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THE RUNOFF IN THE SUDANO-SAHELIAN: a salutary oxymoron

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Abstract

In the sudan-sahelian zone, the struggle for food self-satisfaction since 60 years based on a green revolution has been a failure. The concept of rational innovative management requires the understanding of the variability of the agronomical spatio-temporal potentials of ecosystems. The study deals with the identification and hierarchisation of dominants factors that control the hydrological functioning and the fertility of soils and their modification under the impact of climatic change. The variability of milletlet yield is almost of the same order of magnitude at the scale of the hillslope (0 to 1136kg.ha^{-1}) than at that of the field (21 to 1273kg.ha^{-1}) during a year of strong hydrological stress. These high values of extreme yields cannot result from the fertility of the different morphopedological units or from the agricultural practices. The runon which is a part of the runoff and is defined as "*a natural, complementary and simultaneous irrigation to the rainfall that has generated it in according to natural (topographical, morphological, permeability) anthropogenic (soil tillage) conditions*" must be taken into account in the hydrological balance. The increase of the hydrological and soil nutriments stock due to the runon is correlated to the slope, to the microtopography and to the soil work. These results demonstrate that this runon completed by the deposit of nutriments and sequestration of organic carbon is the dominant factor of this variability. Peasant strategies to face the variability of soils potential have been poorly investigated and badly taken into account by agronomists; thus agronomical research must not ignore anymore the empiric peasant knowledge. With the continuous accentuation of the rain deficit and the erosion, the existence of the runon must be integrated in sustainable models of agricultural management.

Key-words : Runon, runoff, spatial variability, organic carbon sequestration, pearl milletlet, morpho pedological unities, Sudabo-sahelian zone.

Résumé

En zone soudano sahélienne, la lutte pour l'autosatisfaction alimentaire qui perdure depuis 60 ans basée sur la révolution verte a été un échec patent. Le concept d'un aménagement rationnel innovant nécessite la compréhension de la variabilité des potentialités agronomiques spatio temporelles des écosystèmes. L'étude porte sur l'identification et la hiérarchisation des facteurs dominants qui contrôlent le fonctionnement hydrique et de la fertilité des sols et de leur modification sous l'impact du changement climatique. La variabilité du rendement du millet quasiment de la même importance à l'échelle du versant (0 à 1136 kg ha^{-1}) qu'à celle du champ (21 à 1273 kg ha^{-1}) en année à fort stress hydrique en milletieu paysan. ne peuvent pas résulter de la fertilité des différentes unités morphopédologiques ni des pratiquent paysannes. Le report hydrique partie bénéfique du ruissellement qui se définit comme «*une irrigation naturelle, complémentaire et simultanée à la pluie qui l'a générée en fonction des conditions naturelles (topographiques, morphologiques, perméabilité et d'un horizon profond durci) et anthropiques (travail du sol)*» doit être pris en compte dans le bilan hydrique. L'augmentation du stock hydrique et nutritionnel des sols du au report hydrique est corrélée à la pente, à la microtopographie et au travail du sol. Ces résultats démontrent que ce report hydrique complété par des dépôts de nutriments et par la séquestration du CO est le facteur dominant de cette variabilité. Les stratégies des paysans face à la variabilité de la potentialité des sols sont peu étudiées et mal prises en compte par les agronomes et la recherche agronomique ne doit plus ignorer la connaissance empirique des agriculteurs. Avec la persistance de l'accentuation du déficit pluviométrique et de l'érosion, l'existence du report hydrique doit être intégrée dans les modèles d'aménagement sylvagraire durable.

Key-words : runoff, runon, carbon sequestration, spatial variability, millet yield, sudano-sahelian zone

