in all treatments presented some level of intoxication. In Imazapyr treatment, especially, the surviving plants were highly intoxicated with severe scorching symptoms indicating that their growth, if experiment had continued, would be significantly impacted. The treatments diuron, flumioxazine, triclopyr, and oxyfluorfen showed distinct peaks in germination, and by the end of the first evaluation period (35 DAS), the percentage of emerged *A. mangium* ranged from 11.7% to 29.3%.

Among the best performers (indaziflam, saflufenacil, isoxaflutole, sulfentrazone, flumioxazine and metribuzin) only indaziflam had effective control from the beginning, not allowing more than 3.3% of seedlings emerge. At the end of the first evaluation period, indaziflam maintained an average emergence of 0.3%. Metribuzin completely inhibited germination (0.0%), whereas isoxaflutole and sulfentrazone showed low emergence rates of 0.7% and 6.3%, respectively.

Hess (2000) reported that metribuzin is a xylem mobile herbicide. This means that the herbicide is absorbed by the roots and leaves and then translocated from the roots into leaf tissue through the xylem. Similar with the result, the germination that has grown at the initial assessment and will decrease in the next assessment, because the herbicides contained in the soil absorbed by the roots and leaves so the germination that has grown will be intoxicated by the herbicide and will cause germination dead. Khatib (2022) mention that as a triazinone herbicide, metribuzin inhibits photosynthesis by binding to D1 proteins of the photosystem II complex in chloroplast thylakoid membranes. Herbicide binding at this protein blocks electron transport and stops CO2 fixation and production of energy needed for plant growth. The death of plants, however, does not occur primarily from photosynthates depletion but rather from an indirect effect on other processes. Blocking electron transport in PSII systems promotes the formation of highly reactive molecules that initiate a chain of reactions causing lipid and protein membrane destruction that results in membrane leakage allowing cells and cell organelles to dry and rapidly disintegrate.

Metribuzin is highly water-soluble, making it effective as a soil-applied herbicide for controlling a wide range of weeds. However, its solubility also necessitates careful management to minimize leaching, particularly in light-textured soils. Residues of metribuzin in amended soils degrade over time, with the rate and extent of degradation influenced by the type and nature of organic amendments used (Henriksen et al., 2002). This degradation dynamic underscores the importance of understanding soil composition and environmental conditions to optimize its application and reduce potential ecological risks.

Indaziflam, as pre-emergent herbicide, act directly on seeds, by inhibiting cell wall biosynthesis (Tompkins, 2010). Indaziflam decreases growth by suppressing cellulose synthesis (Brabham et al., 2014), and so may reduce seed germination. Indaziflam can potentially constrain the radicle development and root growth of newly germinated seedlings by preventing cellulose formation (Clark, 2019). Barroso et al. (2022), report that higher intoxication values observed in treatments with indaziflam related to the mechanisms of action of these herbicides.

The difference in weed germination among the treatments could be attributed to properties of individual herbicides, which include solubility in the soil, volatilization, photo degradation, microbial breakdown, persistence and weed tolerance. One major challenge with pre-emergent herbicides is that they need to be applied in a moist soil for it to be effective. The pre-emergent herbicides are taken up by roots of germinating weeds (Kaapro and Hall, 2012) or through the coleoptile or meristem of germinating seedling. The uptake by roots will occur when the herbicide is available in soil water. The efficacy of the herbicides also varied depending on the weed species.

Following the completion of the first evaluation period, a second evaluation period was conducted to assess the residual effect of the herbicides. The objective of this second assessment period was to evaluate the persistence of the tested pre-emergent herbicides in controlling *A. mangium*, without any additional herbicide applications. All remaining seedlings and seeds from the first period were removed, and new seeds were sown in the same trays. Among the treatments, indaziflam demonstrated the highest residual efficacy, significantly outperforming the others (Figure 2).

