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Fundamental properties and sensibility to physical degradation of soils used for cotton cropping in Korola watershed, Sikasso region, Mali

Abstract

Soil physical, chemical and biological degradation is an actual global problem, which must be monitored by each country in order to have better decision-making for agriculture and environment. In this case, study has been undertaken in Mali at agricultural watershed scale. The present paper is related to Korola watershed (1245.3 km^2). Here, and in the major part of Sikasso region, cotton cultivation for industry has been introduced during the 1960s. It might be noted that soil degradation is actually considered as a handicap to the improvement of cotton production, a general problem in Western and Central Africa. A deeper understanding of soils and their sensibility to degradation are needed in order to choose better strategies to improve their management and productivity. The methodology used in the present study includes ~~classical soil characterisations~~ (profile descriptions, particle size analyzes, carbon, nitrogen and pH measurement~~)~~, the use of pedotransfer functions, and the determination of the erodibility K. In Korola watershed, 3 soil types (soil1, sol2, sol3) are selected by farmers for cotton cropping. Soil1 (Ginin dugukolo) and soil2 (Mura dugukolo) have a high amount in silt, while soil 3 is rich in sand. All these soils are poor in organic matter (≤ 1%) and present a high risk of acidification. The index of battance (IB) of surface horizons (respectively 15.9, 11.0 and 15.4 for the three soils) indicate a unfavorable structure. The destructuration index (St) indicate a high sensibility to soil erosion. K values are respectively 0.44; 0.55 and 0.09 for the three types of soils.

Key words: Watershed, Cotton, Soil physical degradation, Bagoé River, Sikasso region, Mali.

1. Introduction

Soil physical, chemical and biological degradation is an actual global problem. ~~According Saha, 2003, quoted by Ganasri and Ramesh (2015) [1],~~ human- induced soil degradation is estimated at about 2 billion hectares. It is noted that the mapping of soil degradation shows a varying magnitude of the problem worldwide. Today, it is clear that soil degradation must be monitored by each country in order to have better decision-making for sustainable agriculture, as well as better quality of environment. So, there is a need of reliable assessment tools for the various aspects of soil degradation. Concerning physical degradation, the disponibility of values related to some indexes of soil structure and soil erodibility index (K) is necessary. Numerous studies have shown the variability of these indexes, depending on soils fundamental properties and its environment [2, 3, 4, 5]. Soil sensibility to degradation process must be studied in the different physical and agrosystem contexts. With these considerations, studies have been undertaken in Bagoé river basin in Sikasso region, Mali. They were precisely conducted in the Korola watershed that cover an area of 1245.3 km^2, in the administrative district of Blendio. Industrial cotton cultivation has been introduced in this zone during the 1960s. It should be noted that today land degradation is considered as a serious handicap to the improvement of cotton production in Western and Center Africa [6, 7, 8]. On the other hand, soil degradation, in particular erosion, ~~compromises the availability and quality of water~~.

2. Study area

The Korola watershed (Figure 1) is a sub-basin of the Bagoé, more precisely of the Bagoé medium. The coordinates at the outlet are 6.395°W and 11. 715°N. It covers 1245.3km^2 in

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Sikasso region, where 3 rural communes (Blendio, Dembela, Koufan) are fully inscribed there, as well as villages of the communes of Miria, Niéna, Tiankadi and Kapolondougou.

The Korola watershed is located in the western Sudano-Sahelian belt, characterized by a semi-arid climate. There is only one rainy season where annual rainfall is very variable. At the reference meteorological station (the Sikasso one), during the last 36 years (1986-2016), the two extreme values of annual rainfall were 754.7 mm in 1983 and 1552.8 mm in 2016. The monthly precipitation is mainly concentrated in the period July-September. The annual values of the ETP are from 1634 and 2424 mm. The wind speed is low (generally $2km.h^{-1}$), but exceptional speeds are often recorded in May and June ($72\ km.h^{-1}$). The monthly maximum temperature is higher in March (average 37.5 °) and lower in August (29.9 °). Concerning the monthly minimum temperature, it is higher in April (24.3 °) and lower in January (12.9 °).

