Projet de Recherche et Innovation 2024 – 2025

INFLUENCE OF SLOPE POSITION, SOIL PROPERTIES AND RAINFALL CHARACTERISTICS ON HYDROCHORY PROCESSES IN A STEEP TROPICAL AGROECOSYSTEM

Figure 1 from Khwanrawee Anusorn *Master thesis* (2019)

Research director: Ms. Séraphine GRELLIER

Student: M. Nathan GRAND

INFLUENCE OF SLOPE POSITION, SOIL PROPERTIES AND RAINFALL CHARACTERISTICS ON HYDROCHORY PROCESSES IN A STEEP TROPICAL AGROECOSYSTEM

Unveiling Key Drivers of Seed and Sediment Transport: Insights from Tropical Agroecosystems

Research director: Ms. Séraphine GRELLIER **Student**: M. Nathan GRAND

2024 - 2025

CAUTION

This research involved readings, surveys and interviews. All borrowings from interviews, writings other than strictly personal, all reproductions and quotations, are systematically referenced.

The author of this research has signed an attestation of non-plagiarism.

Formation par la recherche, Projet de Recherche Innovation en génie de l'Aménagement et de l'Environnement

---

La formation au génie de l'aménagement et de l'environnement, assurée par le département aménagement et environnement de l'Ecole Polytechnique de l'Université de Tours, associe dans le champ de l'urbanisme, de l'aménagement des espaces fortement à faiblement anthropisés, l'acquisition de connaissances fondamentales, l'acquisition de techniques et de savoir-faire, la formation à la pratique professionnelle et la formation par la recherche. Cette dernière ne vise pas à former les seuls futurs élèves désireux de prolonger leur formation par les études doctorales, mais tout en ouvrant à cette voie, elle vise tout d'abord à favoriser la capacité des futurs ingénieurs à :

- Accroître leurs compétences en matière de pratique professionnelle par la mobilisation de connaissances et de techniques, dont les fondements et contenus ont été explorés le plus finement possible afin d'en assurer une bonne maîtrise intellectuelle et pratique,
- Accroître la capacité des ingénieurs en génie de l'aménagement et de l'environnement à innover tant en matière de méthodes que d'outils, mobilisables pour affronter et résoudre les problèmes complexes posés par l'organisation et la gestion des espaces.

La formation par la recherche inclut un exercice individuel de recherche, le projet de recherche innovation (P.R.I.), situé en dernière année de formation des élèves ingénieurs. Cet exercice correspond à un stage d'une durée minimum de trois mois, en laboratoire de recherche, principalement au sein de l'équipe Dynamiques et Actions Territoriales et Environnementales de l'UMR 7324 CITERES à laquelle appartiennent les enseignants-chercheurs du département aménagement.

Le travail de recherche, dont l'objectif de base est d'acquérir une compétence méthodologique en matière de recherche, doit répondre à l'un des deux grands objectifs :

- Développer toute ou partie d'une méthode ou d'un outil nouveau permettant le traitement innovant d'un problème d'aménagement
- Approfondir les connaissances de base pour mieux affronter une question complexe en matière d'aménagement.

Afin de valoriser ce travail de recherche nous avons décidé de mettre en ligne sur la base du Système Universitaire de Documentation (SUDOC), les mémoires à partir de la mention bien.

ACKNOWLEDGMENT

I would like to extend a warm thank you to Séraphine Grellier who has followed me and taught me so much throughout this project, always with kindness and patience. It has been a real opportunity for me to get close to the world of research, which arouses deep interest and curiosity in me. Thank you for the trust you have placed in me. I would also like to thank Suphannika Intanon, from Naresuan University, Thailand, who took time out of her busy schedule to try and enlighten me and help me move forward with my work.

A big thank you to Lorinda for helping me to improve my visual aids and for knowing how to make problems smaller, everyday life more colourful and the path smoother. Thank you to my family for their support, even hundreds of miles away, and of course a huge thank you to all my friends at Tours and Albi, who know so much better than this project how to make me laugh.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1. INTRODUCTION

Today's large-scale, efficiency-driven agricultural system cannot afford to take local biodiversity into account, unless it proves its usefulness to performance (Swift *et al*., 2004). Biodiversity is indeed capable of providing great ecosystemic services such as preserving water and soil resources (Faucher *et al.,* 2022) and can therefore be of great interest to the agricultural sector.

This would be especially true for South-East Asia where the current worsening of global warming results in soils getting dryer which lowers their infiltration capability and eventually increases the runoffs and erosion processes (Ma *et al*., 2021). Moreover, crop fields and forests often occupy important land surfaces and thus represent a major challenge for biodiversity (Sodhi *et al*., 2009; Wilcove *et al*., 2013). A better understanding of seed dispersal and especially hydrochory processes (transportation of seeds by water) represents a major mean to preserve and restore habitats and therefore maintain this crucial biodiversity (Faucher *et al.,* 2022).

Hydrochory is mainly governed by the same parameters that also drive soil loss and runoffs (Janeau *et al.*, 2022; Jiao *et al.*, 2009). Even though these latter phenomena are multifactorial (Lal, 2001), they are driven partially by the characteristics of the local rainfall (H. Chen *et al*., 2018; Wang *et al.,* 2014; Mohamadi *et al.*, 2015) and soil properties (Wischmeier 1978). Another key factor characterizing soil erosion and runoffs, and consequently hydrochory, is the type of vegetation present on site (Podwojewski *et al.,* 2011). A multilayered vegetation structure maximizes the runoff and soil loss mitigations (Wang *et al*., 2018). Moreover, litter is more efficient than canopy layer to reduce the raindrop splash erosion effect (Janeau *et al.,* 2014).
However, external factors are not the only ones to play a role. Indeed, the seed's properties themselves also determine their capacity to be carried away by water. D. Wang *et al*. (2012) have shown that mass, elongated shapes and body specificities like appendages, hairs, or ability to secrete mucilage are showing high resistance to water displacement. Furthermore, the influence of the slope's characteristics (length and steepness) and of the position of the seeds along the catena has also been noticed.
Even if the hydrochory process has a way of working of its own, the study of L. Han *et al*. (2010) showed that the **seed transportation is highly related to sediment yield and to runoff amount** as well.
The moment in the season is another parameter of influence that has been enlightened by Yuko Kohmoto *et al.* in 2021. Depending on when the rainfall event occurs in the season, different consequences in terms on runoff and sediment yield can occur because of the difference in the nature of the soil surface (sealed or not) and the state of the vegetation.

If soil properties often differ along the catena (Omokaro, 2023; Rezaei *et al.,* 2015), runoff and soil losses can also be impacted by the position in the catena (Janeau *et al.,* 2022). Janeau *et al*. (2022) showed in South-East Asia a significant impact of the slope position on sediment yield under simulated rainfall. The number of sediments transported by water increased between the middle of the slope and the top position. D. Tuo *et al.* (2018) showed that soil erosion was much more intense at the upper position than at the other positions of the slope. In their study taking place in the Slovakian vineyards, Kenderessy *et al.* (2014) obtained for a result that the erosion was higher on the backslope than on the others positions while Cerdà & Rodrigo-Comino, (2019) showed that the hillslope position does not affect soil detachment. The results are inconsistent and slope position influence seems to be irregular and to depend on other parameters.

The link between hydrochory, rainfalls characteristics, soil characteristics and slope position in tropical agricultural lands is still to be clarified. As being integrated in the SeaWeed Project (PHC grant from Franco-Thai agreement), we would like to answer the following question:

What is the effect of position in the catena and rainfall characteristics on seed loss and sediment transport in steeply sloping agricultural fields in tropical climates?

Based on the above state of the art, we hypothesised that in this context:

Hypothesis H1. Seed loss rate is positively correlated to soil loss rate. Moreover, rainfall intensity shall be the main factor influencing soil loss and then seed loss rate.

Hypothesis H2. Due to different soil properties over the catena, the position in the catena shall influence the quantity of sediments and seeds exported.

To evaluate these hypotheses, we examined seed displacement and sediment transport *in situ*, on agricultural soils, and used two seasons (2018 and 2019) of natural rainfall on 1 m² plots along the catena.

2. MATERIALS AND METHODS

This part consists for one part on extracts from *Slope position and biochar influence soil properties and seed displacement in a tropical agroecosystem* – Janeau *et al*. (2022) and from *Effects of toposequence and soil loss on weed seed bank dynamics in upland maize production* – Master thesis, Khwanrawee Anusorn (2019), as the data of interest in this current paper are coming from the same experiments.

2.1 Site description

The experiment under natural rainfall was conducted in a micro-catchment (1 ha), located at Ban Tub Man 18°19'30.0" N 100°34'17.3" E, about 20 km from Na Noï, Nan Province, Northern Thailand (cf. FIGURE 1). This steeply sloping landscape is representative of the land use (slopes and cultures) observed in this region of Northern Thailand. The Northern Provinces, mountainous areas of Thailand, represent the water supply for the central plains where most of the rice of Thailand (paddy field) is cultivated. It is therefore essential to study the water flow in cultivated fields especially as this area suffers from fierce deforestation. This steeply sloping land endures a strong agricultural pressure, increasing soil erosion (Thothong *et al.,* 2011; Valentin *et al.*, 2008), such as formation of gullies. The elevation ranged from 470 m to 535 m above mean sea level, and the studied catena was 210 m long. The climate is tropical sub humid with an average annual precipitation of approximately 1200 mm and characterised by high rain intensities up to 120 mm h^{-1}. The soils are Alfisols distributed along a steep slope (42 ± 2%). The percentages of sand, silt and clay of topsoil samples (0–10 cm) were determined using the hydrometer method (Ashworth *et al.,* 2001; Bouyoucos, 1962). The soils were characterised as having clay loam texture at the top and lower slope positions and silty clay loam texture at the upper and middle slopes (cf. Table 1).

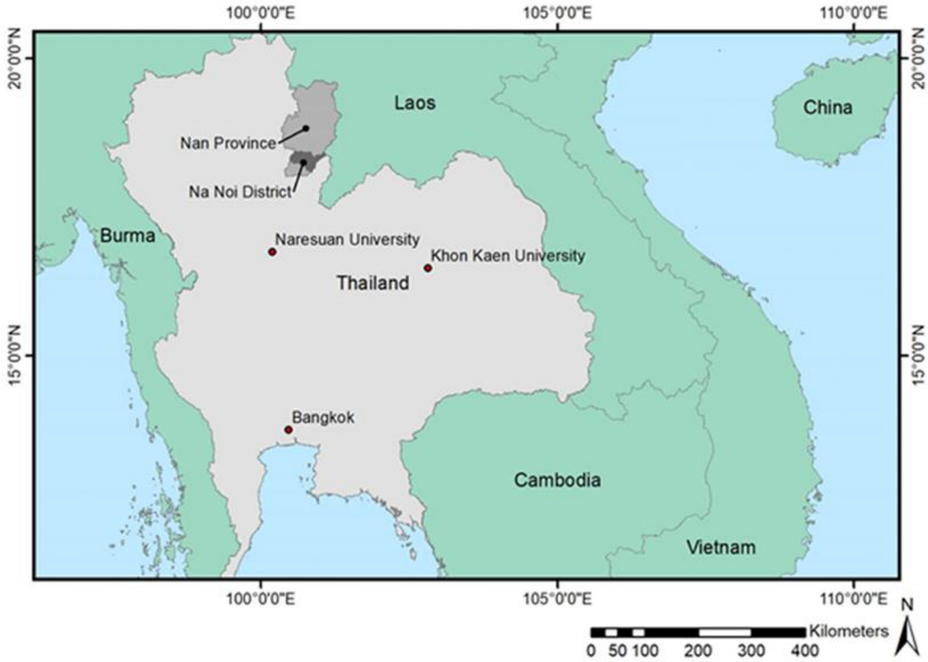


FIGURE 1 Location map of the studied micro-catchment, Na Noï district in Nan province, Thailand.

