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Effect of land use changes on some important soil properties in cotton-based farming system in Burkina Faso

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ABSTRACT

Continuous and intensive cropping without restoration of soil fertility has depleted the nutrient base of most soils in the semi arid zone. A field survey was carried out in 2000 in Bala village in the cotton production zone of western Burkina Faso to assess the effect of land use changes on soil chemical and physical changes. The methodology consisted of land use analysis at contrasted periods, field sampling and measurements, and farmers' interview. Land use analysis was done at three periods: 1952, 1981 and 1999. Soil samples were taken in farmers' fields selected on the basis of their equipment level and the cultivation duration. Two fallows were selected and considered as control situation. Aerial photos analysis showed that the proportion of the land under cultivation was increased at about 38.3% from 1952 to 1999. Soil chemical analysis showed that soil total P and K were significantly higher in soils manually cultivated than in soils cultivated with animals and tractors. Soil pH was lower in motorized farmers' fields than in the other categories. Soil organic matter and N content were not affected by all the studied factors. The percentage of sand in the soil increased with the performance of the equipment. The opposite situation was observed with soil silt content. Soil stability was not significantly affected by any of the factors. But the numerical values showed a more stable soil structure under fallows than when soils were cultivated. From the results, it appeared that the fundamental cause of land degradation in the area is the farming system than the nature of the crop being grown.

Keywords: land use, cotton system, soil fertility, cultivation duration, equipment.

INTRODUCTION

The economy of Burkina Faso is essentially based on agriculture. In fact, agriculture contribution to the national GDP is 36% and 85% of the rural population is involved in farming. The subsistence of local population is based exclusively on natural resources and the farming system in the past was the shifting cultivation system (Bationo et al., 1998). During the last decades, the cultivated lands were significantly extended (Roose, 1994). The fallowing technique used in the past to restore soil fertility was almost abandoned and lands are continuously cropped without any fertilization plan (INERA, 2003). According to Vlaar (1992), the extension of the cultivated lands is one of the most important land degradation causes in the region.

Cotton is the main cash crop in the country. The production of seed cotton was significantly increased during the past two decades (Schwartz, 1993; SOFITEX, 1999). Cotton is often indicated to contribute more to natural resources degradation than any other crop. Up to date, all the studies on crop production in the area were mainly focused on the system inputs such as fertilizers and outputs such as the quantity and the quality of the end product (Dakouo, 1994; Schwartz, 1993). Few results are available on the fields' extension on soil chemical and physical properties changes. The objective of the current work was to determine the effects of cotton production on soil characteristics changes; assuming that these effects will be different depending on the level of equipment used by the farmers and the duration of the land under cultivation.

MATERIALS AND METHODS

Study site

This investigation was done in 2000 in Bala, a village located in the cotton production zone of western Burkina Faso (11°33' N and 4°01' W) in the South Soudanian Zone. The total land extent of the village is about 8592 ha (Laine et al., 1990). The natural vegetation is a typical South-soudanian savannah. The annual rainfall in the area ranged between 957 and 1100 mm with 4 to 5 months of cropping period (May-September). The main soil types encountered in the village are Regosols (FAO/UNESCO classification) (Mando, 2000). The texture of these soils is mainly sandy and poor in N and P (Pieri, 1989).

Mapping the land-use

In order to assess the land use changes in Bala, a map approach was used. The maps were drawn up using aerial photographs collected from Institut Géographique du Burkina (IGB). For map analysis, the GIS software ATLAS GIS (windows version) was used to estimate the diversity and surfaces of the different land use types identified from interpretation of aerial photos. The following categories of land use units were used to characterize the landscape: (a) cultivated fields; (b) fallows; (c) woody savannah; (d) bush savannah; e) forest along river f) artificial vegetation or tree plantations. After drawing the draft maps, a field checking was done. Quantitative analysis of woody vegetation was carried out using SPSS version 12. Arithmetic means of tree density were computed for each land use type.

Three contrasted periods: 1952, 1981 and 1999 were used to produce three maps. These years were selected because 1952 corresponds to the year when cotton was introduced in the area; 1981 corresponds to the beginning of cotton cultivation expansion in the area and 1999 corresponds to the pick in cotton production in the area. The maps from the three periods were considered in order to better understand the main changes that occurred in 30 years (1952-1981), 10 years (1981-1999) and 47 years (1952-1999).