In term of geological context, Korola watershed is located on sedimentary formations in a border area with the Precambrian granite basement. The basic lithological formations in the watershed are sandstone, schist and mixture sandstone-schist. Schist and sandstone have been strongly altered, but unaltered rocks remain in some places. However large surfaces are covered by ferruginous cuirass, usually in a tabular position. The main soils observed are developed on ferruginous cuirass material and colluvium [9]

As regards natural vegetation, the watershed is located in the domain of savanna. A normal distribution of the vegetation is noted, depending on soil patterns and relief. Pedological material influence the floristic composition of the vegetation or at least the relationships of dominance and frequency. The forest gallery is observed along streams.

Concerning agricultural activities, Korola watershed is populated by more than 42,700 inhabitants in 43 villages. It is entirely located in the Malian cotton zone. The main crops are cotton, maize, sorghum and millet. Several other annual crops (rice, fonio, groundnuts, etc.), as well as horticultural crops are cultivated in the watershed. The farmers are generally well equipped with animal-drawn equipment, allowing the mechanization of several farming operations [10]. Livestock are mainly cattle, sheep, goats and donkeys.

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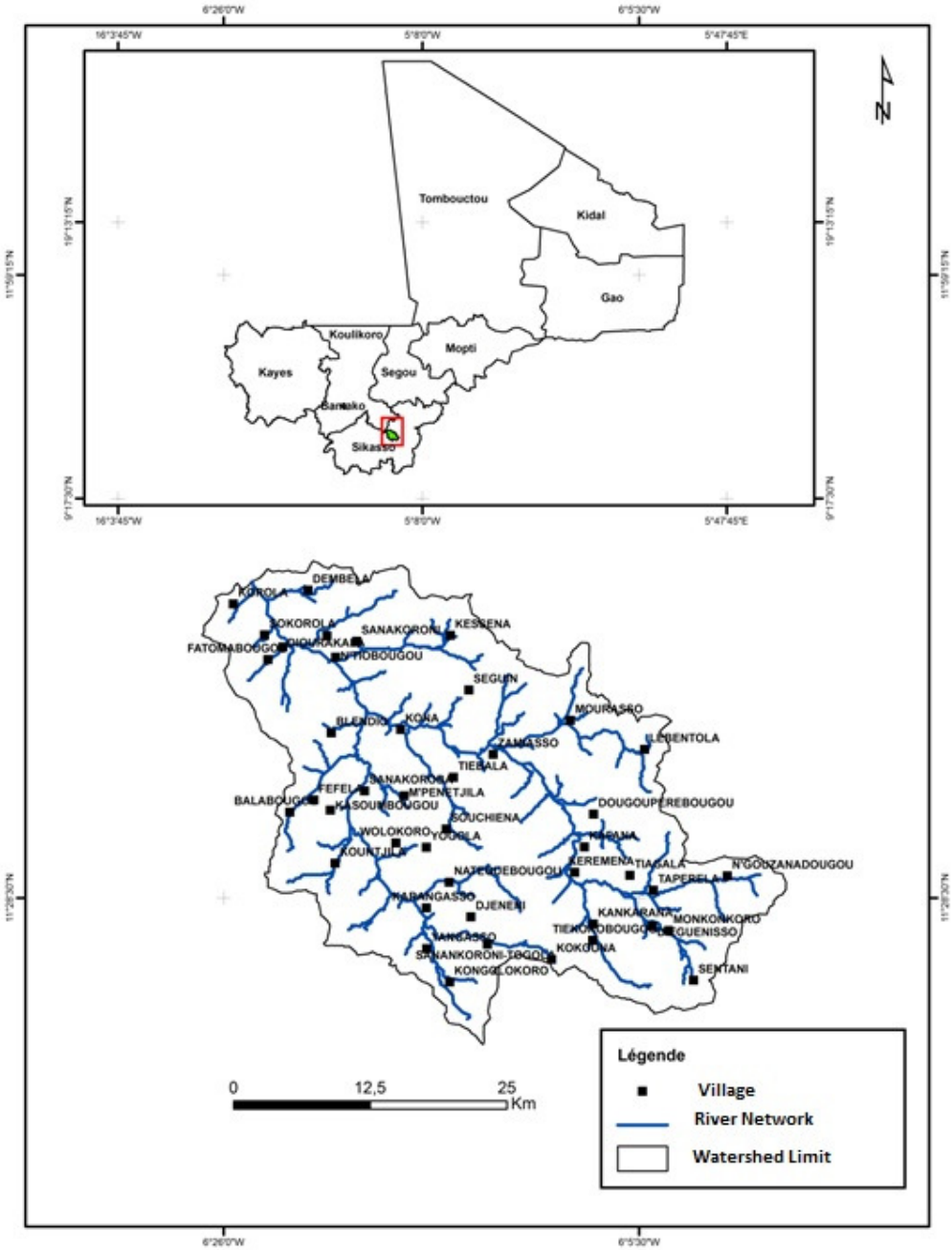

