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Efficacy of Glufosinate Ammonium Herbicide on Weed Control, Impact on Soil Chemical Properties and Heavy Metal Accumulation in Cocoa Plantations

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Abstract

Prolonged use of common herbicides by cocoa farmers such as paraquat and glyphosate have been observed to observe residual effects on the environment. Therefore, there is a need to screen herbicides such as Glufosinate ammonium-based herbicides to be used by cocoa farmers. The experiment was set up at the cocoa experimental plot of the Cocoa Research Institute of Nigeria Headquarters in Ibadan. The 3 treatments which were arranged in a Randomized Complete Block Design are slashing, namely 6.25 mls/L and '12.50 mls/L of glufosinate ammonium. Each experimental unit was 6 m × 6 m comprising nine cocoa stands. The treatments were replicated 3 times. Data of the soil's physico-chemical properties were recorded at initial treatment and after 3 months of treatment application. Mineral and heavy metal were analyzed of the leaves and pods before spraying and 3 months after spraying. The percentage (%) weed control efficacy of the treatments was also observed. Mean data of each treatment were separated using Least Significant Difference (LSD) at a 0.05% probability level. Results showed that glufosinate ammonium applied at both rates did not load the soil, cocoa leaves and cocoa beans with heavy metals. The dosage of 12.50 mls/L had 85.00% weed control followed by 6.25 mls/L (62.70%) and slashing (51.00%) which both had the same statistical result. Glufosinate ammonium at 6.25 mls/L can replace slashing to eliminate drudgery while glufosinate ammonium at 12.50 mls/L can be used for more effective weed control without negative effects on the environment and the crop.

Keywords: Cocoa, glufosinate ammonium, herbicide, weed, heavy metals

INTRODUCTION

Weeds are a major menace to agricultural productivity in the tropics, especially causing heavy losses as they compete for water, light, nutrients (Wilson & Wright, 1990) and decrease in quality and quantity of yield. Significant productivity decline in cocoa in Nigeria can also be attributed to the adverse effect of weed and the lacuna of ineffective measures of weed management. Manual weeding is a common method of weed control, however, it has constituted a serious weed control problem in cocoa because of the required labor for the frequent slashing of the luxuriant weed growth within the wide inter-row spacing in cocoa trees. The scarcity of labor and the huge cost involved in weeding the inter-rows and circles around the cocoa have made some farmers abandon their plantations. Hence the alternative but effective and less drudgery measure is found in the use of chemical herbicides by cocoa farmers. Generally, herbicides represent about 47.5% of the globally used plant protection products (Sharma *et al*., 2019) and it has been successful in increasing crop yield by preventing yield loss due to weed infestation (Zimdahl, 1999). However, the challenge posed by the use of chemical herbicides is the chemical residue accumulation in the environment which poses a great threat to the ecosystem. For instance, the common chemicals used by cocoa farmers in Nigeria such as glyphosate and paraquat-based herbicides have been reported to pose negative residual effects on the environment over time. This apprehension about the toxicity of glyphosate necessitated the need for an alternative herbicide for weed control in cocoa. Similarly, research has shown that the monotonous use of these common herbicides such as glyphosate and paraquat has resulted in significant tolerance and resistance by the weeds and has also been associated with negative environmental effects and potential health risks due to their residual accumulation in the soil and crops. These concerns have significant implications for international trade, as many markets now demand stricter safety standards and certifications for agricultural products. Evaluating alternative herbicides, such as glufosinate ammonium, is crucial for developing safer and more sustainable weed management practices in cocoa plantations. Glufosinate ammonium is a broad-spectrum herbicide with a dynamic mode of action. It is generally regarded as a contact herbicide (Maschoff *et al*., 2000), although Turner & Gillbanks (2003) stated that it is systemically inhibitory in activity. Similarly, Akobundu & Agyakwa (1987) described glufosinate ammonium as a partial systemic post-emergence herbicide used in the control of both annual and perennial weeds in plantations. The use of glufosinate ammonium-based herbicide has been widely reported in Europe with successful outcomes both on the crop and the environment. Similarly in Nigeria, glufosinate ammonium herbicide has proved to be milder on the environment and also effectively suppresses weeds comparable to glyphosate in oil palm cultivation in Benin Edo state. However, there have not been any experiments to test the efficacy of glufosinate ammonium herbicide on the diverse weeds of cocoa in Nigeria, hence, the evaluation of the efficacy of broad-spectrum herbicide, glufosinate ammonium for reducing naturally occurring weed pressure and identifying their effect on short-term weed dynamics in young and old cocoa plantation.