1. INTRODUCTION

In the sudan-sahelian zone, the fight for food sovereignty that lasts for 60 years based on the green revolution has been a severe failure. The concept of rational innovative management requires the comprehension of the spatio-temporal variability of the agronomical potentialities of the ecosystems. The food sovereignty decreases when agrosystems are under hydrological and nutritional stress generated by climatic change or the anthropogenic degradation of soils. Their degradation results of the runoff observed on all morphopedological units whatever their slope despite a good infiltration capacity of the soils. (Hoogmoed et Stroosnijder, 1984; Filcroft et al., 1991; Valet et Sarr, 1989). It was noticed that despite the drought the runoff had increased generating an aggravation of the hydrological stress (Greene et al., 2001; de Rouw, 2004). Moreover the runoff is the main agent responsible for erosion and the loss of nutrients (Wendt et al., 1986). The large spatio-temporal variability of the runoff explains the variability of the milletlet yield on these formations (Valet, 1985b ; Valet et al., 1993 ; Albergel et al., 1990). At different scales, the redistribution of the runoff acts on the very rapid and important reconstitution of the hydrological stocks at the footslope and on the slope and in the dunes (Hanna et al., 1983 ; Valet, 1985a ; Valet et al., 1993 ; Galle, et al., 2001). This phenomenon occurs whatever the soil texture and hydrological retention capacity (Sicot et al., 1991 ; Valet, 1996). It is defined as « a natural irrigation, complementary and simultaneous to the rain that has generated it as a function of the natural (topopographical, morphological, permeability, occurrence of a deep and dense horizon) and antropogenic (soil labour) conditions"(Valet S., 1995 ; Gaze et al., 1997). The variability of the millet yield, similletar at the scale of the slope (0 à 1136 ha^{-1}) to the scale of the field (21 à 1273kg ha^{-1}), in a year with a strong hydrological stress suggests that these values of extreme yields cannot results from the fertility of the different morphopedological units nor the peasant practices, nor the runoff alone. The benefic part of the runoff must be taken into account in the hydrological balance.

The identification at the scale of the parcel, as it was done on the slope, of the causes of the runoff and the runon, and the measurement of the effect on the modification of the hydrological stocks on small distances is necessary to develop a rational and innovative management of the surface fluxes. An experiment was conducted on the hydrological flow processes on a homogeneous peasant field submitted to constrated cultural preparations.

The study is focused on the occurrence of the runon at different scales on different morphopedological units. The goal is to:

1) measure the existence of the variability of the runon;
2) identify the transfer of nutrients and soil particles;
3) evaluate the agropedological consequences.

2. MATERIAL AND METHODS

2.1 Localisation

The study was realised at the Sine Saloum at Thyssé-Kaymor located 70km south-east of Nioro du Rip. The studied parcels are located on a transect on a slope including the watershed S2 of 59ha and S4 of 2,5ha and also inside two fields (Terrace and footslope) of 1,35 et 1,5ha (Fig. 1, 2 et 3A& B).

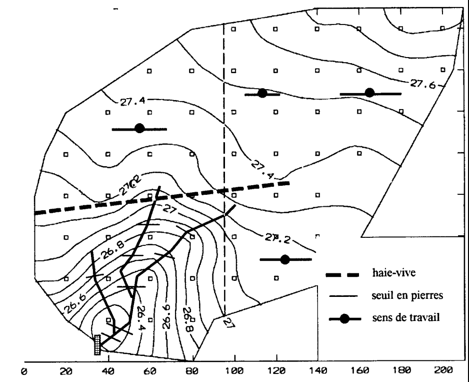


Figure 1- *S4 watershed (2,5ha).*

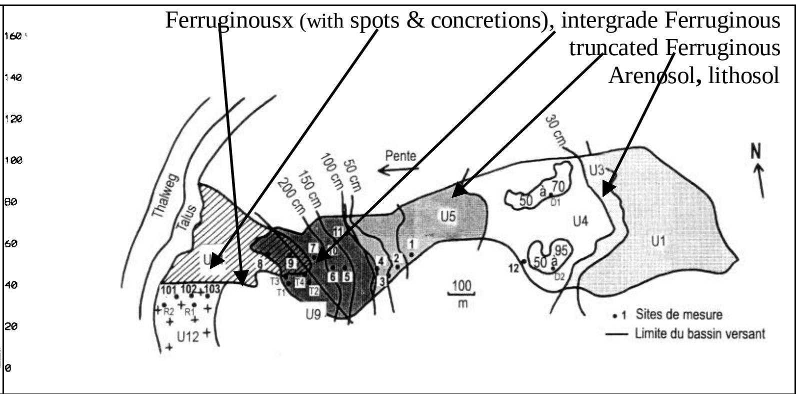
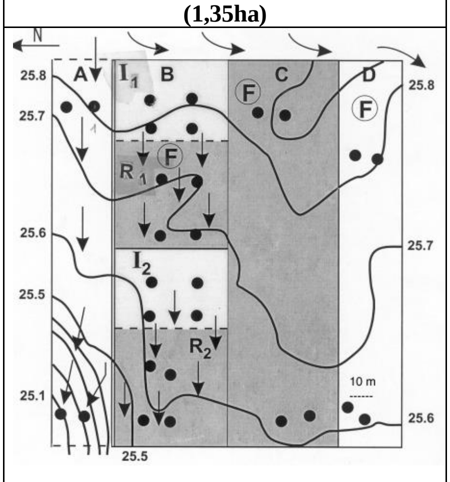