Figure 1: Location of the study area

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3. Methods

3.1 Soil morphological characterization and sampling

The pedological descriptions were carried out in pits (measuring 1 m long, 0.80 m wide and 1.20 m as maximum deep), auger drilled holes and some pre-existing cavities (natural and artificial). Soil profile description criteria were: the thickness and depth of major horizons, their color, texture and structure, the presence of coarse particle, the presence of oxidation and ferruginous concretions, rooting and biological activities. The color has been appreciated

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with the code Munsell. Detailed soil descriptions concerned 14 soil pits, 18 auger bore holes and numerous natural and artificial cavities found on site. The soil morphological description led to the choice of representative soil profiles and to sampling for laboratory analyzes.

3.2 Soil classical analyzes in laboratory

They have focused on the particle size, total carbon, total nitrogen, and the pH. The protocols of these classical analyzes [11], are presented here in a simplified manner. Particle size distribution was determined according to the international method modified by using Robinson's pipette. The textural classes were determined with USDA triangle.

The total carbon was measured according to the Anne method and nitrogen according to the Kjeldhal method. The organic matter content (OM) was calculated from the carbon content of the sample (% OM = % C x 1.72). The $\frac{C}{N}$ ratio was calculated for a global appreciation of the organic matter quality.

The pH was determined by electrometry in a 1:2.5 ratio solution. The pH was measured successively in distilled water (pH water) and in a normal KCl solution (pH KCl).

3.3 Evaluation of soils structure quality and their sensibility to erosion

Soil structure assessment was done by calculating:

- the stability index (R) and the index of battance (IB), proposed by Remy and Martin-Lafleche (1974), quoted by Morel, 1989 [12]; R equation for soils with pH < 7 is considered in this study.
- the destructuration index (St), with the function presented by Pieri (1989) [13].

The indexes R, IB and St are presented respectively by Eq1, Eq2 and Eq3:

$$R = \frac{1{,}5*\mathrm{FS} + 0{,}75*\mathrm{CS.}}{(\mathrm{C}+10*\mathrm{OM})} \qquad \text{(Eq1)}$$

$$\mathrm{IB} = 5\,(R - 0.2) \qquad \text{(Eq2)}$$

$$St = \frac{OM}{(C + FS)} * 100 \qquad \text{(Eq3)}$$

FS, CS, C, OM, are respectively soil contents (%) in fine silt, coarse silt, clay, and organic matter.

3.2.4 Evaluation of hydraulic conductivity (Ks)

Hydraulic conductivity (Ks) has been evaluated using the method of Saxton et al (1986) [14]. This method use the particle size distribution in soil. Here, Ks has been evaluated only for top soil.

3.2.4 Evaluation of the soil erodibility index (K)

Soil erodibility index, noted K, has been evaluated according the nomograph of Wischmeier et al (1971) [15]. The soil properties used in this nomograph are the contents in silt, fine sand and organic matter, structure type and permeability.

4. Results and discussion

4.1 Typology and morphology of soils

In Korola watershed, 3 main soil types (soil 1 to soil 3) are chosen by farmers for cropping cotton (Table 1). All these soils are located on a sloping glacis. The soil1 (*Guinin dugukolo*)

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is around 75 cm deeph and limited by a slab of ferruginous cuirass. It occupies the upstream position, in direct contact with a cuirassed relief. It can be connected to Soil 2 (*Mura dugukolo*), when the original alterite are mainly from schist, or soil 3 (*Cincin dugukolo*), when the original alterite are mainly from sandstone. Soil 2 and soil 3 profiles are without indurated layer in the first 150 cm. The studied soils are enough depth; that can be explain by the high sensibility of schist (a major rock of the watershed) to alteration. Concerning the drainage of all these soils, two parts are usually distinguished in the profile: a good drainage layer (0 to 70- 80 cm) and a poor drainage layer (80 to 100 cm and more). The presence of rock, ferruginous cuirass or clayey material at the base of soil profile is a factor limiting the drainage.