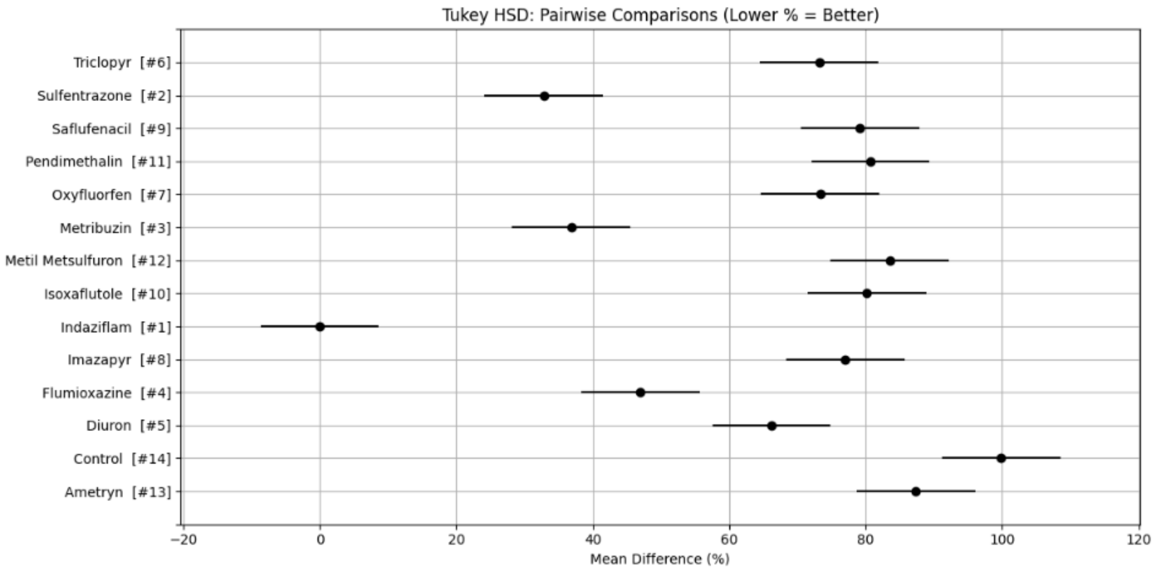

Figure 2. Emergence percentage of *A. mangium* in the second evaluation period.

In the second evaluation period, the emergence percentage of *A. mangium* was significantly influenced by the herbicide treatments. Indaziflam demonstrated the highest efficacy, completely inhibiting seedling emergence (0%). This was followed by sulfentrazone and metribuzin, which both reduced emergence to 30%. Flumioxazin also provided substantial suppression, with an emergence percentage of 45%. In contrast, treatments such as saflufenacil, ametryn, pendimethalin, and others resulted in high emergence rates (above 60%), indicating lower residual effect. The untreated control exhibited the highest emergence rate (100%). The results indicate that indaziflam has the longest residual effect among the herbicides tested and should preferably be evaluated under field conditions for the control of volunteer *A. mangium* in Eucalyptus plantations.

Indaziflam is used for pre emergence control and results in the inability of weed seedlings to grow. Indaziflam provides long-lasting residual activity at low application rates, due to its long persistence in soil (150 days) (EPA, 2010). Indaziflam is a potent herbicide used at low rates, has long soil residual activity (Brabham et al., 2014). Herbicides with residual soil activity are particularly important for controlling the seedbank in the soil (Morris et al., 2009). Indaziflam is also reduced mean time of seed germination (Dutra et al., 2023), thats mean indaziflam have residual effect in the soil.

Indaziflam registered cellulose-biosynthesis inhibitor (CBI) herbicide, can provide broad-spectrum control of annual grass and broadleaf weeds (Brabham et al., 2014). Indaziflam applied alone has little post-emergence activity, it is commonly applied pre-emergence, or as a tank-mix with foliar applied post-emergence herbicides like glyphosate to provide residual weed control. Indaziflam have residual activity on annual weeds in established turf (Brosnan et al., 2012).

The long-term residual control of volunteer *A. mangium* provided by a single indaziflam application could offer the opportunity to significantly reduce volunteer *A. mangium* in the soil seed bank. Sebastian et al. (2017) report that indaziflam has the potential to have positive long-term impacts on the structure and function communities invaded by annual grasses. Indaziflam treatments eliminated further residue inputs via residual control 2 year after treatment to control downy brome.

Indaziflam have significant control to *A. mangium* when conducted in well control conditions (greenhouse). Same result with Sebastian et al. (2017), that in the greenhouse had indaziflam active in controlling a range of winter annual grasses. Given the high quantities of *A. mangium* in the soil seed bank in APRIL concessions in Sumatra, indaziflam could be a key component in providing long-term management.

