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Weed Control by Different Doses Flumioxazin Herbicide in Soybean

Anuar Ramut[1]*, Muhammad Husaini Assauwab[1], Deden Sumoharjo[1], Kartono[2], Muhammad Yassir[3], Mario Pani[4], Era Maulia[5], Yulis Untari[6]

[1] Agrotechnology, Faculty of Agriculture, Universitas Gunung Leuser, Indonesia
[2] Animal Science, Faculty of Agriculture, Universitas Gunung Leuser, Indonesia
[3] Biology Education, Faculty of Teacher Training and Education, Universitas Gunung Leuser, Indonesia
[4] Agrotechnology, Faculty of Agriculture, Syiah Kuala University, Indonesia
[5] Agrotechnology, Faculty of Science and Technology, Universitas Al Washliyah Darussalam Banda Aceh, Indonesia
[6] Agricultural Science, Faculty of Agricultural and Animal Husbandry Science, Universitas Islam Kebangsaan Indonesia, Indonesia

*Corresponding author. Email: anuarramut@gmail.com

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Abstract
Weed management plays a crucial role in soybean cultivation as weeds compete for nutrients, light, and water, leading to reduced crop productivity. Chemical control using herbicides remains the most effective and efficient method due to its ability to save time, labor, and production costs. This study aimed to determine the optimal dose of flumioxazin herbicide for effective weed suppression and improved soybean performance. The experiment was conducted from August to November 2024 at the Experimental Farm, Faculty of Agriculture, Universitas Gunung Leuser, Kutacane, Southeast Aceh, Indonesia. A non-factorial Randomized Complete Block Design (RCBD) with three replications was used, consisting of four flumioxazin doses: D0 = 0 g a.i ha^{-1}, D1 = 400 g a.i ha^{-1}, D2 = 800 g a.i ha^{-1}, and D3 = 1200 g a.i ha^{-1}. Results showed that the 400 g a.i ha^{-1} dose achieved the highest weed control efficiency 42.55 - 75.78%, reduced weed cover by 28.22 – 40.45%, and decreased weed biomass by 60.24 - 60.96% compared to the control. However, higher doses (≥800 g a.i ha^{-1}) caused phytotoxic symptoms such as leaf chlorosis and stunted growth. Consequently, flumioxazin application did not significantly improve plant height, number of leaves, seed number, or dry seed yield compared to untreated plants. The 400 g a.i ha^{-1} dose was therefore identified as the most effective and environmentally safe rate for pre-emergence weed management in soybean cultivation.
Keywords: *flumioxazin, , herbicide, phytotoxicity, soybean, weed control*

1. Introduction

Weeds are plants that cause significant losses to farmers, as their presence in soybean fields often leads to reductions in both the quality and quantity of soybean growth and yield. This occurs because weeds compete with soybean plants for water, nutrients, and growing space, thereby disrupting the overall growth process of soybeans [1], [2]. Therefore, weed management is essential in soybean cultivation. Among the most widely practiced methods is chemical weed control using herbicides, as it is considered more effective and efficient in terms of cost, time, and labor requirements. Herbicide based weed management is more practical, profitable, and relatively rapid to implement [3]. Flumioxazin is a pre-emergence and post-emergence herbicide, which means it can be applied to both soil and weed foliage. The herbicide acts by inhibiting the enzyme protoporphyrinogen oxidase, which is involved in chlorophyll biosynthesis. This inhibition disrupts the photosynthetic process, leading to weed death. Consequently, flumioxazin has been widely used to control grasses, broadleaf weeds, and sedges [4], [5]. Previous studies have shown that application of flumioxazin herbicide suppressed weed growth at 90 days after sowing by 71–88%, this herbicide effectively suppresses broadleaf, grass, and sedge weeds of species such as *Richardia brasiliensis, Mimosa invisa, Poa annua, and Amaranthus* spp [6], [7], [8].