Table 1: Some morphological characteristics of the different soils

Soil	Soil profile deeph	Tichness and color of soil horizon		
		1	2	3
Sol1 Guinin dugukolo	60 to 75 cm	0-9cm ; 5YR5/6, yellowish red	9-24 cm ; 7.5YR7/8, reddish yellow	24-72 cm ; 7.5YR8/8, reddish yellow
Sol2 Mura dugukolo	> 120 cm	0-10 cm ; 10YR5/4, yellowish brown	10-30cm ; 7,5YR6/8, reddish yellow	30-50 cm ; 7.5YR8/8, reddish yellow
Sol 3 Cincin dugukolo	> 120 cm	0-20 cm ; 5YR5/3 reddish brown	20-90 cm ; 7.5YR7/8, reddish yellow	90-120 cm 7.5YR8/6, reddish yellow

Indigenous and scientific classifications of the soils are shown in Table 2.

Table 2: Classification of the soils

Soil	Soil classification		
	Local system	French system CPCS (1967)	Soil taxonomy USDA
Sol 1	Guinin dugukolo	Sol ferrugineux tropical lessivé induré sur cuirasse	Petroferric Haplustults
Sol 2	Mura dugukolo	Sol ferrugineux tropical lessivé à pseudogley	Oxic haplustalfs
Sol 3	Cincin dugukolo	Sol ferrugineux tropical lessivé à tâches et concrétions	Plinthic haplustalfs

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4.2 Soils analytical characteristics

Particle size distribution of the soils are shown in table 3. Soil 1 and soil 2 are rich in silt, especially the top horizons that are silt loam. The rate of clay increase in third horizon of soil1 and the second and third horizon of soil2. Concerning soil3, a high content in sand is noted in all horizons, especially in the top one.
The high levels of fine particles in soils 1 and 2 can be explained by the existence of schist as a major parental material in Korola watershed. The preponderance of sandstone in some parts of the watershed explains the presence of soil3, rich in sand at all depths.

Table 3: Soils texture in Korola watershed

Particle size distribution and textural class	Soil 1 Guinin dugukolo			Soil 2 Mura dugukolo			Soil3 Cincin dugukolo		
	0-9 cm	9-24 cm	24-72 Cm	0-24 cm	24-44 cm	24-120 cm	0-20 cm	20-90 cm	90-120 cm
Clay (%)	12.9	12.0	51.2	20.2	37.6	44.0	3.3	19.2	18.5
Fine silt (%)	23.6	43.3	11.1	4.0	0.3	11.3	4.4	1.9	2.6
Coarse silt (%)	51.8	38.6	27.1	72.5	58.6	39.1	14.0	27.1	39.0
Sand (%)	11.7	6.1	10.6	3.2	3.6	5.6	74.7	39.3	37.3
Textural class	Silt loam	Silt	Clay	Silt loam	Silty clay loam	Silty clay	Loamy sand	Sandy loam	Loam

Organic matter (OM) characteristics and pH of the soils are shown in table 4. Concerning organic matter, soils contents are very low (less than 1%). The soils are much mineralized, as shown by the values of C/N (Table 4). The values of pH show that the soils are low-acid, with the exception of soil 1. In this last soil, top horizon is very acidic (pH water = 4.0). Acidification risk is high ($\Delta pH \geq 1$) in the all soil types.
The low levels of organic matter of these soils can be explained by adverse biomass management practices such as the export of crop residues. Soil low content in OM has been reported by many authors working on soils of West Africa savannah regions [16, 17].

