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Research Paper

Effect of Different Doses of Glyphosate on Soil Physical Parameters in the Prefecture of N'Zérékoré, Guinea

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ABSTRACT

This study examines the effect of different glyphosate doses on the soil texture in four rural communes of the N'Zérékoré prefecture in Guinea. A complete randomized block design was used to assess the impact of glyphosate doses on several soil parameters, including granulometry, aggregate stability, bulk density, and porosity. The analysis of variance (ANOVA) revealed that glyphosate doses significantly influence Granulometry A ($p = 0.02881$) and show a trend toward affecting soil aggregate stability (SI) and overall stability (Sg), although these effects are not significant at the 0.05 threshold. Conversely, glyphosate doses had no significant effect on Granulometry Lf, Granulometry Lg, bulk density, and soil porosity, as these parameters were more influenced by soil type and year. These results suggest that higher doses of glyphosate can alter soil structure, but the effect varies depending on specific environmental conditions, particularly soil type and annual variations. Careful management of glyphosate doses is therefore recommended to preserve soil quality and support sustainable agricultural practices.

Keywords: Glyphosate, granulometry, aggregate stability, bulk density, porosity, Guinea.

INTRODUCTION

Glyphosate is the most widely used herbicide globally due to its effectiveness in eliminating a wide variety of weeds, making it an essential tool for modern farmers (Benbrook, 2016). However, its long-term and large-scale use raises questions about its impact on soil, particularly on soil texture and its ability to support sustainable agricultural practices (Giesy et al., 2000). Soil texture, which refers to the relative proportions of sand, silt, and clay, strongly influences essential characteristics such as water retention, permeability, porosity, and cation exchange capacity (CEC), which are crucial for agricultural productivity (Gee & Bauder, 1986).

Recent research has shown that repeated glyphosate application can lead to changes in the physical composition of soils. These changes may affect soil structure, particularly by disrupting soil aggregates and reducing soil stability (Zobiole et al., 2011). Consequently, soils may lose their ability to retain nutrients, making crops more vulnerable to water and nutrient stress (Silva et al., 2018). Additionally, studies have also highlighted that glyphosate can interact with the organic and inorganic components of soil, influencing particle size distribution and fine particle dynamics, which could have implications for erosion and long-term fertility (Casabe et al., 2007).

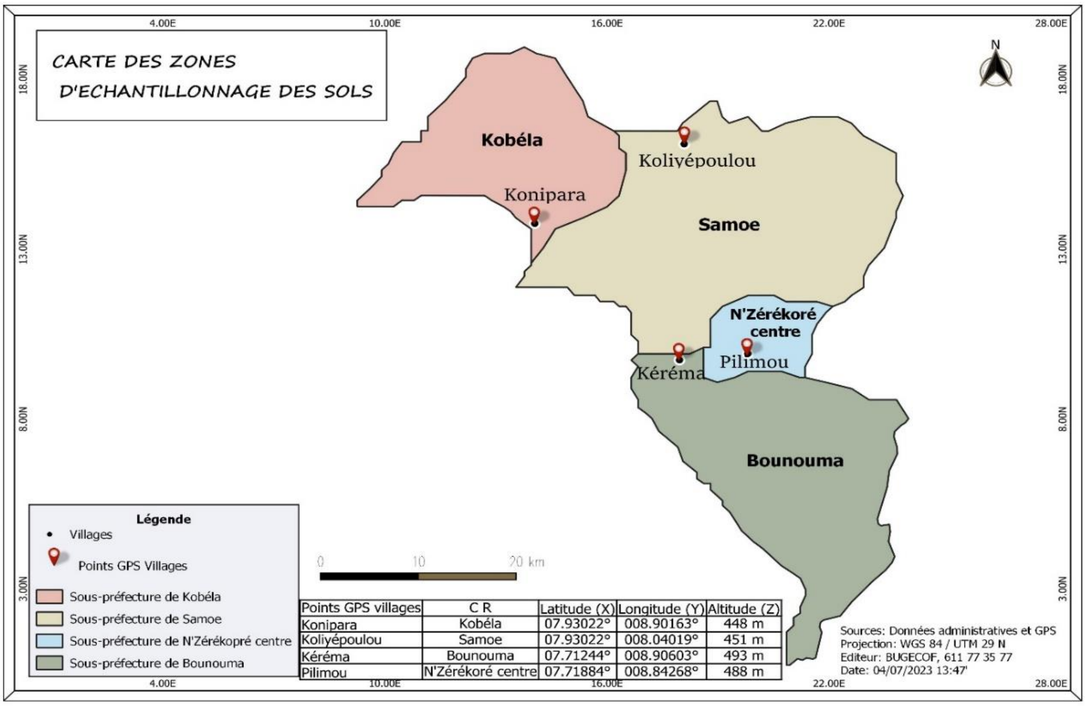
While the impact of glyphosate on soil chemistry and microbial biodiversity has been widely studied, its specific effect on soil texture remains relatively under-researched, especially in tropical regions such as the N'Zérékoré Prefecture in Guinea (Simonsen et al., 2008). This region is characterized by ferralitic soils, subject to intensive agricultural practices, where glyphosate use has become common in agroforestry systems and food crops. It is, therefore, essential to examine how different doses of glyphosate influence soil texture in this specific environmental context.

