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Sedimentation dynamics of soil particles in sylvopastoral half-moons on restored plateaus in the Ouallam department (Niger)

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***Abstract*— *The present study was conducted on the Tondibiya and Satara plateaus, in the Ouallam department (western Niger). The objective is to study the sedimentation dynamics of soil particles deposited in sylvopastoral half-moons of different years (2014, 2016 and 2018). The assessment of sedimentation was done in selected half-moons following a survey on transects. It involved the determination of the thickness of the sedimented horizon, the measurement of the permeability by the single ring infiltrometer and the granulometric analysis in the laboratory. The results obtained showed that the thickness of the sedimented horizon varies according to age and is 14.15, 17.33 and 19.37 cm in the 3, 5 and 7 year old half-moons respectively. Water infiltration was optimised by sedimentation. It was recorded 70 minutes to be constant in the 7-year half-moon and 40 minutes in the 3-year half-moon. The granulometric analysis of the sedimented particles shows their dominance by sands (77.73%). These different results show that the sylvopastoral half-moon is effective in improving the physical parameters of the soil on degraded ferruginous plateaus.*

***Keywords*— Restoration, Soil, Sedimentation, Ouallam, West Niger.**

I. INTRODUCTION

In Niger in general, and in its western part in particular, natural resources are undergoing degradation due to the combined actions of climate and man (Boni *et al*., 2016; Abdou *et al*., 2016). This situation has been accentuated since the droughts of the 1970s and 1980s (Larwanou, 2005). Each year, more than 250,000 ha of arable land are washed away by degradation (GEF-IFAD, 2002). The dynamics of degradation are mainly reflected in the significant retreat of natural vegetation formations (tiger bushes and steppes) in favor of developed landscapes and denuded soils (Issoufou *et al*., 2018). The consequences include a continued decline in agricultural and pastoral production at a time when basic needs are increasing. Increasingly, ecosystem services are being disrupted, significantly impacting the socio-economic conditions of local populations, especially during periods of climate shocks (Douma, 2016).

In view of the increasing degradation of natural resources, the consequences of which contribute to the development of the phenomenon of desertification (Larwanou, 2005), a dynamic of restoration of degraded lands is developing nowadays. Indeed, to restore degraded lands, techniques of Water and Soil Conservation / Soil Defence and Restoration (CES/DRS) have been commonly carried out in Niger. Based on the typology of the landscape unit to be managed, these different techniques have been designed according to the desired goal. Among these CES/DRS techniques, dug structures, including the half-moon for silvopastoral purposes, are the most widely used (Douma *et al*., 2011; Amani *et al*., 2021). However, apart from the respect of design and management standards, the results of the developed areas depend on the age of the construction, but also vary according to the sites (Vlaar, 1992; Laminou *et al*., 2020). It therefore appeared necessary to study the impact of the sylvopastoral half-moon on the physical conditions of the soil. Thus, the objective of this work is to evaluate the physical parameters of sediments deposited in the half-moon on pastoral sites developed in different years.

II. MATERIALS AND METHODS

2.1. Study sites

The department of Ouallam in western Niger was the study area (Fig. 1). The developed plateaus of Tondibiya and Satara, in the rural communes of Tondikiwindi and Simiri respectively, were the study sites for the present work. The climate is tropical arid, with an average annual rainfall of 250-450 mm (Laminou *et al*., 2020). The year is characterised by a dry season of 8 to 9 months and a rainy season of 3 to 4 months. The average minimum temperature is around 18° (December-January) and the maximum around 45° (March-April). This rise in temperature leads to an increase in evapotranspiration, which is around 3000 mm per year, with a minimum of 460 mm in the rainy season and 2460 mm in the dry season (Amadou,2012).

