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SLOPE POSITION AND BIOCHAR INFLUENCE ON SOIL PROPERTIES IN A TROPICAL AGROECOSYSTEM

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CAUTION

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1. INTRODUCTION

Soil erosion is a natural process exacerbated by factors such as steep slopes, high rain intensity, and improper land use management, results in the loss of fertile topsoil, decreased water quality, and reduced agricultural productivity (Lal, 2001; McCool & Williams, 2008; Wang et al., 2022). Spatial variability in soil erosion and crop yield in upland areas is influenced by various factors, including soil properties, landscape position, local climate, land cover, soil type, and management practices (Desta et al., 2021, Lian et al., 2009, Mouazen & Ramon, 2003, Tesfahunegn et al., 2011, Zhang et al., 2011.). This diversity of factors is important to consider for effective soil conservation, nutrient management, and precision farming (Mzuku et al., 2005).

For centuries, upland areas in Southeast Asia were used for swidden agriculture (Belton & Fang, 2022; Bruun et al., 2017). However, the transition to intensive mono-crop production systems, particularly maize production, has led to soil loss, runoff, and nutrient losses, contributing to irreversible soil degradation and environmental issues (Fujisao et al., 2020; Janeau et al., 2022; Lal, 2018; Tsubo et al., 2006; Turkelbloom et al., 2008.). The conversion of forests into monoculture plantations in northern Thailand has resulted in landscape homogeneity, reducing species richness and functional biodiversity (He et al., 2016). Despite high erosion rates, eroded areas are still used for subsistence agriculture.

Soil properties vary along a toposequence due to processes like detachment, transportation, water flows, and deposition (Maniyunda & Gwari, 2013; Muhaimeed & Saleh, 2013). Oo et al. (2012) found that the middle position of the field in a toposequence exhibited superior growth and yield performance compared to other positions along the toposequence. Intensive rice cultivation in upland areas led to nutrient losses through erosion and sediment deposition, impacting agricultural productivity (Dinaburga et al., 2010). Water flows played a significant role in the spatial variability of chemical properties and soil texture parameters, influencing factors like exchangeable potassium, organic carbon, clay content, and yield (Boling et al., 2004).

Biochar, obtained through biomass pyrolysis, is a carbon-rich material with potential benefits for soil fertility, water holding capacity, and nutrient leaching reduction (Basso et al., 2013; Lehmann et al., 2003; Lehmann & Joseph, 2009; Steiner et al., 2007; Toková et al., 2020.). Its application can also reduce soil bulk density, increase cation exchange capacity, neutralize soil acidity, and provide a favourable habitat for beneficial soil organisms (Atkinson et al., 2010; Chan et al., 2008; Igalavithana et al., 2016; Jien & Wang, 2013; Omondi et al., 2016.). The study by Li et al. (2019) observed a 12.2% reduction in total runoff volume with biochar addition, while Lee et al. (2018) found that combined biochar and compost application was most effective in reducing runoff by approximately 17%.

Although existing studies on toposequence have focused on spatial distribution of soil properties and crop yield, limited research addresses the spatial distribution of soil and water concerning slope position and biochar application in upland maize cultivation within tropical regions. This study aims to fill this gap by investigating the combined influences of toposequence and biochar application on soil loss, runoff, and nutrient losses in upland maize areas, providing insights for sustainable agricultural practices.

Based on the analyses of the above literature and the previous study of Janeau et al. (2020) on the same site in simulated rainfall, we hypothesis that in a humid tropical climate and in natural rainfall:

- Hypothesis 1: Biochar will reduce nutrient loss and protect the soil from soil crust formation.
- Hypothesis 2: Position in the catena will have an effect on different soil properties and thus on biochar effect.

2. MATERIALS AND METHODS

2.1 SITE DESCRIPTION

A field experiment was conducted at Ban Tub Man (18°19'30.0"N 100°34'17.3"E), Na Noi District, Nan Province, which is one of the 17 provinces in the Northern region of Thailand. The study area is characterized by hilly topography, with elevations ranging from 444 to 525 meters above sea level. The slope gradients range from 10% to 44%. The study area was divided into four positions (top, upper, middle, and down) with elevations of 512, 498, 480, and 460 meters above sea level, respectively (Figure 1). The top positions are 27.01 meters away from the upper slope positions, the upper slope positions are 31.7 meters away from the middle slope positions, and the middle slope positions are 57.6 meters away from the downslope positions. Maize fields are the major crop in this area. Farmers usually grow maize on sloping areas and till the land every 5 years. The soil at the experimental site was classified as a Typic Haplustalfs according to Soil Survey Staff (2018), with 13.33% sand, 24.91% silt, and 61.76% clay in the topsoil (0–25 cm) and a bulk density (BD) of 1.15 $g.cm^{-3}$. The topsoil had a pH (H_2O) of 6.0, an organic matter content (OM) of 3.57%, an available P (Bray II) content of 21.23 $mg.kg^{-1}$, and an exchangeable K content of 181.29 $mg.kg^{-1}$. The climate of the study area is a tropical savannah, based on Koppen's classification, consisting of three seasons: (I) rainy, (II) dry and cool, and (III) dry and hot. The average annual rainfall was 1,205 mm. The rainy season starts in July and ends in September. Annual temperatures ranged from a high of 32°C to a low of 15°C, with an average temperature of 26°C during the cropping season.

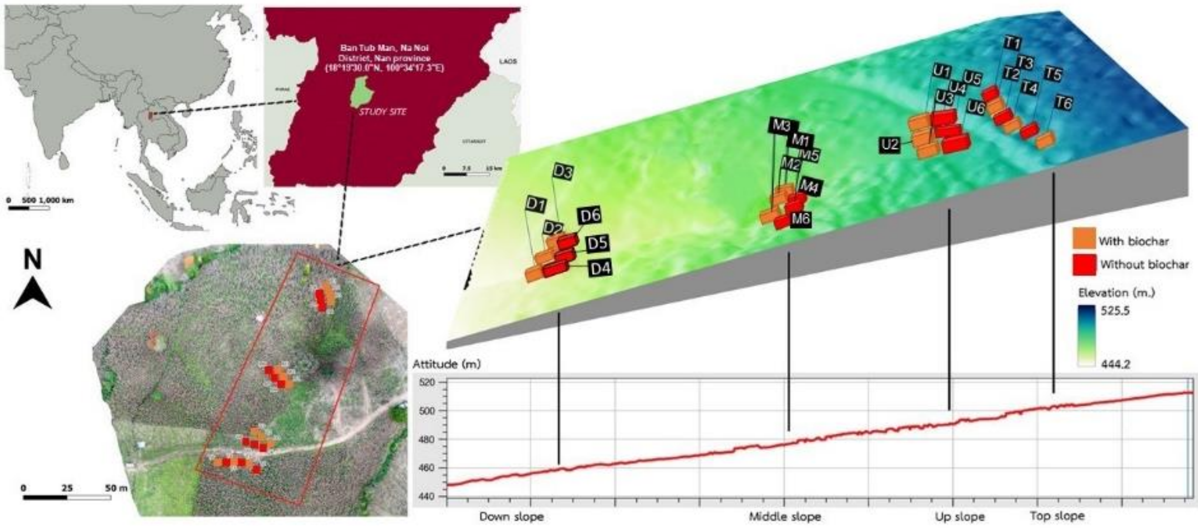


Figure 1. Location of the study site and distribution of the plots along the slope (Wanwisa Pansak, 2022).