This article aims to address this gap by evaluating the effect of multiple doses of glyphosate on soil texture in four rural municipalities in the N'Zérékoré Prefecture. Specifically, this study analyzes changes in soil particle size distribution, porosity, and water retention capacity after the application of various doses of glyphosate. The results of this research will provide practical recommendations for sustainable soil management while offering a better understanding of the underlying mechanisms of glyphosate's impact on soil texture in tropical areas (Duke & Powles, 2008). Furthermore, this study contributes to the broader discussion on the environmental effects of intensive agriculture and on balancing herbicide efficiency with soil sustainability (Mertens et al., 2018).

MATERIALS & METHODS

Study Area

The study was conducted in four rural municipalities (RM) of the N'Zérékoré Prefecture (Konipara in the RM of Kobéla, Kwèliyépoulou in the RM of Samoé, Kéréma in the RM of Bounouma, and Pilimou, a peri-urban area of the city of N'Zérékoré), as shown in Figure 1.



Points GPS villages	C R	Latitude (X)	Longitude (Y)	Altitude (Z)
Konipara	Kobéla	07.93022°	008.90163°	448 m
Koliyépoulou	Samoe	07.93022°	008.04019°	451 m
Kéréma	Bounouma	07.71244°	008.90603°	493 m
Pilimou	N'Zérékoré centre	07.71884°	008.84268°	488 m

Sources: Données administratives et GPS
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Figure 1. Sampling Area in the N'Zérékoré Prefecture.

The climate of the study area is sub-equatorial, with abundant and nearly continuous rainfall throughout the year (approximately 8 to 9 months). The average annual rainfall varies between 1800 and 2300 mm. The temperature remains moderate year-round, averaging around 25°C.

The dense, humid forest promotes the formation and preservation of shallow and relatively thick ferralitic soils. This region is home to both food and industrial crops (Coffea arabica, Theobroma cacao, Cola acuminata, Elaeis guineensis Jacq., Hevea brasiliensis, etc.). Its ecosystem supports three types of agricultural systems: (1) the hillside slash-and-burn food crop system based on rainfed rice cultivation, a staple for the local population, combined with secondary food crops (Abelmoschus esculentus, Capsicum frutescens, Rumex acetosa, Colocasia esculenta) rotated with Arachis hypogaea and Manihot esculenta; (2) complex agroforestry systems, later referred to as “agroforests,” consist of perennial crops, including a primary crop (Coffea arabica, Cola acuminata, Elaeis guineensis Jacq., or Theobroma cacao), along with secondary perennial crops (fruit trees) grown under a forest canopy with varied composition; and (3) lowland farming systems, primarily used for flooded rice cultivation. An analysis of these soils at the 0-30 cm horizon provides the following characteristics (Table 1).