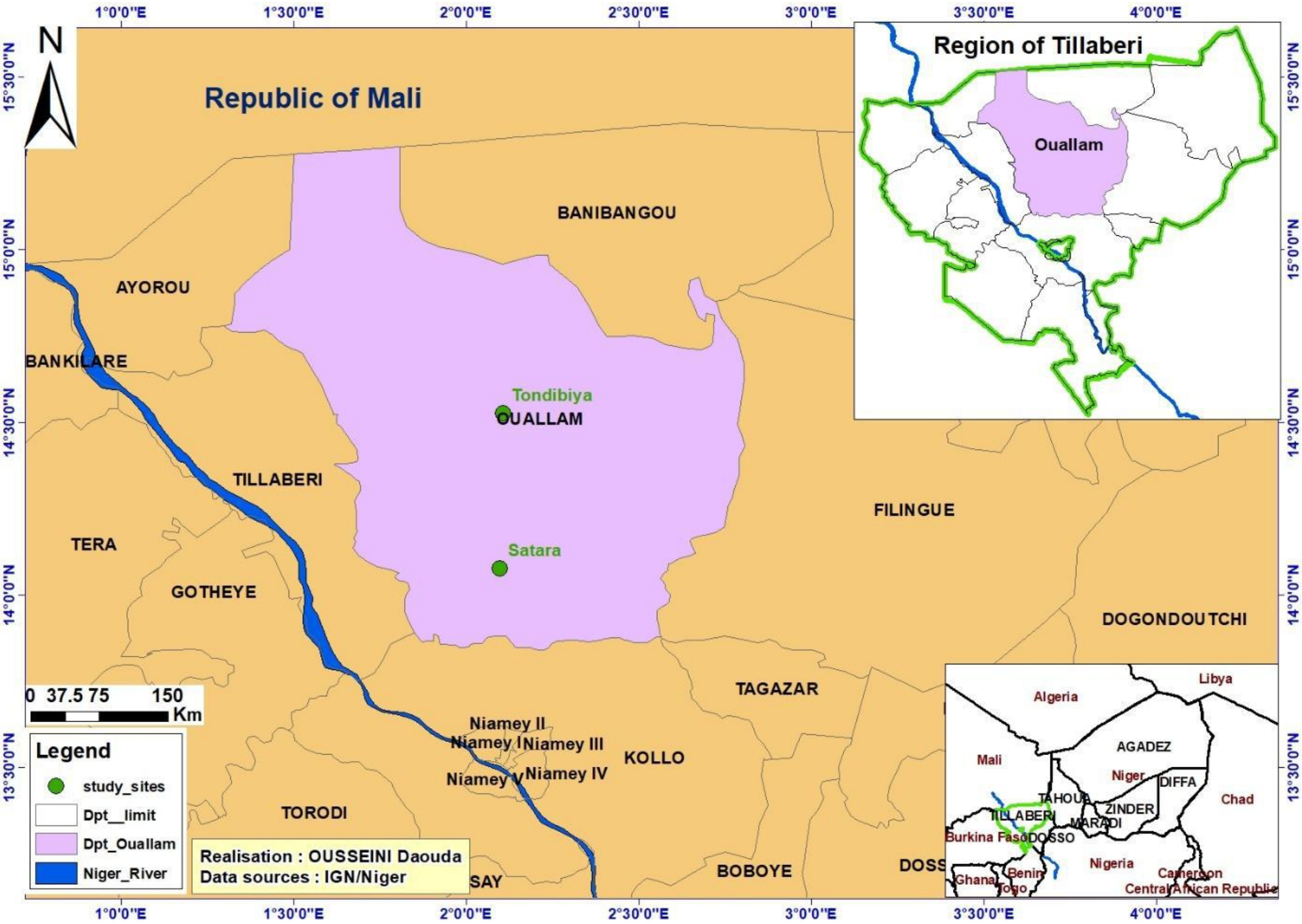

Fig. 1: Map of Department of Ouallam

The sylvopastoral half-moon, the subject of this study, has the characteristics presented in Table 1. Photo 1 illustrates a half-moon.

Table 1: Characteristics of a half-moon

Characteristics of the Half-moon sylvopastoral pastoral	Values
Diameter (m)	4
Depth of the trough (m)	0,15 à 0,30
Bead height (m)	0,30 à 0,40
Area (m^2)	32
Density per hectare	313

Photo 1: a: View of an undeveloped site; b: Compartment of a completed half-moon

The biological treatment given to the structures when they were installed and the natural regenerative power of the environment have allowed vegetation to return. The sites were constructed in different years starting in 2014. Thus, the study selected the 2014, 2016 and 2018 completion sites. Data collection was carried out in 2020 where the respective ages of these sites are 7; 5 and 3 years.