2.2 Soil profile and properties

Along the 108.4-meter transect, soil profiles were collected from the top, upper, middle, downslope positions. The soil profiles were examined using a hand auger. Soil texture, colour, and pH of each horizon were assessed in the field. The soil profiles in the pits were classified using the USDA framework (Soil Survey Staff, 2018). Soil samples were taken from each horizon to determine the physical properties (soil texture). For soil chemical properties, soil organic matter (OM) was analysed by Walkley and Black method (Walkley, & Black, 1934). Available phosphorus in the soil was measured by Bray-II method and the absorbance was measured by spectrophotometer (Bray and Kurtz,1945). Exchangeable potassium was extracted by ammonium acetate and analysed by atomic absorption spectrophotometry (Chapman, 1965). Electro Conductivity (EC) was determined by EC meter, proportion of soil per water as 1:5 (Rhoades, 1996). The soil pH was measured electrometrically in a 1:1 (soil: H_2O) by pH meter (Peech, 1965). Total nitrogen was analysed by Kjeldahl method (Bemner, 1996). Soil aggregate stability at the upper, middle, and lower positions was measured using the wet sieving method.

2.3 Rainfall, soil loss and runoff measurement

The intensity and the quantity of rainfall were measured using an automatic ARG100 Campbell rain gauge connected to CR200X Campbell data logger located at the middle of the slope. The runoff was calculated using difference between rain and collected runoff. The evaporation is considering negligible at this scale (1 m^{-2}) during rain events. To assess runoff and soil losses, microplots (1 m x 1 m) were installed from 2018 to 2019 at the top, upper, middle, and down slope positions along toposequence. The microplots were enclosed by iron frames inserted to a depth of 0.1 m, as described by Janeau et al. (2003). A tube was connected to a 66-liter bucket to collect runoff water and sediments

(Figure 2). Samples of runoff and soil loss were collected after rainfall events that exceeded 25 mm. The quantity of runoff water was measured by using a tape measure inside the buckets (either small or large, depending on the water volume), and then the volume of runoff water was calculated. Suspended sediment fractions were collected along with the runoff water from the buckets. Runoff samples of approximately 1 L were obtained from the buckets after stirring and filtered through Whatman No. 1 filters. After filtration, the particles collected on the filter were dried in an oven at 105 ºC for 24 hours to determine the amount of sediment in the water suspension. Using Casenave & Valentin method (1992), soil surface features and percent of vegetation cover in each microplot were measured at the same time as soil loss and runoff samples.

2.4 MAIZE PLANTING

Land preparation was completed by tilling the soil before starting the experimental study in 2018. Maize (*Zea mays* L.), cv. CP 888, was planted within microplots (1 m^2) along the slope using a planting stick, with a spacing of 25 cm along the row and 75 cm between rows. For fertilizer management, NPK 46-0-0 and NPK 16-20-0 were applied at the planting date at a rate of 25 kg per rai (1 rai = 0.16 ha), and the same fertilizer combination was applied again 30 days after planting at the same rate, following local farming practices. Glyphosate (48% W/V SL) was used by farmers for weed control, applied at a rate of 300-500 g ai/rai (1 rai = 0.16 ha) 15 to 20 days before planting. Maize growth and yield data were shown only in 2008 because in 2009 it was covid-19.

2.5 NUTRIENTS ANALYSIS OF RUNOFF AND SOIL LOSS

Runoff samples were collected after rainfall events for nutrient analysis. They were preserved with one or two drops of 4 M H_2SO_4 and then frozen. The samples were stored until analysis in the laboratory. Total nitrogen was analysed using the Macro-Kjeldahl method. Total phosphorus was analysed using the Vanado Molybdic method. Total potassium was analysed using atomic absorption spectroscopy (AAS). For the sediment samples, total nitrogen was analysed using the Kjeldahl method (Bemner, 1996). Soil organic matter was analysed using the Walkley and Black method (Walkley & Black, 194). Available phosphorus was analysed using the Bray-II method, and the available phosphorus content was determined using a spectrophotometer (Bray and Kurtz, 1945). Exchangeable potassium was extracted using ammonium acetate and analysed using Atomic Absorption Spectrophotometry (Chapman, 1965).

2.6 STATISTICAL ANALYSES

Statistical analyses were evaluated by using R software version 4.3.1 (R CORE Team, 2023). Multivariate analyses were used to assess the structure of the data set using a principal component analysis (ACP) and the package FactomineR. To test our hypothesis, we used 10 variables related to (1) soil properties: biochar % on the soil surface (biochar), moisture, hydraulic conductivity (Ks); (2) soil detachment: runoff, total sediment in runoff; (3) nutrients: nitrogen, phosphorus and potassium in runoff; and (4) soil condition: free elements, vegetal cover and crust % (crust). To examine the impact of biochar and position along catena on physicochemical parameters we opted for non-parametric Kruskal-Wallis test, the normality of model residuals and the homogeneity of variances were not simultaneously validated to use a one-way or two-way analysis of variance (ANOVA). In addition, we employed the Dunn test as a post-hoc test to assess the significance of the different positions in the catena.

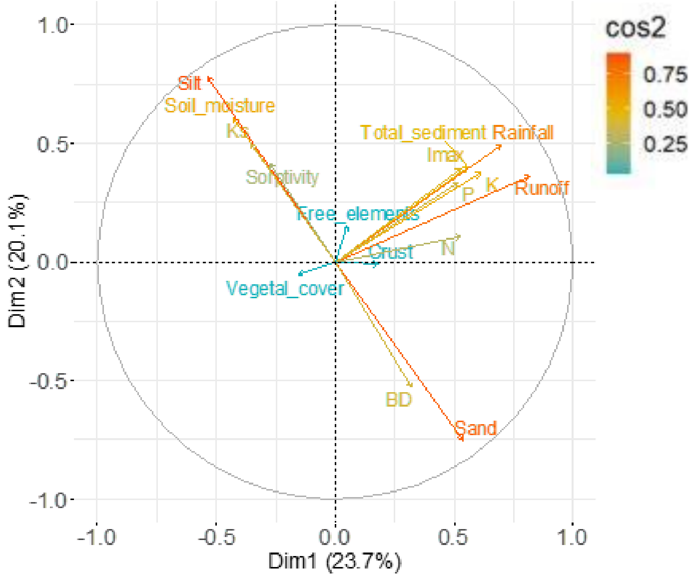
3. RESULTS[1]

3.1 Main relationships by meteoritical variables and soil texture

Results of 2018 and 2019 had similar tendency after PCA analyses. For this reason, we only present here PCA results for 2019. Five main variables were responsible for explaining the variance in our dataset. The two axes of the PCA explained up to 43.8% of the variance of our dataset (cf. Figure 2.A). Rainfall and runoff variables are the two variables driving the first axis (Dim 1), while Silt, Sand contents and soil moisture drove the second axis (Dim 2).

The first axe, explained mostly by quantity of rainfall and runoff, drove clearly the different rainfall events (cf. Figure 2.B). According to our second hypothesis, we observed a clear trend for soil texture and soil moisture along the catena position: these variables globally increased from the up position to the down position (cf. Figure 2.C). Position 1, downslope, presented higher sand content, while position 2 (medium slope) presented higher silt content and soil moisture. Position 3 and 4 (up and top slope) were not very influenced by axe 2.