Therefore, the objective of this study is to:

1. Evaluate the effect of applying glufosinate ammonium-based herbicide on the minerals and heavy metal properties of the soil, cocoa leaves and cocoa beans.
2. Observe the weed efficacy or control potential of glufosinate ammonium at two different rates on the cocoa field.
3. Make recommendations on the use of glufosinate ammonium for use in cocoa production.

MATERIALS AND METHOD

The Study Area

The screenings of glufosinate ammonium-based herbicide were carried out at the Cocoa Research Institute of Nigeria (CRIN) headquarters in Ibadan Oyo state which is geographically located in a derived savannah agro-ecological zone of the country. The cocoa trees on the experimental plot used were not less than 10 years old.

Experimental Treatments, Design, and Plot Sizes

The experiment was established at the Randomized Complete Block Design (RCBD) and comprised of three treatments viz: two rates of glufosinate ammonium-based herbicide (6.25 mls/L of water and 12.50 mls/L of water) compared with slashing (control) as the treatments and replicated three times. Each experimental unit was 6 m × 6 m comprising nine cocoa stands with dense weed diversity of annual classification. The herbicide at the experimented rates was measured with a calibrated measuring cylinder in the required water quantity in an appropriately calibrated 16L knapsack sprayer. The slashed plots were done by the use of a cutlass on the same day the herbicide treatments were applied. Before treatment application, the weed composition and diversity of the experimental plot were determined by quadrant sampling (100 cm × 100 cm) at random placement. Weeds collected were brought to the laboratory for identification the Akobundu & Agyakwa, (1987). Handbook on West African Weeds with heavily dominant weeds scored with +++, dominant weeds as ++ and less dominant weeds as +.

Soil, Cocoa Leaf, and Cocoa Pod (beans) Analysis

Soil samples of the experimental plots were collected randomly at 0-30 cm depth and bulked for soil analysis before herbicide application and three months after application (MAA) in each treatment plot at the end of the screening. The AAS (atomic absorption spectroscopy) was used in identifying the nutrient elements and heavy metals while LOI (Loss-on-Ignition) was used to measure soil organic matter and organic carbon. Total nitrogen was measured using Kjeldahl digestion and phosphorus using the Bray-1 method. Similarly, before treatment application, cocoa leaves and pod samples of the plot were collected for laboratory tests and also at the end of the screening at 3 MAA to observe the minerals and heavy metal status of the samples collected in each treatment plot. The cocoa leaves and beans were analyzed by drying and grinding the samples, followed by chemical digestion. The resulting solutions were analyzed for mineral nutrients and heavy metals.

Glufosinate Ammonium Herbicide Efficacy

Observations of the efficacy of the treatments were made at 24 hours, 2, 4, 6, 8, 10, and 12 weeks after application (WAA) by visual scoring on a 10 to 100% scale where 10 represented the least efficacy and 100 represented greatest efficacy.

Statistical Data Analysis

Data collected were subjected to analysis of variance (ANOVA) procedures using GenStat Discovery 12th Edition. Differences between the treatment means were compared using the least significant difference (LSD) test at a 0.05% significance level.

RESULTS AND DISCUSSION

Weed Diversity and Composition of the Experimental Area

Weeds cause significant reductions in farm production and extensive harm to the environment (Ekwealor *et al*., 2019) with cocoa being one of the major cash crops in Nigeria whose growth and yield can be negatively affected under uncontrolled weed infestation.

At CRIN Ibadan as shown in Table 1, the herbicide screening experimental plot consists of annual weeds of broadleaf, herbs and a grass family. However, the plot was heavily dominated by *Alternanthera brasiliana* while *Pseudosasa japonica* and *Chromolaena odorata* were both dominant. Other weeds as identified in Table 1 were less dominant.