2.2. Data collection

The data was collected mainly on the particles deposited in the half-moon basin. This sedimentation assessment was done along three (3) parallel transects. One transect runs perpendicular to the contour line. On each transect, ten (10) half-moons were selected using the "No sounding" method according to formula (1). The number of half-moons surveyed per site was thirty (30). The sampling by transects and sampling were chosen to have the representativeness of the structures taking into account the factors influencing the dynamics of sedimentation among which the wind (Abdourhamane, 2011).

$$P = \frac{N}{10} \qquad \textbf{P}: \text{No survey} \qquad \textbf{(1)}$$

N = Total number of DLSP on the transect : ∑Xi

Indeed, the deposition of the particles was studied on three parameters: thickness, water permeability and texture. Fig. 2 shows the data collection points in the half-moon.

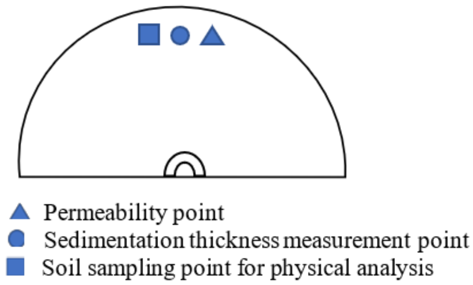

Fig. 2: Collection points in the half-moon

2.2.1. *Thickness of sedimentation*

The thickness of the sediment deposited in the half-moon basin was measured by opening a cultivation profile (Photo 2). The layer representing the deposited soil particles was delimited by means of a visual assessment. The thickness was then measured with a ruler.

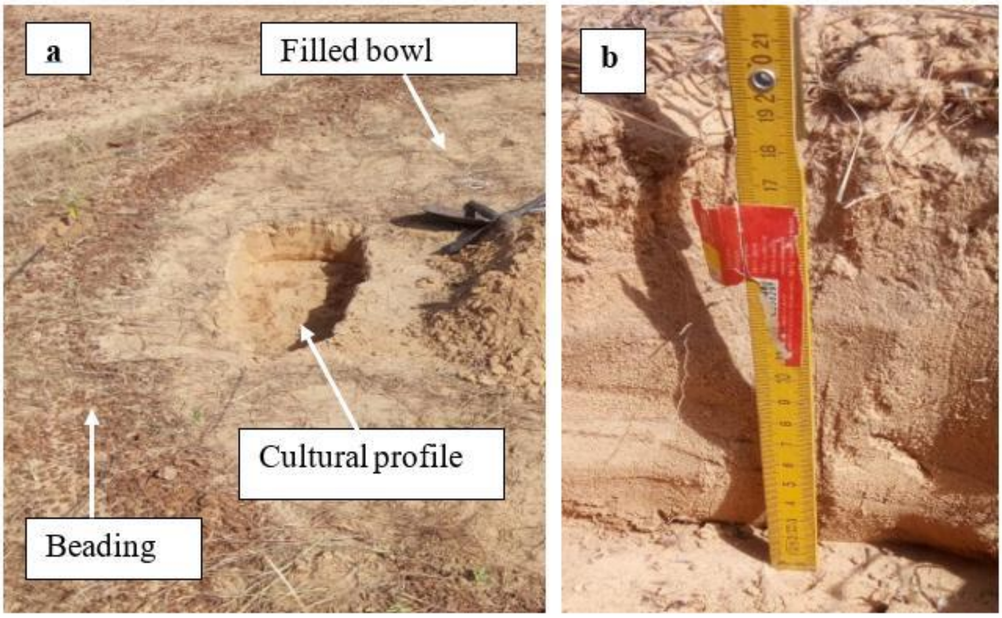

Photo 2: a: Cultural profile in a half-moon filled basin; b: Measurement of deposition

The thickness of the sediment layer depends on the age of the structure. This led to the evaluation of the sedimentation rate as given by formula (2).

$$Vs = \frac{E}{A} \qquad (2)$$

Vs : Sedimentation rate (cm/year); E: Measured sedimentation thickness (cm) and A: Age of the structure in years (year)

The evaluation of the thickness of the sedimentation thus makes it possible to assess the volume of soil available to the herbaceous plants for the development of their subterranean part on the one hand, and available to the water for its infiltration and evaporation flows on the other.

