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Effectiveness of different glyphosate doses in controlling weeds in oil palm plantations in southern Benin

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Abstract

This study evaluated the effectiveness of different doses of glyphosate on weeds in oil palm plantations. A randomized complete block design with four treatments T0 (manual cutting), T1 (960 g), T2 (1920 g), and T3 (2880 g) of glyphosate per hectare was used, each replicated four times. Three 1 m² plots were established in each experimental unit to measure species richness, Shannon diversity index, Pielou's evenness index, and weed cover. The diversity indices of the treatments were compared, and weed cover was analyzed using one-way ANOVA followed by the Student-Newman-Keuls test for mean comparisons. Results showed that the various glyphosate doses were more effective than the manual cutting control in reducing weed species richness. Of the 36 weed species identified initially, 13 species survived in the control plots (manual cutting only, no herbicide), compared to 8, 6, and 5 species for treatments with 960 g (T1), 1920 g (T2), and 2880 g (T3) of glyphosate, respectively. Glyphosate application favored the development of certain weed species, as shown by Shannon indices lower than 2.6 bits. Glyphosate was effective in controlling weed species previously resistant to manual cutting. Soil cover in the manually cut plots (>70%) exceeded that of the herbicide treatments. The lowest glyphosate dose applied already proved effective in weed management compared to the manual control. This study suggests the use of 960 g of glyphosate in oil palm plantations in southern Benin and recommends further research on the effects of this dose on growth, development, and glyphosate residues in oil palm tissues.

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Introduction

In tropical Africa, palm oil holds a central place in agricultural production, trade, and the consumption of vegetable fats (Aholoukpè, 2013). In Benin, the oil palm plays an important economic role and is the most productive oilseed crop (Aholoukpè, 2013). Like all crops, oil palms are constantly threatened by pests, diseases, and especially weeds, which smother seedlings and young plants, ultimately reducing agricultural productivity (Yao *et al.*, 2017). According to the same authors, weeds compete with crops for essential growth resources such as water, nutrients, light, and space. Beyond this competition, weeds can promote the proliferation of rodents and serve as alternate hosts for insect pests and plant diseases (Yao *et al.*, 2017). This highlights the critical need for ongoing weed control efforts (Maroun, 2017). Several weed management strategies have been developed, with the most commonly used being manual weeding, mechanical control, and chemical control using herbicides.

Manual weeding is labor-intensive, especially during planting seasons when labor shortages are common (Ondo *et al.*, 2019). Furthermore, manual weeding is time-consuming and requires a large labor force, measured in man-days per hectare (Aubry and Dounias, 2006). As a result, farmers often turn to chemical herbicides as a practical alternative for managing competitive vegetation in plantations. Miderho *et al.* (2017) indicated that herbicide use can also facilitate fruit harvesting and collection. However, chemical control has its limitations, particularly due to the development of herbicide resistance (Boraud *et al.*, 2010). Among the wide range of available herbicides is glyphosate, a broad-spectrum, non-selective compound from the aminophosphonate family (Mazzella *et al.*, 2009). First commercialized in 1974 by Monsanto, glyphosate is now the most widely used herbicide globally (Duke *et al.*, 2008), including in oil palm plantations in the Plateau Department of Benin (Ogoudjobi *et al.*, 2024). Its wide spectrum of activity has contributed to its popularity (Benbrook, 2016). Nonetheless, literature reports indicate that its use requires careful management and control. A survey conducted by Ogoudjobi *et al.* (2024) revealed that farmers in the Plateau Department use glyphosate at doses of 960 g, 1920 g, and 2880 g (equivalent to 2 L, 4 L, and 6 L per hectare) without any formal recommendations or official approval. As a result, farmers are unaware of the most effective dose for weed management and some overuse the herbicide (Ogoudjobi *et al.*, 2024). This study was therefore initiated to identify the lowest effective dose of glyphosate for weed control in oil palm plantations.

Materials and methods

Study areas

The study was conducted at the oil palm research station of the National Institute of Agricultural Research of Benin (INRAB), located in Pobè, the capital of the Plateau Department in southeastern Benin (2°15'–2°45' E, 6°–7°45' N). The Perennial Crop Research Center (CRA-PP), established in 1922, focuses on improving knowledge and production of oil palm, both for industrial and smallholder purposes.