Table 1. Physical Characteristics of the Soils Studied

Parameters	Upland soil	Lowland soil
Clay (%)	6,5	9,8
Silt (%)	4,2	7,5
Sand (%)	45,7	25,30

Plant Material

For the trial, we first inventoried the weeds in the palm groves at the experimental sites of Konipara in the RM of Kobéla, Kwèliyépoulou in the RM of Samoei, Kéréma in the RM of Bounouma, and Pilimou in the urban municipality of N'Zérékoré. We then proceeded to georeference the soil sampling areas.

Technical Material

This includes: a GPS, a computer, a map of the study area, sprayers (continuous pressure sprayer with a mirror nozzle and a capacity of 450 L/ha, pneumatic sprayer with an adjustable flow rate between 400 and 500 L/ha), buckets, plastic bags, individual protective masks, a rain gauge, a digital camera, a stopwatch, a thermometer, measuring tape, rebar, wire, paint, paintbrushes, arm guards, hoes, and pickaxes.

Laboratory Material

The equipment we used in the laboratory to analyze indicators of soil fertility included: burette, autoanalyzer, colorimetric autoanalyzer, conductometer, and pH meter.

Data Collection, Methodology

Data were collected from field experiments, where measurements of soil chemical parameters were taken at different time intervals after glyphosate treatments were applied. The data were recorded in a database and cleaned to remove outliers and duplicates. Once cleaned, the data were grouped by treatment to facilitate analysis. The experiment was conducted using a randomized complete block design, with four treatment levels corresponding to different glyphosate doses: T (full dose), N, 2/3N, and 3/2N. Four trials were carried out in four rural communes of the N'Zérékoré prefecture over a two-year period (2022 and 2023) to account for annual variations in soil characteristics. The blocks were set up over a length of 19.25 m with a width of 5 m, spaced 1 m apart. The plastic pots for the individual plots, measuring 25 cm in diameter and 35 cm in height, were filled with 3 kg of composite soil samples. Two soil types (Upland and Lowland) were considered in the analysis, allowing for a comparative evaluation of soil responses to different glyphosate doses. Two weeks after treatment, samples were collected from the treated soils, labeled according to sample details, and transported to the National Soil Service Laboratory of Guinea (SENASOL, Guinea).

STATISTICAL ANALYSIS

The collected data were analyzed using a statistical approach to evaluate the impact of glyphosate doses on various soil parameters, including granulometry, aggregate stability, bulk density, and porosity. The analysis proceeded as follows: Analysis of variance (ANOVA) was used to test the main effects and interactions between the following factors: Glyphosate dose (T, N, 2/3N, 3/2N), Soil type (Upland and Lowland), and Year (2022 and 2023).

ANOVA tested the null hypothesis that there were no significant differences between the groups. A significance level of 0.05 was set for all analyses. p-values were used to determine whether the observed effects among the groups were statistically significant.

Following ANOVA, Student-Newman-Keuls (SNK) post-hoc tests were conducted to compare the means of the different groups and identify pairs with significant differences. This allowed for a more detailed analysis of the observed differences between glyphosate doses, soil types, and years for the studied parameters. These tests helped identify specific treatments with significant effects on granulometry, aggregate stability, and other parameters.

In addition to ANOVA and post-hoc tests, a multinomial regression was conducted to evaluate the effect of glyphosate doses on soil texture, considering the different soil types and measurement years. The objective of this regression was to model the likelihood of a specific texture type appearing as a function of applied glyphosate doses, while controlling for factors such as soil type and year.

A multinomial regression was used to examine the association between glyphosate doses and soil texture. The dependent variable in this regression was soil texture, categorized into different classes: Las (reference texture), LS (loamy sand), and Lfs (sandy loam). Glyphosate doses served as the main explanatory variables, with dose levels 3/2N, N, and T (full dose). Soil type (Upland or Lowland) and year (2022, 2023) were included as covariates in the model.