2.2.2. *Water permeability*

The 20 cm diameter single ring infiltrometer was the equipment used to measure water permeability. The activity consisted of installing the infiltrometer and quantifying the infiltrated water depths. The infiltrometer was sunk about 5 cm into the ground to prevent water from leaking onto the ground surface during the test. It is then filled with potable water to a height (H) and allowed to infiltrate for a timed period. At the end of the time, a height (Hf) is obtained from which the infiltrated height (Hi) is obtained by formula (3). The operation is repeated by filling the infiltrometer again to the height H. The activity is thus continued repeatedly until a constant infiltration height is obtained (same Hi value three times in a row). The number of repetitions of the operations during a test (Table 2), depends on the time taken to obtain Hi. The infiltration rate or infiltration coefficient (Yaméogo *et al.*, 2013) was calculated according to formula(4).

$$\mathbf{Hi = H - Hf}$$

Hi : Infiltrated height in millimeters (mm); **H** : Initial height in millimeters (mm); **Hf** : Final height in millimeters (mm)

$$V = \frac{Hi}{t}$$

V: Infiltration speed mm/min; **Hi:** Inf **(4)** height in millimeters (mm); **t:** Time taken in minut)

Table 2: Duration of the survey sheet operations

Filling-infiltration operation	Duration in minutes (min)	Number of repetitions
1	5	6
2	10	6
3	20	3

The infiltration test was carried out in the pit of the structure and on a bare area without vegetation representing the control (Photo 3). The permeability allows the sedimented soil to be compared to the encrusted control, as insufficient water infiltration into the soil is a key factor in land degradation or fodder production on pastureland.

Photo 3: Installation of the infiltrometer on an unfinished control

2.2.3. Analysis of textural elements

The physical analysis of the soil particles concerned the first 10 cm in the basin and an undeveloped area representing the control. Sampling was carried out across a crop profile (Photo 4).

Photo 4: a: Core measurement, b: Soil sampling

A composite sample was taken per transect. Soil samples were analysed in the soil laboratory of the Faculty of Agronomy of Abdou Moumouni University of Niamey. The Robinson Pipette method was used for the particle size analysis. The textural elements concerned are clays, silts and sands. The textural class was determined using the textural triangle.

III. RESULTS

3.1. Thickness of sedimentation

Table 3 shows the sediment layer thickness values at the different sites.

Table 3: Thickness and sedimentation rate as a function of the age of the half-moon

Age of structure (years)	**Deposit thickness (cm)**	**Sedimentation rate (cm/year)**
7	19,37 ± 6,04	2,23 ± 1
5	17,33 ± 1,79	3,46 ± 0,35
3	14,15 ± 1,50	5,85 ±1,80

The results of the sedimentation thickness assessment show that the deposition of particles increases with age. At the 7 year old site, the half-moons are mostly filled in. This has allowed herbaceous species to colonise the basin (Photo 5).