(A) Graph of variables (DIM 1 and 2)



[1] The results of the Kruskal-Wallis and Dunn tests (p-value) are in appendix 1

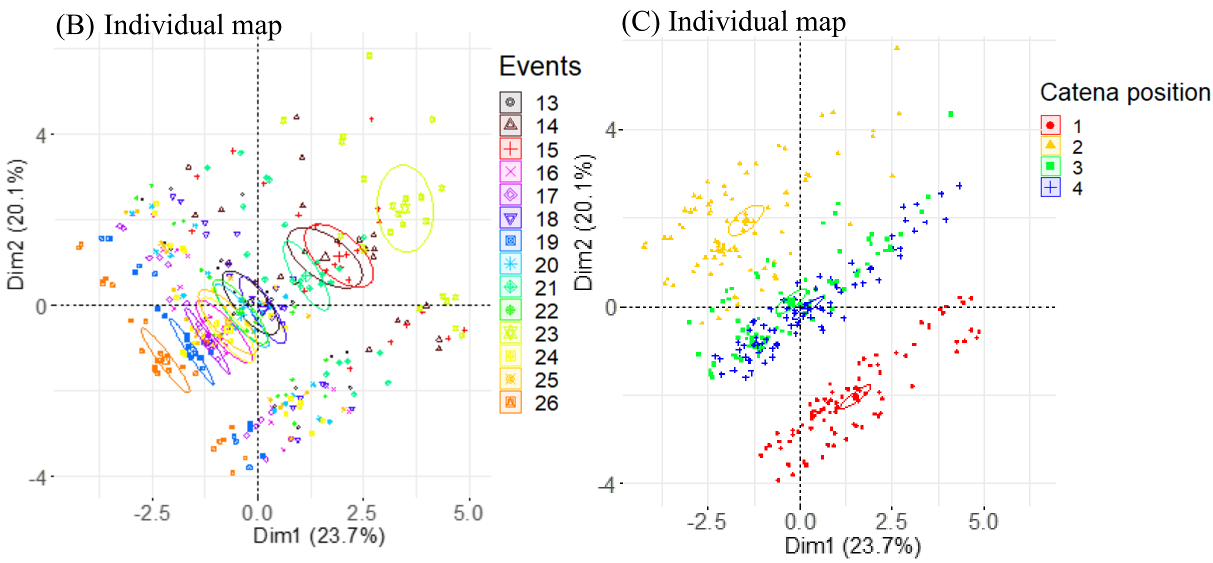


Figure 2. Principal component analyses (PCA) of the explanatory and response variables (A). Variables are represented with a cos2 colour scale indicating their weight on each axe of the PCA. Dimension 1 and 2 explain 23.7 and 20.1% of the variance, respectively. Two individual factor maps are represented with events (B) and position in the catena (C) as factors on dim 1 and 2.

3.2 Runoff and Total sediments

In 2018, the volume of runoff ranged between 0 and 64.4 L with a mean of 15.4 ± 13.5 L, and total sediments ranged between 0 and 1227.4 g m^{-2} with a mean of 78.7 ± 174.5 g m^{-2}. In 2019, the volume of runoff ranged between 0.7 and 65.6 L with a mean of 25 ± 18.1 L, total sediments ranged between 1.0 and 1455.4 g with a mean of 139.7 ± 202.3 g.

Runoff and total sediments were not significantly different with or without biochar. However, runoff was significantly lower during events of 12/06/2018 (85.4 mm and 60 mm h^{-1}), 30/05/2019 (167 mm and 156 mm h^{-1}), 25/07/2019 (42 mm and 38 mm h^{-1}), 02/08/2019 (71.2 mm and 38 mm h^{-1}) and 11/09/2019 (43.2 mm and 40 mm h^{-1}). The biochar effect did not seem to correlate with the intensity of the events, since those occurred with very variable intensities.

The main result concerning the effect of position in the catena was that runoff and total sediments were higher in TOP position (p-value respectively of 5.049×10^{-8} and 1.751×10^{-5}) (cf. Figure 3).

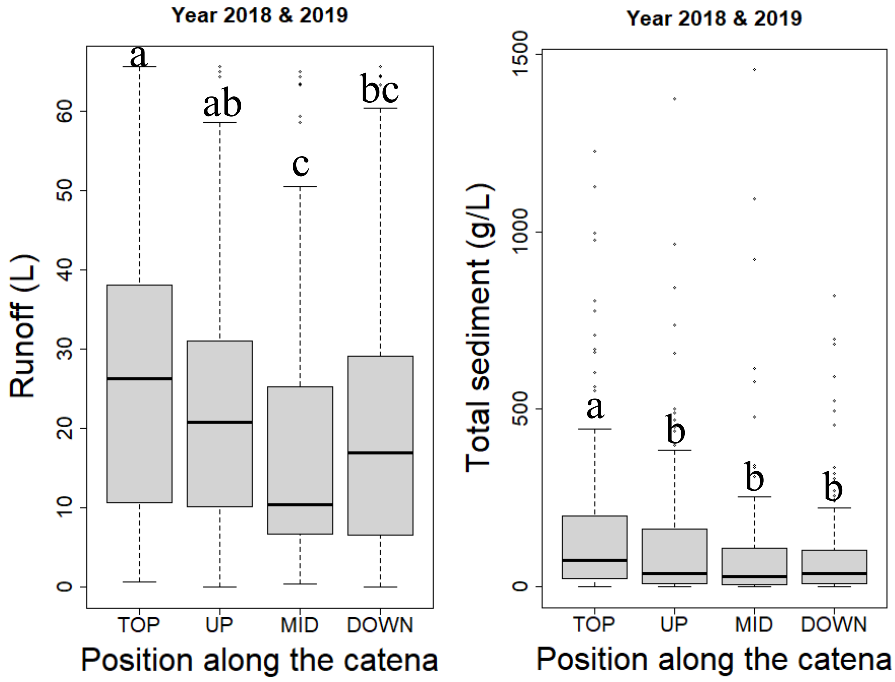
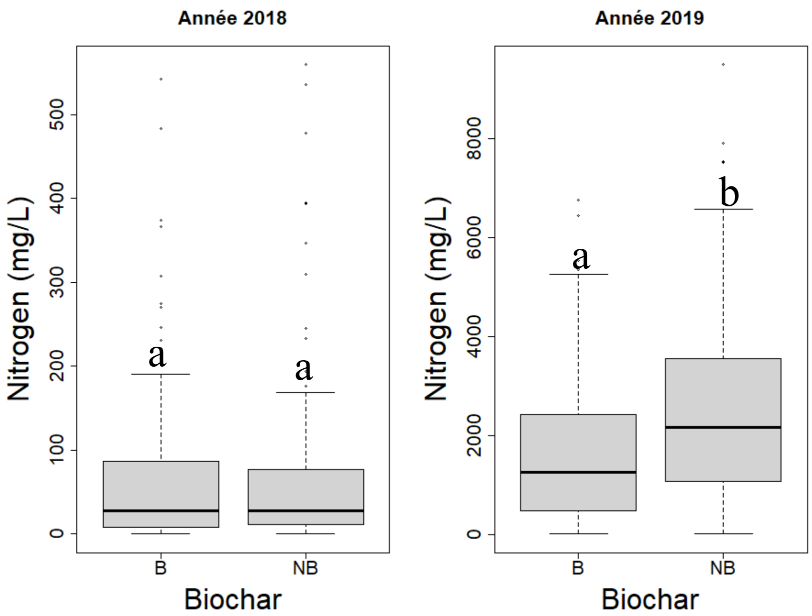


Figure 3. Boxplot of runoff and total sediment according to position in the catena (down, middle, up, top) for year 2018 and 2019 together. Letters indicate significant differences at $p < 0.05$ level.