Table 1. Cumulative weed flora diversity and composition of CRIN Ibadan headquarters.

Plant species	Plant family	Occurrence	Plant type/Growth form
Iodes vitiginea	Icacinaceae	+	Annual broadleaf
Alternanthera brasiliana	Amoranthaceae	+ + +	Annual broadleaf
Dioscorea bulbifera	Dioscoreaceae	+	Annual broadleaf
Cornus florida	Cormaceae	+	Annual herb
Tamarindus indica	Fabaceae	+	Annual herb
Gaulttheria shallon	Ericaceae	+	Annual herb
Pseudosasa japonica	Poaceae	+ +	Annual grasses
Parietaria officandis	Urticaceae	+	Annual broadleaf
Chromolaena odorata	Asteraceae	+ +	Annual herb

Notes: Less dominant = +, Dominant = + +, Heavily Dominant = +++

Chemical Soil Properties and Heavy Metal Status of the Cocoa Plot

The chemical soil properties of the cocoa experimental plot before treatment imposition are shown as the control in Table 2. According to the soil nutrient sufficiency level established by Chude *et al*., (2011), the total % nitrogen (%TN) and available phosphorus (Av. P) of the soil is low at 0.06% and 6.93 mg/kg. The potassium (K) content is moderate at 0.47 cmol/kg. The % organic carbon (%OC) and % organic matter (%OM) is very high at 7.83% and 13.47% respectively. The zinc (Zn) and manganese content of the soil is very low at 0.7 mg/kg and 0.04 mg/kg respectively.

The experimental site's soil textural class is grouped as loamy sand. Loamy sand soils, as observed in the site, have a high percentage of sand, but their small proportion of silt and clay gives them better water and nutrient-holding capacity compared to sandy soils (Sensoterra, 2023). This combination results in rapid infiltration of water and good drainage, making them easy to work with and cultivate (Sensoterra, 2023). Furthermore, (ICCO, 2024) recommended a soil pH range of 5.0 to 7.0 for good growth and yield of cocoa with the soil pH result from this site falling within this range. Cocoa thrives in diverse soils but requires nutrient-rich soil to meet its minimum nutrient needs for optimal growth (Amponsah-Doku *et al*., 2022). When compared with the standard set by WHO (1996); FAO (2001) and WHO (1989) the heavy metals (Fe, Cd, Cu, Cr, and Pb) are extremely lower than the target value for soil which implies that the experimental site is not heavy metal contaminated before herbicide application.

The soil was influenced by the application of herbicide as shown in Table 2 at the end of the experiment. The acidity of the soil (pH) significantly increased when comparing the two rates of applications with the soil from the unsprayed (control) plots. However, the soil pH at the end of the study still falls within the recommended range of 5-7 pH for effective growth and yield (ICCO, 2024). The % Organic matter content of the cocoa plantation was significantly reduced after the application of the herbicides at both rates. Despite the decline in % OM after the application at both rates, the values obtained in Table 2 are still more than the % OM reported by (Dedzoe *et al*., 2001) to support the growth and development of cashew. From Table 2, the application of glufosinate ammonium herbicide at 6.25 mls/L and 12.50 mls/L did not load the soil with heavy metals as a significant reduction in heavy metals and maintenance of the same heavy metal value as the control was observed. Generally, the values of the heavy metals at both rates for Fe (FAO, 2001) and for Cu, Cd, and Cr (WHO, 1996) were extremely lower than the permissible limit.

