Properties and sensibility to physical degradation of soils under cotton cropping in Korola watershed, Sikasso region, Mali

Abstract

Soil physical, chemical and biological degradation is a 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 was introduced during the 1960s. Soil degradation is 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 is needed in order to choose better strategies to improve their management and productivity. The methodology used in the present study includes soil profile descriptions, particle size analyzes, carbon, nitrogen and pH measurement, the use of pedotransfer functions to assess soil structure and their sensitivity to erosion. In Korola watershed, 3 soil types (soil1, sol2, sol3) are selected by farmers for cotton cropping. Soil1(*Guinin dugukolo*) and soil2 (*Mura dugukolo*) have a high amount in silt, while soil3 (*Ciencien dugukolo*) 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 types soils) indicate a unfavorable structure. The destructuration index (St) indicate a high sensibility to soil erosion.The values of soil erodibility index (K) 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 a global problem. It is noted that the mapping of soil degradation shows a varying magnitude of the problem worldwide. In the tropics, accelerated soil degradation affected as much as 500 million ha [1]. Soil degradation leads to a reduction or even a loss of its productivity and crop yields. In addition, it negatively impacts water resources and environment moderating capacity. In 1995, the mean loss of yield due to past erosion in Africa, was estimate to 9% [2]. For this continent, yield reductions by 2020 may be 16.5%, if acccelereted erosion continues unabated. 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 [3, 4, 5, 6]. 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 was introduced in this zone during the 1960s. It should be noted that, land degradation is considered as a serious handicap to the improvement of cotton production in Western and Central Africa [7, 8, 9]. Cotton farming is highly mechanized (plowing, hilling, etc.) and promotes rapid soil degradation in Sudanese areas of subSaharan Africa. A program for improving the integrated management of soil fertility under cotton cultivation must take into account soils diversity and be based on a good knowledge of their fundamental

properties and their behavior. The purpose of the study in Korola watershed is to identify and to characterize the types of soils affected to cotton cultivation by farmers.

2. Study area

The Korola watershed (Figure1) is a sub-basin of Bagoé medium. The coordinates at the outlet are 6°23'45''W and 11°42'54''N ; the altitude is 304 m. It covers 1245.3 km^2 in 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. Figure1 shows the location of the Korola watershed on the map of Mali (upper part). The boundaries of the watershed are shown in the lower part.