3.3 Nutrients – N, P, K

In 2019, nitrogen was 34% lower under biochar (p-value of 5.856×10^{-7}). Nitrogen was also significantly different in the position in the catena in 2018 and 2019 (p-value respectively of 7.905×10^{-16} and of 1.984×10^{-3}). In 2018, nitrogen was higher in TOP position and in 2019 it was higher in DOWN position (cf. Figure 4).

However, in 2018 the nitrogen concentration was in average 69,4 ± 103,0 mg/L while in 2019 it was 2096,1 ± 1692,9 mg/L.



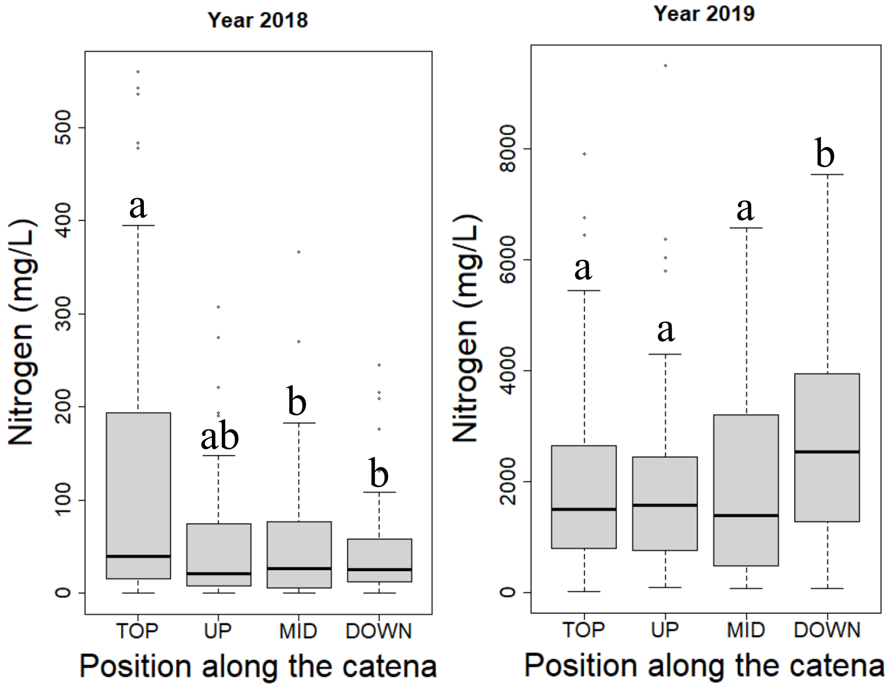


Figure 4. Boxplot of nitrogen according to biochar treatment (B, biochar; NB, no biochar) and position in the catena (down, middle, up, top) for years 2018 and 2019. Letters indicate significant differences at $p < 0.05$ level.

Phosphorus concentration was 74% higher under biochar in 2018 (p-value of 7.734×10^{-5}) and in 2019 we observed the same trend, but without any significant results. Phosphorus concentration was significantly affected by the position in the catena, the highest concentrations were in TOP position compared with MID and DOWN positions (cf. Figure 5).

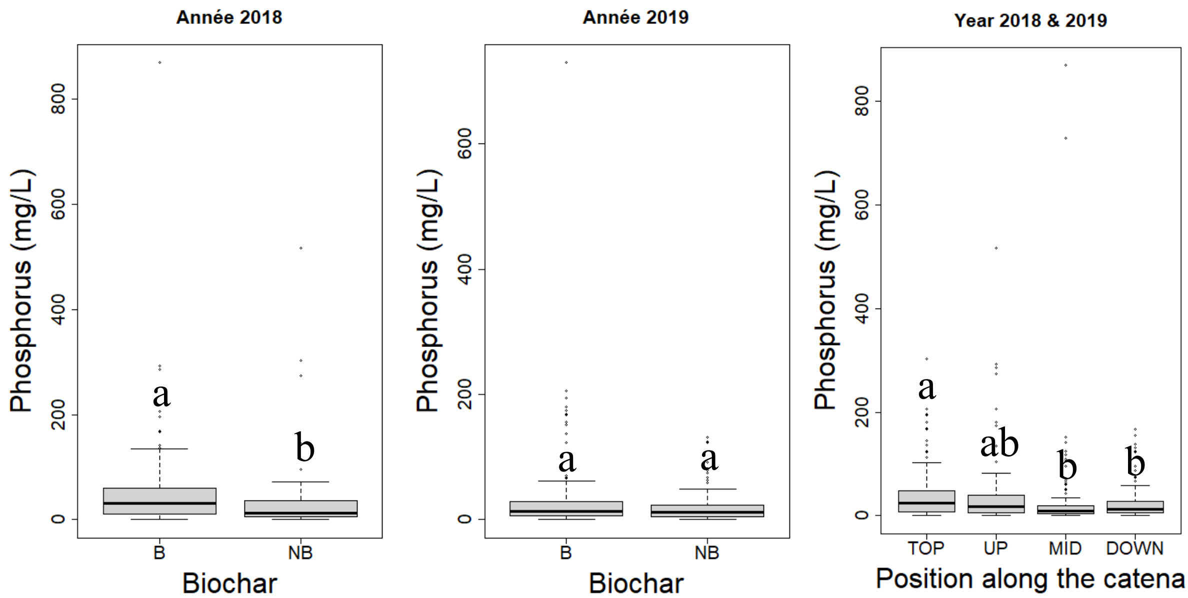


Figure 5. Boxplot of phosphorus according to biochar treatment (B, biochar; NB, no biochar) for years 2018 and 2019 and position in the catena (down, middle, up, top) for years 2018 and 2019 together. Letters indicate significant differences at $p < 0.05$ level.

Potassium concentration in runoff increased significantly by 41% under biochar treatment in 2018 (p-value of 1.114×10^{-2}). In 2019, we observed the same trend than in 2018, without significant differences. Potassium differed also significantly according to position in the catena in 2018 (p-value of 7.075×10^{-4}), with concentrations higher in TOP position than in the others. In 2019, potassium did not show any significant differences along the catena (cf. Figure 6).