Table 2. Chemical soil properties of the cocoa experimental plot before herbicide application (control) and 3 months after treatment application

Parameters	Control	6.25 mls/L	12.50 mls/L
	HQ	HQ	HQ
pH	6.6 [a]	6.1 [c]	6.3 [b]
H^+	0.08 b	0.11 [a]	0.10 [a]
Na (cmol/kg)	0.37 [a]	0.25 [b]	0.27 [b]
K (cmol/kg)	0.47 [a]	0.37 [c]	0.40 [b]
Ca (cmol/kg)	0.21 [a]	0.17 [b]	0.21 [a]
Mg (cmol/kg)	1.17 [a]	0.87 [b]	0.83 [c]
%OC	7.83 [a]	5.71 [b]	5.67 [c]
%OM	13.49 [a]	9.845 [b]	9.765 [c]
%TN	0.06 [a]	0.04 [c]	0.055 [b]
Av. P (mg/kg)	6.93 [a]	4.84 [b]	4.75 [b]
Mn (mg/kg)	0.04 [a]	0.02 [c]	0.03 [b]
Fe (mg/kg)	0.64 [a]	0.48 [b]	0.505 [b]
Zn (mg/kg)	0.70 [a]	0.61 [c]	0.65 [b]
Cu (mg/kg)	0.07 [a]	0.02 [c]	0.03 [b]
Pb (mg/kg)	0.02 [a]	0.01 [a]	0.02 [a]
Cd (mg/kg)	0.03 [a]	0.01 [a]	0.02 [a]
Cr (mg/kg)	0.006 [a]	0.006 [a]	0.002 [b]
CEC	2.29 [a]	1.76 [b]	1.81 [b]
%BS	96.40 [a]	94.02 [b]	94.61 [b]

Note: H^+= Hydrogen ions concentration; Na = Sodium; K = Potassium; Ca = Calcium; Mg = Magnesium; %OC = Percentage of organic carbon; %OM = Percentage of organic matter; %TN = Percentage of total nitrogen; Av. P.= Available phosphorus; Fe = Iron; Zn = Zinc; Mn = Manganese; Cu = Copper; Pb = Lead; Cd = Cadmium; Cr = Chromium; CEC = Cation exchange capacity; %BS = Percentage of base saturation; Means with the same letter across each parameter are not significantly different.

Chemical Properties and Heavy Metal Status of the Cocoa Leaves

The mineral nutrient constituent and traces of heavy metals in unsprayed cocoa leaves (control) are shown in Table 3. The leaves contain 3.91 g/100 g N, 1.40g/100 g K and 0.53 g/100 g Ca. When compared with the standard set by WHO (1996) the heavy metals (Fe, Cu, Cr, and Pb) in the cocoa leaves did not exceed the permissible limits in plant while Cd (0.08mg/kg) exceeded the permissible limit in a plant sample. The Iron (Fe) concentration of 0.71 mg/kg in the leaves is extremely low as the permissible limit for Fe in plants is 425.5 mg/kg (WHO, 1989).

The chemical composition of the cocoa leaves as influenced by the herbicide rates is also shown in Table 3. Cocoa plant leaves were 6.25 mls/L and 12.50 mls/L of glufosinate ammonium herbicide was applied all had significantly lower mineral elements than cocoa leaves where no herbicide applied (Control) at the end of the experiment. However, the comparable reduction in the mineral elements could not only be a result of the herbicide applied but could also be a result of the diversion of nutrients generated by the plant from vegetative development to reproductive development as it has been observed that more nutrient is needed by plants towards fruit or seed formation (Dennis Jr, 1984; Davies & Gan, 2012).

Comparable and non-comparable reduction in the heavy metal content of the cocoa leaves where 6.25 mls/L and 12.50 mls/L of the glufosinate ammonium herbicide was applied was observed except Cu which had a higher value than the control where 6.25 mls/L was applied. However, the cocoa leaves heavy metal content such as Fe (FAO, 2001), Pb, Cu, and Cr (WHO, 1996) were all lower than the permissible limit in plants. The Cd content

Table 3. Cocoa leaf chemical composition from the experimental plot before herbicide application (control) and at 3 months after treatment application