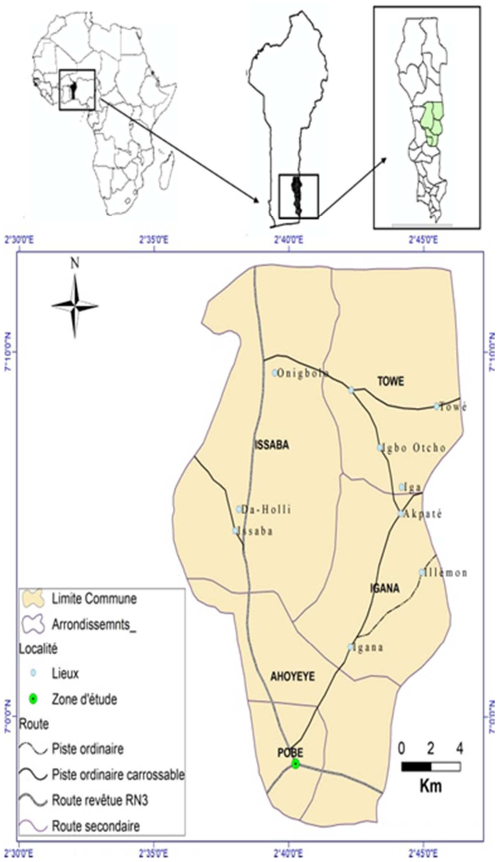

Fig. 1. Map of the study area

The station is situated in the municipality of Pobè (Fig. 1), at 6°58'04" N latitude and 2°40'45" E longitude. The region has a subequatorial climate with two rainy and two dry seasons. The soils are mainly red ferrallitic soils formed on the Continental Terminal, along with vertisols, hydromorphic soils, and tropical ferruginous soils (Aholoukpè, 2013). The station covers 708 hectares, including 423 hectares planted with oil palm and 115 hectares of botanical reserve. Current research activities focus on:

1. Agronomic studies to enhance the production potential of improved plant materials;
2. Physiological studies, mainly on oil palm response to water stress;
3. Breeding and seed production for drought- and fusarium-tolerant, high-yielding varieties;
4. Research and development aimed at disseminating improved plant materials to farmers of all scales.

Materials used

The plant material consisted of pre-existing oil palms of the Tenera variety, planted in 2016. The study plot covered 2.72 hectares with a standard planting density of 143 palms per hectare. The soil in the area is ferrallitic, formed on Continental Terminal formations. The herbicide used was the registered commercial product "MAGIC", whose active ingredient is glyphosate. One (1) liter of this herbicide contains 480 g of glyphosate in the form of isopropylamine salt. This herbicide is designed for total weed control, either before crop establishment or between crop rows.

Experimental design

Four treatments were evaluated in this study:

1. T0: Manual cutting (no herbicide application) – used as the relative control;
2. T1: 2 liters of MAGIC/ha (960 g of glyphosate/ha);
3. T2: 4 liters of MAGIC/ha (1920 g of glyphosate/ha);
4. T3: 6 liters of MAGIC/ha (2880 g of glyphosate/ha).

These treatments were determined based on the manufacturer's recommendations and the practices of producers. The manufacturer provides dosage guidelines according to weed families. For annual grasses, the recommended dose is 2.25 to 3 liters per hectare; for annual or biennial dicotyledons, 2.25 to 4.5 liters per hectare; for perennial grasses, 3 to 5.25 liters per hectare; and for perennial dicotyledons, 3 to 6 liters per hectare. Additionally, survey results conducted in the Plateau department of Benin by Ogoudjobi *et al.* (2024) showed that the doses of glyphosate-based herbicides used by producers under oil palm plantations vary between 2 and 6 liters per hectare. These doses of 2 to 6 liters per hectare were tested here, divided into treatments of 2 l/ha, 4 l/ha, and 6 l/ha. These three treatments, along with a control treatment consisting of mowing without herbicide application, were arranged in a complete randomized block design with four replications. These treatments were applied every quarter over three agricultural seasons (three years).

Data collection and analysis methods

Weed diversity indices

The trial was established in June 2021. At that time, the oil palms were five (5) years old and had just entered production. A plot of this age was chosen to begin observing the effects of the treatments on oil palms over a shorter period (3 years instead of 8 years). Since the installation of this trial, data on weeds have been collected, including species richness (the number of species per m^2) and the total number of weeds per m^2. Species richness corresponds to the number of species recorded (David, 2015). For each measurement, three 1 m^2 quadrats were placed on each plot unit. Weeds were identified using the "Guide to the Weeds of West Africa" by Okezie Akobundu and Agyakwa (1989). Measurements were taken monthly. Species were mainly identified at the start of the trial before the first application to determine which weed species had colonized the plot. After 12, 24, and 36 months of the trial, identifications were repeated to determine which species were resistant to each glyphosate dose using the same guide and to calculate species diversity indices. These included the Shannon-Weaver diversity index (H') and Piélou's equitability index

(EQ). Species diversity characterizes the more or less large number of species present within a population.