Figure 2– *Geomorphologic unities and soils in S2 watershed (59ha).*

For the two fields the treatments include tow bands of 120m long arranged in the direction of the slope and large of 25 to 35m (Figure 3 A & B). The measurements of the 16 to 24 plots inside the fields and the 14 plots on the slope can be considered as reproductible.

Terrace
(1,35ha)



North ----- South

Fallow

Chiselling

Ploughing

I 1-2 : impluvium
R 1-2: compluvium
F : fertilisation
Runoff
36 **Plots**
25.8= altitude meter.

Footslope
(1,50ha)

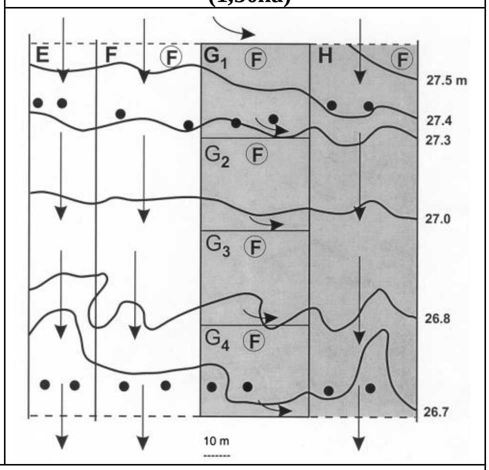


Figure 3- Trial location in A terrace and B footslope with treatment stripes and plots.

2.2. Climate

The drought since 1968, characterised by a loss of 30% of the rain with an increase of its random repartition, has changed the north sudan climate into a south sahelian one. This loss has little changed the dates of the optimal sowing but generated the reduction of the rain levels, particularly in July and August, as it was observed for the whole sudan-sahelian zone (Morel, 1990). If the first rain falls at the same dates, the last ones occur earlier. The pluviometric years have the following probalistic levels: deficit = 387mm (1984); median = 491mm (1991); meadow = 780mm (1989); excess = 946mm (1988).

2.3. Soils

At the Sine Saloum, little evolved sols, lithosol, arenosol, acrisol, ferruginous intergrade, ferruginous little to not leached with spots and concretions develop on a homogenous substrate made of argilous greys of the Continental Terminal (Bertrand, 1972). In all cases they have a superficial horizon poor in clays and organic carbon.

3. RESULTS AND DISCUSSION

3.1. Variability of water stocks

3.1.1. At the scale of the hillslope

On these slopes the structural instability increased toward the top of the slope explaining the higher risks of soil crusts (Valentin, 1990).

A  B 

Photo. 1- A : Generalized crusting on the top of hillslope & **B**: bended leaf and erosion by runoff during dried year.

The measurements of the runoff show that it is proportional to the size of the 5 watershed, from 2,5 to 1200ha, at the end of the dry season on the soil completely covered by crusts ; but it is inversely proportional as soon as the soil has been chiselled, for a same rain of 35mm (Valet et al. 2007- Fig. 5- Photos 1 A & B). This explains why the runon and the runoff increase in general with the increase of scale after each soil chiselling to break the crusts.

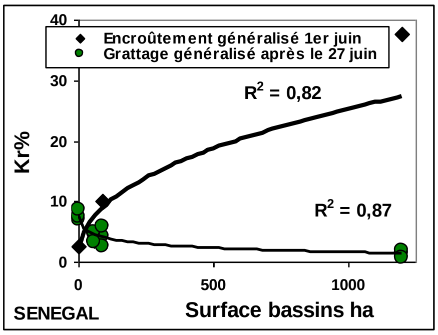


Figure 5-Watershed surface vs KR% after two 35mm rains before and after surface crusted soil.

Along a typical slope for a rain of 35mm, the water stocks increase progressively from the top with an iron pan (Sites 2 and 4) towards the bottom without the pan (Sites 9 and 10 -Fig. 6). These stocks are much smaller than the rain at the top and get stronger towards the bottom. This due to the generalised runoff generated by a system of superficial crusts that develop between each soil work under the action of the kinetic energy of rain and of the runoff as shown before (Smith et al., 1990; Valet S., et al., 2007).