The effectiveness of an herbicide is strongly influenced by its application rate. An inappropriate dose may result in crop injury when applied excessively or insufficient weed control when applied at too low a dose [9], [10]. Research conducted indicated that flumioxazin applications at 9 – 142 g a.i ha^{-1} were not sufficient to increase soybean dry weight or yield [11], [12], [13], [14], [15]. Meanwhile, other studies by demonstrated that flumioxazin application at 75 – 250 g a.i ha^{-1} significantly reduced total weed biomass, broadleaf weed biomass, and the biomass of *Richardia brasiliensis* and *Mimosa invisa*. However, these doses were still ineffective against grass weeds and did not result in improvements in soybean plant height or population [8], [16], [17]. Based on the aforementioned findings, further research is required to determine the appropriate dose of flumioxazin herbicide for effective weed control in soybean cultivation. Therefore, this study aims to identify the optimal dose of flumioxazin herbicide that can effectively suppress weed growth while enhancing the growth and yield of soybean plants.

2. Material and Methods

This study was conducted from August to November 2024 at the experimental farm of the Faculty of Agriculture, Universitas Gunung Leuser, Kutacane, Southeast Aceh Regency, Aceh Province. The tools used included a 15 L knapsack handsprayer, measuring cylinder, 0.5 × 0.5 m quadrat frame, hoe, raffia rope, label paper, oven, and analytical balance. The materials used consisted of soybean seeds (*Glycine max* L.) var. *Grobogan*, *flumioxazin* herbicide, *deltamethrin* insecticide, urea, SP-36, and KCl fertilizers. The experiment was arranged in a non-factorial Randomized Complete Block Design (RCBD) with three replications, resulting in 12 experimental units. The treatment factor was the dose of flumioxazin herbicide, consisting of four levels: D0 = 0 g a.i ha^{-1}, D1 = 400 g a.i ha^{-1}, D2 = 800 g a.i ha^{-1}, and D3 = 1200 g a.i ha^{-1}. The observed variables included weed control percentage, weed cover, weed fresh weight, plant height, number of leaves, number of seeds per plant, and dry seed yield of soybean. The percentage of weed control was visually evaluated by five assessors by comparing weed growth in the treated plots with that in the control plots, using a rating scale ranging from 0% (no weed control) to 100% (complete weed control). The percentage of weed coverage was also visually assessed by five evaluators by estimating the proportion of land area covered by weeds compared with the control, using a rating scale from 0% (weed-free) to 100% (fully covered by weeds). Fresh weed biomass was determined by collecting weed samples within a 50 × 50 cm quadrat at four sampling points in each plot, after which all weeds were weighed to obtain the total fresh weight. Plant height was measured from the base of the stem to the shoot apex using a measuring tape. The number of leaves was counted manually, the number of seeds per plant was determined by counting all seeds per sampled plant, and dry seed yield was measured by weighing soybean seeds with a 14% moisture content from each plot. Data were analyzed quantitatively using *Analysis of Variance (ANOVA)*, followed by *Duncan's Multiple Range Test (DMRT)* for mean separation, and descriptively presented in tables. The agronomic practices included the application of flumioxazin herbicide at one day after sowing (DAS) according to the respective treatment doses. Fertilizers applied consisted of urea, SP-36, and KCl at doses of 70, 80, and 90 kg ha^{-1}, respectively. Fertilization was carried out in two stages: half of the urea and all of SP-36 and KCl were applied at planting, while the remaining half of urea was applied at 30 DAS. Maintenance activities included watering twice daily (morning and evening). Pest control was performed during the generative growth stage using deltamethrin insecticide, applied once a week.

3. Results and Discussion

3.1 Weed Growth

Table 1 shows that the application of flumioxazin herbicide at a dose of 400 g a.i ha^{-1} was already able to increase the percentage of weed control. This indicates that higher herbicide doses enhance the toxic effect due to the greater amount of active ingredient, which causes weed seeds to die and consequently increases weed control efficacy. This finding is consistent with reported that flumioxazin was capable of controlling broadleaf weeds by 50 – 85% up to 90 DAS [8]. Field observations in this study also confirmed that the increased percentage of weed control was maintained until 63 DAS and was visually evident even up to harvest. Table 1 also demonstrates that flumioxazin at 400 g a.i ha^{-1} was able to reduce weed cover percentage. This result is in line with the increase in weed control percentage, as higher weed suppression corresponded to lower weed cover. This agrees with the statement of reported that flumioxazin herbicide reduced both weed cover and weed biomass [18]. Similarly, reported that the application of flumioxazin at doses of 71 – 480 g a.i ha^{-1} effectively controlled *Episcia, Ambrosia artemisiifolia* L., *Setaria viridis* L., *Chenopodium album* L., and *Amaranthus retroflexus*, thereby reducing the extent of land area covered by weeds [11].