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Table 4: Soils organic matter and pH in Korola watershed

Analytical characteristics		Soil 1 Guinin dugukolo			Soil 2 Mura dugukolo			Soil3 Cincin dugukolo		
		0-9 cm	9-24 cm	24-72 cm	0-24 cm	24-44 Cm	24-120 cm	0-20 cm	20-90 cm	90-120 cm
Organic matter (OM)	C (%)	0.52	0.58	0.12	0.29	0.12	0.12	0.13	0.26	0.3
	N (%)	0.05	0.04	0.03	0.04	0.04	0.03	0.02	0.02	0.05
	C/N	10	15	4	7	3	4	6.5	13	6
	OM (%)	0.9	1.0	0.2	0.5	0.2	0.2	0.2	0.46	0.06
pH	pH eau	4.0	5.5	5.6	5.7	5.7	5.7	6.9	5.0	6.0
	pH kcl	3.6	4.0	4.0	4.2	4.1	4.0	5.3	4.9	4.9
	ΔpH	0.4	1.5	1.6	1.5	1.6	1.7	1.6	0.1	1.1

4.3 Soil hydraulic properties

According hydraulic conductivity (Ks) values shown in table 5, soils 1 and 2 have poor permeability while soil 3 is permeable.These values of Ks are explained by the particles size distribution in top soil.

Table 5: Cotton soils hydraulic conductivity (Ks) in Korola watershed.

Soil type	Soil 1 Guinin dugukolo	Soil 2 Mura dugukolo	Soil3 Cincin dugukolo
Ks ($cm.hr^{-1}$) of the top soil	2.5	1.4	7.3

4.4 Soils structure quality

In table 6, values of some soil structure indexes are shown: index of stability (R), index of battance (IB) and index of destructuration (St). R and IB are very high (R > 2; IB > 9) attesting instable structure and high sensibility to battance. Concerning the index St, the 3 soil types have St < 5%. So, they are Soils are unstructured and have a high sensibility to erosion. Comparing all the soils, the structure of soil 2 is the best, whereas that of soil1 is the worst.

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The poor structure of the studied soils can be explained by the high silt content and the low organic matter content. Indeed, it is sufficiently established that the silt-rich horizons have an unfavorable structure [18]. On the other hand, a low organic matter content is not favorable to the formation and maintenance of aggregates in the soil. In a very general way, the texture and the organic matter content are cited among the factors that influence the structural stability of the soil [19].

Table 6: Top soil structure quality indexes in Korola watershed

Soil type	Soil 1 Guinin dugukolo	Soil 2 Mura dugukolo	Soil3 Cincin dugukolo
R	3.4	2.4	3.3
IB	15.9	11.0	15.4
St	2.5	2.1	2.5

4.5. Identified values of soils parameters for soil erodibility (K) calculation

Following the characterization of the soils, erodibility K has been calculated with parameters values shown in Table 7.

Table 7: Soil parameters values used for K calculation

Parameter	Soil 1 Guinin dugukolo	Soil 2 Mura dugukolo	Soil3 Cincin dugukolo
Structure class	2	3	2
OM content (%)	0.9	0.5	0.2
Silt content (%)	75,4	76,6	18,4
Very fine sand content (%)	2,6	0,8	38,8
Permeability class	3	4	2

4.5 Soils erodibilityn (K)

Table 8 shows that soil 3 has a very low erodibility compared to soil 1 and 2. Comparing to K values of West African soils, measured in the 1980s [4, 20], it should be noted that:
- soil 1 has an erodibility like gravelly soils;
- soils 2 and 3 have a value of K exceeding that of tropical ferruginous soils (K= 0,20 à 0,30).
It has been reported by many scientists that, soil texture and its content in organic matter have a high influence on K. In this order, for example, Stone et Hilborn (2000) [21] show for a loam silt soil of Canada: K= 0.41 when OM < 2% ; K= 0.37 when OM > 2%.

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The better erodibility of soil 3 in this study can be mainly explained by its high content in coarse sand.

Table 8: Index K of Korola watershed soils.

Soil type	Soil 1 Guinin dugukolo	Soil 2 Mura dugukolo	Soil3 Cincin dugukolo
K	0.44	0.50	0.09

5. Conclusion

In korola watershed, there 3 soils type chosen by the farmers for growing cotton. They are quite deep. The high content in silt and the low content in organic matter, characterizing these soils, promote poor soil structure. All these soils have a high susceptibility to erosion.

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