TABLE 1 The percentages of sand, silt and clay, soil texture and bulk density of topsoil samples (0–10 cm) at the different slope positions

	%				
Positions in the catena	**Clay**	**Sand**	**Silt**	**Soil texture**	**Bulk density (g cm^{-3})**
Top	29.77	23.94	46.29	Clay loam	1.10a
Up	33.72	19.84	46.44	Silty clay loam	1.13a
Middle	34.69	16.70	48.62	Silty clay loam	1.13a
Down	28.26	28.72	43.01	Clay loam	1.22b

Note: Different letters indicate significant results among positions in the catena at the $p < 0.05$ level.

2.2 Plot and soil surface characteristics

The experiment took place in January 2019 on twelve 1 m² plots installed on a steep slope along a representative catena of this relief. We delimited four zones in the catena (top, up, middle, and down). On each zone, 6 plots were set up along the contour line with a minimum distance of 4 m to avoid interaction. These 12 plots were bound by a metallic square frame of 20 cm high. The metallic frame was driven into the soil at a depth of 10 cm, leaving 10 cm above the soil surface to avoid any upstream runoff entering the plot. This experimental design is often used in studies dealing with soil loss processes along the catena and at 1 m² scale (Janeau *et al*., 2003; Janeau *et al*., 2014; Jouquet *et al*., 2012; Mügler *et al*., 2021; Podwojewski *et al*., 2011; Ribolzi *et al*., 2011).

2.3 Seed bank experiment

Soil samples were collected randomly around the micro plot using a soil core (8 cm diameter x 10 cm depth). Three soil cores were taken and combined on each of left, right, and top sides of each micro-plot to be three sub-samples for each micro plot (cf. FIGURE 2).

Soil samples were then stored in labelled plastic bags and transported to a greenhouse to be air-dried and sieved through 5 mm size to remove stones and residues. Weed germination method modified from Bhatt and Singh (2007) was used to study the soil seed bank and estimate the viable seeds in soil. Soil volume of 1 125 cm^3 were spread on top of peat moss covered with landscape fabric in a plastic tray size 25x25 cm^2. The soil samples were kept in a greenhouse and watered daily. Seedling were counted every 2 weeks. The seedlings were either identified and removed from the tray or transplanted for later identification. Once the initial germination phase was complete, soil samples were air-dried for a week, soil in the tray was stirred to expose ungerminated seeds to favourable conditions of emergence and re-watered to restart the next germination cycle.

FIGURE 2 Position of soil samplings (red dots) and groups of sub-replications in each micro-plot for soil seed bank study.

To normalize the number of seeds collected thanks to this method and obtain a number of seeds/m^2, we used the following formula:

$$X = \frac{N \times 1.34 \times 10000}{150.79}$$

- X is the number of $seeds.m^{-2}$.
- N is the number of counted seeds inside of the 9 cylinders around the plot.
- 1.34 is the following ratio $\frac{\pi \times R^2 \times h \times 3}{1125}$ where $R = 4\ cm$; $h = 10\ cm$ are respectively the radius and the height of the cylinders.
  3 is the number of cylinders (corresponding to one side of the plot) out of which 1125 cm^3 of sediments have been used for germination. The entire quantity (1507.9 cm^3) has not been taken because of the sorting with a 5mm sieve, eliminating rocks. Then, the volume has been capped at 1125 cm^3 in order to have the same amount of sediment for each micro-plot.

This ratio is used as a factor to have a quantity of seeds equivalent to the one we would have had in 1507.9 cm^3 of sediments.

- $\frac{10000}{150.79}$ is the ratio used to obtain $seeds.m^{-2}$ and to convert cm^3 to m^3.

2.4 Natural rainfall and runoff seed experiment

For the natural rainfalls, we continued the monitoring of the twelve 1 m² plots during two rainy seasons (2018 and 2019). Runoff water and sediments were collected from the bucket connected with a micro-plot, as previously described, after each rainfall event of at least 25 mm/hr between June and November 2018 and between May and October 2019 (cf. FIGURE 3). Runoff water and sediments were filtered through a cotton fabric of 0.15 mm mesh size, which was smaller than the diameter of the smallest seeds in the study area. The sediments were air-dried and transported to laboratory for germination study. Then, sediments were washed and passed through 3 different sieve sizes 0.71, 0.30, and 0.15 mm to sort seeds by size and remove litter. Sediments from each sieve size were used for germination study by being spread on top of germination paper in a petri dish and being watered as needed. Petri dishes with sediments were kept at 25 °C and 12 hr photoperiod. When seedlings emerged, they were counted, identified and removed weekly until no seedling emergence. Each month, the sediments were dried at 35°c for 24 hr, remixed and watered to start the next germination cycle.

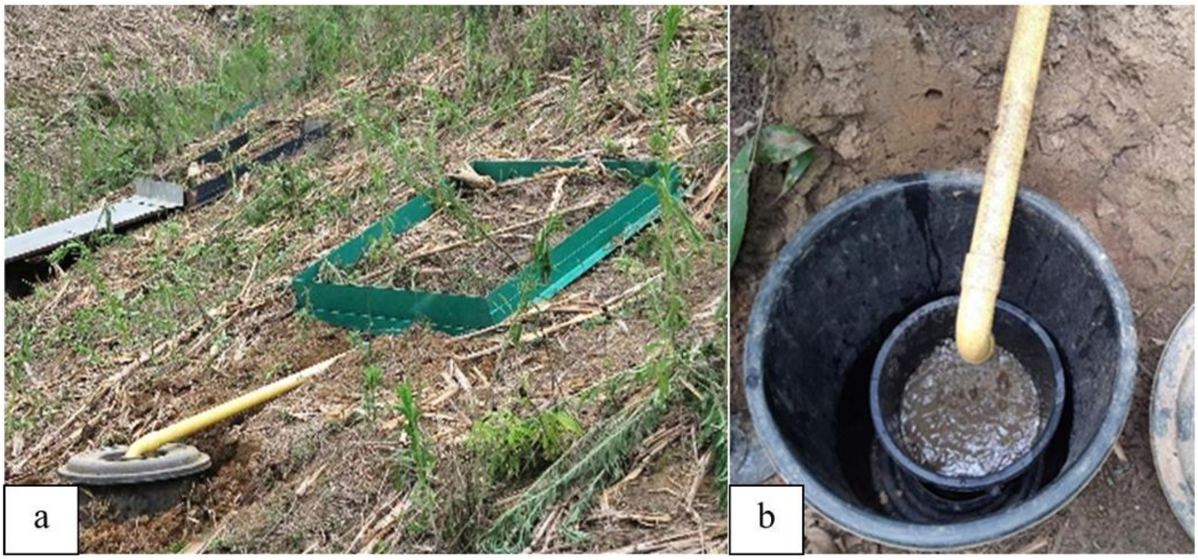


FIGURE 3 Micro-plot structure. A bucket and tubes are linked with each micro-plot to store runoff water and sediments. Side view (a) and Top view (b).

2.5 Seed rain experiment

Seed rain was collected using seed rain trap in a cone shape which has been described as the best trapping method for getting high number of seeds in Kollmann and Goetze (1998) and H. Zhang and Chu (2015). A seed rain trap consisted of a 20 cm diameter of plastic funnel with a 0.5 mm mesh at the end to protect the bag from predators. Fabric of a 0.15 mesh was attached to the funnel. The funnel was put on a metal frame 1 to 2 cm above soil surface to avoid seed decomposition by runoff and removal by ground animals. Four traps were installed on top of the micro-plot (cf. FIGURE 4). The trap was about 25 cm above ground. Weed seeds passing through the funnel and falling into the bags were collected monthly from December 2018 to May 2019. Seeds were identified in the laboratory using a dissecting microscope (Jakobsson, Eriksson, & Bruun, 2006).

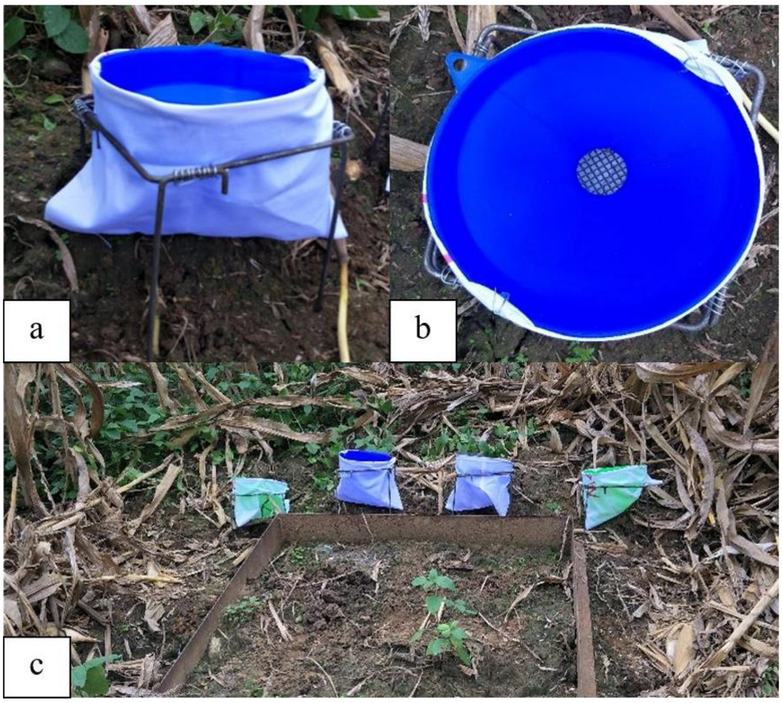


FIGURE 4 Seed rain trap structure. Side view (a); top view (b) and seed rain traps on top of a micro-plot (c).

2.6 Statistical analysis

Statistical analyses were conducted using R software version 4.4.1. Multivariate analyses, in particular principal component analysis (PCA), were used to explore the structure of the dataset. For each natural rainfall event, the 12 plots were evaluated based on 14 numerical variables. Non-numerical variables like *Date*, *Position in the catena* or numerical but irrelevant, like *Event,* have been removed to conduct the PCA. Interdependent variables have been eliminated to avoid counting a phenomenon twice or more times. *Clay* is described in *Sand* and *Silt* and information on *Infiltration* is contained in *Runoff*; the *Clay* and *Infiltration* variable have therefore been removed.

Lines containing the value of plot U5 for event 1 and M4 for event 3 have been removed from the dataset for analysis because they contained *NA* value for *Total sediment* and *Runoff* and for *Total sediment* respectively.

Soil characteristics variables (a) were *Soil moisture*, *Sand*, *Silt, BD, Sorptivity* and *Ks*. As a lot of *NA* values were present for the *N, P* and *K* variables, we kept them out of the PCA to have enough observations remaining.

Soil cover variables (b) were *Total sediment export, Seed loss, Vegetation cover, Crust* and *Free elements*.

Precipitation variables (c) were the average intensity of precipitation (named *Rainfall*) and the maximum intensity of precipitation (*Imax*) as well as *Runoff*.

The ANOVA and Kruskal-Wallis tests were used to determine whether position in the catena had an influence on the quantity of seeds and sediments exported.

The NMDS test have been conducted to determine whether the position in the catena had an influence on the quantity of seeds by species. Even though these results have not been analysed in this report, they are presented in annex 1 and 2.

3. RESULTS

3.1 The ground and the sky (rainfall) rule the process

The PCA analysis gave a good overview of the relationship between the different variables. The 3 first dimensions explained up to 58,4% of the variance of the dataset and the 2 first, 44,2%. The first principal component (Dim1) seemed to be clearly driven by the soil characteristics and especially by the **nature of the soil**, *Sand* or *Silt*, which opposed one another. Dim2 was led by the **rainfall characteristics** *Rainfall* (average intensity), *Imax* (maximal intensity) and *Runoff*. The last dimension, Dim3, was driven by the **nature of the soil surface**, *Vegetal cover* and *Crust* (cf. FIGURE 5).