RESULT

• Granulométry (A)

The analysis of variance for granulometry (A) shows that the glyphosate dose factor has a significant effect (p = 0.02881), indicating that different glyphosate doses influence soil granulometry. Additionally, the year factor has a highly significant effect (p = 0.00308), suggesting that granulometry varies depending on the year. In contrast, neither the soil type factor (p = 1.000) nor the interaction between glyphosate dose and soil type (p = 1.000) have significant effects. These results show that granulometry is affected by glyphosate doses and year-specific conditions but not by soil type.

The SNK structuring test reveals differences in granulometry based on doses and years. In 2022, the T dose (full dose) shows the highest value (22.80%), followed closely by the 2/3N (20.80%) and 3/2N (20.08%) doses. The N dose shows the lowest granulometry (16.80%). In 2023, the values are generally lower, with the T dose (18.80%) remaining slightly higher than the others, while the 2/3N, N, and 3/2N doses have similar, lower granulometric values. This shows that high glyphosate doses increase granulometry A, but these effects can vary depending on the year (Table 2, Figure 2).

• Granulométry (Lf)

The analysis of variance (ANOVA) for Granulometry Lf indicates that the glyphosate dose factor has no significant effect on granulometric proportions (p = 0.715). This suggests that different glyphosate doses do not significantly influence soil granulometry. Similarly, soil type (p = 1.000) and year (p = 0.138) have no significant effect on this variable. The interaction between glyphosate dose and soil type (p = 1.000) is also non-significant. These results reveal that variations in Granulometry Lf are not related to glyphosate doses, soil type, or years.

In summary, Granulometry Lf appears relatively stable regardless of the glyphosate doses applied, soil types, and years considered. These results indicate that Granulometry Lf may be less sensitive to glyphosate treatments or that other unmeasured factors could influence this characteristic. It could also suggest homogeneity in soil texture for this specific granulometry, independent of treatment variations (Table 2, Figure 2).

• Granulométry (Lg)

The analysis of variance (ANOVA) for Granulometry Lg shows that the glyphosate dose factor has no significant effect on granulometric proportions (p = 0.1605). This indicates that different glyphosate doses do not significantly influence soil granulometry. Similarly, soil type has no significant effect (p = 1.000), nor does the interaction between glyphosate dose and soil type (p = 1.000). However, the year factor has a significant effect (p = 0.0331), indicating that variations in Granulometry Lg may be influenced by year-specific conditions. The SNK structuring test reveals that Granulometry Lg in 2023 is higher than in 2022, with respective values of 5 and 4. This difference suggests that factors related to the year, such as climatic conditions or management practices, may affect Granulometry Lg.

In summary, while glyphosate doses have no significant impact, the observed variations in Granulometry Lg are mainly due to yearly conditions, highlighting the importance of considering environmental factors when evaluating this soil characteristic (Table 2, Figure 2).

• Soil Aggregate Stability (SI)

The analysis of variance (ANOVA) for SI (Soil Aggregate Stability) indicates that the glyphosate dose factor shows a significant trend (p = 0.0927), although it is not quite at the traditional significance level of 0.05. This suggests a potential influence of glyphosate doses on soil aggregate stability, but this influence should be interpreted cautiously. The other factors, namely soil type (p = 1.000) and year (p = 0.6986), have no significant effect on SI. Furthermore, the interaction between glyphosate dose and soil type (p = 1.000) is not significant, indicating that the effects of glyphosate doses on aggregate stability are not modified by soil type.

These results indicate that, while glyphosate doses do not show a significant effect, a trend may suggest some influence on aggregate stability. It would be worthwhile to further explore this relationship through additional analyses or larger sample sizes to better understand the potential impact of glyphosate doses on soil structure and stability (Table 2, Figure 2).

