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The effectiveness of different formulations of glyphosate herbicides under simulated rainfall conditions in controlling various weeds

Abstract. Herbicide effectiveness is affected by herbicide formulation, rainfall, and weed type. Differences in glyphosate salt formulations and 2,4 D amine mixtures may result in variations in the herbicide's ability to wash off the herbicide due to rain. This study aimed to assess the effectiveness of different glyphosate herbicide formulations under varying rainfall in controlling various weeds. The experiment took place in a controlled greenhouse environment, utilizing a split-plot experimental design with four replications. The main plot was assigned to six different rainfall timings: 0 hours after application (HAA), 1 HAA, 2 HAA, 3 HAA, 4 HAA, and no rainfall. The subplots involved different herbicide formulations, namely isopropylamine glyphosate (h1), potassium glyphosate (h2), sodium glyphosate (h3) and glyphosate herbicide, IPA herbicide glyphosate + 2,4 D Amine (h4) and without any herbicide application (h0). Various parameters were observed, including weed dry weight and percentage of mortality growth. The results showed that the effectiveness of each herbicide formulation was different among weed species under simulated rainfall conditions. *Ageratum conyzoides* could be controlled using isopropylamine glyphosate and potassium glyphosate with rainfall at 1 HAA. *Axonopus compressus* could be controlled by isopropylamine glyphosate and sodium glyphosate with rainfall at 1 HAA, while *Borreria alata* and *Cyperus rotundus* were effectively controlled by isopropylamine glyphosate with rainfall at 1 HAA.

Keywords: 2,4 D amine · Formulations · Glyphosate · Rainfall · Weed

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Introduction

A weed is a plant that grows in an area where it is seen as unwanted by humans because it interferes with their requirements, ambitions, or preferences (Borah, 2023). Weeds are a significant biological element in crop production that reduces yield, accounting for about 45% of crop yield loss (Korav et al., 2018). Weeds have the potential to reduce agricultural yield and quality of production by competing with crops for nutrients including water, light, fertilizer, and growing space (Khan et al., 2021).

Losses due to weeds can be reduced with proper weed control. Herbicide application is the most practical, effective, and economical way to reduce weed problems, crop losses, and production costs (Latiff et al., 2009). Glyphosate herbicide is the most widely used and popular herbicide in the world (Baylis, 2000; Singh et al., 2011). Glyphosate is a non-selective systemic herbicide that has a broad spectrum. Glyphosate herbicide is effective against more than 100 broadleaf and grass weeds and more than 60 species of annual weeds (Singh et al., 2011).

Continuous application of glyphosate—sometimes more than twice a year in the same crop—has put the flora under a lot of selection pressure, which has led to the emergence of weeds that are tolerant or resistant to glyphosate (Heap, 2020). Efforts that can be made are by mixing herbicides to broaden the spectrum of weed control, and reducing weed resistance to one herbicide to prevent homogeneous weed vegetation in an area (Sembodo & Wati, 2021). Glyphosate herbicide can be mixed with 2,4 D Amine. Palma-Bautista et al. (2021) stated that glyphosate with 2,4-D in a tank mix is an effective substitute for managing weeds that are resistant to and tolerant to glyphosate.

Apart from that, the active ingredient glyphosate is applied in the form of a salt addition formulation due to its low solubility. The addition of different salts to glyphosate formulations can increase water solubility by up to 90% (Shaner, 2014; Dalazen et al., 2020). Differences in herbicide formulations and concentrations can affect the rate of absorption and translocation of herbicides and the effectiveness of weed control (Martini et al., 2003; Souza et al., 2014). The glyphosate salt formulation used in this experiment is isopropylamine, potassium, and sodium.

Effective herbicide applications require successful deposition, retention, uptake, and translocation of the herbicide onto the plant (Zwertvaegher et al. 2014). Environmental factors such as rain also determine the effectiveness of herbicides. The amount of rainfall and the time of rain significantly impact the effectiveness of the herbicide (Stewart et al., 2012). Unexpected rain causes the herbicide to leach, thereby reducing its effectiveness (Kurniadie et al., 2022). The efficacy of glyphosate herbicides was reduced by 50% after 1 hour of rain after application (Bariuan et al., 1999).

Herbicide effectiveness is also influenced by the characteristics of the target weeds. Various weed species exhibited varying reactions to rainfastness, as leaf features impact absorption and hence herbicide efficiency (Rodrigues, 2018). The effectiveness of herbicide absorption is affected by species, growth stage, habitat, morphology, and leaf wax composition of weeds (Costa et al., 2017). This study aims to determine the ability of several glyphosate herbicide formulations with different rainfall times to control various types of weeds.