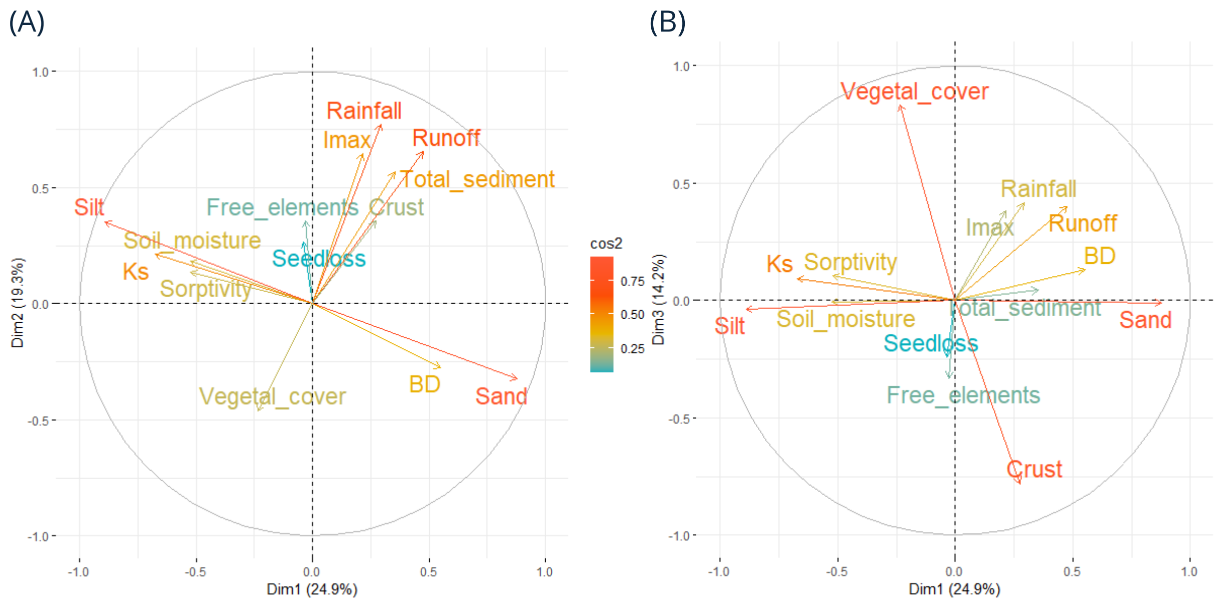


FIGURE 5 Principal component analysis (PCA) of the explanatory and response variables. Variables are represented with a cos2 colour scale indicating their weight on each axe of the PCA. Dimensions 1 and 2 explain 24.9 and 19.3% of the variance, respectively (A). Dimension 3 represents 14.2 % of the variance (B).

The distribution of the evaluated plots during the fourteen rain events over the Dim1 - Dim2 space showed that there was a clear difference in the soil properties between the 4 positions on the catena (cf. FIGURE 6 (A)). While TOP and UP positions were made of "mixed" soil texture (sand and silt), we can observe a strict distinction between the MID and DOWN positions, mostly composed of silt and sand respectively (cf. FIGURE 6 (A)). On the other hand, (B) shows that there was no more evident difference between the catena positions when it comes to rainfall characteristics or soil surface nature.

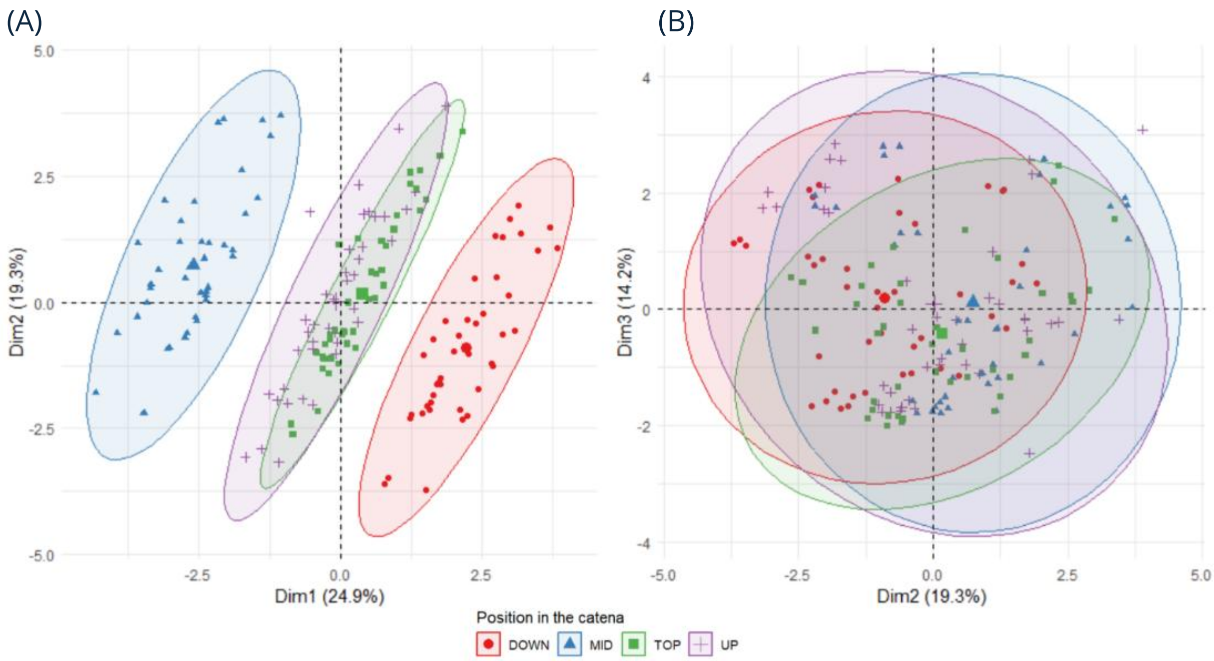


FIGURE 6 Individual maps coloured by the catena positions on the 2-dimensional space made of Dim1 - Dim2 (A) and Dim2 - Dim3 (B).

Although we could not show an effect of the position in the catena on the **vegetal cover**, it was the variable with the highest Spearman correlation to seed loss (**r = - 0.56** with a p-value of 10^{-15}) (cf. FIGURE 7).

The seed loss variable presented Spearman coefficient values of **r = 0.23** with rainfall intensity and **r = 0.05** with runoff (cf. FIGURE 7).
It is important to notice that the soil loss variable named *Total_sediment* represents the quantity of sediments contained in the runoff water collected in the bucket of each plot, calculated from a sample of 1L of this water. Thus, the sediments weighted are mostly fine sediments, which can be in suspension in water while rocks and other heavy sediments remained on the bottom of the bucket. The Spearman coefficients presented in the matrix (cf. FIGURE 7), related to this variable, shall not been considered. Indeed, another sediment variable and its correlation coefficients will be presented later.

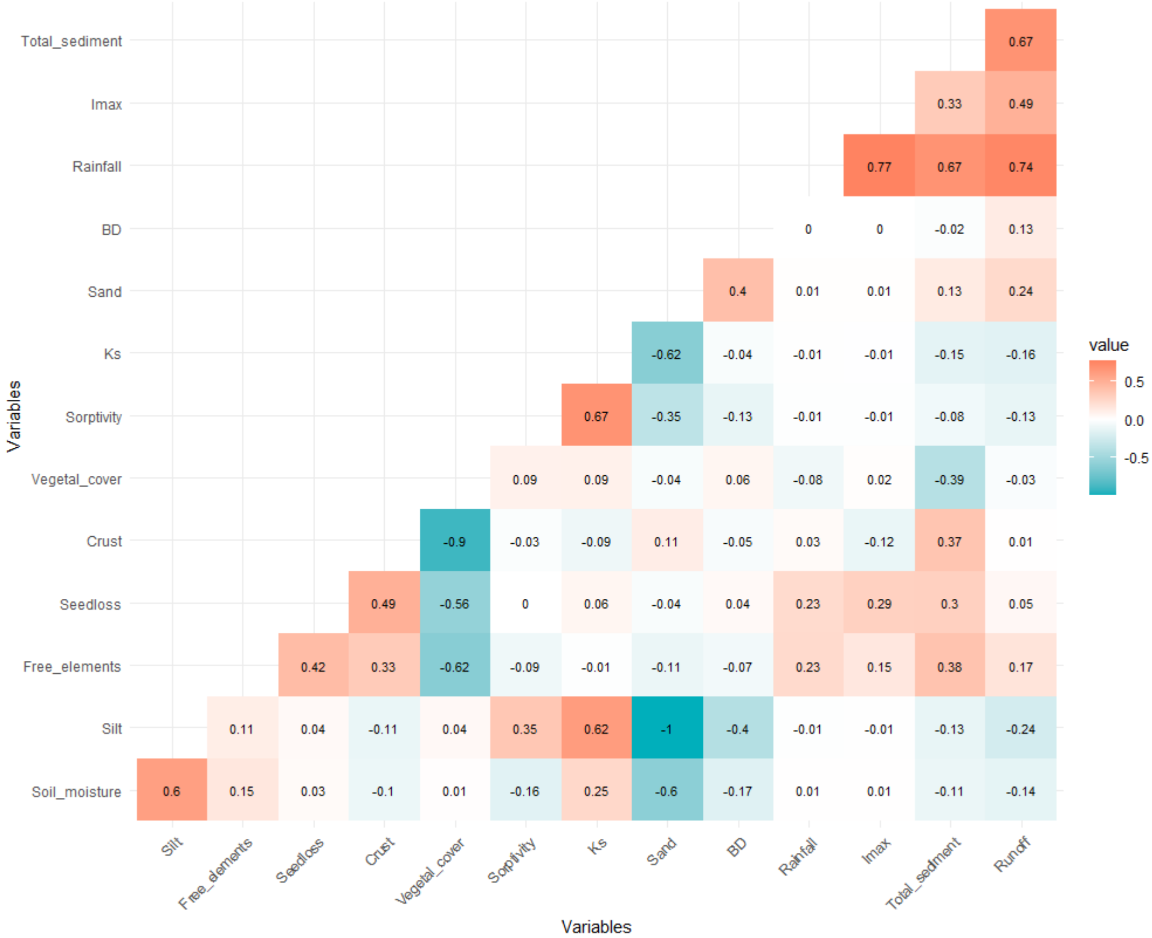


FIGURE 7 Correlation matrix displaying the Spearman coefficient for each pair of variables. A value close to 1 indicates a strong positive correlation and a near -1 value indicates a strong negative correlation.

If the weak dependence of the seeds' exportation on the rainfall intensity exists, then what does hydrochory depends on, apart from vegetal cover?

3.2 The extent of seed loss is a matter of time

If we could not show any clear correlation between seed loss and soil loss with the previous data, the analysis showed that the number of seeds exported by water was highly dependent on **the occurrence of rainfall events.**

We showed that more than **75% of the seeds exported throughout the entire 2019 rainy season, were exported during the very first rainy episodes of this season and almost 98% during the 4 first episodes** (cf. FIGURE 8).

Thus, the **chronology of the rainfall events** represents a crucial parameter of the quantity of seeds lost.
Furthermore, we can observe FIGURE 8 (B) that the correlation between seed loss and soil loss is **r = 0.66** with a p-value = 0.010.
Here, the variable considered for sediment transport was measured thanks to the entire quantity of sediments present in the bucket, after getting rid of the water. These sediments are partly made of fine sediments but are also made of small rocks, biochar and maize. However, the 1L aliquot of water-sediment sampled to calculate the previous sediment variable, has not been added up to count the total sediment quantity of this current variable.