• Overall Soil Stability (Sg)

The analysis of variance (ANOVA) for Sg (overall soil stability) shows a significant trend for the glyphosate dose factor (p = 0.0927), indicating a potential effect of glyphosate doses on overall soil stability. However, this result does not meet the traditional significance threshold of 0.05, meaning these conclusions should be drawn with caution. Other factors, such as soil type (p = 1.000) and year (p = 0.6986), have no significant effects on overall soil stability. The interaction between glyphosate dose and soil type is also not significant (p = 1.000), indicating that the effect of glyphosate doses is not modified by soil type.

These results suggest that, although the effect of glyphosate doses on overall soil stability is not yet fully established, a trend may reveal some influence. This may warrant further research to explore this relationship more deeply and determine if significant effects might emerge under different conditions or with additional samples (Table 2, Figure 2).

Table 2: Summary of Physical Parameters According to Glyphosate Dose

Year	**Glyphosate Dose**	**Granulométry A? Mean ± Standard Deviation**	**Granulométry_Lf Mean ± Standard Deviation**	**Granulométry Lg Mean ± Standard Deviation**	**SI Mean ± Standard Deviation**	**Sg Mean ± Standard Deviation**	**Da Mean ± Standard Deviation**	**Porosity Mean ± Standard Deviation**
2022	**2/3N**	20.8 (± 0) ab	2.00 (± 0.1) a	4.00 (± 0) b	29.3 (± 0) a	43.9 (± 0) a	1.07 (± 0.0707) a	45.8 (± 2.12) a
2022	**3/2N**	20.1 (± 0) abc	4.00 (± 1.96) a	4.00 (± 0) b	28.5 (± 0) a	42.7 (± 0) a	1.09 (± 0.0424) a	44.8 (± 0.707) a
2022	**N**	16.8 (± 0) bc	4.00 (± 1.92) a	4.00 (± 0) b	30.1 (± 0) a	45.1 (± 0) a	1.12 (± 0.0707) a	45.5 (± 1.41) a
2022	**T**	22.8 (± 0) a	2.00 (± 0).2 a	4.00 (± 0) b	28.5 (± 0) a	42.7 (± 0) a	1.12 (± 0.0283) a	46.3 (± 3.54) a
2023	**2/3N**	16.8 (± 0) bc	6.00 (± 3.6) a	6.00 (± 2.96) a	28.5 (± 0) a	42.7 (± 0) a	1.10 (± 0.0283) a	44.1 (± 2.12) a
2023	**3/2N**	14.8 (± 0) c	2.00 (± 0.92) a	6.00 (± 3.1 a	30.9 (± 0) a	46.3 (± 0) a	1.16 (± 0.141) a	45.5 (± 1.41) a
2023	**N**	16.8 (± 0) bc	4.00 (± 0) a	4.00 (± 2.6) b	30.1 (± 0) a	45.1 (± 0) a	1.20 (± 0.106) a	47.1 (± 2.83) a
2023	**T**	18.8 (± 0) abc	8.00 (± 0) a	4.00 (± 1.6) b	27.7 (± 0) a	41.5 (± 0) a	1.13 (± 0.0707) a	45.3 (± 2.83) a