Table 1 presents the average percentage of weed control, weed cover, and weed fresh weight as affected by different doses of flumioxazin herbicide

Treatment	Percentage of Weed Control			
	21 DAS	35 DAS	49 DAS	63 DAS
Dose of Herbicide	%			
0 g a.i ha^{-1}	18.33a	12.07a	11.90a	6.13a
400 g a.i ha^{-1}	75.78b	63.00b	42.69b	42.55b
800 g a.i ha^{-1}	83.78b	73.00b	54.86bc	53.33c
1200 g a.i ha^{-1}	92.00b	81.07b	75.00c	74.50d
Treatment	Percentage of Weed Cover			
	21 DAS	35 DAS	49 DAS	63 DAS
Dose of Herbicide	%			
0 g a.i ha^{-1}	90.33a	92.30a	94.47a	99.40a
400 g a.i ha^{-1}	28.22b	29.55b	39.67b	40.45b
800 g a.i ha^{-1}	21.67b	24.11b	36.00bc	36.67b
1200 g a.i ha^{-1}	12.56b	16.17b	19.60c	20.13b
Treatment	Weed Fresh Weight			
	21 DAS	35 DAS	49 DAS	63 DAS
Dose of Herbicide	g			
0 g a.i ha^{-1}	9.81a	16.51a	47.65a	50.77a

400 g a.i ha^{-1}	3.83b	14.86ab	15.20b	20.18b
800 g a.i ha^{-1}	4.97b	9.62bc	14.23b	18.28b
1200 g a.i ha^{-1}	1.16c	6.93c	7.38b	11.59b

The numbers followed by the same letter in the same column are not significantly different in Duncan's 5% test.

Furthermore, Table 1 indicates that flumioxazin applied at doses of 800 – 1200 g a.i ha^{-1} significantly reduced weed fresh weight. As a protoporphyrinogen oxidase (PPO) inhibitor, flumioxazin disrupts weed physiology by interfering with chlorophyll biosynthesis, which leads to tissue necrosis. The reduction in fresh weed biomass observed at higher doses demonstrates that increasing herbicide concentrations further suppress weed physiological development. The decrease in fresh weed biomass was closely associated with higher weed control percentages, lower weed cover, fewer weed species, and reduced weed populations. Also reported that the application of flumioxazin in no-tillage soybean systems increased weed control efficacy and reduced the dry biomass of annual grasses, with consistent effects observed up to 65 DAS in the second year of application [19]. Then it was added that the application of flumioxazin herbicide effectively increased the percentage of weed control and reduced the total number and dry weight of weeds per square meter compared with the control [20], [21].

3.2 Soybean Growth

Table 2 shows that flumioxazin herbicide applied at doses of 800 – 1200 g a.i ha^{-1} reduced soybean plant height. This indicates the occurrence of phytotoxic effects on soybean plants due to the high concentration of flumioxazin. The symptoms of toxicity were evident shortly after application, as seedlings began to emerge three days after sowing but appeared stunted. Visual observations confirmed that the higher the dose applied, the more severe the stunting symptoms became, demonstrating that excessive flumioxazin concentrations were detrimental to soybean growth. Explained that the active ingredient in herbicides functions according to its intended purpose; however, increasing the dose intensifies its suppressive effect while reducing crop selectivity, leading to crop injury [22], [23].

Table 2 presents the average plant height and number of leaves of soybean as affected by different doses of flumioxazin herbicideWeed Growth

Treatment	Plant Height			
	21 DAS	35 DAS	49 DAS	63 DAS
Dose of Herbicide	-------------------------------- cm ----------------------------------			
0 g a.i ha^{-1}	15.71a	35.17a	37.33a	41.28a
400 g a.i ha^{-1}	10.92ab	27.75ab	30.00ab	31.00a
800 g a.i ha^{-1}	8.60bc	15.50b	19.67ab	23.60ab
1200 g a.i ha^{-1}	4.33c	12.67b	14.00b	8.00b
Treatment	Number of Leaves			
	21 DAS	35 DAS	49 DAS	63 DAS
Dose of Herbicide	-------------------------------- ----------------------------------			
0 g a.i ha^{-1}	11.25a	25.83a	29.33a	34.33a
400 g a.i ha^{-1}	11.33a	18.83ab	21.67ab	26.67ab
800 g a.i ha^{-1}	9.33ab	11.33b	15.00ab	17.67ab
1200 g a.i ha^{-1}	4.67b	9.67b	10.33b	11.33b

The numbers followed by the same letter in the same column are not significantly different in Duncan's 5% test.