(A)

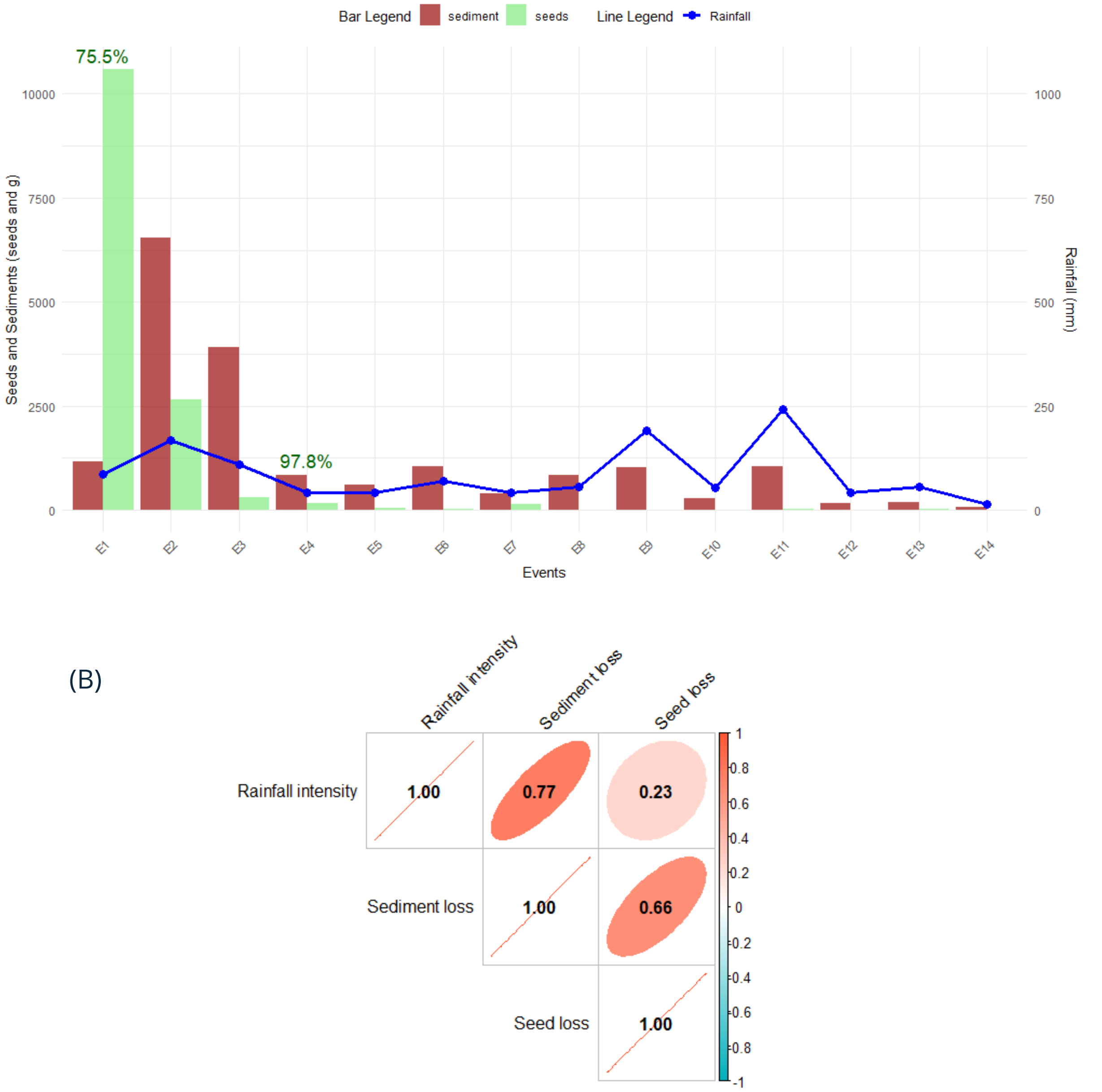


FIGURE 8 Evolution of rainfall intensity, seed loss and sediment loss across the 14 rainfall events of 2019 (A). Correlation matrix of Spearman between rainfall intensity, sediment export et seed loss (B).

On another note, we noticed that the moment of the season also impacts the amount of vegetal cover on the catena (cf. FIGURE 9). During the 7 first events of the season, the vegetal cover is almost always under 10% regardless of the position on the catena. We observe an increase on the cover since E8 until the end of the rainy season.

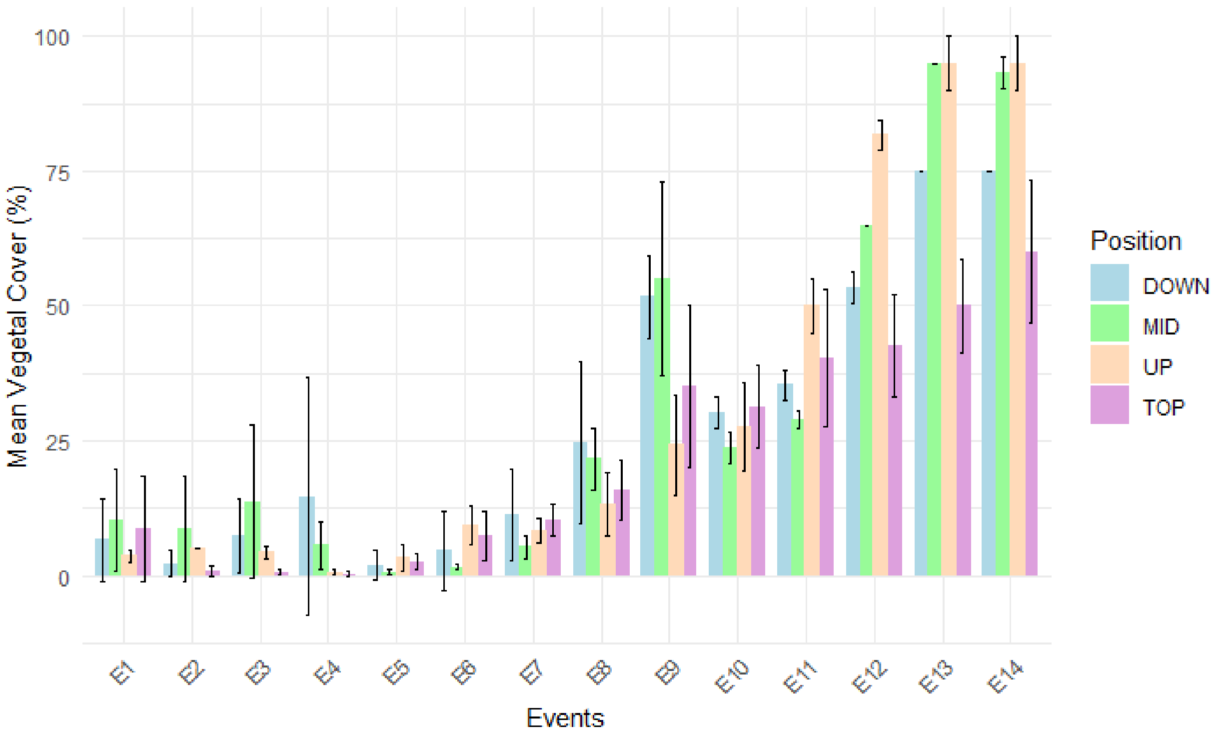


FIGURE 9 Mean percentage of vegetal cover for each position in the catena over the 2019 rainy season.

<u>Effect of the position in the catena on seed losses</u>

As it can be seen on FIGURE 10, which shows the evolution of seed losses during the 2019 season for each position of the catena, the number of seeds exported appears to differ according to position, particularly during E1 and E2.

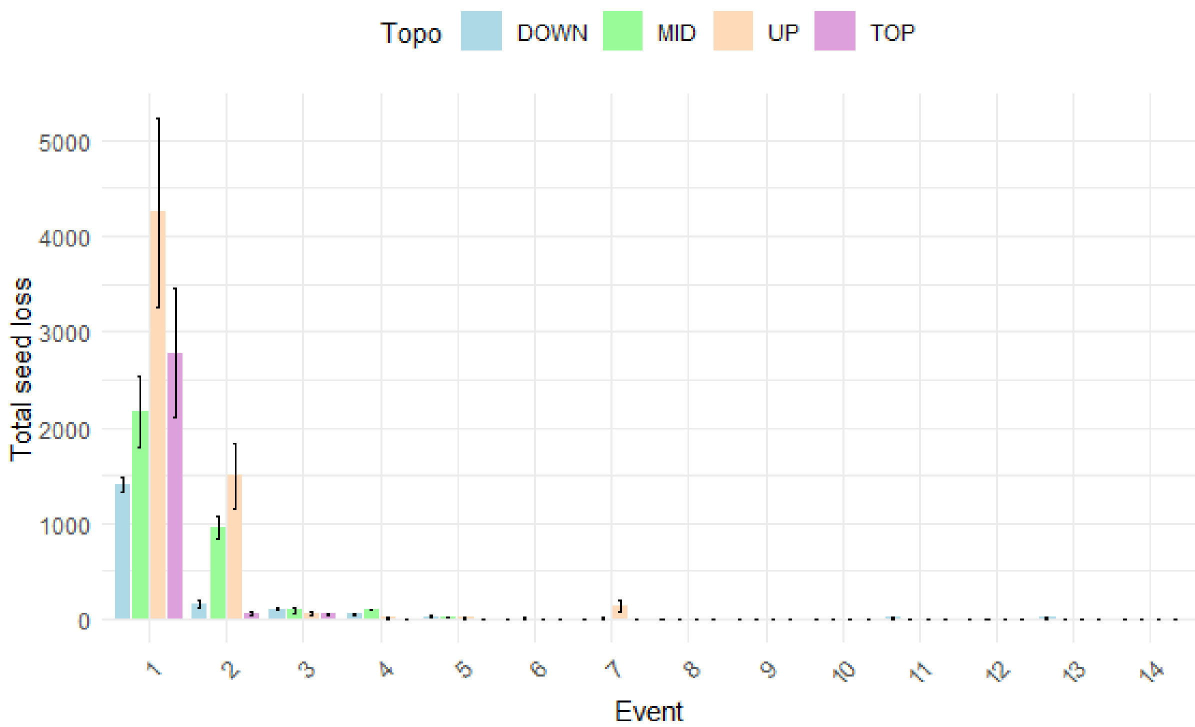


FIGURE 10 Number of exported seeds for each catena position and for each rain events ordered chronologically (E1 to E14)

Some ANOVA and Kruskal-Wallis tests have been conducted on the data using the following hypothesis:

H0 : The position in the catena has no influence on the amount of seed loss
H1 : The position in the catena does have an influence on the amount of seed loss

- E1, E2, E3 dataset

The condition of normality checked with a Shapiro-Wilk test was not verified. The Kruskal-Wallis test gave a *p-value = 0.549* > 0.05. H0 cannot be rejected.

- E2, E3, E4 dataset

Here again the normality condition was not verified and Kruskal's ***p-value = 0.0347 < 0.05.*** H0 can be rejected.
The post-hoc Dunn test, presented on FIGURE 11, showed there was a significant difference between MID and TOP.

```
Kruskal-Wallis chi-squared = 8.627, df = 3, p-value = 0.03


                           Comparison of x by group
                                (No adjustment)
Col Mean-|
Row Mean |       DOWN        MID        TOP
---------+---------------------------------
     MID |  -1.223310
         |     0.1106
         |
     TOP |   1.738858   2.910251
         |     0.0410    0.0018*
         |
      UP |   0.322437   1.536121  -1.416420
         |     0.3736     0.0623     0.0783

alpha = 0.05
Reject Ho if p <= alpha/2
```

FIGURE 11 Results of the Dunn-test presenting the significant seed loss differences between the positions in the catena for E2, E3 and E4.

- E2 dataset

Although the condition of homogeneity of the variances was not met to proceed the ANOVA, the Kruskal test gave a ***p-value = 0.0329 < 0.05***. H0 can be rejected.

The post-hoc Dunn test, presented on FIGURE 12, showed there was a significant difference between MID and TOP and between TOP and UP.

```
data: x and group
Kruskal-Wallis chi-squared = 8.7436, df = 3, p-value = 0.03


                           Comparison of x by group
                                (No adjustment)
Col Mean-|
Row Mean |       DOWN        MID        TOP
---------+---------------------------------
     MID |  -1.585187
         |     0.0565
         |
     TOP |   0.566138   2.151326
         |     0.2856    0.0157*
         |
      UP |  -1.924870  -0.339683  -2.491009
         |     0.0271     0.3670    0.0064*

alpha = 0.05
Reject Ho if p <= alpha/2
```

FIGURE 12 Results of the Dunn-test presenting the significant seed loss differences between the positions in the catena for E2.

This result can make us think that a link of influence exists between the position over the catena and the amount of seed displaced by water. It still must be confirmed though.

Indeed, rainfall events E1 and E2 indicated that the quantity of seeds transported increased from DOWN to UP position and decreases on the TOP position (FIGURE 10). However, this is only a tendency, as most of the statistical tests were not significant or solid enough (Anova or Kruskal-Wallis).

3.3 The catena position has not said its last word

Our results under natural rainfall showed a **similar tendency for rainfall events 1 and 3** which had a rainfall intensity of 86.8 $mm.h^{-1}$ and 110.6 $mm.h^{-1}$ respectively. The only difference was that the DOWN position presented a higher amount of soil losses compared to all other catena positions (cf. FIGURE 13).
Event 2, more intense (167 $mm.h^{-1}$) than the two others, presented a very different breakdown.