The Shannon-Weaver index (Shannon, 1948)

$$H' = -\sum_{i=1}^{s} \frac{N_i}{N} * \log_2\left(\frac{N_i}{N}\right)$$

Where: Ni = number of individuals of species *i*, with *i* ranging from 1 to *s* (total number of species), N = total number of individuals, log = base-10 logarithm.

The index H' is expressed in bits, and it typically ranges between 1 and 5 bits. A high H' value (H' > 3.5) indicates high species diversity within the plant community, suggesting that environmental conditions at the site are highly favorable for the establishment of a large number of species in nearly equal proportions. A low H' value (H' < 2.6) indicates low diversity, meaning that site conditions are unfavorable and lead to high species specialization. In this case, the plant community is dominated by a few species that occupy most of the available ground cover.

Pielou's Evenness Index (Pielou, 1969)

$$EQ = \frac{H'}{\log_2 N_0}$$

Where: No = total number of species, H' = Shannon-Weaver diversity index.

The Pielou index (EQ) ranges from 0 to 1. It tends toward 0 when nearly all individuals belong to a single species and reaches 1 when all species have exactly the same abundance or coverage.

Weed cover

According to David (2015), weed cover is a visual estimate of the proportion of a plot's surface covered by weeds. It is expressed as a percentage (%), ranging from 0% (no weed presence) to 100% (complete weed coverage). This assessment was carried out quarterly, before each treatment application. The average annual cover was calculated for each treatment by summing the quarterly values and dividing by 4, as each growing season includes four quarters.

Results

Effect of different glyphosate doses on weed diversity indices

Specific diversity indices allowed for the assessment of the floristic variation of weeds under oil palms over three years. Thus, species richness, the Shannon index, and Pielou's evenness index for each treatment by year are presented in Table 1.

Table 1. Weed diversity indices

Traitement	Species Richness				Shannon Index (H)				Pielou's Evenness Index (E)			
	2021	2022	2023	2024	2021	2022	2023	2024	2021	2022	2023	2024
T0	14	11	12	13	2,10	2,04	2,05	2,03	0,11	0,14	0,13	0,12
T1	12	8	7	8	1,79	1,74	1,44	1,61	0,11	0,15	0,15	0,15
T2	13	6	5	6	1,93	1,30	1,33	1,56	0,11	0,16	0,24	0,18
T3	17	5	4	5	2,42	1,42	1,51	1,52	0,10	0,21	0,30	0,21

Legend:T0: Mowing (no herbicide application); T1: 2 liters of MAGIC/ha (960 g of glyphosate/ha); T2: 4 liters of MAGIC/ha (1920 g of glyphosate/ha); T3: 6 liters of MAGIC/ha (2880 g of glyphosate/ha).

Analysis of this table showed that after glyphosate application, species richness decreased according to the dose. The higher the glyphosate dose, the less rich the palm grove was in weed species. The control plot had the highest species richness. After three years of glyphosate application, the plots treated with 6 liters of MAGIC/ha, equivalent to 2880 g of glyphosate/ha, were the least diverse, with only 5 species present out of a total of 17 species recorded at the beginning of the trial before herbicide applications. The smallest glyphosate dose applied (2 liters of MAGIC/ha, or 960 g of glyphosate/ha) proved more effective than the control treatment in reducing weed species richness. Indeed, after three years of applying this dose, species richness was eight (8) compared to thirteen (13) for the control (a difference of 5 between T0 and T1). During the three years of glyphosate application, the Shannon diversity index (H) ranged from 1.30 to 2.42 bits (H < 2.6), indicating that regardless of treatment and year, the Shannon diversity index remained low. Similarly, Pielou's evenness index was low (E < 0.50). Both indices demonstrated that there was some weed diversity within the plots. However, it was noted that the Shannon index for the control treatment was higher than those observed under the different glyphosate doses. This finding shows that glyphosate, even at the lowest dose, reduces weed diversity more than the control treatment (manual mowing).