Indaziflam has a relatively long half-life (>150 days) in the soil. Field studies have shown that indaziflam provides superior downy brome and feral rye control compared to imazapic. Indaziflam provided 83 to 100% downy brome control 2 and 3 YAT (year after treatment) (Sebastian et al., 2016).

4. Conclusion

Indaziflam, metribuzin, saflufenacil, sulfentrazone, and isoxaflutole were effective in controlling *A. mangium*, with less than 7.0% seedling emergence observed at 35 DAS, compared to 92.3% in the untreated control at the end of the first evaluation period. The assessment of residual effect, conducted at 35 DAS at the end of the second evaluation period, showed that indaziflam provided the highest levels of sustained control, resulting in 0.0% seedling emergence, whereas the control treatment showed 100.0% emergence. Based on these results, indaziflam should be prioritized for further testing under larger-scale field conditions, as it represents a promising option for effective pre-emergent control of *A. mangium* and as a long-term strategy for seed bank depletion and volunteer *A. mangium* management in Eucalyptus plantations.

Acknowledgments

The authors are grateful for the support granted by APRIL Group and also management of Research and Development Department for supporting the development of the research, insights and assistance that have significantly enriched our research process and contributed to the success of our endeavors.

References

Barroso GM, De Carvalho AJE, Custódio IG, Correa JM, Duque TS, Silva DV, et al. Sensitivity of Eucalyptus clones to herbicides associated with foliar fertilizers. Forests. 2022; 13(9):1490. Available from: https://doi.org/10.3390/f13091490

Brabham C, Lei L, Gu Y, Stork J, Barrett M, DeBolt S. Indaziflam herbicidal action: a potent cellulose biosynthesis inhibitor. Plant Physiol. 2014; 166(3): 1177-85. Available from: https://doi.org/10.1104/pp.114.244061

Brosnan JT, Breeden GK, McCullough PE, Henry GM. PRE and POST control of annual bluegrass (Poa annua) with indaziflam. Weed Technol. 2012; 26(1): 48-53. Available from: https://doi.org/10.1614/WT-D-11-00086.1

Chhokar RS, Sharma RK, Sharma I. Weed management strategies in wheat – a review. J Wheat Res. 2012; 4(2):1–21. Available from: https://doi.org/10.25174/0975-5071/2012/002574

Clark SL. [A new paradigm in rangeland restoration: using a pre-emergent herbicide to assist in native plant establishment and release] [thesis]. Fort Collins: Colorado State University; 2019. Available at: https://hdl.handle.net/10217/197322.

Clark SL, Sebastian DJ, Nissen SJ, Sebastian JR. Effect of indaziflam on native species in natural areas and rangeland. Invasive Plant Sci Manag. 2019; 12(2):60-67. Available from: https://doi.org/10.1017/inp.2019.4

Dutra FB, Almeida LS, Pinto GCV, Furlaneto LF, Souza TKS, Viveiros E, et al. Pre-emergent indaziflam can enhance forest seed germination in direct seeding. Braz J Biol. 2023; 83:e268716. Available from: https://doi.org/10.1590/1519-6984.268716

United States Environmental Protection Agency (US EPA). Pesticide fact sheet: conditional registration. Washington, DC: United States Environmental Protection Agency; 2010. 108 p. Available from: https://www.epa.gov/ingredients-used-pesticide-products/indaziflam

Foster DC, Dotray PA, Baughman TA, Byrd SA, Culpepper AS, Dodds DM, et al. Performance of tank-mix partners with isoxaflutole across the Cotton Belt. Weed Technol. 2021;35 (6):1014-1022. Available from: https://doi.org/10.1017/wet.2021.76

Gehrke VR, Camargo MP, Balbinot LR., Freitas TC. A new selective herbicide for the control of Amaranthus species. Agron Journal. 2019; 111 (4): 1956-65. Available from: https://doi.org/10.2134/agronj2018.11.0718

Grossmann K, Hutzler J, Caspar G, Kwiatkowski J, Schutz W. Saflufenacil (Kixor®): biokinetic properties and mechanism of selectivity of a new protoporphyrinogen IX oxidase-inhibiting herbicide. Weed Sci. 2017; 65(3): 238-247. Available from: https://doi.org/10.1017/wsc.2016.32

Haskins B. Using pre-emergent herbicides in conservation farming systems. Orange: New South Wales Department of Primary Industries; 2012. Available from: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farmingsystems.pdf.