Materials and Methods

The experiment was carried out at the Experimental Laboratory of the Faculty of Agriculture, Universitas Padjadjaran from January to March 2019. The materials used were *Ageratum conyzoides, Borreria alata, Axonopus compressus*, *Cyperus rotundus*, herbicide Isopropylamine glyphosate 486 g/L, potassium glyphosate 660 g/L, sodium glyphosate 170 g/L, and mixed herbicide IPA glyphosate 300 g/L + 2.4 D amine 100 g/L with a recommended dose of 1.5 L each /Ha. This study used a split-plot experimental design with four replications. The main plot was assigned to six different rainfall timings: 0 hours after application (HAA), 1 HAA, 2 HAA, 3 HAA, 4 HAA, and no rainfall. The subplots involved different herbicide formulations, namely isopropylamine glyphosate (h1), potassium glyphosate (h2), sodium glyphosate (h3) and glyphosate herbicide, IPA herbicide glyphosate + 2,4 D amine (h4) and without any herbicide application (h0).

Each weed with 2-3 growing leaves was transferred to a 20 cm diameter pot filled with planting medium, and then maintained properly for two weeks. After two weeks, the weeds that had grown were moved into a 4 x 4 m plot

(Figure 1) and each herbicide was applied according to the time it rained. The rainfall used is 10 mm/day (rainfall in the area of PTPN VIII Subang). If the rain gauge used has a diameter of 20 cm, as shown in Figure 1.

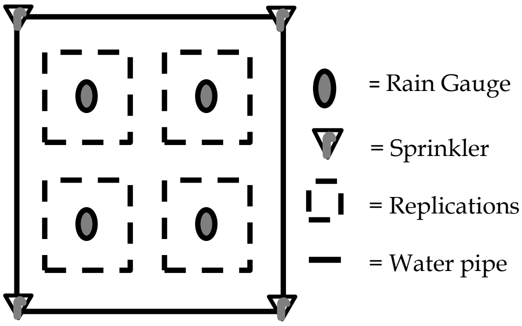

Figure 1. Layout of sprinklers, rain gauges, and location of experimental plots on a rain simulation plot.

The herbicide was applied using a semi-automatic knapsack sprayer and T-Spray nozzles with a pressure of 15-20 psi and a volume of 400 l/ha. The rain simulation was carried out according to the rain time treatment after herbicide application. Observation of dry weight is done by weed harvesting at 3 weeks after application (WAA). The weeds from each treatment were taken and cleaned from the soil, then added to the weeds and heated in the oven until they reached a constant weight at 80°C. After baking, weeds were weighed for dry weight. The percentage of weed damage is calculated by the following formula (Chuah et al., 2004):

$$\% \text{ Damage} = (1- (\frac{\text{dry weight of treatment}}{\text{dry weight of control}}))\times 100$$

The results obtained were analyzed by analysis of variance with the F test and the average treatment used Scott Knott's advanced test at a significant level of 5%. The original dry weight data were transformed by root transformation (x+0.5) and the original data on weed damage percentage were transformed by root arc sin transformation (%+0.5).

Results and Discussion

The target weeds tested in this study were broadleaf: *Ageratum conyzoides,* and *borreria alata,* grass weed: *Axonopus compressus*, sedge weed: *Cyperus rotundus* that is the dominant weed in the oil palm plantation area of PTPN VIII Subang. *Boreria alata, Ageratum conyzoides, Asystasia intrusa, Imperata cylindrica, Paspalum conjugatum, Setaria plicata, Emilia sonchifolia,* and *Erigeron sumantresis* including weeds that are almost always present or dominant in oil palm plantations (Purwasih et al., 2013).

Weed dry weight and percentage *Ageratum conyzoides.* Based on observations of dry weight and percentage of weed damage in *Ageratum conyzoides* the herbicides isopropylamine and potassium glyphosate with a raining time of 1 HAA had a lower dry weight and a higher percentage of damage compared to other treatments with the same raining time and relatively the same as the treatment without rain. This shows that the application of isopropylamine and potassium glyphosate herbicides with 1 HAA rainfall time has been able to control weeds *Ageratum conyzoides* (Table 1). The same results were also shown by the research of Kurniadie & Umiyati (2019) that the herbicide potassium glyphosate was able to control weeds *Ageratum conyzoides* with a rain time of 0-1 hour after application. The effectiveness of isopropylamine glyphosate and potassium glyphosate in controlling *Ageratum conyzoides* can be due to their good absorption. Increasing the absorption ratio is one of the keys to improving herbicide efficacy, according to Li et al. (2019).