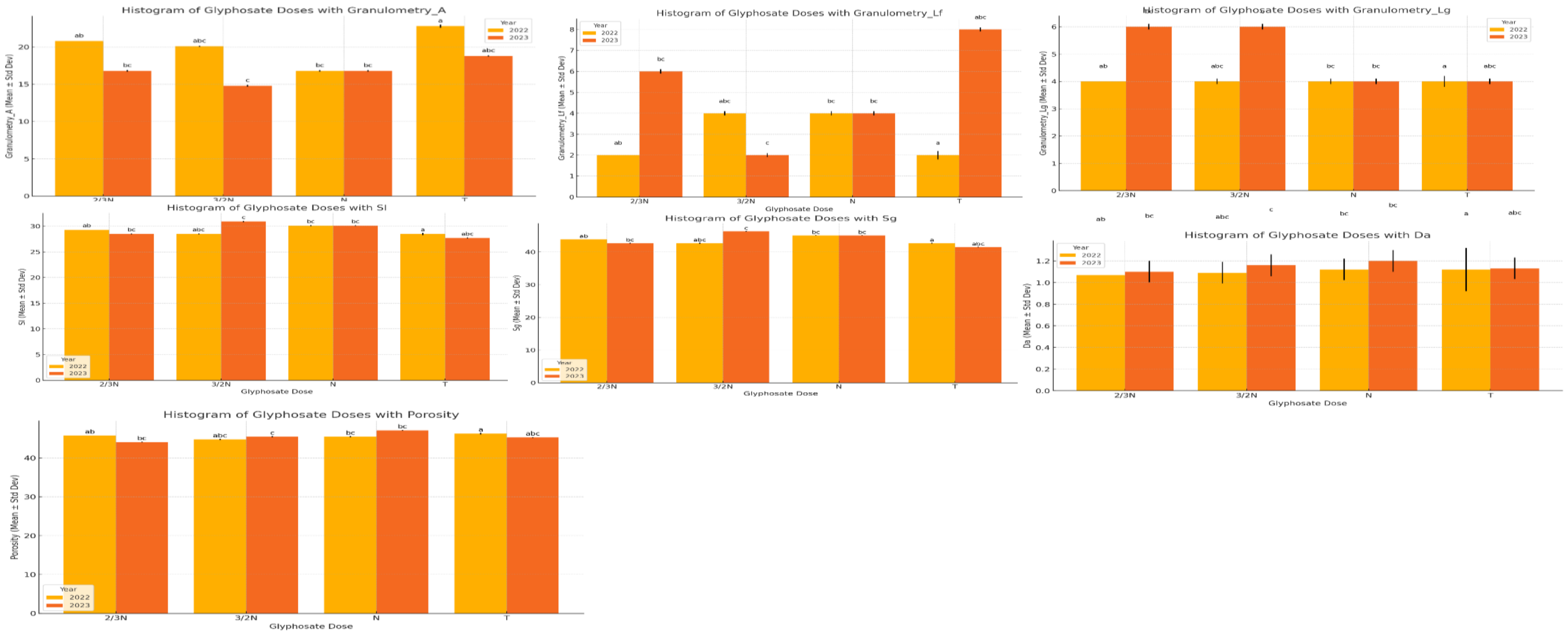

Figure 2. Boxplot of soil physical parameters according to glyphosate dose treatments.

- **Overall Soil Stability (Sg)**

The analysis of variance (ANOVA) for Sg (overall soil stability) shows a significant trend for the glyphosate dose factor (p = 0.0927), indicating a potential effect of glyphosate doses on overall soil stability. However, this result does not meet the traditional significance threshold of 0.05, meaning these conclusions should be drawn with caution. Other factors, such as soil type (p = 1.000) and year (p = 0.6986), have no significant effects on overall soil stability. The interaction between glyphosate dose and soil type is also not significant (p = 1.000), indicating that the effect of glyphosate doses is not modified by soil type.

These results suggest that, although the effect of glyphosate doses on overall soil stability is not yet fully established, a trend may reveal some influence. This may warrant further research to explore this relationship more deeply and determine if significant effects might emerge under different conditions or with additional samples (Table 2, Figure 2).

- **Bulk Density (Da)**

The analysis of variance (ANOVA) for Da (bulk density) reveals that the glyphosate dose factor has no significant effect (p = 0.15384), indicating that different glyphosate doses do not appear to influence soil bulk density. However, soil type shows a significant effect (p = 0.00132), indicating that soil type has a marked impact on bulk density. Additionally, the year also has a significant effect (p = 0.04663), suggesting that variations in environmental or management conditions from year to year may influence this soil characteristic. The interaction between glyphosate dose and soil type is not significant (p = 0.55497), meaning that the effects of glyphosate doses on bulk density are not modified by soil type.