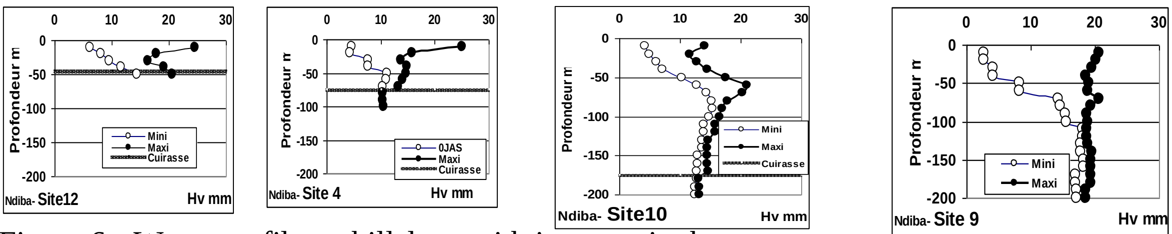


Figure 6-. Water profile on hillslope with iron pan in the top.

3.1.2. At the field scale

The hydrological behaviour varies depending on the treatments: on the footslope, the comparison between a band non protected from the runoff (E°) and protected (H) shows two types of hydrological behaviour :

- on the convexe micromodelling, stocks are similar for both units or slightly stronger without runoff (Fig. 7: E-AVS-3 and H-AVS4) ;
- on the concave micromodelling, stocks are significantly higher under the runoff (Fig. 7 : E-AMN3 et H-AMN3).

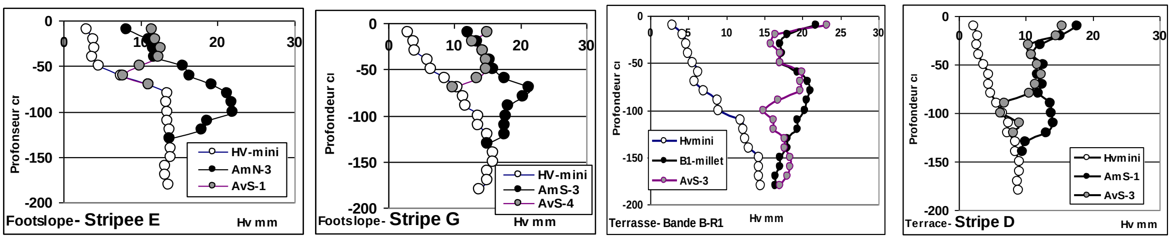


Figure 7- Minimum and maximum water profiles in footslope and terrace with and no runon and concave and convex microtopography).

On the colluvio-alluvial terrace water stocks are always higher under the runoff than without whatever the micromodelling (Fig. 7 B-R1 and D).

This suggests that the runoff is more important on the footslope as the soil is less permeable; the average infiltration capacity if from 3 to 6cmh^{-1} against 7 to 14 on the terrace (Valet, 1985a). On the terrace, despite a good infiltration, the rapid development of the crust generates a runon and the filling of soil, thus generating a drainage even in a deficitary year.

The variability of the hydrological functioning multi-scale shows that this hydro-pedological system is open. The sum of the stocks on the hillslope and even at the field is not equal to zero and this variability must be taken into account in the hydrological balance of the crops; in contrast to the hypothesis developed by Lal (1991) et Klaij and Vachaud (1992) that consider that in the calculation of the hydrological balance, surface fluxes equal to zero at the scale of the parcel as this results from their redistribution inside the parcel (Gaze et al., 1996).

The importance of the variability of the water stocks obtained at the scale of a small watershed and fields are logical compared to results conducted on a square meter (Pérez, 1994) and other on a watershed of 5ha (Rockström, 1997; Rockström and Valentin, 1997) as well as a banded vegetation pattern (Galle and al., 1997).