Table 2. Weed species identified in the experimental plot

Sl	Famille	Weed species	T0	T1	T2	T3
1	Acanthaceae	*Justicia flava*	-	-	-	-
2	Acanthaceae	*Asystasia gangetica*	-	-	-	-
3	Amaranthaceae	*Alternanthera brasiliana*	-	-	-	-
4	Amaranthaceae	*Cyathula prostrata*	-	-	-	-
5	Amaranthaceae	*Achyranthes aspera*	-	-	-	-
6	Asteraceae	*Tridax procumbens*	-	-	-	-
7	Asteraceae	*Chromolaena odorata*	-	-	-	-
8	Asteraceae	*Blumea aurita*	-	-	-	-
9	Asteraceae	*Eclipta prostrata*	-	-	-	-
10	combretacea	*Combretum hispidum*	+	+	+	-
11	Commelinaceae	*Commelina diffusa*	+	+	+	+
12	Commelinaceae	*Commelina benghalensis*	+	+	+	+
13	Commelinaceae	*Aneilema beniniense*	+	+	+	+
14	Cyperaceae	*Cyperus difformis*	-	-	-	-
15	Cyperaceae	*Scleria naumanniana*	+	-	-	-
16	Cyperaceae	*Kyllinga squamulata*	+	-	-	-
17	cyperaceae	*Kyllinga bulbosa*	+	-	-	-
18	Cyperaceae	*Scleria Verrucosa*	+	+	+	+
19	Cyperaceae	*Cyperus rotundus*	+	+	+	+
20	Cyperaceae	*Cyperus iria*	-	-	-	-
21	Cyperaceae	*Cyperus haspan*	-	-	-	-
22	Cyperaceae	*Fimbristylis ferruginea*	-	-	-	-
23	Cyperaceae	*Mariscus longibracteatus*	+	+	-	-
24	Cyperaceae	*Killinga pumila*	-	-	-	-
25	Cyperaceae	*Mariscus alternifolius*	+	+	-	-
26	Cyperaceae	*Fuirena ciliaris*	+	-	-	-
26	Euphorbiaceae	*Mallotus oppositiffilius*	-	-	-	-
28	Euphorbiaceae	*Phyllanthus amarus*	-	-	-	-
29	hippocrateaceae	*Hippocratea indica*	-	-	-	-
30	Lamiaceae	*Hyptis suaveolens*	-	-	-	-
31	Lamiaceae	*Leucas martinicensis*	-	-	-	-
32	loganiaceae	*Spigelia anthelmia*	-	-	-	-
33	Malvaceae	*Sida acuta*	-	-	-	-
34	Melastomataceae	*Dissotis rotundifolia*	-	-	-	-
35	Mimosaceae	*Albizia zygia*	-	-	-	-
36	Poaceae	*Digitaria horizontalis*	+	-	-	-

Legend: (+) indicates the presence of the species; (–) indicates the absence of the species; T0: Mowing (no herbicide application); T1: 2 liters of MAGIC/ha (960 g of glyphosate/ha); T2: 4 liters of MAGIC/ha (1920 g of glyphosate/ha); T3: 6 liters of MAGIC/ha (2880 g of glyphosate/ha). Visual weed cover

Effect of treatments on weed species resistance

Table 2 presents the weed species identified in the experimental plot at the beginning of the trial (before treatment applications) and their response after three (3) years of treatment. Analysis of the table shows that thirty-six (36) weed species belonging to fourteen (14) different families were initially recorded in the plot. Species from the Cyperaceae family were dominant, with 13 species present at the start of the trial. After three years of treatment, it was observed that the various doses of glyphosate eliminated more weed species than the control treatment. Specifically, of the 36 species initially identified, thirteen (13) remained under mowing (T0), while only eight (08), six (06), and five (05) species persisted under T1 (2 liters of MAGIC/ha or 960 g glyphosate/ha), T2 (4 liters/ha or 1920 g glyphosate/ha), and T3 (6 liters/ha or 2880 g glyphosate/ha), respectively. It was also observed that *Combretum hispidum* was resistant under T0, T1, and T2, but not under T3, indicating that higher doses of glyphosate are effective in controlling weed species that were previously resistant to mowing.

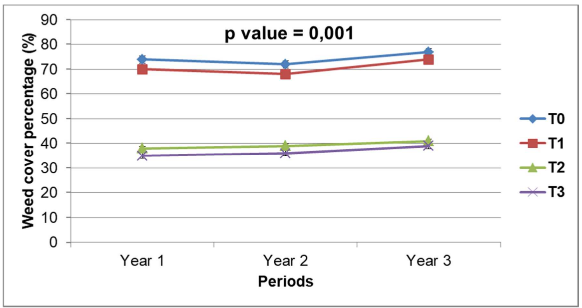

Fig. 2. Visual weed cover

Legend: T0: Mowing (no herbicide application); T1: 2 liters of MAGIC/ha (960 g of glyphosate/ha); T2: 4 liters of MAGIC/ha (1920 g of glyphosate/ha); T3: 6 liters of MAGIC/ha (2880 g of glyphosate/ha).