Furthermore, Table 2 indicates that the dose of 1200 g a.i ha^{-1} reduced the number of soybean leaves. Phytotoxicity symptoms at higher herbicide doses caused soybean leaves to appear thickened and curled. This effect was already visible during the germination stage, where soybean plumules experienced difficulty unfolding due to thickened hypocotyls and curled cotyledons. Such conditions disrupted the photosynthetic process in the early stages of growth, ultimately reducing vegetative development. Emphasized that photosynthesis is a key physiological process that drives subsequent metabolic activities in plants. Thus, any disruption at this stage leads to a decline in overall soybean growth [24]. Disturbances in the photosynthetic process, caused by fluctuations in light intensity, environmental stress, or suboptimal field management, have been reported to reduce photosynthetic efficiency, consequently suppressing soybean growth and yield performance [25], [26].

3.3 Components of Soybean

Table 3 shows that the application of flumioxazin herbicide at 400 g a.i ha^{-1} did not significantly increase the number of soybean seeds per plant compared to the untreated control. Although the number of seeds was statistically similar, field observations revealed that seeds produced under the 400 g a.i ha^{-1} treatment were relatively larger than those from the control plots without herbicide application. This indicates that effective weed control contributes more to seed quality than to seed quantity. The smaller seed size observed in the control treatment was likely due to limited nutrient availability for pod and seed formation, as soybean plants competed heavily with weeds for growth resources. Explained that when herbicides successfully suppress weed growth, soybean plants are able to develop more leaves, which enhances photosynthesis. As a result, assimilates accumulate more efficiently [27], thereby improving seed development and increasing the number of seeds per plant.

Table 3 presents the average plant height and number of leaves of soybean as affected by different doses of flumioxazin herbicideWeed Growth

Treatment	Number of Soybean Seeds	Dry Seed Yield of Soybean
Dose of Herbicide		g
0 g a.i ha^{-1}	12.92a	12.24ab
400 g a.i ha^{-1}	41.50ab	76.48a
800 g a.i ha^{-1}	2.00b	1.87b
1200 g a.i ha^{-1}	0.33b	1.47b

The numbers followed by the same letter in the same column are not significantly different in Duncan's 5% test.

Furthermore, Table 3 indicates that flumioxazin application at 400 g a.i ha^{-1} did not significantly increase dry seed yield of soybean. This finding suggests that although herbicide application effectively controlled weeds, some level of crop phytotoxicity may have limited yield improvement. Weed management is considered effective when control is achieved up to 8 – 9 weeks after sowing [28], [29], [30], [31]. Field observations in this study confirmed that flumioxazin application extended weed suppression up to 13 weeks after sowing (WAS) or until harvest. However, this extended weed control did not translate into significant yield improvement. Despite this, the 400 g a.i. ha^{-1} dose performed better than higher doses, which induced stronger phytotoxic effects on soybean plants. This finding is supported by evidence that increasing the herbicide dose to twice the recommended rate significantly elevates phytotoxicity levels, thereby reducing crop yield [32], [33], [34], [35], [36].

4. Conclusion

The application of flumioxazin herbicide at a dose of 400 g a.i ha^{-1} was effective in increasing weed control percentage 42.55 – 75.78 %, reducing weed cover 28.22 - 40.45 %, and decreasing weed biomass 60.96 – 60.24% compared to the control in soybean cultivation. Previous studies indicated that flumioxazin applied at rates below 250 g a.i. ha^{-1} was ineffective in controlling grass weeds and did not improve soybean growth. The present study demonstrated that increasing the application rate to 400 g a.i. ha^{-1} effectively suppressed weed growth. However, it caused phytotoxic effects that resulted in reduced plant growth and yield.

These findings highlight the importance of determining the appropriate herbicide dosage to achieve effective weed suppression without compromising soybean growth and yield performance.

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