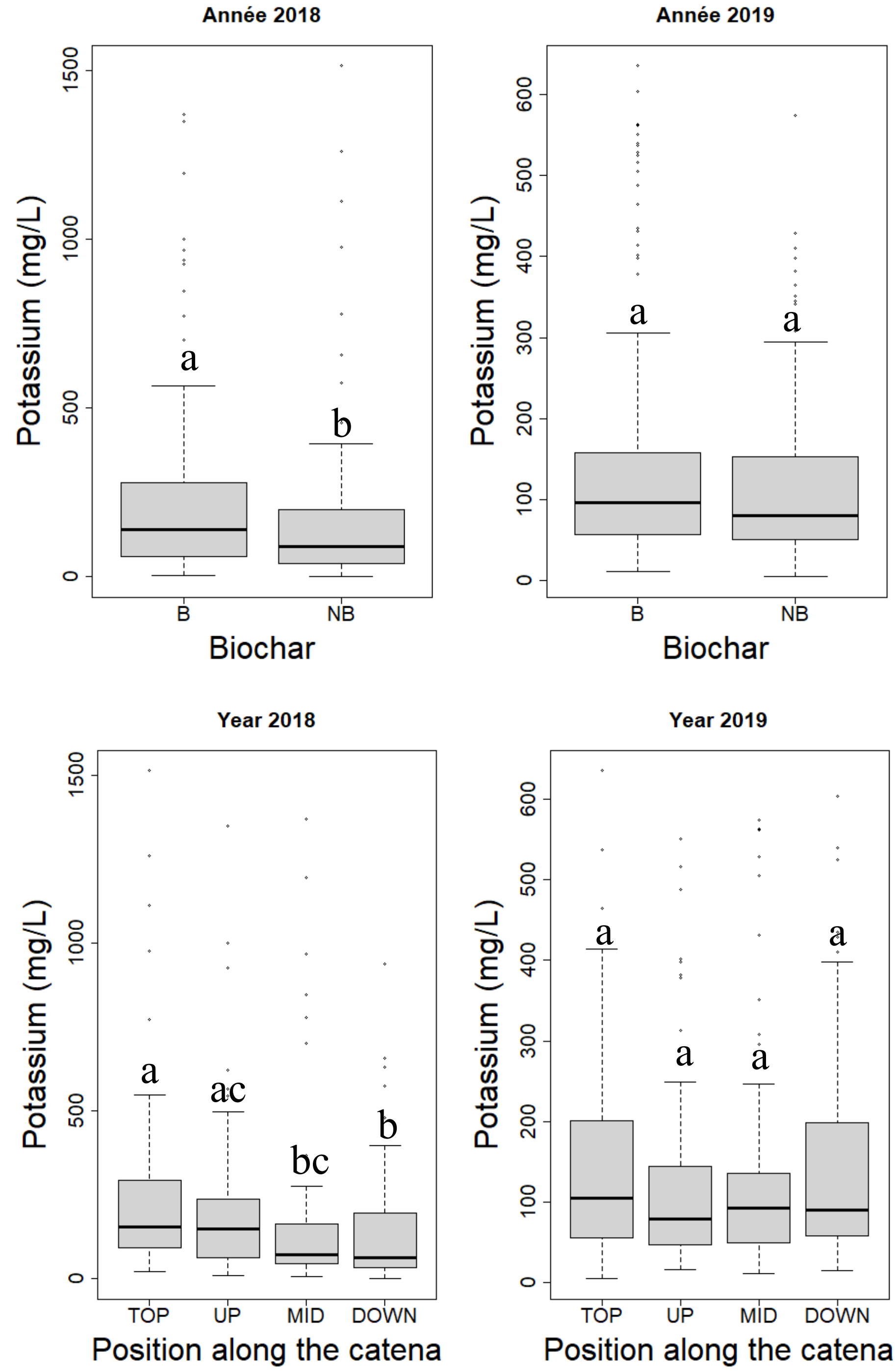


Figure 6. Boxplot of potassium according to biochar treatment (B, biochar; NB, no biochar) and position in the catena (down, middle, up, top) for years 2018 and 2019. Letters indicate significant differences at $p < 0.05$ level.

3.3 Hydrological variables

For both years, soil moisture was higher under biochar (p-value of 4.764×10^{-3}). Soil moisture was also significantly affected by position in the catena (p-value of 8.967×10^{-7}), the MID position was higher than the DOWN and TOP position (cf. Figure 7).

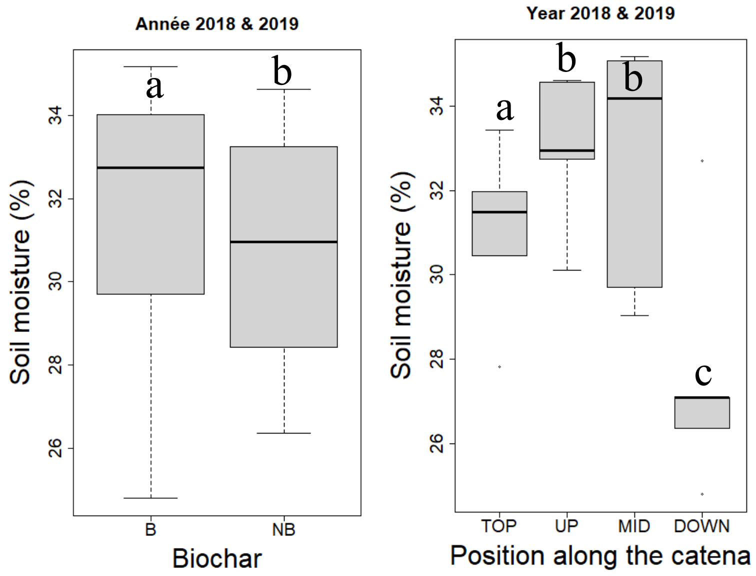


Figure 7. Boxplot of soil moisture according to biochar treatment (B, biochar; NB, no biochar) and position in the catena (down, middle, up, top) for year 2018 and 2019 together. Letters indicate significant differences at $p < 0.05$ level.

Hydraulic conductivity present contradictory results: it was 59% higher with biochar in 2018 (p-value of 2.295×10^{-5}) and 24% lower in 2019 (p-value of 1.534×10^{-2}) compared with control. In 2018 hydraulic conductivity was significantly lower in UP position and in 2019 it was significantly higher in MID position (cf. Figure 8).