Fields survey

Three land use types were taken into account for field inventory: (i) cultivated lands, (ii) fallow of short duration (less than 5 years), (iii) and fallow of long duration (more than 20 years). Fallows aged between 10-20 years were not present in the village at the time of the study, justifying why they were excluded from the sample. Fallows were used as control plots to be compared to the cultivated treatments. Two types of fallows were selected: a) short term fallow; i.e. < 5 years fallowing, b) long term fallow; i.e. 20 years or more fallowing.

The fallow which corresponds to traditional soil fertility management technique consists of laying out the soil without cultivation where the natural vegetation (grasses and trees) grows.

In the cultivated lands, a further subdivision of field types was made, based on two criteria: level of mechanization and field ages.

- For the level of mechanization, farmers were classified according to the equipment they were using. Four classes were considered: 1) manual agriculture class corresponds to farmers without any modern equipment; 2) partially mechanized class where farmers are using animal strength to perform some field operations like tillage and/or weeding, while the other operations are done manually; 3) completely mechanized farmers class using animal strength to perform all the field operations; 4) motorized class using a tractor for field operations.
- Three types of field ages were considered: a) fields continuously cultivated during < 10 years, b) fields continuously cultivated during 10-20 years; c) fields cultivated during > 20 years. Forty eight (48) plots were selected in cotton fields for

sampling and measurements; sixteen (16) plots in each field age.

The size of the plots was 100 m x 100 m (1 ha) in cultivated fields and 50 m x 50 m (0.25 ha) in fallows.

Sampling, measurements and farmers interview

Farmers were interviewed on their cropping system, their trees and soils fertility management in the past and at present, using a questionnaire. In each survey plot (in the cultivated fields and in the fallows) an inventory was done on trees (number of species, height and diameter of trees). Soil samples were taken randomly at a depth of 0-20 cm in experimental plots. The current paper focuses on land use and soil properties changes. Results on vegetation inventory are presented in another paper.

Determination of Soil chemical and physical properties

Soil samples were sun dried, grounded and sieved through a 2 mm mesh prior to analysis. Soil total organic matter and N contents were determined using Walkey and Black (1965) and Kjedahl digestion methods respectively. For total P and K determination, soils were digested in a sulphuric acid solution. Total P and K were measured by colorimetry and flame photometry, respectively. Soil pH water was measured using a soil: water ratio of 1: 2.5. Soil particles (sand, silt, clay) size was determined using Féodoroff (1960). Soil stability index (SI) was then determined using the ratio % clay: % silt. For SI > 2.5, soils were considered slippery with an unstable structure and for SI < 2.5 soils were considered stable (Féodoroff, 1960).

Data analysis

The analysis of variance was performed using SPSS software version 11. The means were separated using the least significant difference of means at probability of 5%. For photos analysis, ATLAS GIS software was used.

RESULTS

Land use changes from 1952 to 1999

In 1952, 91% of the village lands were uncultivated (represented by fallows, woody and bush savannah and forest along rivers) (Table 1). 29 years later in 1981, 82% of Bala lands were uncultivated i.e. 9% less than in 1952. In 1999, only 52% of the lands in the village were uncultivated; 30% less than in 1981 and 39% less than in 1952 (Table 1). From these results it appeared that from 1981 to 1999 there was a sharp increase in cultivated lands and a significant decrease in the savannah zone and fallows. The maps from the three periods showed an appearance of tree plantation areas in 1981 and 1999. These maps indicate also different agricultural landscapes during the three periods. In 1952 and 1981, the cultivated fields were small and distributed all over the village. In 1999, the agricultural landscape was characterized by large surface of continuous fields which is characteristic of high agriculture pressure.

Table 1: Evolution of lands occupation in Bala at three periods. Bala, 2000, Burkina Faso.

	Extent (ha)			**Land use rate (%)**		
	1952	**1981**	**1999**	**1952**	**1981**	**1999**
Fields (cotton, maize, sorghum, rice etc.)	781.1	1505.5	4146.6	9.1	17.5	48.3
Fallows	220.3	727.9	170.7	2.6	8.5	2.0
Woody savannah	4518.2	1747.7	1121.6	52.6	20.3	13.1
Bush savannah	2338.2	3872.8	2414.3	27.2	45.1	28.1
Forest along rivers	734.3	734.3	734.3	8.5	8.5	8.5
Trees plantation	0	3.6	4.6	0.0	0.0	0.1

Evolution of soil chemical properties

The soils of Bala showed a pH value ~5.4 (Table 2). Soil pH was significantly affected by the equipment level. In fact, soil pH was lower in fields cultivated with the tractor compared to fields cultivated manually or with animal strength.