The SNK test shows that bulk density is highest for upland soil in 2023, with an average of 1.2075, followed by the same soil type in 2022 (1.1375). The densities for lowland soil are lower, with values of 1.0850 for 2023 and 1.0625 for 2022, with no significant differences between them. This highlights the importance of soil type in evaluating bulk density and suggests that environmental factors, such as moisture or soil texture, may play a role in the observed variations. Overall, although glyphosate doses have no significant impact on bulk density, soil type and year have notable effects that should be considered in soil management (Table 2, Figure 2).

- **Porosity**

The analysis of variance (ANOVA) for porosity reveals that the glyphosate dose factor has no significant effect (p = 0.334655), indicating that different glyphosate doses do not appear to influence soil porosity. However, soil type has a significant effect (p = 0.000901), highlighting the importance of soil nature in determining porosity. Lowland soils show higher porosity (47.04) compared to upland soils (44.04). The effect of year is not significant (p = 0.818274), suggesting that porosity variations are not dependent on the measurement year. Furthermore, the interaction between glyphosate dose and soil type is not significant (p = 0.358258), indicating that glyphosate dose effects on porosity are not influenced by soil type.

The SNK test confirms that porosity is significantly higher in lowland soil compared to upland soil. These results demonstrate that soil porosity, which is essential for air and water movement, varies significantly by soil type, potentially impacting land management practices. It is therefore important for farmers and soil managers to consider these differences when applying treatments and implementing soil management practices to optimize soil and crop health. In conclusion, although glyphosate doses do not seem to influence porosity, soil type plays a crucial role, justifying the need for a management approach tailored to soil type (Table 2, Figure 2).

- **Texture**

Since texture is categorical with multiple levels, the odds ratio (OR) analysis through multinomial regression reveals significant impacts of different glyphosate doses on membership in soil texture classes, particularly “Ls” and “LS” compared to the reference “LAS.” For the “LS” class, the odds ratio for the “N” dose is very high (7.42e+16), indicating that this dose substantially increases the odds of belonging to this class compared to the reference. In contrast, the “3/2N” dose has a very low odds ratio (3.74e-6), suggesting an almost negligible probability of belonging to the “Ls” class. Upland soil and year show weak effects on this class, with odds ratios close to zero or one, indicating that these factors do not significantly influence membership in the “Ls” class.

For the “LS” class, the odds ratio for the “intercept” is 3.27e-1, indicating a reduced probability of belonging to this class compared to the reference. The “N” and “T” doses show odds ratios (4.19e-1), which also suggest decreased odds of belonging to the “LS” class. However, upland soil has a positive effect with an odds ratio of 2.38, indicating that this soil type increases the chances of belonging to the “LS” class. Overall, these results highlight the importance of glyphosate doses and soil type in determining soil texture, revealing complex interactions that merit careful attention when interpreting data (Table 3).

DISCUSSION

The results of this study show that glyphosate doses have varied effects on soil granulometric and physico-chemical characteristics. For Granulometry A, glyphosate doses significantly influence soil texture, with higher doses tending to increase the proportion of coarse particles. This corroborates the observations of Silva et al. (2018), who demonstrated that repeated applications of glyphosate can disrupt the physical structure of soil, thereby reducing aggregate stability. Zobiole et al. (2011) also reported similar effects on soil structure in intensive agricultural systems.

Granulometry Lf, however, appears to be relatively stable, regardless of the glyphosate doses applied. This result suggests that certain granulometric types may be more resistant to herbicide-induced changes. Duke and Powles (2008) suggested that soil resistance to certain chemical alterations could be linked to intrinsic properties such as base texture and mineral composition. Furthermore, the relative stability of Granulometry Lf in this study may indicate that other environmental factors, such as agricultural management practices or climatic conditions, play a more determining role in preserving this specific soil characteristic.