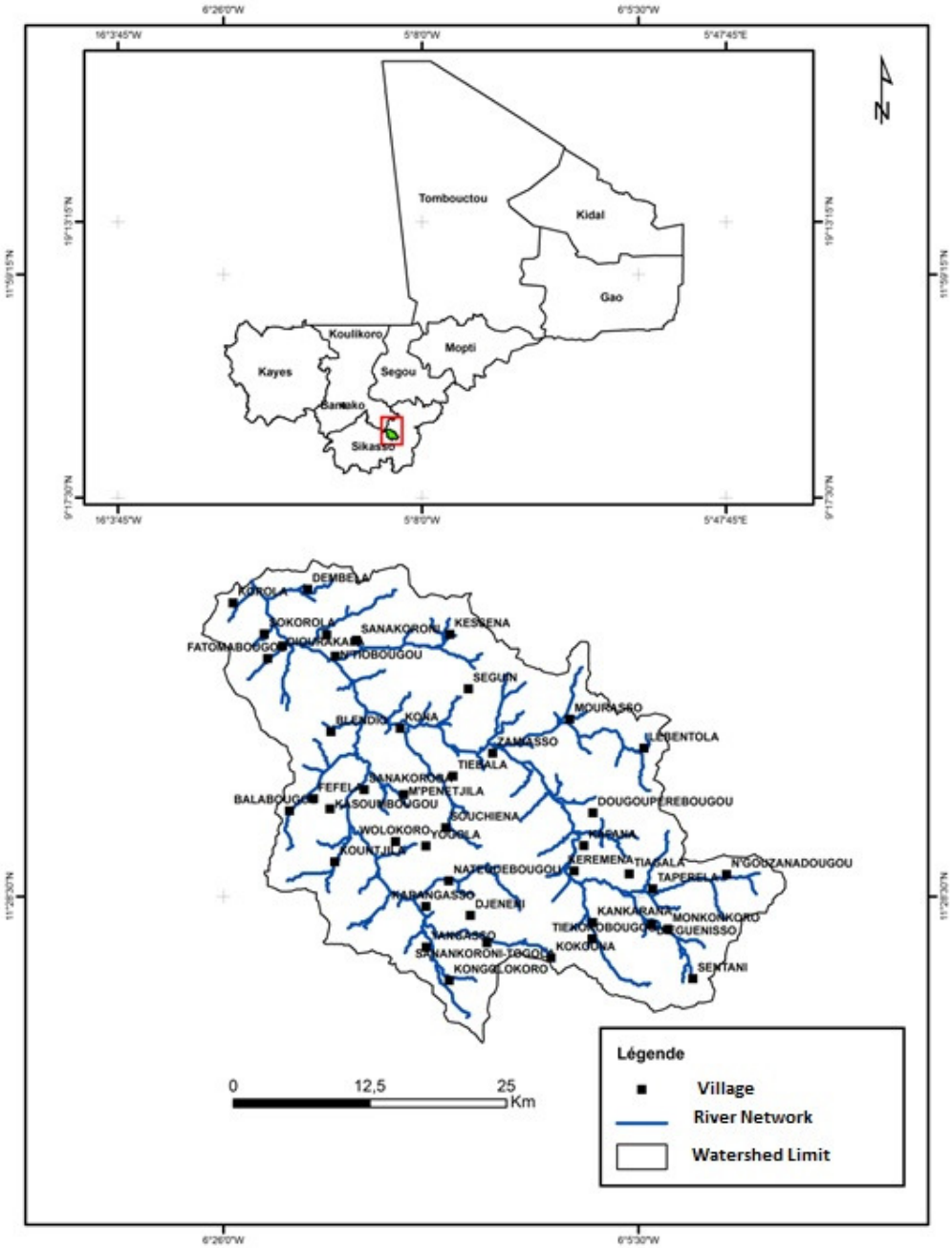

Figure 1: Location of the study area

Korola watershed is located in the western Sudano-Sahelian belt, a semi-arid region. There is only one rainy season (from May to October) 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 potential evapotranspiration (PET) are variable from 1634 to 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°). Monthly minimum temperature, is higher in April (24.3°) and lower in January (12.9 °).

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 were developed from ferruginous cuirass material and colluvium [10].

The watershed is located in a savannah ecosystem. 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.

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. Other annual crops that include rice, fonio, and groundnuts, 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 [11]. Livestock are mainly cattle, sheep, goats and donkeys.

3. Methods

3.1 Soil morphological characterization and sampling

The pedological descriptions were carried out in pits (measuring 1m 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 with the code Munsell. Detailed soil descriptions were conducted on 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 laboratory analyzes

They have focused on the particle size, total carbon, total nitrogen, and the pH. The protocols of these analyzes [12], are presented here in a simplified manner. Particle size distribution was determined according to the international method modified by using Robinson's pipette. So it is possible to quantify clay, different fractions of silt and sand. 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 (OM) content 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 H_2O) and in a normal KCl solution (pH KCl). In the solution there are 1 part for soil and 2.5 parts for H_2O or 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 [13] ; R equation for soils with pH < 7 is considered in this study.
- the destructuration index (St), with the function presented by Pieri (1989) [14].

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) [15]. 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) [16]. The soil properties used in this nomograph are the contents in silt, fine sand and OM, structure type and permeability.

4. Results and discussion

4.1 Typology and morphology of soils

In Korola watershed, 3 main soil types (soil1, soil2 and soil3) are chosen by farmers for cropping cotton (table1). All these soils are located on a sloping glacis. The soil1 (*Guinin dugukolo*) is around 75 cm deep 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 Soil2 (*Mura dugukolo*), when the original alterite are mainly from schist, or soil3 (*Cincin dugukolo*), when the original alterite are mainly from sandstone. Soil2 and soil3 profiles are without indurated layer in the first 150 cm. 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 studied soils have enough depth; that is explained by the strong pedological evolution occurring in the watershed. The presence of rock, ferruginous cuirass or clayey material at the base of soil profile is a factor limiting the drainage.

Table1: Some morphological characteristics of the different soils

Soil	Soil profile location			Soil profile depth (cm)	Tichness and color of soil horizon		
	Altitude (m)	Longitude	Latitude		1	2	3
Sol1 *Guinin dugukolo*	340	6°14'48''W	11°32'42''N	60 to 75	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*	309	6°20'30''W	11°39'36 ''N	> 120	0-10 cm ; 10YR5/4, yellowish brown	10-30cm ; 7,5YR6/8, reddish yellow	30-50 cm ; 7.5YR8/8, reddish yellow
Sol3 *Cincin dugukolo*	321	6°12'54''W	11°35'45''N	> 120	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 table2.