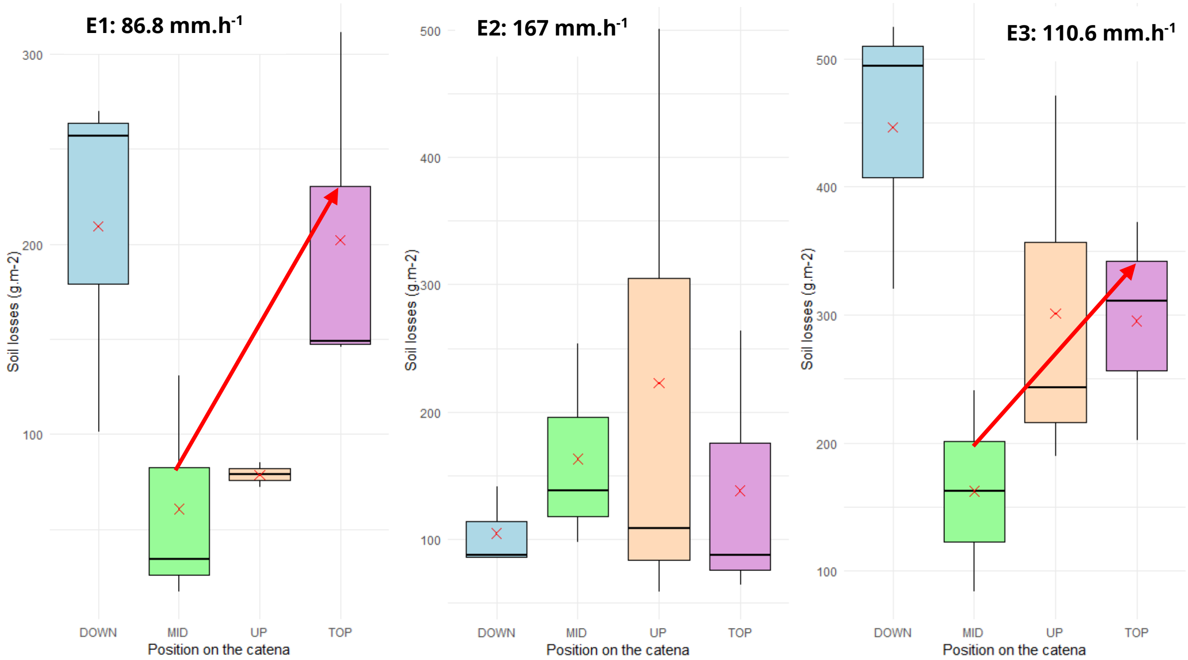


FIGURE 13 Boxplots of the amount of soil losses (g.m^{-2}) depending on the 4 positions in the catena (DOWN, MID, UP, TOP) for the 3 first rain events : E1 : 86.8 mm.h^{-1} ; E2 : 167 mm.h^{-1} ; E3 : 110.6 mm.h^{-1}.

To try confirming this influence of the position in the catena on the soil loss, an ANOVA test has been realized on the E1 and E3 data.

- Conditions checking for ANOVA :
  - *Normality of the residuals*

The condition of normality of the residuals has been verified using a Shapiro-Wilk test for which the following hypothesis have been formulated :

H0 : The distribution of the residuals is normal

H1 : The distribution of the residuals is not normal

If the *p-value* of this test is superior to 0.05 we can affirm with a 95% confidence interval that the distribution of the residuals is normal.
The results of this test are displayed in FIGURE 14, with a p-value of 0.758 > 0.05. H0 cannot be rejected so the distribution can be considered to be normal.

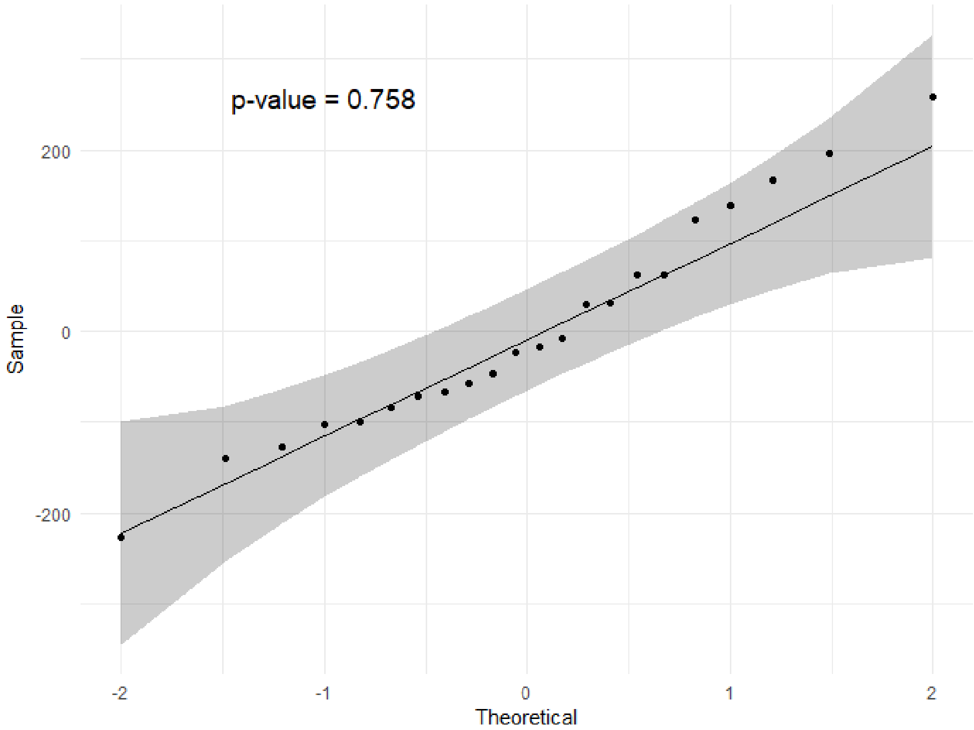


FIGURE 14 QQ-plot of the Shapiro-Wilk test checking on the normality of the residuals for E1 and E3 *Total_sediment* variable.

- *Homogeneity of variances*

The condition of homogenity of the variances has been checked with a Bartlett test using the following hypothesis :

H0 : The variances are homogeneous

H1 : The variances are non-homogeneous

Here again, *p-value* > 0.05 would lead to affirm with a 95% confidence interval that the variances are homogeneous.
We obtain p-value = 0.5083 > 0.05. The variances can be considered homogeneous.

The conditions are met for the ANOVA test, the results of which are shown in FIGURE 15.

The hypothesis for this test are as following :

H0 : The position in the catena has no influence on the amount of soil loss

H1 : The position in the catena does have an influence on the amount of soil loss

p-value = 0.07 > 0.05. Even if it is close to the threshold, it does not authorize to reject H0 and to conclude on a significant influence of the slope position on the sediment yield.
The post-hoc Tukey test, although it cannot be fully relevant because of the ANOVA result, does signify a significant difference between the DOWN and MID positions.

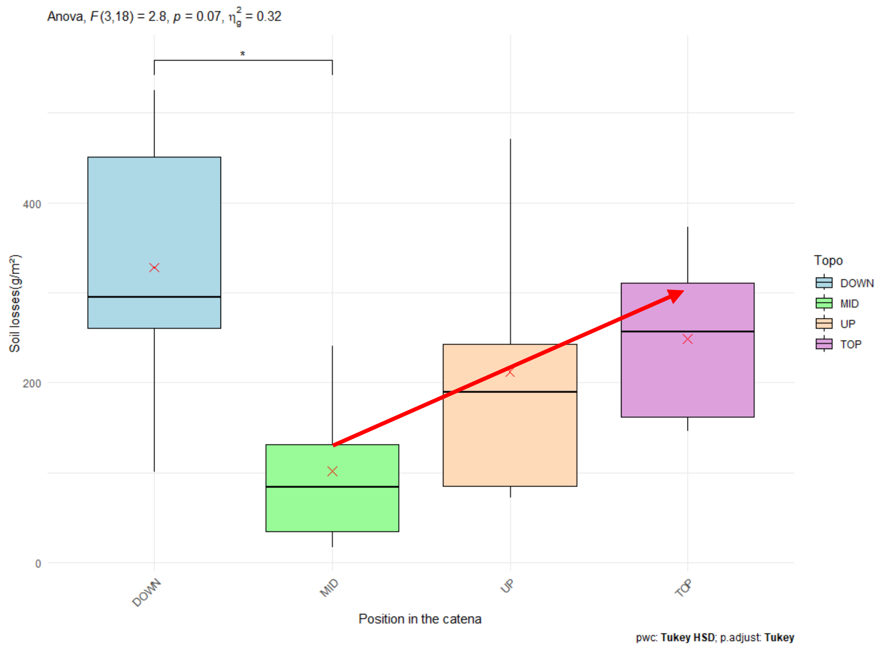


FIGURE 15 Boxplot of the soil losses according to the position in the catena (DOWN, MID, UP, TOP) for E1-E3 dataset also displaying the results of the ANOVA test and Tukey post-hoc test.

The Kruskal-Wallis test gave conducted on E1 and E3 gave the following results (cf. FIGURE 16), ***p-value = 0.0408 < 0.05,*** showing a significant difference between MID and TOP position again.

```
Kruskal-Wallis chi-squared = 8.2664, df = 3, p-value = 0.04


                           Comparison of x by group
                                (No adjustment)
Col Mean-|
Row Mean |       DOWN        MID        TOP
---------+--------------------------------
     MID |   2.746650
         |    0.0030*
         |
     TOP |   0.711286  -2.068465
         |     0.2385    0.0193*
         |
      UP |   1.475053  -1.217461   0.796867
         |     0.0701     0.1117     0.2128

alpha = 0.05
Reject Ho if p <= alpha/2
```

FIGURE 16 Results of the Dunn-test presenting the significant soil loss differences between the positions in the catena for E1 and E3.

3.4 Stages of a seed and intercompartment flows

As seeds can be dispersed and eventually stored in the soil, we have investigated their presence in different compartments. Indeed, a seed found somewhere in the catena on the soil surface, can be there because of multiple factors. It could have been transported by anemochory, barochory (seed rain) or hydrochory on the soil surface. Alternatively, the seed could also be transported by zoochory, but this variable has not been measured.
Once it has found its place on the plot, the seed can be transported again by the same phenomena or slowly integrate the soil seed bank (cf. FIGURE 17). In our case the metal

frame around the micro-plot prevents seed arrival by runoff and diminishes the risk of seed loss by zoochory.

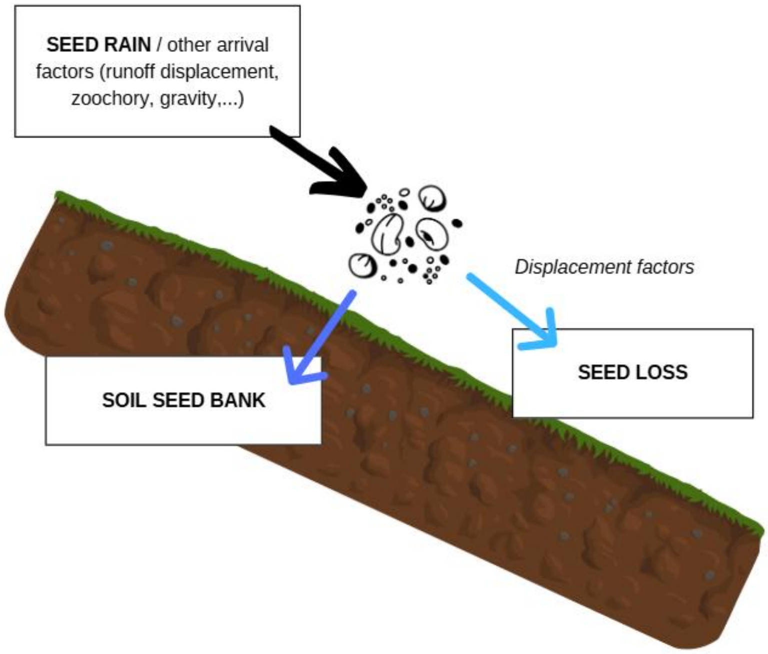


FIGURE 17 Relationship between the different compartments of a seed's life cycle.

