

IMPACT OF LAND USE EFFECT ON CHEMICAL AND PHYSICAL SOIL CHARACTERISTICS IN COLLINE DEPARTMENT OF BENIN

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Abstract

Identifying sustainable alternatives to shifting cultivation and related bush fallow system in the subhumid tropics is a high priority for achieving food security, and minimising risks of soil and environment degradation (Lal, 1978). Decline in soil quality with intensive cultivation, as is evidenced by the degradation of soil physical and chemical properties, is an important factor finding a sustainable use of soil resources.

The objective of this study was to assess temporal changes in soil physical and chemical properties under land-use and cultivation. The emphasis was on quantifying changes in soil texture, gravel content, bulk density, soil pH, soil organic matter content, CEC, and exchangeable bases as affected by cultivation duration and farming system. In our investigations measurements of soil physical and chemical properties were made on Ferric Luvisols within the study area being the most cultivated soils and covering about 20 % of the study area.

In general, the sand content increased with cultivation (54.6% to 78.3%). In contrast to the sand content, the silt and clay content decreased with cultivation (from 28.1% to 12.0% and 16.3 % to 9.1 % respectively). The bulk density increased over time under land use (1.40 g cm⁻³ in 1992 to 1.57 g cm⁻³ in 1995). The temporal changes in Nt were similar to those of SOC content with a rate of decrease of about 0.05 to 0.08 % year⁻¹ for the 0-20 cm depth (SOC) and at the rate of 0.004 to 0.008 % year⁻¹ for TSN at the same depth. After 10 or 25 years cultivation, available phosphorus increased in maize/cotton rotation system due to the regular application of phosphatic fertilisers for cotton. The Ca²⁺, Mg²⁺ and K⁺ contents show significant differences between woodland or Savanna and cultivated soils. The rate of decline of Mg²⁺ concentration about one-quarter of that of Ca²⁺ concentration. There was a definite trend of decrease in CEC with cultivation in the topsoil. These results confirm soil depletion of N and K in the study area through permanent maize/cotton cultivation in spite of regular application of N P K-fertilisers.

1. Introduction

In 1990 Edouard Saouma wrote that most serious problem of African countries in the future can be that of land degradation (FAO, 1990).

To understand how and why land has become degraded or are likely to become so, one needs some knowledge of the physical environment, population, cultivation history and farming systems.

The traditional land use in Benin since the beginning of the second half of the 19th century has been extensive shifting cultivation (low input agriculture) which has not changed significantly the soil qualities because this traditional farming was based on an alternating crop short-term and long-term fallow system. As long as population pressure was low, the cropping phase was short compared to the fallow period. Three or four years of cropping to ten years or more of fallow, for example allows the accumulation of easily degradable organic matter and some dust to regenerate soil fertility (Gaiser 1993, Herrmann 1996). Where population increases, available land per person is reduced and fallow period must be shortened.

Farming which accounts for 30 % of the gross domestic product in Benin, is the primary or sole source for income for 80 % of the population. At least 60 % of the cropland is under food crops. As the current cropping practices include no soil improvement, no soil maintenance and little or no manuring, soil productivity decreases. When the land is cropped continuously, productivity declines fast (Brabant et al. 1996).

Most soils of the study area are red sandy clay loam soils with or without ferric proprieties (Ferric/ Chromic Luvisols, Ferric/ Humic Alisols, Ferric Lixisols, Haplic Acrisols and Eutric Plinthosols). These soils occur on 35% of the study area and are most cultivated by farmers because tillage is easy. 55% of these soils are Luvisols and therefore this study is concentrated on the degradation of the Luvisols.

For Benin the extensive agriculture, overgrazing, deforestation and wood cutting, extension of cropped fields, shortening of fallow periods and wind and water erosion were named the major reasons for degradation of the land (Roose 1976, Van Diepen 1982, Floquet and Mongbo 1998, Mama 1998). These effects, however, do not explain the specific impact on soil, surface factor and vegetation.