Fig. 2 presents the weed cover. Its analysis showed that the use of glyphosate significantly influenced weed cover. It was observed that during the three cropping seasons, the soil in plots without glyphosate application (T0) and those treated with the lowest dose (960 g of glyphosate/ha) had weed cover rates above 68%. Soil cover under T0 exceeded 70%, while under T1 (the lowest dose used in this study), it ranged between 66% and 70%. Weed cover in T2 and T3 treatments was below 50%. Thus, the difference was not significant between T0 and T1 on one hand, and between T2 and T3 on the other.

Discussion

Weed control is a key step for efficient agriculture (Ondo *et al.*, 2019). The results of this study showed that different doses of glyphosate significantly reduced the species richness of weeds. Mowing, compared to the various doses of glyphosate applied, proved less effective in weed control. This means that glyphosate is very effective for managing weeds under oil palm plantations and also explains why it is currently the most widely used herbicide worldwide (Birgit, 2021). Moreover, as the glyphosate dose increases, weeds become less abundant and the plot is cleaner, meaning weed cover is low. According to a study by Boraud *et al.* (2010), glyphosate alone, regardless of dose, has an efficacy of 80 to 90% on characteristic species of the environment by eliminating less resistant weeds in favor of more robust ones. After three years of chemical weeding of the plantation, it appears that the most favorable treatment for weed eradication is T3, corresponding to 2880 g of glyphosate/ha. This dose allowed the eradication of *Combretum hispidum*, which is resistant to mowing, 960 g of glyphosate/ha (T1), and 1920 g of glyphosate/ha (T2). This result is likely due to the high glyphosate concentration used. This confirms the result found by Ogoudjobi (2021), although the observation period in that study was much shorter. He found that this dose effectively manages weeds under oil palm plantations. The floristic inventory of the plot after three years of treatment application revealed that the weed species that succumbed to the different glyphosate doses mostly belonged to the families Cyperaceae and Poaceae. The disappearance observed in these weed families intensifies as the glyphosate dose increases. This explains the disappearance of a higher number of weed species under the 2880 g glyphosate/ha dose compared to other doses and mowing. This means that glyphosate affects some weed families more than others. Indeed, during studies by Colliot (1978) and Marnotte (1992), chemical control using systemic herbicides, glyphosate (Round UP): $C_3H_8NO_5P$ was proposed as the most effective product against Cyperaceae. On the other hand, most of these weed families reproduce both sexually and asexually. This shows that glyphosate has no effect on weeds depending on their mode of reproduction. Regarding species richness, the higher the herbicide dose, the lower the species richness. This means species richness decreases according to the applied glyphosate dose. It should also be noted that producers controlled weeds by manual mowing, and a lack of labor led them to adopt chemical weeding. In this study, the lowest glyphosate dose proved more effective than manual mowing. This is explained by the fact that mowing has no effect on weed roots, while glyphosate is a non-selective systemic herbicide absorbed through the foliage with rapid translocation throughout the plant (Birgit, 2021). Thus, mowing does not kill plant roots, leading to regrowth, which is not the case with chemical weeding (glyphosate) that kills the entire plant by attacking the roots of the targeted weed. The smallest glyphosate dose (960 g glyphosate/ha) tested in this study proved more effective than the mowed control without glyphosate application in managing weeds under oil palm plantations. This result is explained by the fact that applications were repeated every three months, and thus repeated accumulation of glyphosate allowed better weed control than the control.

Conclusion

This study on the effect of different glyphosate doses on weeds in oil palm cultivation showed that chemical weeding in oil palm farming is effective. Regarding the doses used, it was observed that 1920 g glyphosate/ha (T2) and 2880 g glyphosate/ha (T3) are more effective on weeds compared to the control (T0) and 960 g glyphosate/ha (the smallest dose in this study). However, it should be noted that treatment T1 showed a better efficacy level than T0 (manual mowing) practiced by producers (relative control). All glyphosate doses applied in this study proved more effective than manual mowing practiced by producers. Therefore, this study recommends the use of treatment T1 (960 g glyphosate/ha) to control weeds under oil palm plantations since it is already more effective than treatment T0 practiced by producers. However, it is important to study the effect of each glyphosate dose on soil fertility and oil palm health.

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