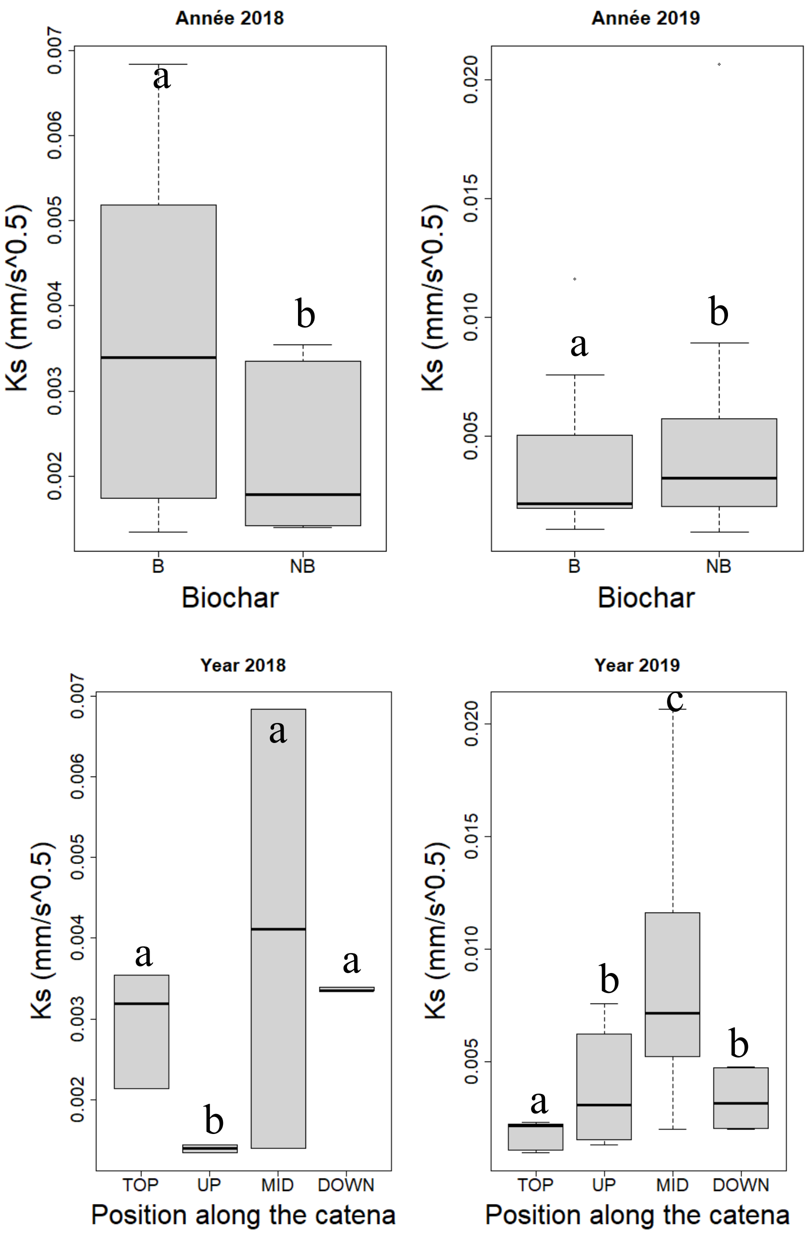


Figure 8. Boxplot of hydraulic conductivity according to biochar treatment (B, biochar; NB, no biochar) and position in the catena (down, middle, up, top) for years 2018 and 2019. Letters indicate significant differences at $p < 0.05$ level.

3.3 Soil condition

In 2018, vegetal cover increased significantly by 29% with biochar (p-value of 4.283×10^{-2}), and free elements decreased significantly by 68% with biochar (p-value of $1.425*10^{-4}$) (cf. Figure 9). For these two variables, the 2019 results were not significant but we observed the same trend. For both years combined, vegetal cover and free elements were not significantly different along the catena (graphic not shown).

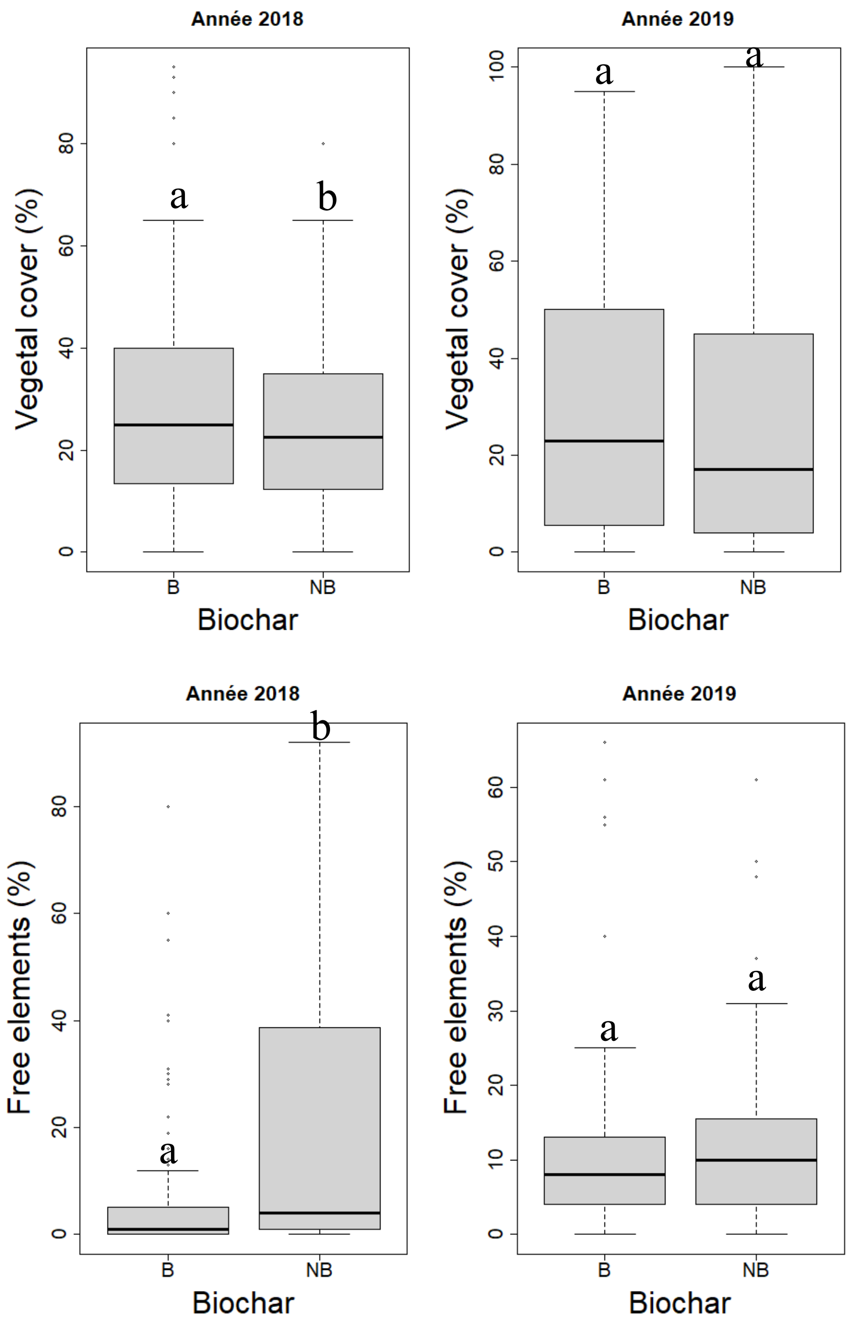


Figure 9. Boxplot of vegetal cover and free elements according to biochar treatment (B, biochar; NB, no biochar) for years 2018 and 2019. Letters indicate significant differences at $p < 0.05$ level.

For both years, percentage of crust decreased of 54% under biochar (p-value of $2.437\ 10^{-17}$) and was significantly higher in TOP position than in MID position (cf. Figure 10).