Soil organic matter was not affected significantly by any of the studied factors. However, it was numerically higher in soils being manually cultivated than in soils where oxen or tractors were used even though these differences were not statistically significant. Table 2 shows also that soil organic matter decreased with cultivation duration.

Soil total nitrogen (N) content was not also affected by any of the factors. Oppositely, soil total phosphorous (P) and potassium (K) were all affected by the equipment being used in the field. The soils content of these two nutrients was significantly higher in fields being manually cultivated than in fields cultivated with animal strength or tractors (Table 2).

Evolution of soil physical properties: Soil texture and stability index (SI)

All the soils were characterized by their high sand content (always > 70%). The percentage of sand significantly increased with the performance of the agricultural equipment. Fields cultivated with animals or tractors showed a higher sand content (Table 3).The results showed also a low soils clay content and this was independent of the cultivation duration or the equipment level. Soil silt content was also affected by equipment. Fields cultivated with tractors and animals showed lower silt content compared to fields manually cultivated.

Soil stability index (SI) was different depending on the fallowing time, the cultivation duration and the equipment level. But none of the studied factors was significant (Table 3). Table 3 shows that soils in the fallows are stable since SI < 2.5. Land being continuously cultivated during 10-20 years showed SI > 2.5 so unstable soil structure, compared to lands being cultivated during less than 10 years or more than 20 years. Equipment level also affected the stability index. In fact, the SI was > 2.5 for soils cultivated with complete animal equipment. Surprisingly the SI was < 2.5 in fields cultivated with tractors.

Table 2: Soils chemical characteristics changes as a function of fallowing period, cultivation duration and equipment. Bala, 2000, Burkina Faso.

		MO (%)	pH water	N (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})
Fallow (n= 32)	<5 years	0.79 (0.09)	5.39 (0.19)	0.30 (0.03)[1]	198.3 (40.2)	408.4 (63.0)
	>20 years	1.08 (0.07)	5.48 (0.16)	0.35 (0.02)	156.1 (41.4)	727.8 (61.9)
	P (5%)	***0.13***	***0.75***	***0.43***	***0.55***	***0.07***
	Significance	**ns**	**ns**	**ns**	**ns**	**ns**
Cultivation duration (n=48)	< 10 years	0.98 (0.08)	5.09 (0.08)	0.30 (0.05)	153.30 (22.2)	664.37 (57.3)
	10-20 years	0.86 (0.09)	5.14 (0.09)	0.19 (0.05)	186.90 (27.0)	533.39 (69.6)
	>20 years	0.75 (0.10)	5.21(0.09)	0.20 (0.06)	116.16 (29.8)	531.82 (76.7)
	P (5%)	***0.27***	***0.67***	***0.26***	***0.25***	***0.27***
	Significance	**ns**	**ns**	**ns**[2]	**ns**	**ns**
Equipment (n=48)	Manual	1.05 (0.09)	5.34 (0.08)	0.33 (0.07)	257.16 (33.4)	858.2 (85.9)
	Partly mechanized	0.73 (0.09)	5.32 (0.08)	0.21 (0.06)	112.30 (31.9)	568.7 (82.2)
	Completely mechanized	0.76 (0.07)	5.09 (0.06)	0.20 (0.06)	118.03 (31.2)	362.9 (80.4)
	Motorized	0.76 (0.09)	4.99 (0.08)	0.19 (0.05)	121.04 (25.5)	516.2 (65.6)
	P (5%)	***0.06***	***0.007***	***0.45***	***0.02***	***0.007***
	Significance	**ns**	**s**	**ns**	**s**[3]	**s**

* Between brackets = standard errors, ns = not significant at p<5%, s = significant at p<5%, N= Nitrogen, P= phosphorous, K= potassium

Table 3: Soils physical characteristics changes as a function of fallowing period, cultivation duration and equipment. Bala, 2000, Burkina Faso.