The drainage measured under some parcels submitted to a strong runon, at different scales, cannot be considered as a local loss in water as mentioned by some agronomists (Pérez, 1994; Vallée and al., 1994; Rockström and al., 1997). It is a loss for the bottom parcels that would not benefit from this runon. Zheng et al. (2000) have shown that under the conditions of occurrence of the drainage, the runon diminishes as well as the sediments transported. It must be demonstrated that this drainage generates the leaching of exchangeable cations, phosphorous and soil organic matter and increasing its acidity as predicted by agronomists (Piéri 1976; Sène and Garin, 1990; Guillobez and Zougmoré, 1990). During excess rain, the risk of increase of the drainage is not greater as the superficial saturation is faster, leading to a diminution of the rain and a loss of its intensity limiting the infiltration and generating an earlier start of the runoff as for a dry year (Casenave and Valentin, 1991)

3.2. Transfer of fertility

3.2.1. At the scale of the hillslope

The physico-chemical analysis of the sediments transported by the runoff shows that compared to the soil-test the sediments are rich in organic carbon, clays, silts and nutrients with an increase of the pH, and this more strongly on a small watershed than for the larger ones (Fig. 8).

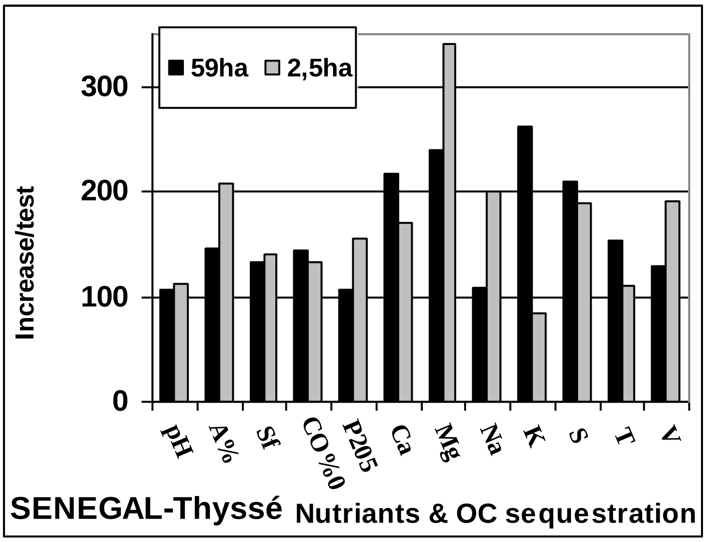


Figure 8- OC, pH, clay+silts and nutriants% increasing in soil losses of two watersheds.

3.2.2. At the field scale:

On the footslope

- the rate of silts and calys is higher in the absence of runon on the parcels with runon whereas it is no different for the organic carbon;
- this rate diminishes from the convexe forms, to the plan then to the concave forms with or without runon ;
- in contrast organic carbon increases (Fig. 9A).

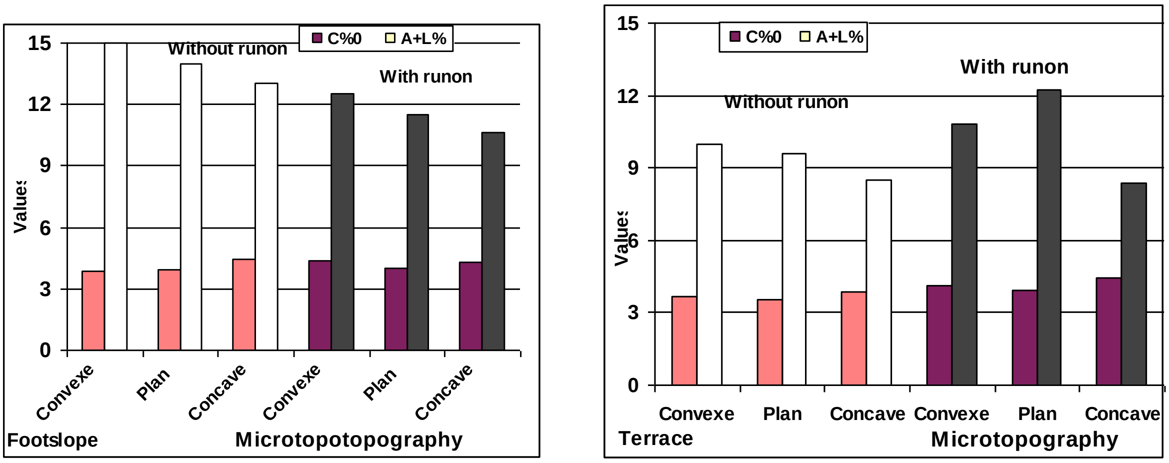


Figure 9- Microtopography vs OCg/kg and Clay+silts sequestration on A: footslope and B: terrace.