	Parameters	Control	6.25 mls/L	12.50 mls/L
Mineral Analysis	Na (g/100g)	0.810 [a]	0.710 [b]	0.675 [b]
	K (g/100g)	1.400 [a]	1.200 [b]	1.195 [b]
	Ca (g/100g)	0.530 [a]	0.340 [b]	0.300 [b]
	N (g/100g)	3.910 [a]	2.930 [b]	2.85 [c]
	Mg (g/100g)	1.610 [a]	1.400 [b]	1.360 [b]
Heavy Metals	Fe (mg/kg)	0.710 [a]	0.655 [b]	0.625 [b]
	Cu (mg/kg)	0.310 [b]	0.360 [a]	0.320 [b]
	Pb (mg/kg)	0.060 [a]	0.030 [a]	0.040 [a]
	Cd (mg/kg)	0.080 [a]	0.040 [c]	0.060 [b]
	Cr (mg/kg)	0.020 [a]	0.010 [a]	0.020 [a]

Notes: Na = Sodium; K = Potassium; Ca = Calcium; Mg = Magnesium; N = Nitrogen; Fe = Iron; Cu = Copper; Pb = Lead; Cd = Cadmium; Cr = Chromium; Means with the same letter across each parameter are not significantly different.

of the leaves was all higher than the permissible limit in plants across the three treatments. It could be inferred from Table 3 that the high Cd observed in all the treatments is not influenced by the application of the herbicide as a higher Cd value was observed in the control treatments of which lower values of Cd were observed where 6.25 mls/L and 12.50 mls/L of the herbicide was applied.

Chemical Properties and Heavy Metal Status of Cocoa Beans

The control section of Table 4 shows the chemical composition of cocoa beans before spraying. The beans consist of 1.74g/100g N, 3.82g/100g K and 1.84g/100g Ca. According to the permissible limit of heavy metals in plants set by WHO, the heavy metal values of the beans are extremely lower than the permissible limit for Cu, Pb, Cd, Cr (WHO, 1996), and Fe (WHO,1989).

The cocoa bean is the most economical part of the tree and it is also important to observe the effect of applying the herbicide on the mineral elements and most especially, the heavy metal content of the bean as shown in Table 4. After the application of the herbicide at both rates, there was a significant increase in Na and Mg when compared with the control treatment. K has statistically the same value when comparing the control treatment with 6.25 mls/L while a comparable decrease in K was observed between the control and 12.50 mls/L. Other mineral parameters are either statistically higher or the same as the control treatment. Heavy metals such as Pb, Cd, and Cr remained insignificantly low and constant across the three treatments of the cocoa beans. Fe in the cocoa bean significantly increased after the application of the herbicide using both rates when compared with the control. Generally, the heavy metal content of the cocoa bean where extremely lower than the permissible limit in a plant material according to WHO (1996) for Cd, Cu, Cr, Pb, and WHO (1989) for Fe.

Efficacy Result of the Glufosinate Ammonium Herbicide at 6.25 mls/L and 12.50 mls/L.

Table 5 shows the effect of different rates of Glufosinate ammonium herbicide application at the experimental plots 24 hours after application (HAA) to 12 weeks after application (WAA). The values in the table represent the percentage of weed control achieved by each treatment at the specified period. At 24 HAA, slashing (control) had the highest weed control percentage (100%)

followed by 12.50 mls/L (60%) and 6.25 mls/L (30%). Slashing had the highest weed control percentage at 24 HAA and 2 WAA. However, 12.50 mls/L showed superiority over the other treatments at 4 WAA to 12 WAA. This implies that there was a steady re-growth of weeds on the slashed plot immediately after slashing while the full weed control potential of the herbicide at 12.50 mls/L (95.67%) was reached at 4 WAA surpassing slashing. 6.25 mls/L application also archived maximum weed control at 4 WAA (80.67%. However, 12.50 mls/L had a comparably higher weed control percentage than both 6.25 mls/L and Slashing from 4 WAA to 12 WAA (Table 5). 6.25 mls/L and slashing had non-comparable weed control from 4 WAA to 12 WAA. 85.00% weed control was archived by 12.50 mls/L, 62.70% by 6.25 mls/L and 51.00% by slashing at 12 WAA with no comparable difference observed between 6.25 mls/L and slashing. This implies that the highest weed control was archived using 12.50 mls/L for the herbicide while 6.25 mls/L and slashing had the same result. Higher rates of herbicides have been observed to control and suppress weed growth than lower rates (Steckel *et al*., 1997; Faccini & Puricelli, 2007). As observed in this study, the weeds on the slashed plots regenerated faster than the 2 herbicide treatments. This observation was also reported by Berk *et al.* (2021) in their study. The herbicide treatments slowed down the regeneration rate of the weeds on the cocoa plot than the slashed plots. However, the higher rate (12.50 mls/L) suppressed weed re-growth more. In addition, the prolonged weed suppression experienced within the 12 weeks of the trial in each treatment was also aided by the canopy already formed by cocoa plants on the plot. It has been observed from the reports of (Mwendwa *et al*., 2020; Little *et al*., 2021) that canopy development in farms and orchards suppresses weed growth.