		Sand (%)	Silt (%)	Clay (%)	Stability index (SI)
Fallow	<5 years	76.0 (3.12)	12.0 (1.58)	12.1 (2.10)[1]	0.96 (0.16)
(n= 32)	>20 years	72.0 (3.16)	10.1 (1.52)	18.0 (1.80)	0.56 (0.10)
	P (5%)	***0.46***	***0.46***	***0.17***	***0.22***
	Significance	**ns**	**ns**	**ns**	**ns**
Cultivation	< 10 years	78.5 (1.61)	13.2 (1.25)	8.29 (1.08)	1.95 (0.42)
duration	10-20 years	81.2 (1.96)	13.6 (1.52)	5.18 (1.31)	2.75 (0.50)
(n=48)	>20 years	79.1 (2.16)	13.3(1.68)	7.62 (1.44)	2.02 (0.56)
	P (5%)	***0.56***	***0.98***	***0.21***	***0.45***
	Significance	**ns**	**ns**	**ns**[2]	**ns**
Equipment	Manual	74.3 (2.42)	17.7 (1.88)	8.03 (1.61)	2.42 (0.62)
(n=48)	Partly mechanized	82.3 (2.31)	10.4 (1.80)	7.25 (1.55)	1.65 (0.59)
	Completely mechanized	78.1 (2.26)	14.8 (1.76)	7.11 (1.51)	2.52 (0.58)
	Motorized	83.7 (1.85)	10.5 (1.44)	5.73 (1.23)	2.35 (0.48)
	P (5%)	***0.04***	***0.03***	***0.69***	***0.72***
	Significance	**s**	**s**[3]	**ns**	**ns**

* Between brackets = standard errors, ns = not significant at p<5%, s = significant at p<5%

DISCUSSION

The maps from aerial photos showed decreasing natural vegetation and an important extension of cultivated lands from 80s to 90s (Figure 1). According to Roose (1994), the important extension of cultivated lands in the area can be attributed to a demographic growth leading to important food need for an increasing population. For farmers, the use of modern equipment (oxen and tractors) and the extension of cotton production area are the reasons for that important pressure. The results from previous surveys carried out in the area (Bélem, 1985; Parkan, 1986; Schwartz, 1991) are in the same line as farmers. These workers concluded that during the 80s, many big exploitations were divided into many small households scattered over the village. The extension of cultivated area is the consequence of the creation of many new fields. Finally, the expansion of cultivated lands observed during the 80s can be attributed to three main factors: demographic growth, extension of cotton areas and introduction of modern equipment. However, the results showed no significant impact of the extension of cultivated lands on soil chemical and physical properties. On the other hand, the cultivation duration and the level of mechanization seem to affect soil properties.

The tendency observed on the possible effect of cultivation duration on soil organic matter can be attributed to the fact that under cultivation, there is a rapid mineralization of soil organic stock especially in the tropical area. For Delville (1996), the rate of mineralization in the area is 2% year^{-1}, which corresponds to a mineralization of 640 kg of organic matter ha^{-1} year^{-1} for the first 20 cm of a soil. To compensate the losses, 2 tons of organic manure with 30% organic matter should be supplied every year. These losses are not compensated by a consequent fertilization leading to a soil mining from year to year.

The results obtained for soil total N content are in line with those reported by Gandah et al. (2003) for Niger. For these authors, nitrogen supplied by rain and wind borne dust, and chemical and organic elements applied by farmers permit the maintenance of a minimum soil fertility level.

The impact of equipment performance on soil P and K content can be attributed to the fact that P and K are immobile and located in the topsoil. Ploughing leads to an even distribution of the nutrients in the soils (Cruz, 1982). Soil structure degradation in subsistence farming is reported in comparable soil physical characteristics as those reported in our survey (Douglas et al., 1999). The continual use of tillage implements over long periods of time frequently results in the formation of dense plough pans containing few pores large enough to be penetrated by crop roots. Soane and van Ouwerkerk (1994) reported that the hoofs of horse and oxen have pressures of ground contact up to 150 kPa and 250 kPa, respectively; at least equal or greater than a tractor tyre. These conclusions are similar to our results reported earlier.

Soil structure degradation is a worldwide problem that spans all soils and levels of farming input. Soil structure degradation is not restricted to large, mechanized farms. Human-pulled equipment and draft animals can also cause soil structure degradation.