On the colluvio-alluvial terrace:

- the behaviour is identical for organic carbon and clays and silts in the absence of runon;
- it is similar for organic carbon but variable for clays and silts under a runon and higher for parcels not submitted to the report (Fig. 9B).

It is interesting to notice that this experiment is only on one cultural season. Thus on two morphopedological units, the terrace with more sand than the footslope, located at 100m from each other, their hydrological and sedimentary functioning differ significantly. The variability of these superficial water fluxes suggests a variability of the water offers to plants that attenuate during the rainy years.

3.3. Diverse effects

3.3.1. Effect on the pedogenese

The variability of runon in spots on small distances intra and inter units generates a large variability of drainage. In the absence of deep drainage, these results in a diminution of leaching whereas the concentration of soil solution increases, enhancing the localisation of surface pedological processes characteristic of the sahelian pedogenesis. The drainage, even during very dry years, generates a leaching. This hydrological behaviour with specific differences between and inside the soil units is not taken into account in soil taxonomy. Building a classification on the intinsic hydrological properties is more universal than the classifications relying on the notion of hydrological regime. For the last one is related to the environmental conditions (climatic and anthropogenic factors) that are very random and regional and submitted currently to important changes. Moreover intrinsic morphopedological factors are neglected.

3.3.2. Effect on the variability of water fluxes

At the field scale, the variability of the surface properties and the related fluxes and sediments, for a given pedological unit, is not necessary random but related to processes with variable intensities (Microtopography, open and closed depressions, concave, convexe and plan forms on the field distributed non randomly) that affect them inside the landscape as demonstrated by Daniels and al. (1985a) at the scale of the slope. Ruelle and al. (1989) have demonstrated that on the terrace the hydrological stocks assimilated to regional variables showed an isotropic structure with an instable auto-correlation of 100m with a nugget effect. The nugget effect not explained by these researchers corresponds in fact to the variable runon (on distances smaller than 10m), according to the variability of the microtopography. The occurrence of similar phenomena generating water fluxes of the same nature, at different scales, reflects the existence of an imbricated structure that introduces the hypothesis that these variations of the water fluxes including the runon can respond to a fractal law as verified on several soils on a hillslope (Bartoli and al., 1995).

3.3.3. Effect on the millet yield

The analysis of the millet yields realised during the dry season on all these morphopedological units show a large multi-scale variability (Valet, 1985b; Valet and al., 1993 -Tableau 1). If the minimal yields can be explained by the deficit in water due to the dry year and the runoff, the maximal values suggest not only the occurrence of this runon playing the role of a complementary to rain irrigation but also the transfer of fertility produced where it infiltrates. This contradicts the conceptions of some agronomists that consider that the infiltration followed by drainage leads to the acidification of soils.

Table 1- Millet mean, median and CV% yield at different scales for all treatment.

Yield	**Mean**	**Médian**	**CV%**
Hillslope	244,9 (0-1136)	172,5	81,89
Footslpe	354,5 (131-898)	301	56,08
Terrace	399,4 (21-1273)	198	105,2

4. CONCLUSION

The principal results of this study, including the impact of climatic change on the changes of the hydrological functioning of the eco(agro)systems, generate questions on the

different means to sustain an environmental resilience. The variability of the biophysical environment must be better analysed. In fact the results on the runoff show its aspect of oxymoron. If it is a major loss of the hydrological offer for plants at the location where it is generated it becomes an asset where it infiltrates, in general in soils deeper and less eroded thus with better runon. It assumes a transfer of fertility by depositing fine elements, organic carbon and nutrients at the place where it infiltrates each year. Because the importance of this transfer (water and nutrients) on the hillslope and on the field, on small distances, agrogeological landscapes must be read carefully under the angle of hydrological resources and fertility, the quality of the morphopedological units and their ecological functioning.
This study must be conducted again in a year with average, median and excess rain to verify the biophysical and hydrological functioning of the ecosystems. A new classification based on the intrinsic water properties must be developed, as it will more universal than the one based on the notion of water regime. This transfer of nutrients is an effective contribution to the sequestration of organic carbon and to the fight against climate change. This indicator can be used to assess the durability of a cultural system in semi-arid to sub-humid conditions (Feller and al., 2005). The elaboration of new modes of management of the sahelian environment must rely on the analysis of the spatio-temporal dimension of the ecological and hydrological dynamics. The control of the runoff to get rid of its erosive capability by traditional and innovative techniques must foresee a management and a valorisation of the runon where it can increase the yields.

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