Therefore land degradation can be defined as a process resulting from certain human activities which disturb one or more, or all, of the essential functions of the soil. This reduces, to a greater or lesser degree, the land's capacity to provide for the requirement of human life (Brabant et al 1996).

The most widespread types of land degradation in Central Benin are:

- a) physical degradation: thinning of the organic layer and reduction of the soil depth through water erosion, destabilisation of aggregate structure in the topsoil, surface crusting;
- b) chemical degradation: loss of plant nutrients and acidification;
- c) biological degradation: decrease in organic matter content and reduction of biological activity in the soil.

2. Methodology

In order to maintain and confirm existing data, fields surveys were made by toposequence method with clinometer on about 11000 km². The transects were positioned both along tracks or roads and across the bush. On the surveyed area, more than 1050 observations by auger drillings and profiles were done. Soil profile description were made according to the Guidelines for Soil Profile Description (FAO, 1990).

More than 1000 soil horizon samples were taken. The soil samples were air-dried, ground, sieved to pass a 2 mm sieve and analysed at Centre National d'Agro-Pedologie (CENAP) using methods described by Boko et Tranh (1979). Analyses included: texture, pH (H₂O, KCl), electrical conductivity, (EC) exchangeable cations (Na, K, Ca, Mg), cation exchange capacity (CEC), total carbon, total nitrogen and available phosphorus.

Generally in the study area, the Ferric Luvisols are well to moderately drained soils, brown loamy sand in the topsoil (0-30 cm) and red sandy-clay-loam in the subsoil (30-120 cm). In these soils the gravel content is comprised between 13 % in the topsoil and 44 % under 30 cm. In individual soil with continuous cropping and intensive land use the gravel content became higher in the profile (54 to 70%). The structure was single grain when the soil is poor in organic matter content to platy in the 5 first cm when the soil was long time cultivated. The structure becomes massive with high gravel content or with petroferric phase.

In woodland conditions, the soil is well drained very dark greyish sandy loam in topsoil to red sandy-clay-loam in subsoil. The gravel content increased with the depth. The structure was crumb in the topsoil and subangular blocky to massive in the subsoil.

The objective of this study was to assess temporal changes in soil physical and chemical properties under land-use and cultivation duration. The emphasis was on quantifying changes in soil texture, gravel content, soil pH, soil organic matter content, CEC, and exchangeable bases as affected by cultivation duration and farming system. In our investigations

measurements of soil physical and chemical properties were made on Luvisols within the study area being the most cultivated soils and covering about 20 % of the study area.

3. Results and discussion

3.1 Physical degradation

The most extended form of physical degradation and probably the most severe in the study area is structural surface crust formation (ST1, rough surface made of coalescing loamy-clayey aggregates, Casenave and Valentin 1989). In addition, it is possible to observe erosion and runoff crusts between the ridges. Continuous crusts can be observed on many hundred meters particularly in the degraded savanna and fallow. These crusts decrease water infiltration in the soil and favoured runoff. They also form obstacles to rooting and plant emergence (d'Herbès and Valentin 1997). Casenave and Valentin (1989) demonstrated that, if soil surface is no longer in equilibrium with vegetation and soil fauna, surface crusting is a successional process corresponding to specific degradation stages.

Physical degradation was also expressed by thinning of the organic layer, destabilisation of aggregate structure in the topsoil, the granular structure becomes a layered and platy structure. Continuous cropping and intensive land use also affected the particle size distribution. The data in Table 1 show that land use can have effects on sand content at either 0-20 cm or 20-40 cm depths, and sand content differed between the two depths. In general, the sand content of the both layers increased with increasing time or cultivation duration (54.6% to 82.7% in 0-20 cm).