Hess FD. Light-dependent herbicides: an overview. Weed Sci. 2000; 48(2):160–170. Available from: https://doi.org/10.1614/0043-1745(2000)048[0160:LDHAO]2.0.CO;2

Hoverstad IR, Gunsolus JL, Johson GA, King RP. Risk-efficiency criteria for evaluating economics of herbicides based weed management system in corn. Weed Technol. 2004; 18(3): 687-697. Available from: https://doi.org/10.1614/WT-03-143R

Kaapro J, Hall J. Indaziflam, a new herbicide for pre-emergence control of weeds in turf, forestry, industrial vegetation, and ornamentals. Pak J Weed Sci Res. 2012; 18 (3): 267-270. Available from: https://doi.org/10.28941/pjwsr.v18i3.48

Khatib K. Herbicide symptoms (photosystem II inhibitors). Davis: University of California Agriculture and Natural Resources; 2022. Available from: https://

herbicidesymptoms.ipm.ucanr.edu/MOA/Photosystem_II_Inhibitors.

Kostopoulou S, Ntatsi G, Arapis G, Aliferis KA. Assessment of the effects of metribuzin, glyphosate, and their mixtures on the metabolism of the model plant Lemna minor L. applying metabolomics. Chemosphere. 2020; 239: 124582. Available from: https://doi.org/10.1016/j.chemosphere.2019.124582

Morris C, Monaco TA, Rigby CW. Variable impacts of imazapic rate on downy brome (Bromus tectorum) and seeded species in two rangeland communities. Invasive Plant Sci Manag. 2009; 2(2): 110-9. Available from: https://doi.org/10.1614/IPSM-08-119.1

Osiecka A, Minogue P. Herbicides for weed control in eucalyptus culture. Gainesville: University of Florida, IFAS Extension; 2013. Available from: https://doi.org/10.32473/edis-fr378-2013.

Orwa F, Muinga E, Kibe K, Ndegwa E, Ochieng S. Terminalia catappa Linn. In: Agroforestry Database 4.0. Nairobi: World Agroforestry Center (ICRAF); 2009. Available from: https://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=1506

Siregar S, et al. Unpublished report. Riau (Indonesia): APRIL Group; 2020.

Sebastian DJ, Sebastian JR, Nissen SJ, Beck KG. A potential new herbicide for invasive annual grass control on rangeland. Rangeland Ecol Manag. 2016;69(3): 195-198. Available from : https://doi.org/10.1016/j.rama.2016.01.001

Sebastian SJ, Fleming M, Patterson E, Sebastian JR. Indaziflam: a new cellulose biosynthesis Inhibiting herbicide provides long-term control of invasive winter annual grasses. Pest Manag Sci. 2017; 73(10): 2149-2153. Available from: https://doi.org/10.1002/ps.4602

Seedorf RH. Using indaziflam for integrated weed management in managed and natural ecosystems [thesis]. Fort Collins: Colorado State University, Department of Agricultural Biology; 2020. Available from: https://hdl.handle.net/10217/219375

Silva DM, Mendanha JF, Buss, RN, Siqueira GM. Multiscale properties of weeds in no-till system. Adv Weed Sci. 2022; 40:e020220034. Available from: https://doi.org/10.51694/AdvWeedSci/2022;40:seventy

Tompkins, J. Pesticide fact sheet: indaziflam. Washington, DC: United States Environmental Protection Agency; 2010. Available from: https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-080818_01-Aug-10.pdf

Vargas F, Gonzalez-Benecke CA, Rubilar R, Sanchez-Olate M. Modelling the effect of weed competition on long-term volume yield of eucalyptus globulus Labill. plantations across an environmental gradient. Forests. 2018;9(8):480. Available from: https://doi.org/10.3390/f9080480

Volova T, Demidenko A, Kurachenko N, Baranovsky S, Petrovskaya O, Shumilova A. Efficacy of embedded metribuzin and tribenuron-methyl herbicides in field-grown vegetable crops infested by weeds. Environ Sci Pollut Res. 2020; 28(1): 982-994. Available from: https://doi.org/10.1007/s11356-020-10494-1

Zhao N, Zuo L, Li W, Guo W, Liu W, Wang J. Greenhouse and field evaluation of isoxaflutole for weed control in maize in China. Sci Rep. 2017; 7: 12690. Available from: https://doi.org/10.1038/s41598-017-13039-2