Table 4. Cocoa bean chemical composition from the experimental plot before herbicide application (control) and at 3 months after treatment application.

	Parameters	Control	6.25 mls/L	12.50 mls/L
Mineral Analysis	Na (g/100g)	2.73 [b]	2.95 [a]	2.92 [a]
	K (g/100g)	3.82 [a]	3.80 [a]	3.72 [b]
	Ca (g/100g)	1.84 [a]	1.93 [a]	1.91 [a]
	N (g/100g)	1.74 [a]	1.86 [a]	1.81 [a]
	Mg (g/100g)	2.79 [c]	3.02 [a]	2.9 [b]
Heavy Metals	Fe (mg/kg)	1.72 [c]	1.865 [a]	1.81 [b]
	Cu (mg/kg)	0.21 [a]	0.20 [a]	0.22 [a]
	Pb (mg/kg)	0.001 [a]	0.001 [a]	0.001 [a]
	Cd (mg/kg)	0.001 [a]	0.001 [a]	0.001 [a]
	Cr (mg/kg)	0.001 [a]	0.001 [a]	0.001 [a]

Note: Na = Sodium; K = Potassium; Ca = Calcium; Mg = Magnesium; N = Nitrogen; Fe = Iron; Cu = Copper; Pb = Lead; Cd = Cadmium; Cr = Chromium; Means with the same letter across each parameter are not significantly different.

Table 5. Efficacy of glufosinate ammonium herbicide using visual scoring (%) from 24 hours after application (HAA) to 12 weeks after application (WAA)

Treat	24 HAA	2 WAA	4 WAA	6 WAA	8 WAA	10 WAA	12 WAA
6.25 mls/L	30.00 [c]	76.70 [b]	80.67 [b]	78.40 [b]	72.20 [b]	70.30 [b]	62.70 [b]
12.50 mls/L	60.00 [b]	82.70 [b]	95.67 [a]	94.67 [a]	92.17 [a]	89.00 [a]	85.00 [a]
Slashing	100.00 [a]	95.60 [a]	80.10 [b]	76.40 [b]	70.50 [b]	64.20 [b]	51.00 [b]
LSD @ 0.05%	9.330	7.060	7.350	7.440	7.120	9.400	15.700

Note: HAA = Hours after application; WAA = Weeks after application; treatment means with the same letter are not significantly different; Treatment means with the same letter within each period are not significantly different. Visual scoring on a scale of 0 to 100% where 0 represents the least efficacy and 100 represents the greatest efficacy.

CONCLUSION

The application of glufosinate ammonium-based herbicide at concentrations of 6.25 mls/L and 12.50 mls/L in water as observed in this study did not lead to contamination of soil, leaves, or cocoa beans with heavy metals, indicating that the herbicide is safe in this regard. Additionally, the herbicide concentration of 12.50 mls/L provided the most effective weed control, achieving an 85% reduction after 3 months, compared to 62.70% for the 6.25 mL/L concentration and 51.00% for manual slashing.

As a substitute for slashing, 6.25 mls/L of glufosinate ammonium-based herbicide can be used to achieve the same result there by reducing the cost of manually weeding the cocoa plot. However, for more cleaner and effective weed control, 12.50 mls/L of water is recommended. It is important to note that the herbicide's prolonged effectiveness and also slashed plots were aided by the already established canopy formed on the cocoa experimental plot. It is therefore encouraged that subsequent glufosinate ammonium-based herbicide trials should be done on newly established or young cocoa plots with excessively less canopy formation.

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