Table -1: Evolution of soil texture under different land use/cover

Land use/ Cover	Location		Depth 0-20 cm				Depth 20-40 cm			
	Lati.	Long.	Grav.	Clay	Silt	Sand	Grav.	Clay	Silt	Sand
DE1	7.5326	2.078	22.8	16.3	28.1	54.6	21.6	20.9	23.8	59.9
Woodland										
DE2*	7.5315	2.082	18.7	6.0	17.2	75.5	49.8	5.5	15.5	78.2
Savanna										
DE3**	7.5313	2.081	21.3	4.5	17.0	77.2	47.7	6.8	17.7	74.1
Maize/ cotton										
DE4***	7.5324	2.078	53.9	4.5	11.4	82.7	71.3	6.9	11.2	80.9
Maize/cotton										

* secondary savanna, ** 10 years cultivation, *** > 25years cultivation

In contrast to the sand content, the silt and clay content decreased with cultivation duration (from 28.1% to 11.4% and 16 % to 5 % respectively in the topsoil).

Furthermore, the decrease in clay content was consistent, and more pronounced at 0-20 cm depth (about 4 times) than 20-40 cm depth (3 times). The loss in clay and silt contents, which was of about the same magnitude as the gain in sand content, was probably due to erosion and illuviation (Lal, 1996).

The gravel increased on the surface with the cultivation duration. In the case of land use DE4 (25 years of cultivation) the gravel content increased more than two times in the topsoil compared to no cultivated soil (DE1). In the soil depth 20-40 cm, the increase of gravel content is more pronounced (more than 3 times). It is due to the erosion of the toplayers of the soil. Accelerated soil erosion can lead to preferential removal of clay and humus fraction (Lal, 1976).

3.2 Chemical degradation or soil nutrient depletion

Identifying sustainable alternatives to shifting cultivation and related bush fallow systems in the humid and sub-humid tropics is a high priority for achieving food security, and minimising soil and environment degradation (Nye and Greenland, 1962, 1964; Greenland 1974; Lal 1987). Decline in soil quality with intensive cultivation, as is evident by degradation of soil chemical properties, is an important factor searching ways to sustainable use of soil resources. Several experiments conducted in Benin and elsewhere in the tropics have demonstrated a rapid decline in soil chemical properties following deforestation and intensive cultivation (Lal and Kang 1982; Piéri 1989; Azontondé 1993; Igué 1992; Cretenet 1993; Igué and Youssouf 1995; Lal 1996; Gaiser et al. 1999; Graef 1999).

Agboola (1981) reported a rapid decline in soil organic matter content and plant nutrient reserves with intensive cropping. Lal (1976) observed that rapid decline in soil organic matter content, cation exchange capacity, and exchangeable cations was related to accelerated soil erosion. In a 4-year study conducted on Ultisols (Acrisols) in south-central Nigeria, Ghuman and Lal (1991) noted that soil organic carbon and available P decreased with cropping time.

3.2.1 Soil pH

In the Woodland (DE1), the pH (H₂O) was slightly basic (7.5) at depth 0-20 cm and neutral (7.2) in the soil depth 20-40 cm (Table 2). Likewise, in the land use/cover DE2, DE3 and DE4, the pH were neutral in the topsoil (7 to 6.6) but there was a decline in pH with

cultivation time (7.5 to 6.9 and 6.6 when land use/cover DE1 is compared to DE3 and DE4) with a rate of decline of about 0.04 to 0.06 units year⁻¹. A decrease of pH (7.2 to 6.7 and 6.4) is also observed in the soil depth 20-40 cm.

Table 2: Evolution of soil characteristics under different land use/cover (depth 0-20)

Land use/ Cover	Depth 0-20 cm					
	PH (H ₂ O)	PH (KCl)	SOC	TSN	C:N	Pav.
DE1	7.5	6.9	1.8	0.15	12	6
DE2*	7.0	6.6	1.3	0.10	13	2
DE3**	6.9	6.3	1.0	0.07	14	10
DE4***	6.6	5.9	0.6	0.06	10	10

* secondary savanna, ** 10 years cultivation, *** > 25years cultivation

Table 3: Evolution of soil characteristics under different land use/cover (depth 20-40)

Land use/ Cover	Depth 20-40 cm					
	PH (H ₂ O)	PH (KCl)	SOC	TSN	C:N	Pav.
DE1	7.2	6.4	1.0	0.10	10	1
DE2*	6.8	5.9	1.0	0.10	10	1
DE3**	6.7	5.8	0.5	0.06	8	0.5
DE4***	6.4	5.7	0.4	0.05	8	0.4