For Granulometry Lg, the results show that variations are mainly influenced by annual conditions rather than by glyphosate doses or soil type. This is in line with the studies of Mertens et al. (2018), who demonstrated that annual climatic conditions, such as temperature and humidity, can significantly affect soil structure, independently of agricultural inputs. The changes observed between 2022 and 2023 may therefore be attributed to climatic factors, such as precipitation, which directly influence the distribution of fine particles and soil compaction.

Aggregate Stability (SI) and overall stability (Sg) show a trend toward an impact of glyphosate doses, although the results are not quite significant at the 0.05 threshold. These trends suggest that with higher doses or prolonged applications, glyphosate could influence overall soil structure. Simonsen et al. (2008) demonstrated that the accumulation of glyphosate in soil could alter soil microstructure by affecting interactions between clay particles and organic matter. Additionally, Casabe et al. (2007) noted that indirect effects of glyphosate on soil microbial communities could reduce the production of binding substances, thereby compromising aggregate stability.

Bulk density (DA) and porosity were more influenced by soil type and annual conditions than by glyphosate doses. This demonstrates that intrinsic soil characteristics, such as texture and composition, play a more significant role in these parameters than chemical inputs. Gee & Bauder (1986) emphasized that bulk density is heavily influenced by granulometry and organic matter content, two factors not directly modified by glyphosate. Furthermore, Giesy et al. (2000) demonstrated that herbicide use can have differentiated impacts depending on soil type, with clay soils more likely to retain herbicide residues than sandy soils.

In summary, although glyphosate doses have a perceptible effect on some aspects of soil texture, such as Granulometry A and aggregate stability, other characteristics, like Granulometry Lf and bulk density, are more influenced by soil type and environmental conditions. These results highlight the complexity of interactions between agricultural practices and soil quality and underscore the importance of adopting integrated soil management to mitigate the negative impacts of herbicides on soil structure.

The impact of glyphosate on soil physical characteristics also raises concerns, particularly regarding soil structure, texture, and porosity. Many authors have examined the effects of glyphosate on the physical properties of soil due to its frequent use in agricultural practices. For example, Cerdeira and Duke (2006) showed that glyphosate can influence the physical composition of soil by altering its structure. Continuous exposure to this herbicide can affect soil aggregate stability, leading to compaction and reduced porosity (Simonsen et al., 2008). This can decrease the soil's ability to retain water and promote air circulation, which is essential for plant root health and soil organism activity. Consequently, more compact soils may also reduce root penetration, limiting the ability of plants to access water and nutrients (Zobiole et al., 2011).

Moreover, the effect of glyphosate on soil texture may vary depending on specific soil properties and management practices (Duke & Powles, 2008). For example, glyphosate application may alter soil particle distribution, which can influence water retention and infiltration capacity (Giesy et al., 2000). In some cases, this may also impact erosion dynamics, as less-structured soil is more vulnerable to runoff losses (Silva et al., 2018). Thus, while glyphosate may offer agronomic benefits as an herbicide, it is essential to carefully assess its impact on soil physical characteristics. Proper management of glyphosate applications is crucial to minimizing adverse effects on soil structure, ensuring agricultural sustainability, and preserving ecosystem health (Casabe et al., 2007).

CONCLUSION

This study revealed that glyphosate doses differently influence soil granulometric and physico-chemical characteristics. Granulometry A showed significant responses to glyphosate doses, indicating that high doses can alter soil particle distribution. In contrast, Granulometry Lf and bulk density appear to be more influenced by soil type and environmental conditions rather than herbicide doses. These results highlight the need for careful management of glyphosate doses, particularly in tropical regions like N'Zérékoré, where soils are fragile and subjected to intensive agricultural use. Sustainable management practices, including regulating herbicide doses and paying close attention to soil types, could contribute to the long-term preservation of soil structure and fertility. Future research could explore the long-term effects of glyphosate accumulation in tropical soils and examine other environmental factors, such as organic matter management and the impact of climate change on soil resilience to chemical inputs. These studies would support the development of sustainable agricultural strategies that balance productivity and soil health.

Declaration by Authors

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