Sodium glyphosate and IPA glyphosate+2,4 D amine with a raining time of 3 HAA showed dry weight and percentage of weed damage in *Ageratum conyzoides* same as with the no rain treatments. *Ageratum conyzoides* are effectively controlled by the sodium glyphosate and IPA glyphosate+2,4 D amine after three hours without rain. Research by Pedrinho Junior et al. (2002) stated that EPSPS-inhibiting herbicide formulations were effective in controlling weeds by simulating rain for up to four hours after application. Herbicide 2,4 D amine without rain for 30 minutes is still effective in controlling *Senna obstusifolia* (Souza et al., 2014).

Weed dry weight and percentage of *Borreria alata* weed damage. Table 2 shows that isopropylamine glyphosate with 1 HAA raining time has been able to control *Borreria alata* which was indicated by a lower dry weight and a higher percentage of damage than the other treatments and relatively the same as the treatment without rain. The effectiveness of glyphosate herbicides is not affected by rainwater washing within 2 hours after application (Girsang, 2005).

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Table 1. The effect of various herbicide formulations with differences rainfall times on weed dry weight and percentage of *Ageratum conyzoides* weed damage

Time occurrence of rain	Dry weight (g)					Percentage of weed damage (%)			
	Herbicide formulation					Herbicide formulation			
	h0	h1	h2	h3	h4	h1	h2	h3	h4
0 HAA	2.58 a A	0.73 a B	0.85 a B	1.93 a A	2.38 a A	75.12 b A	69.23 b A	39.70 c B	24.62 d B
1 HAA	2.63 a A	0.08 b C	0.23 b C	0.73 b B	1.23 b B	96.43 a A	91.43 a A	75.49 b B	66.35 c B
2 HAA	2.33 a A	0.00 b C	0.00 b C	0.40 b B	0.45 c B	100.0 a A	100.0 a A	88.32 b B	87.44 b B
3 HAA	2.45 a A	0.00 b B	0.00 b B	0.13 c B	0.00 d B	100.0 a A	100.0 a A	95.12 a A	100.0 a A
4 HAA	2.10 a A	0.00 b B	0.00 b B	0.00 c B	0.00 d B	100.0 a A	100.0 a A	100.0 a A	100.0 a A
No rainfall	3.25 a A	0.00 b B	0.00 b B	0.00 c B	0.00 d B	100.0 a A	100.0 a A	100.0 a A	100.0 a A

Note: The average number followed by the same lowercase letter in the column (type of herbicide) and uppercase letter in the row (time of rain) is not significantly different based on the Scott-Knott test at the 5% level. HAA: hours after application, h0: without herbicide, h1: isopropylamine glyphosate, h2: potassium glyphosate, h3: sodium glyphosate, h4: IPA glyphosate +2.4 D amine

Table 2. The effect of various herbicide formulations with different rainfall times on weed dry weight and percentage of *Borreria alata* weed damage

Time occurrence of rain	Dry weight (g)					Percentage of weed damage (%)			
	Herbicide formulation					Herbicide formulation			
	h0	h1	h2	h3	h4	h1	h2	h3	h4
0 HAA	2.70 a A	0.53 a C	1.15 a B	1.43 a B	1.43 a B	82.44 b A	59.73 b B	50.32 c B	52.21 c B
1 HAA	2.10 a A	0.00 b C	0.75 a B	1.00 a B	1.25 a B	100.0 a A	76.13 b B	60.34 c B	60.78 c B
2 HAA	2.20 a A	0.00 b C	0.00 b C	0.33 b C	0.63 b B	100.0 a A	100.0 a A	90.55 b B	77.07 b B
3 HAA	2.48 a A	0.00 b B	0.00 b B	0.00 b B	0.00 c B	100.0 a A	100.0 a A	100.0 a A	100.0 a A
4 HAA	2.75 a A	0.00 b B	0.00 b B	0.00 b B	0.00 c B	100.0 a A	100.0 a A	100.0 a A	100.0 a A
No rainfall	3.08 a A	0.00 b B	0.00 b B	0.00 b B	0.00 c B	100.0 a A	100.0 a A	100.0 a A	100.0 a A

Note: The average number followed by the same lowercase letter in the column (type of herbicide) and uppercase letter in the row (time of rain) is not significantly different based on the Scott-knott test at the 5% level. HAA: hours after application, h0: without herbicide, h1: isopropylamine glyphosate, h2: potassium glyphosate, h3: sodium glyphosate, h4: IPA glyphosate +2.4 D amine

Potassium glyphosate herbicide can control *Borreria alata* with a rain-free time of up to 2 hours after application. *Borreria alata* can be controlled by the herbicide sodium glyphosate and IPA glyphosate + 2.4 D if there is no rain up to 3 hours after application. Kurniadie & Umiyati (2019) reported that potassium glyphosate herbicide is effective in controlling *Borreria alata* with rain time 2 hours after application.