Table2: Place of the soils in different classification system

Soil	Soil classification		
	Local system	French system CPCS (1967)	Soil taxonomy USDA
Sol1	*Guinin dugukolo*	Sol ferrugineux tropical lessivé induré sur cuirasse	Petroferric Haplustults
Sol2	*Mura dugukolo*	Sol ferrugineux tropical lessivé à pseudogley	Oxic haplustalfs
Sol3	*Cincin dugukolo*	Sol ferrugineux tropical lessivé à tâches et concrétions	Plinthic haplustalfs

4.2 Soils analytical characteristics

Soil1 and soil2 are rich in silt, especially the top horizons that are silt loam (table 3) . 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.

Table 3: Soils texture in Korola watershed

Soil attribute	Soil1 *Guinin dugukolo*			Soil2 *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

The soils had very low OM content (less than 1%), which is characterized by a strong biological activity 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 soil1. In this last soil, top horizon is very acidic (pH H_2O = 4.0). Acidification risk is high ($\Delta pH \geq 1$) in the all soil types.

Table 4: Soils organic matter and pH in Korola watershed

Analytical characteristics	Soil1 *Guinin dugukolo*			Soil2 *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
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 H_2O	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

The high levels of fine particles in soil1 and soil2 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.
The low levels of OM of these soils can be explained by adverse biomass management practices (the export of crop residues, the practice of bushfires, etc). Soil low content in OM has been reported by many authors working on soils of West Africa savannah regions [17, 18].
In view of the morphological and analytical characteristics of soils, it is noted that farmers choose the best soils of the catchment for growing cotton. Indeed, the other soils of the watershed are generally shallow and gravelly. Such soils observed in the Sudanian areas of Mali are of low agricultural value [19]. The choice of the farmers is based on their good knowledge of the soils of their environment and the pedological requirements of the cotton cultivated here, since 5 to 6 decades. These findings confirm the numerous studies attesting that local populations have good relationships with their environment [20, 21].

4.3 Soil hydraulic properties

Hydraulic conductivity (Ks) values imply that, soil1 and soil2 have poor permeability while soil3 is permeable (table 5).
These values of Ks are explained by the particles size distribution in top soil. The high silt content explains the low permeability of soils1 and soil2, compared to the soil3. It should be noted that in the semi-arid regions of West Africa, soils permeability can be greatly influenced by the presence of erosion crust [22].

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

Soil type	Soil1 *Guinin dugukolo*	Soil2 *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 unstructured and have a high sensibility to erosion. Comparing all the soils, the structure of soil2 is the best, whereas that of soil1 is the worst.
The poor structure of the studied soils can be explained by the high silt content and the low OM content. Indeed, it is sufficiently established that the silt-rich horizons have an unfavorable structure [23]. On the other hand, a low OM 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 [24].

Table 6: Top soil structure quality indexes in Korola watershed in Mali

Index	Soil1 *Guinin dugukolo*	Soil2 *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

NB : R , IB and St are respectively index of structure stability, index of battance and index of destructuration

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 the index 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 erodibility index (K)

Table 8 shows that soil3 has a very low erodibility compared to soil1 and soil2. Comparing to K values of West African soils, measured in the 1980s [5, 25], it should be noted that:
- soil1 has an erodibility like gravelly soils;
- soil2 and soil3 have a value of K exceeding that of tropical ferruginous soils (K= 0,20 à 0,30).

The three types of soils all belonging to the great class of tropical ferruginous soils, however have different K values. That can be mainly attribute to their texture and OM content. Indeed, it has been reported by many scientists that, soil texture and its content in OM have a high influence on K [26, 27]. Concerning OM content, for example, Stone et Hilborn (2000) [26] show for a loam silt soil of Canada: K= 0.41 when OM < 2% ; K= 0.37 when OM > 2%. The better erodibility of soil 3 in the present study can be mainly explained by its high content sand. The nomograph of Wischmeier, which is used here, is a widely and reliable method for soil erodibility evaluation [4, 28].

Table 8: Soil erodibility index (K) of Korola watershed soils

Soil type	Soil1 *Guinin dugukolo*	Soil2 *Mura dugukolo*	Soil3 *Cincin dugukolo*
K	0.44	0.50	0.09

5. Conclusion

The study made it possible the identification of the soils used for cotton growing in the Korola watershed. These soils are chosen by farmers fromrelevant ethnopedological knowledge. The morphological characterizations of these soils, followed by analyzes of

samples in the laboratory, made it possible to know some of their fundamental properties, such as particle size distribution and organic matter contents. Calculation of structural indexes with pedotransfer functions made it possible to know that the soils have unfavorable structure and a high susceptibility to erosion.These soil behaviors are mainly explained by their high silt content and low organic matter content.

6. Recommendation

The soils of Korola watershed are fragile, sensitive to physical degradation and erosion. To avoid irreversible degradation, inputs of organic matter and the application of soil conservation techniques are necessary.

7.References

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