FIGURE 18 shows that the quantity of seed rain on the upper position seems to be relatively high (A), as well as the exported quantity (C), while the upper position for the soil seed bank is significantly lower than the DOWN et MID positions (B). Nevertheless, the results described for A and C are non-significant.

The soil seed bank shows significant differences between positions in the catena and two pairs of positions that show no difference with each other: DOWN/MID and UP/TOP.

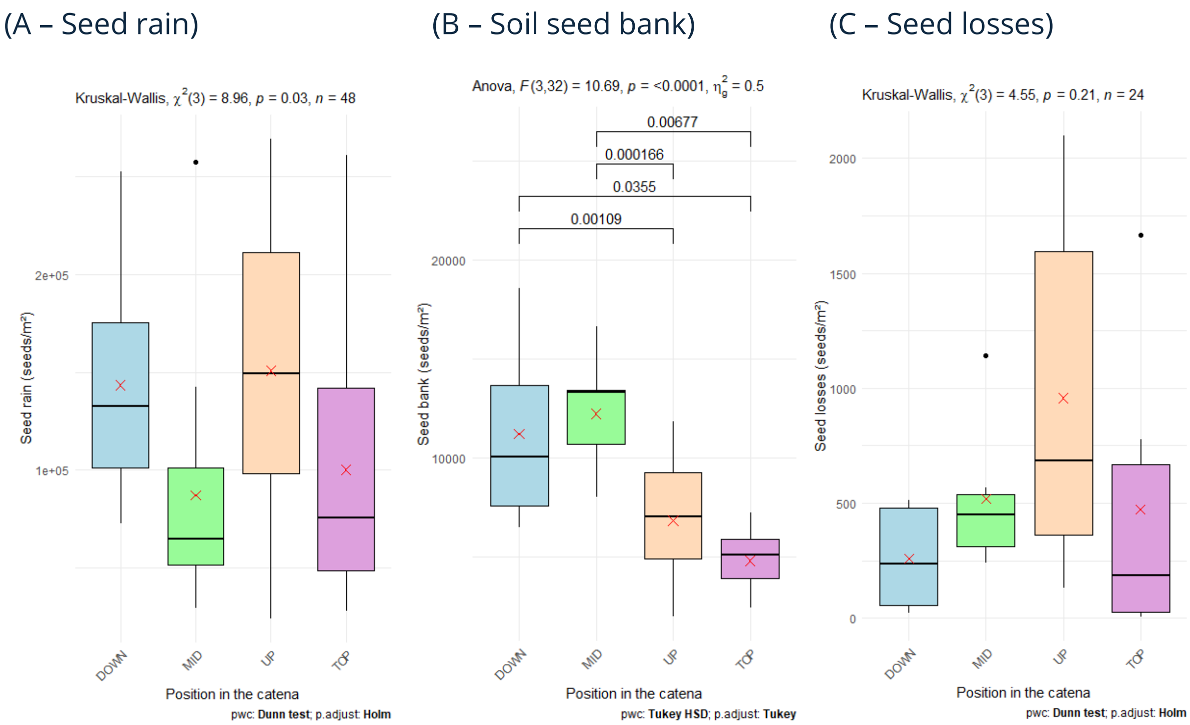


FIGURE 18 Total seed rain of the 2019 season (A), Seed bank (B) and Seed losses of E1 and E2 (C) according to the position in the catena.

4. DISCUSSION

4.1 Concerning the seed losses, it is all about "WHEN?"

We have shown that the **crucial period for seed loss is the very beginning of the rainy season**, especially the first to the four first rain events.
As the infiltration capacity of the soil differs across the year (Cerdà, 1997), the dry soils at the end of the dry season encourage runoff during the first rainy events (Bissonnais & Singer, 1992) and eventually hydrochory. Moreover, early in the monsoon, the vegetal cover is still extremely poor (cf. FIGURE 9), less than 10%, compared to what it is later in the season. Being the variable with the highest Spearman coefficient with seed loss (r= -0.56), it could be part of the explanation for the important loss of seeds at the start of the season.

The strong correlation coefficient between vegetal cover and seed loss is quite confirming the results of Huang *et al.* (2012); Kato *et al*., 2009 and Molina *et al*., 2007. Under simulated rainfall experiments, Huang *et al.* (2012) evaluated the recharge coefficient, defined as "the percentage of the total rainfall that ends up as infiltration water." (Huang *et al.,* 2012). They showed that this coefficient was mostly determined by vegetation cover and rainfall intensity. This recharge coefficient could also be defined as the ratio of $1 - \text{runoff}$ over the rainfall amount, which reveals the runoff factor, one of the 2 most influential factors of seed loss (Han *et al*., 2010).
Even though runoff and seed loss share this common driver, our study did not manage to show a significant correlation between them: r = 0.05; p-value = 0.54. Indeed, after few rains, there is no more seed to export, while there is still runoff. Consequently, over the season, the correlation between these 2 variables cannot be good.

On another note, runoff and soil loss are strongly dependant of rainfall intensity (Wang *et al.*, 2014; Mohamadi *et al.*, 2015). In the study of Han *et al,* (2010) under rainfall simulation, the rate of sediment yielding was positively proportional to the intensity and to the duration of precipitation, except for the weaker intensity (50 $mm.h^{-1}$) for which it decreases with time. Moreover, their seed loss rate increased with rainfall intensity. Although it has been shown in our study that soil loss was indeed strongly correlated with rainfall intensity, up to **r = 0.77** (cf. FIGURE 8) with a p-value of 0.0013, seed loss was poorly correlated with rainfall intensity **r = 0.23**, p-value = 0.0031, as well as **with soil loss rate r = 0.66**, p-value = 0.010.

Thus, the **H1** hypothesis can be considered **partially true**. Indeed, even though soil loss and seed loss share a significant positive correlation, rainfall intensity has a much more dominant effect on soil loss than on seed loss.

These results must be considered in the light of an experimental limitation to be interpreted correctly. Indeed, the metal frame around each plot prevents the flow of water, sediments and seeds from the upper slopes from reaching the plot. The capacity of these results to describe and represent real natural phenomena is therefore limited.

4.2 Slope position's effect is still to be confirmed

The Kruskal-Wallis test conducted on the E2 rainfall event confirmed the significant effect of the position in the catena on hydrochory processes.

Significant differences highlighted that TOP position showed a smaller number of seeds exported than the MID and UP positions. These differences could be explained by a difference in soil characteristics between these positions. It is important to notice that the large quantity of seeds lost at the upper position could be a measure biased by the presence of a road between the UP and TOP positions which might be responsible of pushing down some seeds. This bias is still to be confirmed though because over 1 m² surfaces it could have no effect. In addition, this significant result remains less solid than an ANOVA on several events would have been. Indeed, the ANOVA and Kruskal-Wallis tests failed to deliver convincing results when conducted on E1, E2 and E3. Indeed, our dataset presented a large standard deviation for the upper position (especially during the E1), making the results difficult to interpret.

On the other hand, the distribution of soil loss on the catena showed an increase between MID and TOP positions and a decrease between DOWN and MID positions for E1 and E3 rainfall events (p-value = 0.04 Kruskal Wallis test).
These results confirm those obtained by Janeau *et al*. (2022) under rainfall simulation of 120 mm.h^{-1} intensity, showing the exact same tendency (cf. FIGURE 19).

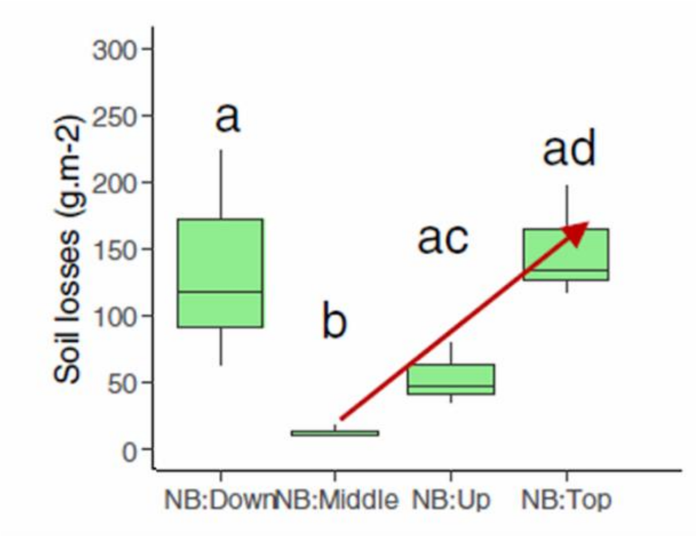


FIGURE 19 Boxplot of soil loss (g.m-2) in a slope at different positions in the catena (down, middle, up and top) under rainfall simulation of 120 mm.h^{-1} during 30 min (after a first rainfall for soil humidity homogenisation). Letters indicate significant differences at p < 0.05 level. *Figure 3 from Slope position and biochar influence soil properties and seed displacement in a tropical agroecosystem - Janeau et al., 2022.*

In this case, rainfall intensity is of great importance, as we could only show this result for rainfall of similar or smaller intensities than the rainfall simulation (E1= 86.8 mm.h^{-1}, E3= 110.6 mm.h^{-1}). E2 (167 mm.h^{-1}) presented a higher rainfall intensity. A **threshold** might exist between 110.6 mm.h^{-1} and 167 mm.h^{-1}, above which the dispersion of soil losses changes in the catena. Soil loss in DOWN position was the highest on the catena for E1 and E3, while it was the smallest for E2 with a higher rainfall intensity.

Our results on seed loss and soil loss showed differences along the catena, even if there is still no clear understanding of the processes/parameters involved. Further studies shall complete the investigation to clearly confirm **H2 hypothesis**.

4.3 Intercompartment flows

As a seed can go through various stages during its life in the catena, understanding the relationships and influences between these stages could be of great interest in improving the management of endemic species and ultimately biodiversity. FIGURE 18 (A and C) showed that the distributions of seed rain and seed loss over the 4 positions of the catena were homogeneous except for DOWN position.
On the other hand, FIGURE 18 (B) showed a decreasing seed bank pattern with increasing slope position from the MID to TOP positions.
The case of the UP position on the catena, which had the highest quantity of seeds falling on the soil surface (seed rain) and transported by water and, at the same time, the lowest quantity of seeds integrating the soil bank, leads us to formulate the following hypothesis:

Ha: The fact that more seeds were transported by water than elsewhere on the catena leaves fewer seeds to integrate the soil seed bank of the UP plot.

On the other hand, during the first events of the seasons the number of seeds over the soil surface was high due to the seed rain occurring during the previous dry season (cf. FIGURE 20).

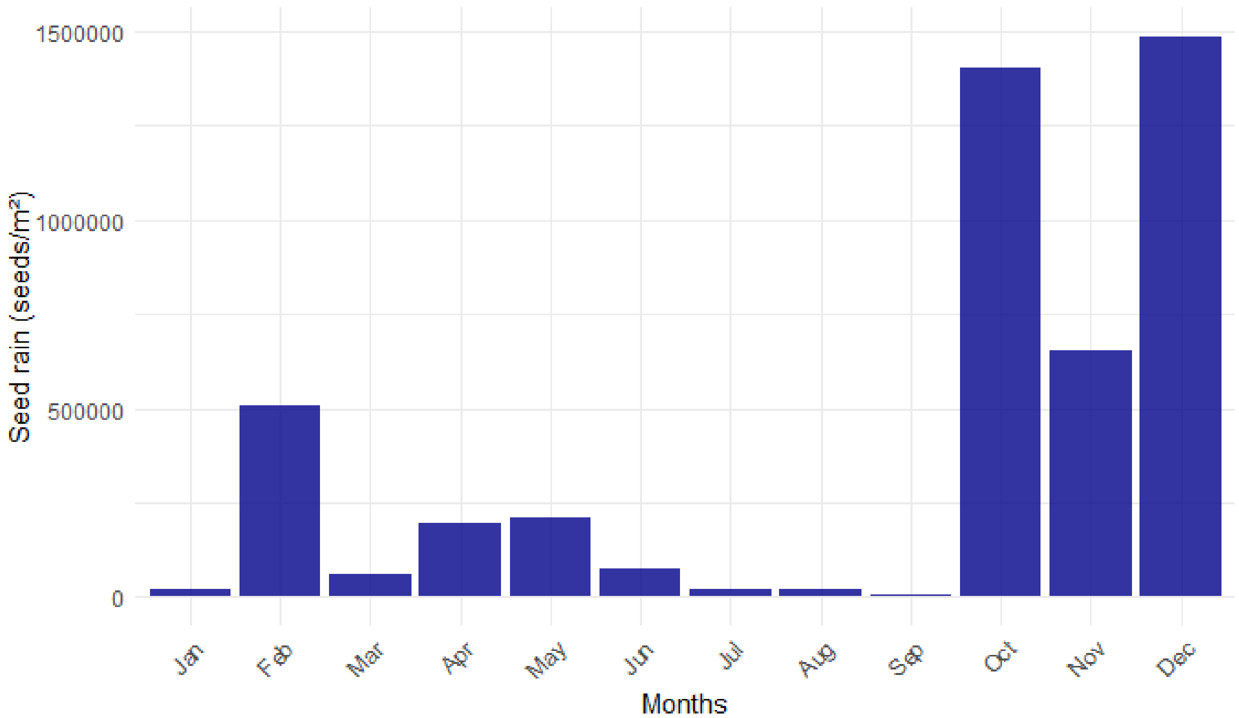


FIGURE 20 Evolution of seed rain (seeds/m²) across the year 2019.