Weed Dry Weight of *Axonopus compressus*. Results of observations of weed dry weight *Axonopus compressus* showed that isopropylamine and sodium glyphosate herbicides with 1 HAA raining time were able to control weeds *Axonopus compressus* which is shown with low dry weight and does not differ from the treatment without rain (Table 3). Rain that occurs 15 minutes – 6 hours after herbicide application can reduce the efficacy of glyphosate herbicides (Boerboom, 2006).

Table 3. The effect of various herbicide formulations with different rainfall times on dry weight *of Axonopus compressus*

Time occurance of rain	Herbicide formulation				
	h0	h1	h2	h3	h4
0 HAA	3.65 a A	1.90 a B	1.33 a B	1.68 a B	2.20 a B
1 HAA	3.48 a A	0.63 b B	0.68 a B	0.70 b B	1.10 a B
2 HAA	4.03 a A	1.18 a B	0.50 a B	1.30 a B	1.73 a B
3 HAA	3.85 a A	0.00 b C	0.88 a B	1.63 a B	1.20 a B
4 HAA	3.85 a A	0.00 b B	0.00 b B	0.55 b B	0.95 a B
No rainfall	5.03 a A	0.00 b B	0.00 b B	0.00 b B	0.00 b B

Note: The average number followed by the same lowercase letter in the column (type of herbicide) and uppercase letter in the row (time of rain) is not significantly different based on the Scott-Knott test at the 5% level. HAA: hours after application, h0: without herbicide, h1: isopropylamine glyphosate, h2: potassium glyphosate, h3: sodium glyphosate, h4: IPA glyphosate +2.4 D amine

Weed Damage Percentage *of Axonopus compressus.* Table 4 shows that the results of observations on the percentage of damage show the independent effect of the herbicide formulation and the time it rains. The herbicides isopropylamine glyphosate and potassium glyphosate showed a higher percentage of damage compared to the sodium glyphosate and IPA glyphosate+2.4 D amine treatments, while the 4 HAA treatment had a high percentage and was relatively the same as the no-rain treatment. Potassium glyphosate herbicide that was rained 0 – 4 hours after application was not effective in controlling growth of *Asystasia intrusa* weed (Priambodo, 2017).

Dry Weight and Percentage of *Cyperus rotundus* Weed Damage. Table 5 shows the results of observing the dry weight of *Cyperus rotundus* that the herbicides isopropylamine glyphosate, potassium glyphosate, and sodium glyphosate with a raining time of 1 HAA had a dry weight of *Cyperus rotundus* relatively the same as the treatment without rain. Observation of damage percentage showed that the herbicide isopropylamine glyphosate with 1 HAA rain time showed a high percentage of weed damage and was relatively the same as the treatment without rain. Rain simulation with 1 hour after application reduced the efficacy of glyphosate on *Abutilon of Theophrastus, Cyperus esculantus* and *Echinochloa cruss-galli* (Reddy & Singh, 1992).

Table 4. The effect of various herbicide formulations with different rainfall times on the percentage of *Axonopus compressus* weed damage

Treatments	Percentage of weed damage (%)	
Time occurance of rain :		
0 hours after application	64.67	c
1 hours after application	85.48	b
2 hours after application	73.76	c
3 hours after application	80.12	b
4 hours after application	92.60	a
No rainfall	100.00	a
Herbicide formulation :		
Isopropylamine glyphosate	87.39	a
Potassium glyphosate	88.22	a
Sodium glyphosate	80.42	b
IPA glyphosate + 2,4 D Amine	75.05	b

Note: The average score followed by the same letter is not significantly different based on the Scott-Knott test at the 5% level.

Cyperus rotundus effectively controlled with glyphosate potassium, sodium glyphosate, and IPA glyphosate +2,4 D amine with 2 HAA rain simulation. Souza et al. (2011) revealed that the effectiveness of herbicides is closely related to absorption, the lower the absorption, the lower the effectiveness. In general, herbicide absorption by weeds takes more than 2 hours (Sriyani, 2010).

Each herbicide formulation showed different abilities in controlling various target weeds with different rainfall periods. Differences in the efficacy of glyphosate herbicides in controlling various types of weeds depend on different rain-free periods (Kurniadie & Umiyati, 2019). The rain-free period for herbicide efficacy depends on the chemical nature of the herbicide and the degree of application (Ganon & Yalverton, 2008).