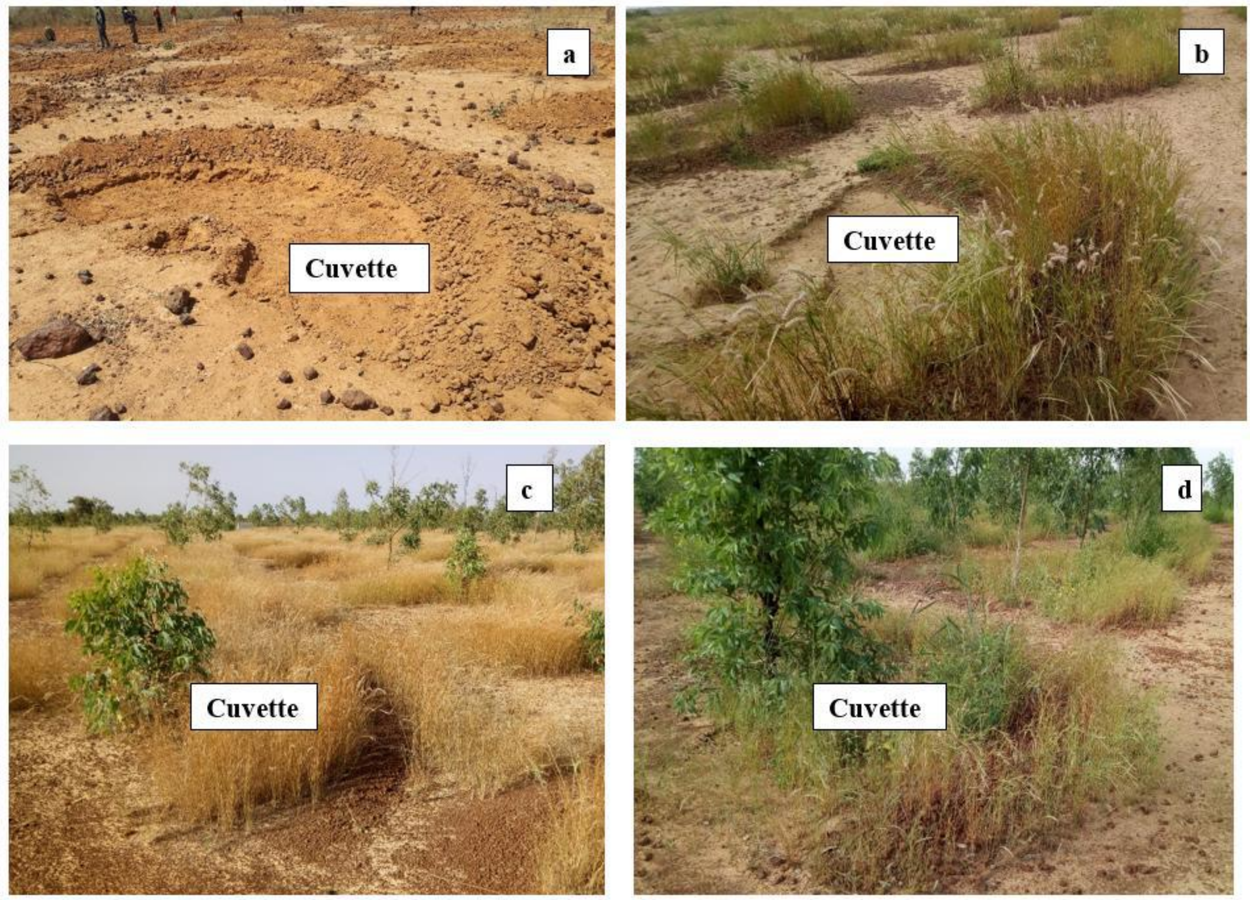

Photo 5: a: Half moons achieved; b: Half moons of 2 years; c: Half moons of 7 years

The sedimentation of soil particles in the half-moon basin has improved the vegetation cover with increasing age. This has an impact on forage production by improving species diversity but also by increasing the amount of biomass.

3.2. Water permeability

The water infiltrates more into the sedimented soil of the basin than into the control. This is due to the coarse-textured granulometry and the porosity found. The cumulative infiltration heights and the infiltration time are different depending on the site. Table 4 gives the cumulative infiltration heights prior to constant infiltration. For the time, 70 minutes were recorded for constant infiltration in the 7-year basin and 40 minutes for those of 5 and 3 years.

Table 4: Cumulative heights at constant infiltration

Measuring points	**Cuvette**		**Witness**	
Age of Half moons (years)	Hc (cm)	Tc (mn)	Ht (cm)	Tt (mn)
7	8	70	1	10
5	22,4	40	4,7	15
3	27,9	40	57,2	50

Hc: Cumulative infiltration heights before constant infiltration in the basin; Tc: Duration from which infiltration was constant in the basin, Ht: Cumulative infiltration heights before constant infiltration on the control and Tt: Duration from which the infiltration was constant on the control.

It can be seen that the volume infiltrated and the time taken to obtain constant infiltration on the sedimented soil are greater than those of the control, with the exception of the 3 year old structure. The permeability study shows that infiltration and its speed increase with the age of the structure (Fig. 3 and 4).