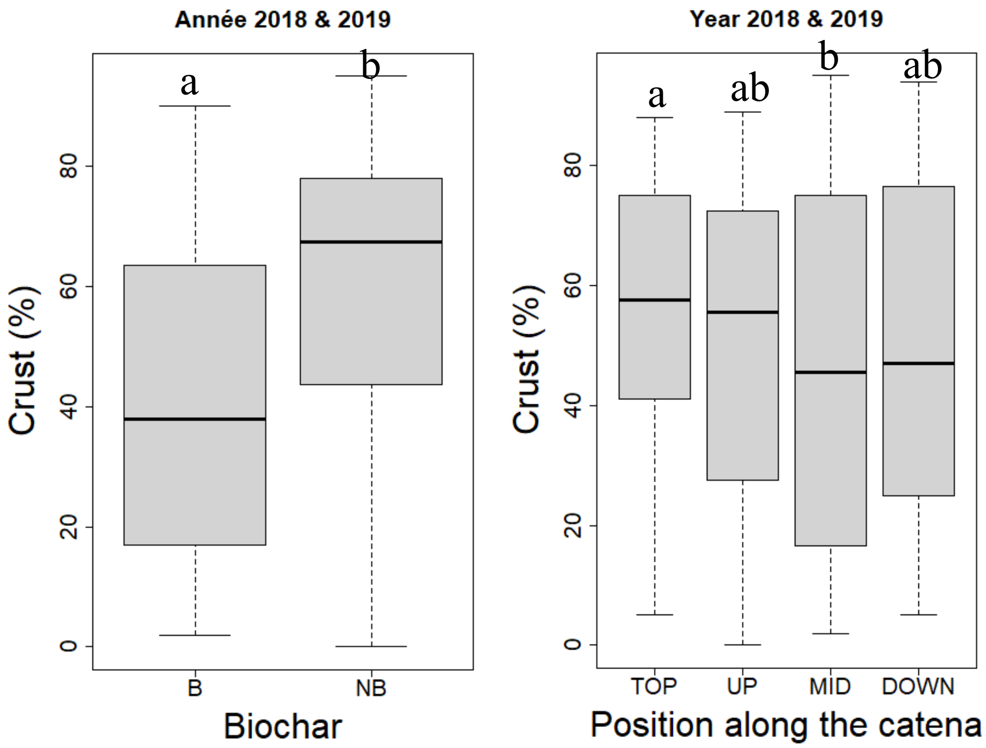


Figure 10. Boxplot of crust according to biochar treatment (B, biochar; NB, no biochar) and position in the catena (down, middle, up, top) for years 2018 and 2019. Letters indicate significant differences at $p < 0.05$ level.

4. DISCUSSION

4.1 Effect of biochar

We showed that, for the year 2019, biochar decreased the concentration of nitrogen. This result was also found by Liu et al. (2019) using a regression modelling of machine learning based on data compiled from the literature. However, the effect of biochar on nitrogen may be influenced by fertilization procedure applied by farmers each year. This may explain the high difference between the mean concentration of nitrogen for the year 2018 and 2019.

The effect of biochar on phosphorus and potassium was confirmed by Limwikran et al. (2018) who also showed an increase under bamboo wood biochar that can release these nutrients.

Some authors have shown that incorporated biochar in topsoil (0-15cm) increase soil moisture (Haider et al., 2017). This support our results of increased moisture in both years under biochar treatment incorporated in the 5-10 cm into the soil surface.

We found that biochar increased hydraulic conductivity by 59% in 2018. This is in line with Yan et al. (2021) who shown that, if biochar quantity increase, then hydraulic conductivity increase.

Biochar can accelerate the germination, the height and shoot biomass of some species like *Robinia pseudoacacia L.* (Bu et al., 2020). In our study, this mechanism could explain the increase of vegetal cover by 29% for 2018.

For some of our variables (phosphorus, potassium, vegetal cover) we found an effect of biochar for 2018 and not for 2019. This can be explained by: (1) according to Janeau et al. (2020) who did rainfall simulation in same study site, there was a significant amount of soil loss, and natural erosion process has resulted in the removal of the top millimetres of soil, allowing biochar (less dense particles) to emerge on the soil surface. In addition to that, the presence of biochar in soil surface could also have acted as a crust. After two years of biochar treatment in 2019, the effect of biochar as a crust was different from the effect in 2018. (2) In simulated rainfall, runoff decreased the quantity of biochar (Li et al., 2020). These two elements can decrease the potential effect of biochar for 2019.

We found that biochar decreased crust for both year and decreased free elements for 2018 compared to 2019. Indeed, the presence of biochar on the soil surface did not allow creating sedimentation crust (or in limited extent) and space was occupied by biochar which limits also free elements on the soil surface. Biochar acted itself as a crust on the soil surface but apparently did not have any effect on runoff and total sediment loss.

Li et al. (2024) conducted a study in China and found opposite results to our study. Their research demonstrated that application of biochar reduced runoff and soil loss. There are some different points between their study and ours: biochar was made by pyrolyzing clippings of apple tree branches; soil was classified as loessial soil, belonging to loess-derived silt loam (38.1% sand, 53.9% silt, 8.0% clay); the mean accumulated rainfall ranged between 497 and 679 mm annually, from 2017 to 2020 (almost half the average annual precipitation on our site); finally, their runoff and collection covered an area of 18m², significantly larger than our 1m² plot. We know that scale effect can be very important in soil erosion processes (Wu et al., 2021). We can also remember that different processes may have acted here due to the uplift movement of biochar on the soil surface.

4.2 Effect of position in the catena

As a reminder, the slope gradients range from 10% to 44%. The four positions (top, upper, middle, and lower) had elevations of 512, 498, 480, and 460 meters above sea level, respectively. The soil texture was clay loam for the top and lower positions and silty clay loam for the upper and middle positions.

Some authors have explored the impact of topographical position within a catena. They showed higher nitrogen levels in the TOP position compared to lower positions (Rezaei et al.,2015; Tsui et al.,2004). Tsui et al. (2004) agree with our results concerning a higher concentration of potassium in TOP position, they differed in their observation of higher phosphorus concentration in the same position.

Magdić et al. (2022) validated the influence of catena position on soil moisture, in a vineyard field. However, they showed that soil water content was higher in the upper slope positions than on lower slope positions associated with clay content, they conclude that soil moisture on the slope is more influenced by soil texture than the position on the slope.

In contrast, Sobieraj et al. (2002), in a tropical rainforest, did not find significant change in hydraulic conductivity as a function of topography. However, they found some dependency of hydraulic conductivity (Ks) on topography only at the 90-cm depth. In addition to that, our hydraulic conductivity was significantly different depending on catena position, but this difference makes Ks ranged between 10^{-3} and 10^{-2} mm $s^{-0.5}$ which are both representative of a permeable soil.

We observed elevated levels of total sediment in TOP position, indicating higher erosion in the top of the slope. In agreement with us, Farmanullah et al. (2013), while analysing soil properties on eroded soil, found that effects of soil erosion are higher at top slope as compared to mid and bottom slope. Soil erosion results in finer particles being carried downhill, leaving coarser material at the top, increasing soil density. Conversely, suspended finer particles move downward, boosting clay and silt content at the bottom, with higher porosity and lower density. It may be interesting to analyse the gradient of the slope to see whether or not there is greater erosion.

Concerning vegetal cover, we did not find significant effect by position in the catena, Lieffers and Larkin-Lieffers (1987) highlighted that certain species can be found on most positions on the slope. However, some other were mostly restricted to summit and upper slope positions, their study show that slope position and aspect were most important in describing distribution of species.

We obtain contradictory results concerning runoff, we found higher runoff in top position compared to other positions. Whereas, Azuka and Igué (2020) did not found effect of slope position on runoff in northern Benin. Notably, their study focused on a different ecological context with annual rainfall ranging between 900 and 1200 mm and specific land use patterns involving tilled maize-beans intercrop and fallow shrub-grassland, the soils in the microplots sites are mostly Plinthosols with gravelly or plinthic horizons.