Based on the data on dry weight and damage percentage, it is known that the herbicide isopropylamine glyphosate was able to control all the weeds tested with 1 HAA rainfall. Research on glyphosate salt with rain simulation reported that glyphosate isopropylamine salt formulation controls *Brachiaria decumbens* better than potassium and diammonium (Costa et al.,

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2017). Glyphosate formulations that increase acid absorption can increase herbicide efficacy (Travlos et al. 2007). Nalejawa et al. (1996) stated that glyphosate isopropylamine salt showed better absorption than other salts.

Isopropylamine glyphosate, potassium glyphosate, and sodium glyphosate with a raining time of 1 HAA were still effective in controlling some of the target weeds. IPA glyphosate+2,4D Amine herbicide is effective in controlling *Cyperus rotundus* with a rain time of 2 HAA. Research from Souza et al. (2014) reported that glyphosate herbicide formulations (Roundup original, Roundup Transrob, Roundup Transrob R, and Roundup Ultra) treated after 15 minutes were still effective in controlling *Senna obtusifolia.* Weed control is reduced when rainfall occurs soon after post-herbicide treatment because the herbicide is rinsed off the leaves before absorption is complete (Thakur et al., 2018).

The effectiveness of herbicides is affected by the time it rains and the intensity of the rain. Glyphosate herbicides (720 and 1440 g ha-1) at *I. purpurea,* and *Euphorbia heterophylla* with six rain cycles after application, showing a decrease in dry weight decreasing as the rain interval increases after application (Monquero & Silva, 2007). Rain that occurs 15 minutes – 6 hours after herbicide application can reduce the efficacy of glyphosate herbicides (Boerboom, 2006). Manik & Dad's research (2020) shows that a rainfall intensity of 5 mm/hour can reduce the effectiveness of herbicides in controlling *Ageratum conyzoides* and *Cyperus rotundus.*

The resistance of various herbicide formulations to rain is influenced by many factors. The relationship between rainfall, speed, and volume of glyphosate absorbed by plants and the effectiveness of glyphosate herbicides depends on processes such as retention of the herbicide on the leaf surface, leaf penetration, translocation, and inhibition of the EPSPS target enzymes (Costa et al., 2017). Satchivi et al. (2000) revealed that the uptake and translocation of glyphosate is species dependent. Species with high epicuticular wax can inhibit herbicide absorption, while high stomata density can increase herbicide uptake (Costa et al., 2017).

Conclusion

Isopropylamine glyphosate with a rainfall period of 1 HAA was able to control all the weeds tested, while the herbicide potassium glyphosate with a rainfall period of 1 HAA was able to control *Ageratum conyzoidess.* Sodium glyphosate herbicide with 1 HAA rain time had been able to control *Axonopus compressus* while IPA glyphosate herbicide + 2.4 D amine with 2 HAA rain time could control *Cyperus rotundus.*

Table 5. The effect of various herbicide formulations with differences in the timing of rainfall on weed dry weight and percentage of *Cyperus rotundus* weed damage

Time occurrence of rain	Dry weight (g)					Percentage of weed damage (%)			
	Herbicide formulation					Herbicide formulation			
	h0	h1	h2	h3	h4	h1	h2	h3	h4
0 HAA	1.00 b A	0.78 a A	0.88 a A	0.80 a A	0.85 a A	38.41 b A	35.00 c A	41.03 c A	35.64 c A
1 HAA	0.93 b A	0.25 b B	0.15 b B	0.23 b B	0.68 a A	75.83 a A	73.04 b A	67.65 b A	66.59 b A
2 HAA	0.90 b A	0.03 b B	0.00 b B	0.00 b B	0.00 b B	97.92 a A	100.0 a A	100.0 a A	100.0 a A
3 HAA	0.85 b A	0.00 b B	0.03 b B	0.03 b B	0.00 b B	100.0 a A	98.53 a A	98.53 a A	100.0 a A
4 HAA	1.03 b A	0.00 b B	0.00 b B	0.03 b B	0.08 b B	100.0 a A	100.0 a A	97.50 a A	100.0 a A
No rainfall	1.40 a A	0.00 b B	0.00 b B	0.00 b B	0.00 b B	100.0 a A	100.0 a A	100.0 a A	100,0 a A

Note: The average number followed by the same lowercase letter in the column (type of herbicide) and uppercase letter in the row (time of rain) is not significantly different based on the Scott-Knott test at the 5% level. HAA: hours after application, h0: without herbicide, h1: isopropylamine glyphosate, h2: potassium glyphosate, h3: sodium glyphosate, h4: IPA glyphosate +2.4 D amine

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