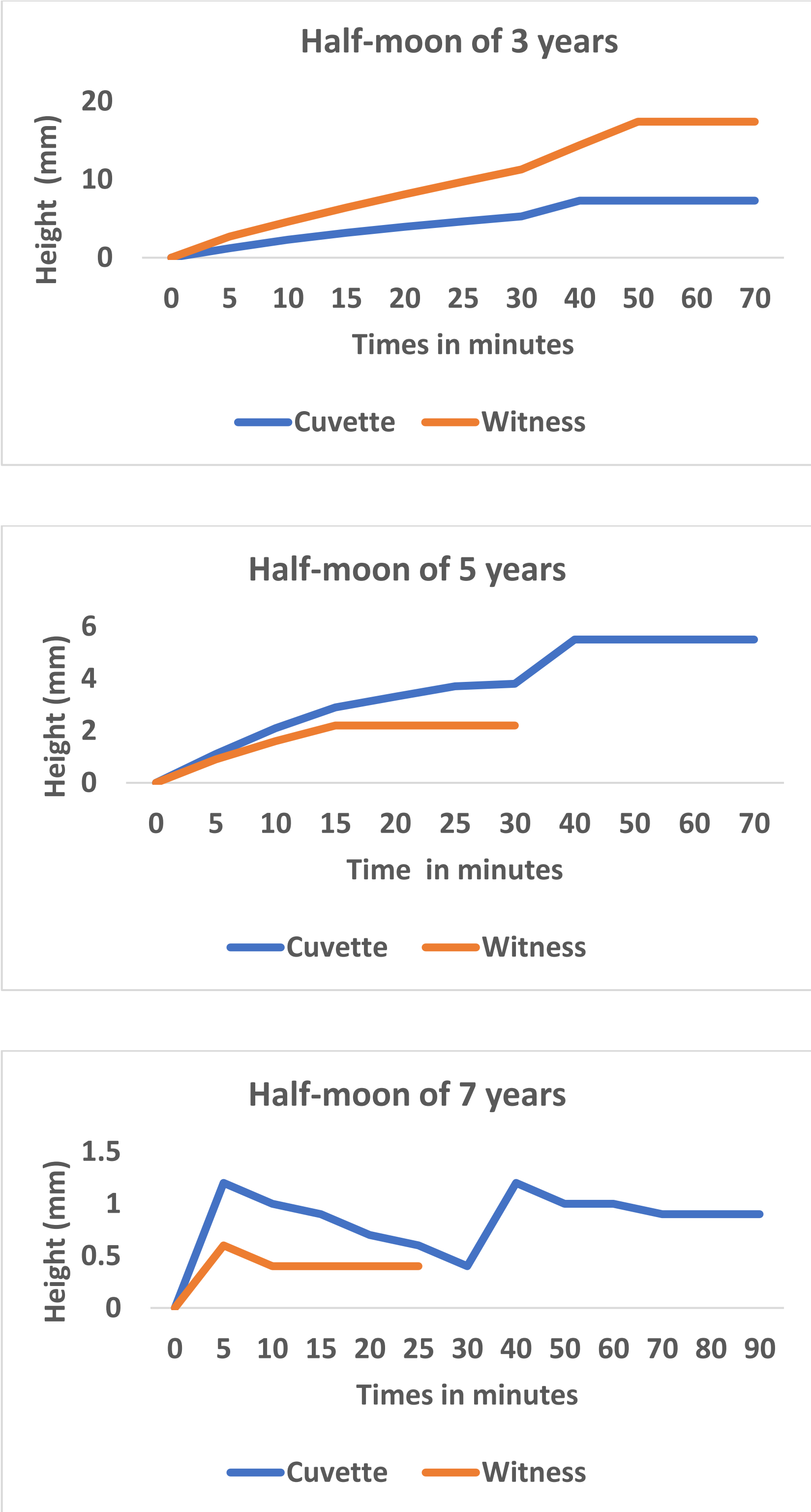

Fig. 3: Evolution of water infiltration in the half-moon

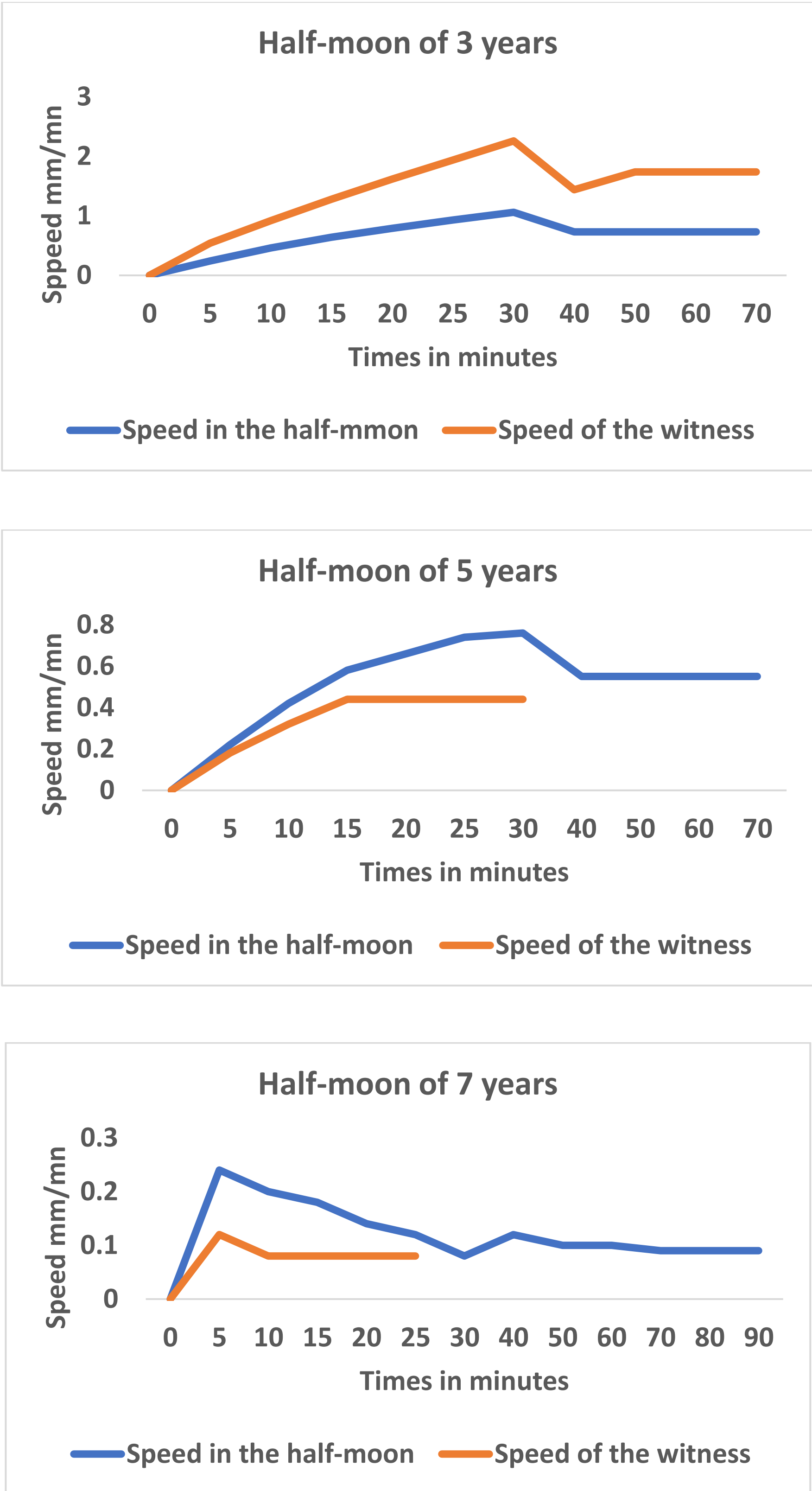

Fig. 4: Evolution of the water infiltration rate

It can be seen that infiltration has been improved by the half-moon. The better infiltration recorded on the 3 year old control site is explained by the fact that the upper soil horizon has more pores than the sedimented layer in the half-moon.

3.3. Particle size parameters

Table 5 presents the results of the particle size analysis.

Table 5: Soil particle size

Half-moon age (years)	Clay	Fine silts	Coarse silts	Fine sands	Medium sands	Coarse sands	sands	Clay + Fine silts	Texture
7	3,78	9,13	9,37	26,26	41,78	9,69	77,73	22,28	Sandy-silt
5	2,52	15,03	12,87	21,96	36,00	11,61	69,57	30,42	Silty-sandy
3	1,01	12,36	11,93	30,37	33,71	10,61	74,69	25,30	Sandy-silt
TCD	3,04	12,09	15,36	21,77	33,21	14,52	69,5	30,49	Silty-sandy

Clay $\phi < 2$ µm; Fine silts: $2 < \phi < 20$ µm; Coarse silts $20 < \phi < 50$ µm; Fine sands: $50 < \phi < 200$; Medium sands $200 < \phi < 500$ µm and Coarse sands $500 < \phi < 2000$µm and TCD: Completely degraded control

The granulometric analysis reveals that sands dominate. They represent at least 2/3 of the particles with a dominance of medium sands. It also appears that the texture of the sedimented soil in the basin of the structure tends to be coarse. The 7-year-old half-moon recorded more sands compared to the 5- and 3-year-old half-moons.

IV. DISCUSSION

The deposition of particles in the basin has the role of reconstituting the essential functions of soils as a support for species, particularly plant species, as a nutrient bank and as a catalyst for exchange between the edaphic environment and the atmosphere (Ay *et al*., 2020). The thickness of the sedimentation varies between sites, but the trend shows that it increases with the age of the half-moon. It increases from 14.15±1.5 cm in the 3-year-old half-moon to 19.37±6.04 cm in the 7-year-old half-moon. Apart from age, factors influencing the deposition of particles in the basin can include wind erosion, crumbling of the bead by raindrops, the texture of the developed soil and the type of development works. In their study in the commune of Simiri (Niger), Laminou *et al.* (2020) found a sedimentation thickness of between 8 and 15 cm in the 3-year-old pastoral bench, the structure sharing the same basic principles and functioning with the pastoral half-moon. This proves that excavated structures cause sedimentation of particles in their trough.