5. CONCLUSION

Biochar offers potential benefits in enhancing soil characteristics and reducing nutrient leaching. As expected in our hypothesis, the incorporation of biochar amendments has shown positive effects by reducing the loss of soil nutrients, especially nitrogen. Additionally, biochar has been observed to contribute to the improvement of vegetation cover, reduction of free elements, and prevention of crust formation on the soil surface. The experiment indicated that when biochar is present on the soil surface, it exhibits characteristics similar to a soil crust, providing protection against crust formation. To prevent this phenomenon, it is recommended to bury biochar deeper under the soil surface. Interestingly, the presence of biochar did not have a significant impact on sediment loss or runoff.

Moreover, as we expected in our hypothesis, this study emphasizes the importance of tailoring agricultural practices to specific sections of the catena due to the non-uniform distribution of soil properties along the slope. The position along the slope has been identified as a significant factor influencing nutrients, runoff, and soil loss.

To optimize ecological services, the application of biochar should be adjusted based on the diverse soil properties along the catena. As emphasized by various researchers, the effectiveness of biochar in improving soil structure and promoting structural stability becomes more apparent after a maturation period in the soil. Therefore, extending the survey over a longer timeframe is crucial to observe the continuous evolution of soil structure following multiple natural rainfall events.

APPENDIX

Table 1. Kruskal-Wallis test results on the variables

	Total_sediment	Runoff	N	K	P	Soil_moisture	Sorptivity	Ks	Vegetal_cover	Free_elements	Crust
p-value biochar 2018	-	-	-	0.01114	7.734e-05	-	5.119e-11	2.295e-05	0.04283	0.0001425	2.169e-19
p-value biochar 2019	-	-	5.856e-07	-	-	0.03629	-	0.01534	-	-	1.069e-05
p-value biochar 2018 & 2019	-	-	0.02186	0.004608	0.0002476	0.004764	2.517e-08	-	0.009676	0.002244	2.439e-17
p-value topo 2018	1.429e-08	7.905e-16	0.03532	0.0007075	3.136e-07	2.002e-25	2.66e-10	3.346e-21	0.008771	0.03843	-
p-value topo 2019	-	0.007984	0.004704	-	0.0004201	3.861e-36	7.965e-24	3.743e-22	-	-	-
p-value topo 2018 & 2019	1.751e-05	5.049e-08	-	0.01535	5.219e-07	8.967e-62	8.258e-11	1.343e-24	-	-	0.03547

Table 2. Dunn test results on the variable on 2018 and 2019

	Total_sediment	Runoff	N	K	P	Soil_moisture	Sorptivity	Ks	Vegetal_cover	Free_elements	Crust
p Kruskal-Wallis	1.751e-05	5.049e-08	-	0.01535	5.219e-07	8.967e-62	8.258e-11	1.343e-24	-	-	0.03547
p Dunn DOWN/MID	-	-	-	-	-	7.492e-51	1.876e-07	0.00179	-	-	-
p Dunn DOWN/TOP	0.0006892	0.0009561	-	0.02916	0.001622	2.347e-16	-	8.782e-06	-	-	-
p Dunn MID/TOP	6.676e-06	3.099e-08	-	0.009536	1.51e-07	4.457e-11	2.521e-09	1.362e-15	-	-	0.01189
p Dunn DOWN/UP	-	-	-	-	-	2.292e-44	-	4.389e-09	-	-	-
p Dunn MID/UP	-	0.0001243	-	-	0.001518	-	4.501e-08	6.413e-21	-	-	-
p Dunn TOP/UP	0.0106	-	-	-	-	3.073e-08	-	-	-	-	-

Table 3. Dunn test results on the variable on 2018

	Total_sediment	Runoff	N	K	P	Soil_moisture	Sorptivity	Ks	Vegetal_cover	Free_elements	Crust
p Kruskal-Wallis	1.751e-05	5.049e-08	-	0.01535	5.219e-07	8.967e-62	8.258e-11	1.343e-24	-	-	0.03547
p Dunn DOWN/MID	-	-	-	-	-	7.492e-51	1.876e-07	0.00179	-	-	-
p Dunn DOWN/TOP	0.0006892	0.0009561	-	0.02916	0.001622	2.347e-16	-	8.782e-06	-	-	-
p Dunn MID/TOP	6.676e-06	3.099e-08	-	0.009536	1.51e-07	4.457e-11	2.521e-09	1.362e-15	-	-	0.01189
p Dunn DOWN/UP	-	-	-	-	-	2.292e-44	-	4.389e-09	-	-	-
p Dunn MID/UP	-	0.0001243	-	-	0.001518	-	4.501e-08	6.413e-21	-	-	-
p Dunn TOP/UP	0.0106	-	-	-	-	3.073e-08	-	-	-	-	-

Table 3. Dunn test results on the variable on 2018

	Total_sediment	Runoff	N	K	P	Soil_moisture	Sorptivity	Ks	Vegetal_cover	Free_elements	Crust
p Kruskal-Wallis	-	0.007984	0.004704	-	0.0004201	3.861e-36	7.965e-24	3.743e-22	-	-	-
p Dunn DOWN/MID	-	0.002231	0.008803	-	0.002397	2.726e-30	1.841e-06	1.368e-09	-	-	-
p Dunn DOWN/TOP	-	-	0.01626	-	-	4.996e-10	0.0002934	0.001014	-	-	-
p Dunn MID/TOP	-	-	-	-	0.0003784	8.125e-07	1.955e-18	2.829e-22	-	-	-
p Dunn DOWN/UP	-	-	0.007172	-	-	1.722e-26	7.741e-05	-	-	-	-
p Dunn MID/UP	-	-	-	-	-	-	1.13e-19	7.009e-12	-	-	-
p Dunn TOP/UP	-	-	-	-	-	3.84e-05	-	0.01509	-	-	-

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TITLE: Slope position and biochar influence soil properties in a tropical agroecosystem

ABSTRACT

Soil erosion is a natural process intensified by improper land use. It leads to the loss of fertile topsoil, reduced water quality, and lower agricultural productivity. Spatial variability in soil erosion and crop yield in upland areas is influenced by various factors such as soil properties, landscape position, local climate, land cover, soil type, and management practices. This variability is crucial for effective soil conservation, nutrient management, and precision farming. There are different agro-ecosystem options to mitigate soil and nutrient loss and to preserve native plant biodiversity; biochar introduction is one of them. Conducting an on-site experiment on a steep maize field affected by rainfall and tillage erosion in Northern Thailand, we aim to explore the impact of catena position and biochar use on seed displacement, soil loss, and nutrient losses. Our objective was to test under natural rainfall the effect of catena position and biochar use on soil loss and nutrient losses. We used 24 plots of 1 m2 located at four positions in the catena (top, up, mid, down). Biochar incorporated into the soil was tested. We measured runoff volume, soil and nutrient losses and soil surface features. After a period of two years and 26 rainfalls, our findings indicate that incorporating biochar amendments into the topsoil can effectively reduce soil nutrient loss, particularly nitrogen. This practice also contributes to an improved vegetal cover, increased soil moisture, and decreased presence of free elements. In the course of this study, we observed the reappearance of previously integrated biochar at the soil surface after 8 months under natural conditions. This re-emergence manifested as a crust on the soil surface. Catena positions exhibit a discernible impact on various soil properties, including nutrients and runoff. Considering the influence of catena position is essential for enhancing soil management and implementing suitable agroecological practices.

KEYWORDS

biochar, catena, nutrient losses, runoff, soil loss, steep slope