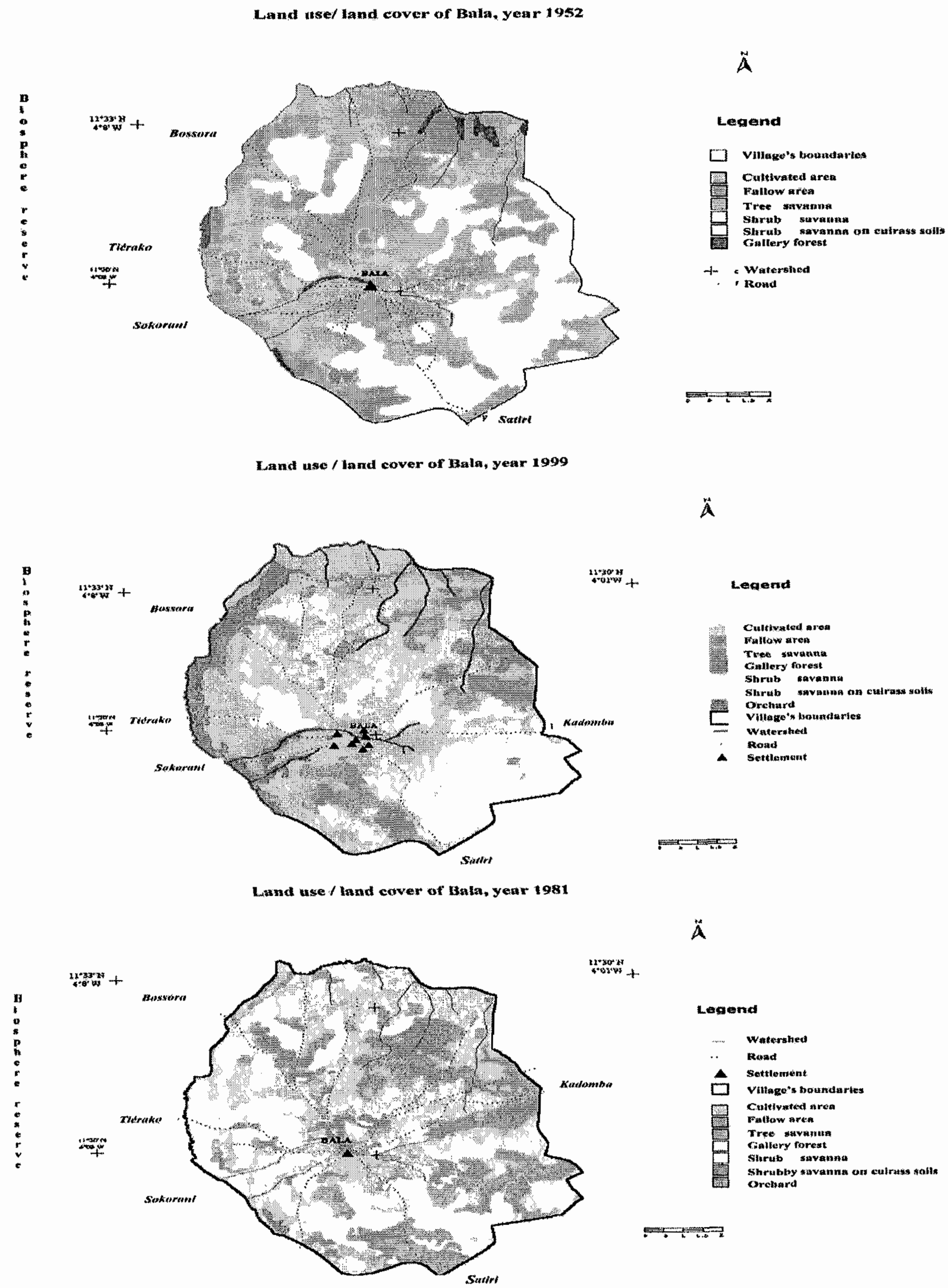

Figure 1: Maps of Bala showing the land use/ land cover in 1952, 1981, and 1999

Conclusion

The current survey showed that changes in soils physical and chemical properties were closely linked to the equipment farmers are using than any other factor. Cultivation methods and techniques remained the key for the conservation and the restoration of soil fertility. The cultivation duration did not significantly affect the soils chemical and physical properties. The survey showed clearly the negative impact of field equipment on soil structure. Overall soil properties changes are not related to the nature of crop being grown, but to the farming system and the equipment level. More investigation should be oriented toward the impact of this equipment for more sustainable use of lands.

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