Depending on the site, the infiltration of water, the height of infiltration, the time from which it becomes constant and the speed of infiltration are different. This difference tends to become apparent as the age of the structure increases. In this sense, the duration from which the infiltration becomes constant is 40 and 70 minutes respectively for the 3 and 7 year old half-moon. This is explained by the thickness of the sedimentation which increases with age. The high infiltration rate or infiltration coefficient of the structures is 1.06 mm/min, obtained in the basin of the 3-year old half-moon. Laminou *et al.* (2020) found an average infiltration rate of 1 cm/min (10 mm/min). This difference may be due to the heterogeneity of the plateau horizons and the age of the structure. In Burkina, Yaméogo *et al.* (2013) obtained an infiltration coefficient of 0.1.10-3 m/s (6.25 mm/min) and 0.04.10-3 m/s (2.5 mm/min) in the zaï, respectively for the basin and the control. These results confirm that infiltration depends on the type of development techniques, the nature of the soil and also the age of the structure. The various results show that the excavated structures significantly improve the permeability of water in the soil.

Indeed, the improvement of the permeability in the half-moon following the deposition of particles, leads to the improvement of the humidity in the structure. Thus, Kagambega *et al.* (2011) found that the development of the half-moon significantly influenced the humidity rate both in the middle of the rainy season (August) and at the beginning of the dry season (end of October) in Burkina Faso. In their work on water balance modelling (Burkina Faso), Zouré *et al.* (2019) stated that half-moons are able to mitigate the effect of droughts by keeping water available for plants over extended periods of up to three weeks. This ability of the half-moon was possible due to the infiltration and availability of water in the basin. Meanwhile, in southwest Niger, Douma *et al.* (2011) found that an estimated 7% improvement in moisture was achieved in the first year of the silvopastoral trenches. They added that the moisture could further increase in the future with the age of the structures due to progressive sedimentation. This highlights the decisive character of time in the production of ecosystem services, illustrating a dynamic in the structures on the restored sites.

The evolution of the silty-sandy texture of the completely degraded control (TCD) to that of the sandy-silty texture of the 7-year-old half-moon implies that the accumulation of sands has taken place. This constitutes an improvement of the structure, of which the herbaceous flora is the main beneficiary, given that encrustation remains the main cause of the degradation of the plateaus. The age and the structure are factors determining the textural dynamics in the structures. Development therefore favors the deposition of sand (André *et al*., 2008) and the development of herbaceous plants due to their strong resilience to the Sahelian climate. In their study, Amani *et al.* (2021) found that the creation of the bench induced a change from medium to fine texture dominated by clays. This points to the fact that the excavated works of degraded land reclamation techniques contribute to the evolution of the texture on the degraded ferruginous plateaus of western Niger, dominated by medium and low or non-sandy textures (CILSS, 2016). In parallel to the developed plateaus, Tidjani (2013) obtained on a stabilised dune flat in the department of Gouré (Niger), 91.11% of sands for the A horizon (0 to 25 cm). These results show that the sediments deposited would be related to the nature of the soil and the type of development on the one hand and confirm that the techniques of recovery of degraded land make the texture of the soil evolve on the other hand. Land reclamation techniques have always improved the physical characteristics of soils (Hamado, 2011; Abdou *et al*., 2020). Despite their low physico-chemical potential, reclaimed degraded soils offer very appreciable fodder production (Kiema *et al*., 2012).

V. CONCLUSION

At the end of this study, it was found that the half-moon allowed the deposition of soil particles. The thickness of the sediments increases with the age of the structure. After seven years, the basin is completely filled in. This sedimentation provides a support for vegetation, particularly herbaceous vegetation, which has developed. We note the evolution of the texture which becomes coarse thanks to the accumulation of sand in the structure. This has led to an improvement in the infiltration of water into the soil. The result is an improvement in humidity, which creates a microclimate at the scale of the half-moon. As with all techniques for reclaiming degraded land, the sylvopastoral half-moon creates edaphic conditions for the development of herbaceous species, especially grasses, which have a high ecological resilience in the Sahel. This implies that the plateaus are suitable for sylvopastoral recovery.

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