Hb: Most of the seeds transported by the hydrochory process come from the seed rain (present on the soil surface) and fewer come from the soil seed bank. Which would explain the difference of losses between sediment losses and seed losses.

4.4 An idea to assess the influence of the morphological parameter

D. Wang *et al* (2013) have shown that there were negative correlations between seed removal indexes and seed **mass, length, width, height, surface and volume.** The most important factors that influence seed displacement by water turned out to be seed mass and size, while shape, appendages and seed's ability to segregate mucilage when wetted can sometimes play a role in their ability to be displaced.
To assess if one or several of our studied species were more likely to be exported by water than others, an idea was to calculate de percentage of seeds exported in regard of the amount of seeds available in the seedbank. This way, the dominance of quantity of *Ageratum Conyzoïdes* would have had no effect. After having calculated this percentage for each species and for each rainfall events on each of the 12 plots, the morphologies of the species with the higher percentages could be compared to try noticing some specific characteristics that would make the seeds more displaceable by water.

The soil bank samples have been collected between E3 and E4. It means that the bank data could only be compared to the E4 seed loss data. Otherwise, we need to formulate a hypothesis about the seed balance over the catena to compare the bank to E1, E2 and E3 in which a lot more seeds have been displaced. We could make the hypothesis of an equal balance between what is taken from a plot and what is brought to it by water during a rainfall event. This would mean that the soil seed bank could be considered constant across time and rain events which appears to be a very strong hypothesis, especially considering the potential existing flows mentioned in the previous paragraph (4.3.).
It could have been more relevant to evaluate the soil seed bank before the occurrence of the first rainfall event.

4.5 Graphical abstract

A summary of the different processes driving hydrochory on agricultural steep slope in Thailand is presented in FIGURE 21.

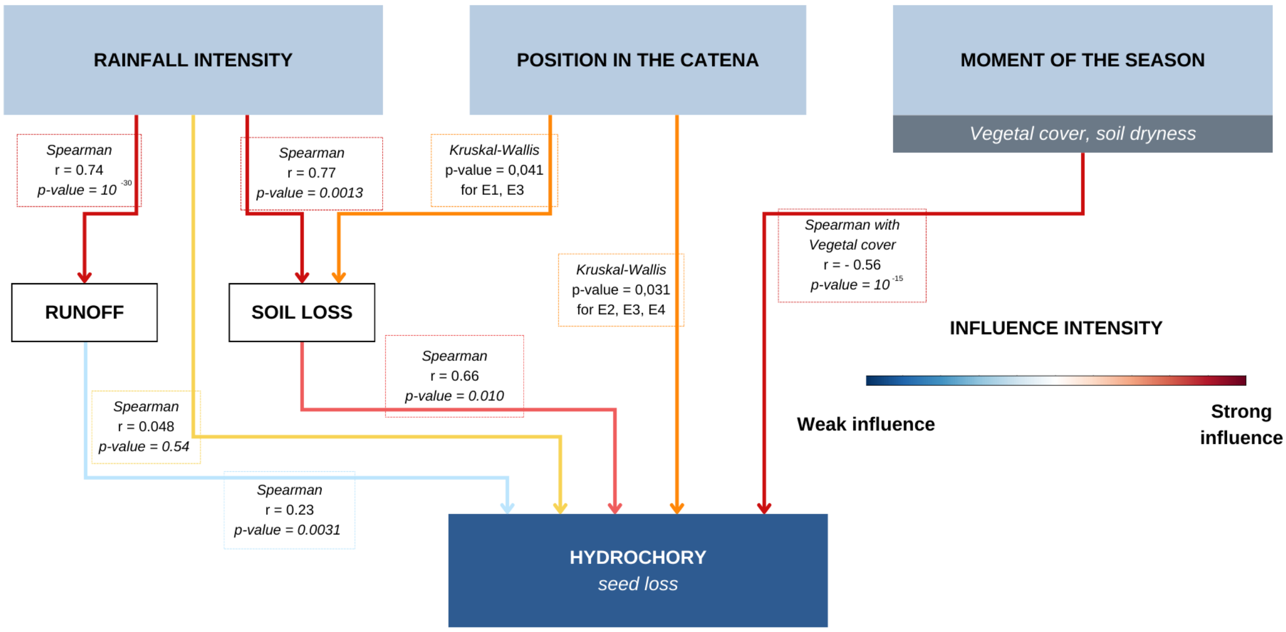


FIGURE 21 Mind map presenting the factors of influence of hydrochory and the strength of their influence (from weak to strong, blue to red respectively).

5. CONCLUSION

This study highlights the complex interplay between rainfall characteristics, slope position, and seed and sediment loss on agricultural slopes in tropical climates. Through an experiment using two years of natural rainfall on agricultural plots, focusing on hydrochory and soil dynamics, we were able to *study the effect of catena position and rainfall characteristics on seed loss and sediment transport in steep tropical agroecosystems.*

Our two main hypothesizes were partly validated. (H1) seed loss rates correlated with soil loss, and particularly gross sediments. (H2) catena position influenced sediment and seed loss, but these results were heterogeneous for the different rainfall events.

The results demonstrated that the early monsoon period was critical for seed loss due to low vegetation cover and a high number of seeds on the soil surface, confirming the importance of the timing of rainfall events for hydrochory processes. While rainfall intensity strongly influences soil erosion, its impact on seed loss was less pronounced, indicating distinct dynamics between these two processes.

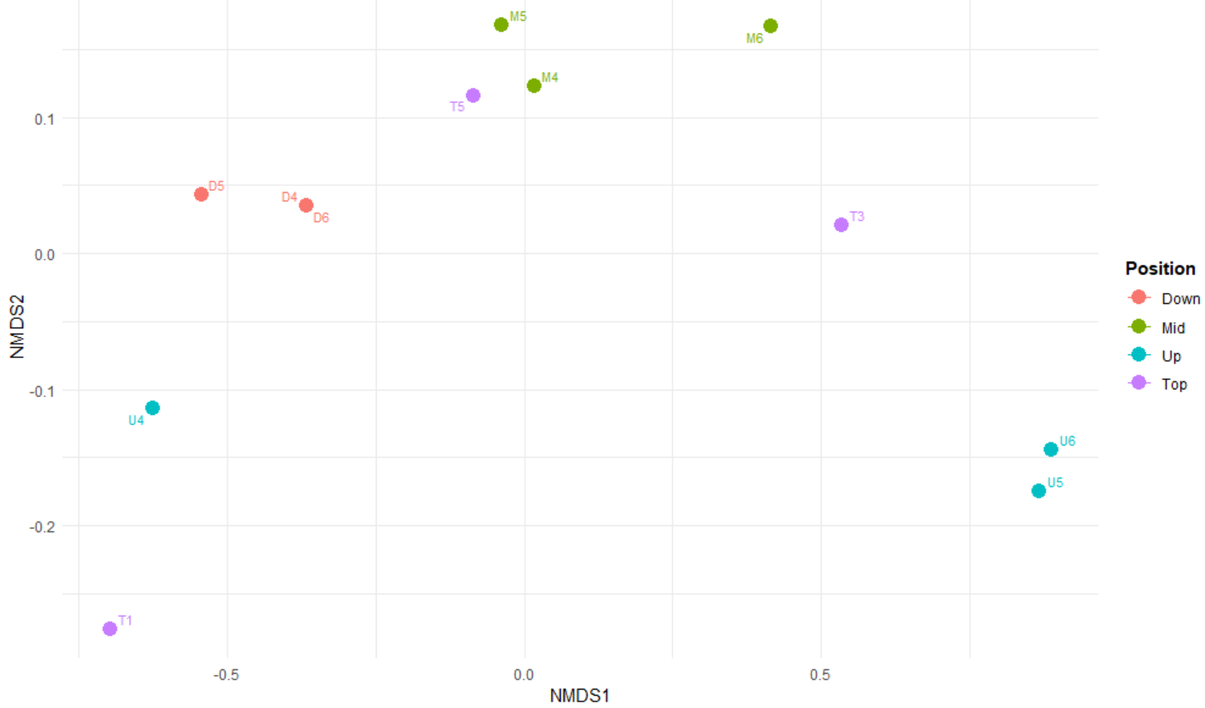
The influence of slope position remains unclear, as significant differences were inconsistent across events and positions. Moreover, the variability of sediment and seed losses with slope position and rainfall intensity suggests thresholds and interactions that warrant further explorations.

Furthermore, experimental limitations have been noticed, such as the metal plot frames isolating seed flow, the moment when the seed bank was. These limits also constrain the interpretation of the findings.

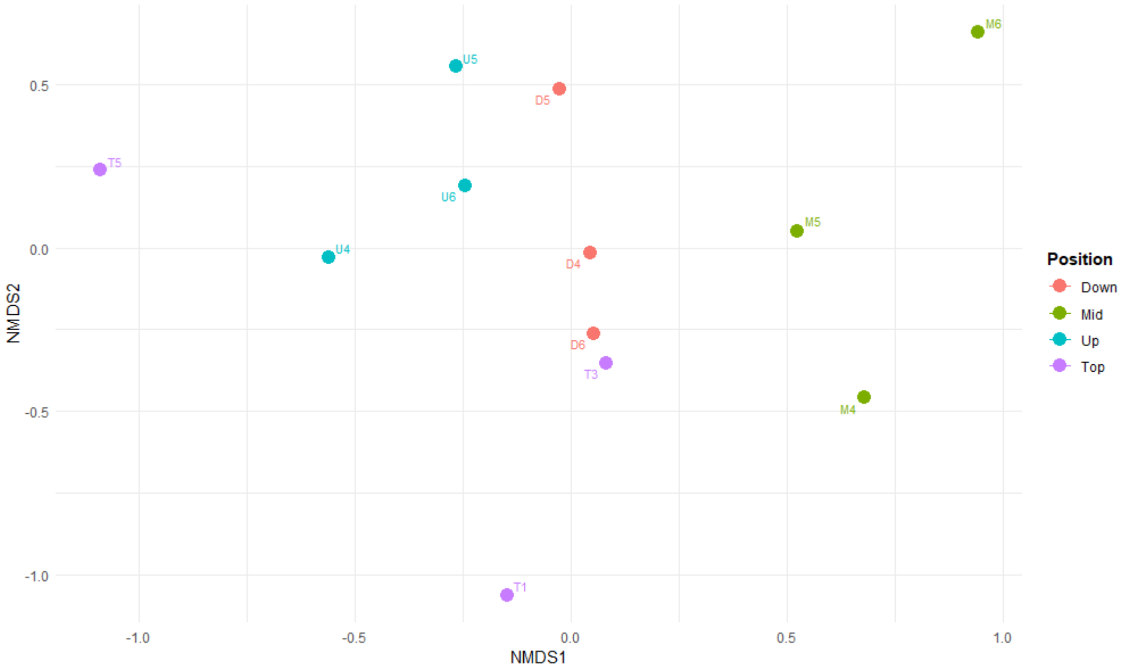
Future studies should aim to overcome these limitations by expanding datasets, exploring intercompartment flows, and incorporating seed morphological traits to better understand hydrochory dynamics. Insights from this research could guide more effective management strategies for biodiversity conservation and soil preservation in tropical agricultural systems.

ANNEXES

Annex 1: NMDS presenting the dispersion of the plots' soil seed bank by position in the catena, on a bidimensional space where axis represent seed species.



Annex 2: NMDS presenting the dispersion of the plots' soil seed bank by position in the catena, on a bidimensional space where axis represent seed species, without *Ageratum Conyzoides.*



REFERENCES

Ashworth, J., Keyes, D., Kirk, R., & Lessard, R. (2001). Standard procedure in the hydrometer method for particle size analysis. Communications in Soil Science and Plant Analysis, 32, 633–642.

Bhatt, M., & Singh, S. (2007). Soil seed bank dynamics of weed flora in upland and lowland paddy cultivation areas of far western Nepal. Scientific World, 5(5), 54 59.

Bissonnais, Y. L., & Singer, M. J. (1992). Crusting, runoff, and erosion response to soil water content and successive rainfalls. *Soil Science Society of America Journal*, *56*(6), 1898–1903.

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. Agronomy Journal, 54, 464–465.

Cerdà, A. (1997). Seasonal changes of the infiltration rates in a Mediterranean scrubland on limestone. *Journal of Hydrology*, *198*(1–4), 209–225.

Cerdà, A., & Rodrigo-Comino, J. (2019). Is the hillslope position relevant for runoff and soil loss activation under high rainfall conditions in vineyards? *Ecohydrology & Hydrobiology*, *20*(1), 59–72.

Chen, H., Zhang, X., Abla, M., Lü, D., Yan, R., Ren, Q., Ren, Z. J., Yang, Y., Zhao, W., Lin, P., Liu, B., & Yang, X. (2018). Effects of vegetation and rainfall types on surface runoff and soil erosion on steep slopes on the Loess Plateau, China. Catena, 170, 141–149.

Faucher, M., Bailly, J.-S., and Vinatier, F.: Hydrochory in agricultural landscapes, IAHS-AISH Scientific Assembly 2022, Montpellier, France, 29 May–3 Jun 2022, IAHS2022-428

Han, L., Jiao, J., Jia, Y., Wang, N., Dong, L., & LinYu, L. (2011). Seed removal on loess slopes in relation to runoff and sediment yield. Catena, 85(1), 12–21.

Huang, J., Wu, P., & Zhao, X. (2012). Effects of rainfall intensity, underlying surface and slope gradient on soil infiltration under simulated rainfall experiments. *CATENA*, *104*, 93–102.

Jakobsson, A., Eriksson, O., & Bruun, H. H. (2006). Local seed rain and seed bank in a species-rich grassland: effects of plant abundance and seed size. Botany, 84(12), 1870-1881.

Janeau, J. L., Bricquet, J. P., Planchon, O., & Valentin, C. (2003). Soil crusting and infiltration on steep slopes in northern Thailand. European Journal of Soil Science, 54, 543–553.

Janeau, J.-L., Chanisara, R., Grellier, S., Hammecker, C., Intanon, S., Khwanrawee, A., & Pansak, W. (2020). Dataset from an in-field experimental rainfall simulation—Thailand, Nan Province, 2019. DataSuds.

Janeau, J. L., Gillard, L. C., Grellier, S., Jouquet, P., Le, T. P. Q., Luu, T. N. M., Ngo, Q. A., Orange, D., Pham, D. R., Tran, D. T., Tran, S. H., Trinh, A. D., Valentin, C., & Rochelle-Newall, E. (2014). Soil erosion, dissolved organic carbon and nutrient losses under different land use systems in a small catchment in north ern Vietnam. Agricultural Water Management, 146, 314–323.

Janeau, J., Intanon, S., Pansak, W., Rodprai, C., Anusorn, K., Hammecker, C., & Grellier, S. (2022). Slope position and biochar influence soil properties and seed displacement in a tropical agroecosystem. European Journal Of Soil Science, 73(2)

Jiao, J., Zou, H., Jia, Y., & Wang, N. (2009). Research progress on the effects of soil erosion on vegetation. *Acta Ecologica Sinica*, *29*(2), 85–91.

Kato, H., Onda, Y., Tanaka, Y., Asano, M., 2009. Field measurement of infiltration rate using an oscillating nozzle rainfall simulator in the cold, semi-arid grassland of Mongolia. Catena 76, 173–181.

Kenderessy, P., & Lieskovsky, J. (2014). Impact of the soil erosion on soil properties along a slope study Horný Ohaj Vineyards, Slovakia. ResearchGate.

Kohmoto, Y., Watanabe, T., Sipaseuth, N., & Funakawa, S. (2021). Analysis of surface runoff water and sediment generations using a short-term water budget in the steeply sloping agricultural land of northern Laos. Soil Science and Plant Nutrition, 67(4), 359–370.

Kollmann, J., & Goetze, D. (1998). Notes on seed traps in terrestrial plant communities. Flora, 193(1), 31-40.

Khwanrawee, A. (2018). Effects of toposequence and soil loss on weed seed bank dynamics in upland maize production. Master Thesis, Naresuan University.

Lal, R. 2001. Soil degradation by erosion. Land Degradation & Development 12:519-539.

Ma, X., Zhao, C., & Zhu, J. (2021). Aggravated risk of soil erosion with global warming – A global meta-analysis. *CATENA*, *200*, 105129.

Mohamadi, M. A., & Kavian, A. (2015). Effects of rainfall patterns on runoff and soil erosion in field plots. *International Soil and Water Conservation Research*, *3*(4), 273–281.

Molina, A., Govers, G., Vanacker, V., Poesen, J., Zeelmaekers, E., Cisneros, F., 2007. Runoff generation in a degraded Andean ecosystem: ineration of vegetation cover and land use. Catena 71, 357–370.

Mügler, C., Ribolzi, O., Viguier, M., Janeau, J.-L., Jardé, E., Latsachack, K., Henry-Des-Tureaux, T., Thammahacksa, C., Valentin, C., Sengtaheuanghoung, O., & Rochelle-Newall, E. (2021). Experimental and modelling evidence of splash effects on manure borne Escherichia coli washoff. Environmental Sci ence and Pollution Research, 28, 33009–33020.

Omokaro, G. O. (2023). A review on the impacts of toposequence on soil properties. *American Journal of Environment and Climate*, *2*(3), 114–120.

Patin, J., Mouche, E., Ribolzi, O., Chaplot, V., Sengtahevanghoung, O., Latsachak, K. O., Soulileuth, B., & Valentin, C. (2012). Analysis of runoff production at the plot scale during a long-term survey of a small agricultural catchment in Lao PDR. Journal of Hydrology, 426–427, 79–92.

Podwojewski, P., Janeau, J. L., Grellier, S., Valentin, C., Lorentz, S., & Chaplot, V. (2011). Influence of grass soil cover on water runoff and soil detachment under rainfall simulation in a sub-humid south African degraded rangeland. Earth Sur face Processes and Landforms, 36, 911–922.

Rezaei, H., Jafarzadeh, A.A., Alijanpour, A., Shahbazi, F. and Kamran, K.V. (2015) Effect of Slope Position on Soil Properties and Types along an Elevation Gradient of Arasbaran Forest, Iran. International Journal on Advanced Science, Engineering and Information Technology, 5, 449-456.

Ribolzi, O., Patin, J., Bresson, L. M., Latsachack, K. O., Mouche, E., Sengtaheuanghoung, O., Silvera, N., Thiebaux, J. P., & Valentin, C. (2011). Impact of slope gradient on soil surface features and infiltration on steep slopes in northern Laos. Geomorphology, 127,53–63.

Sodhi, N. S., Posa, M. R. C., Lee, T. M., Bickford, D., Koh, L. P., & Brook, B. W. (2009). The state and conservation of Southeast Asian biodiversity. *Biodiversity and Conservation*, *19*(2), 317–328.

Swift, M., Izac, A., & Van Noordwijk, M. (2004). Biodiversity and ecosystem services in agricultural landscapes—are we asking the right questions? *Agriculture Ecosystems & Environment*, *104*(1), 113–134. https://doi.org/10.1016/j.agee.2004.01.013

Thothong, W., Huon, S., Janeau, J., Boonsaner, A., De Rouw, A., Planchon, O., Bardoux, G., & Parkpian, P. (2011). Impact of land use change and rainfall on sediment and carbon accumulation in a water reservoir of North Thailand. *Agriculture Ecosystems & Environment*, *140*(3–4), 521–533.

Tuo, D., Xu, M., & Gao, G. (2018). Relative contributions of wind and water erosion to total soil loss and its effect on soil properties in sloping croplands of the Chinese Loess Plateau. *The Science of the Total Environment*, *633*, 1032–1040.

Valentin, C., Agus, F., Alamban, R., Boosaner, A., Bricquet, J. P., Chaplot, V., de Guzman, T., de Rouw, A., Janeau, J. L., Orange, D., Phachomphonh, K., Phai, D. D., Podwojewski, P., Ribolzi, O., Silvera, N., Subagyono, K., Thiebaux, J. P., Toan, T. D., & Vadari, T. (2008). Runoff and sediment losses from 27 upland catchments in Southeast Asia: Impact of rapid land use changes and conservation practices

Wang, D., Jiao, J., Dong, L., Wang, N., Du, H., & Jia, Y. (2013). Effects of seed morphology on seed removal and plant distribution in the Chinese hill-gully Loess Plateau region. Catena, 104, 144–152.

Wilcove, D. S., Giam, X., Edwards, D. P., Fisher, B., & Koh, L. P. (2013). Navjot's nightmare revisited: logging, agriculture, and biodiversity in Southeast Asia. *Trends in Ecology & Evolution*, *28*(9), 531–540.

Wischmeier, W. H., Smith, D.D., 1978. Predicting rainfall erosion losses. A guide to conservation planning. USDA, Washington D.C 20402.

Zhang, H., & Chu, L. (2015). Seed rain and seedling survival are major factors limiting vegetation regeneration on rehabilitated quarries. Landscape and ecological engineering, 11(1), 29-38.

Cités, Territoires,
Environnement et Sociétés

citeres
UMR 7324

POLYTECH
TOURS
Département
Aménagement et Environnement

Research Director:
Séraphine GRELLIER

Student:
Nathan GRAND
PRI – DAE5
ADAGE
2024 - 2025

Title: Influence of slope position, soil properties and rainfall characteristics on hydrochory processes in a steep tropical agroecosystem

ABSTRACT

Seed and sediment displacement on tropical agricultural slopes are key processes shaped by rainfall characteristics, vegetation cover, and slope position, yet their interactions remain poorly understood. This study aimed to explore the effects of catena position and rainfall dynamics on seed loss and sediment transport in steep tropical agroecosystems. Specifically, we addressed the question: *What is the effect of slope position and rainfall characteristics on seed displacement and sediment transport in tropical agricultural fields?*

We hypothesized that (H1) seed loss rates would correlate with soil loss, primarily driven by rainfall intensity, and that (H2) slope position would influence sediment and seed loss due to variations in soil properties along the catena.

Using 12* 1 m² plots distributed across four slope positions (DOWN, MID, UP, TOP), seed and sediment loss were monitored during the 2019 rainy season under natural rainfall conditions. Results revealed that seed loss peaked during the early rainy season, likely driven by sparse vegetation cover, dry soils, and a high density of surface seeds before the monsoon. Soil loss strongly correlated with rainfall intensity ($r = 0.77$), while seed loss showed a weaker correlation ($r = 0.23$). Despite seasonal variability, seed and sediment loss were strongly linked ($r = 0.66$). However, the influence of catena position on seed and sediment dynamics remained inconclusive, suggesting a complex interplay of local soil properties.

These findings underscore the complexity of hydrochory processes and highlight the importance of further research to optimize biodiversity conservation in tropical agroecosystems.

KEYWORDS

hydrochory, soil loss, seed loss, runoff, rainfall, catena, soil characteristics