* secondary savanna, ** 10 years cultivation, *** > 25years cultivation,

3.2.2 Soil organic carbon and total nitrogen

There were significant temporal changes in SOC content at both depths (Tables 2 and 3). The SOC content was 1.8 % at 0-20 cm depth and 1.0 % at 20-40 cm depth in uncultivated or origin soil (DE1) and decreased to 1.0 % after 10 years and to 0.6 % after 25 years of cultivation, with a rate of decrease of about 0.05 to 0.08 % year⁻¹ for the 0-20 cm depth. The SOC content for the 20-40 cm depth decreased from 1.0 % to 0.5 % after 10 years and to 0.4 % after 25 years of cultivation, with a rate of decrease of 0.02 % to 0.05 % year⁻¹. Duration of cultivation also had significant effects on SOC content.

Temporal changes in TSN were similar to those of SOC content (Tables 2 and 3). The TSN was 0.15 % at 0-20 cm depth and 0.10 % at 20-40 cm depth in uncultivated soil (DE1). The TSN also differed significantly between land use/cover, and decreased with cultivation time from 0.15 % in DE1 to 0.07 after 10 years and to 0.06 % after 25 % of cultivation, decreasing

at the rate of 0.004 to 0.008 % year⁻¹ for 0-20 cm depth. Similarly, the TSN for the 20-40 cm depth decreased from 0.10 % in DE1 to 0.06 % and to 0.05 % in DE3 and DE4 respectively, at the rate of about 0.004 to 0.002 year⁻¹.

Comparison of the data of SOC and TSN in Tables 2 and 3 provides some useful information about temporal changes in the C:N ratio for different land use/cover. The C:N ratio was 12 for the 0-20 cm depth compared with 10 for the 20-40 cm depth. Furthermore, the C:N ratio increased to 14 after 10 years and decreased to 10 after 25 years of cultivation. In general, the C:N ratio decreased with cultivation time at a rate of about 0.02 to 0.08 units year⁻¹ for both depths.

3.2.3 Bray-phosphorus

The available phosphorus concentration (P_{av}) in the soils of the study area is very low (Tables 2 and 3). Therefore, P_{av} was 6 mg kg⁻¹ at 0-20 cm depth compared with 1mg kg⁻¹ at 20-40 cm depth (Tables 2 and 3) under land use/cover DE1. After 10 or 25 years cultivation, available phosphorus increased to 10 mg kg⁻¹ at 0-20 cm depth due to the regular application of phosphatic fertilisers for cotton. At 20-40 cm depth, Bray-P content decreased by 50-60 % after cultivation of 10 to 25 years compared to woodland conditions.

3.2.4 Exchangeable cations and cation exchange capacity

The data on Ca²⁺ (Tables 4 and 5) show significant differences between woodland (DE1) and cultivated soil (DE4). The Ca²⁺ content was 9.54 cmol kg⁻¹ at the depth 0-20 cm compared with 6.36 cmol kg⁻¹ at 20-40 cm depth under DE1 conditions, and progressively decreased with cultivation time at both depth.

Table 4: Evolution of soil characteristics under different land use/cover

Land use/ Cover	Depth 0-20 cm						
	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	SB	BS	CEC
DE1	9.54	2.27	0.82	0.11	12.7	>100	11.4
DE2*	5.15	1.94	0.59	0.14	8.0	89	9.0
DE3**	4.13	1.21	0.28	0.08	5.7	85	6.7
DE4***	2.84	0.69	0.25	0.32	3.9	78	5.0

* secondary savanna, ** 10 years cultivation, *** > 25years cultivation

The Ca²⁺ content at 0-20 cm depth decreased from 9.54 cmol kg⁻¹ to 4.13 cmol kg⁻¹ in DE3 and to 2.84 cmol kg⁻¹ in DE4, with a rate of decrease of about 0.27-0.54 cmol kg⁻¹ year⁻¹. In

comparison the Ca^{2+} content at 20-40 cm depth decreased from 6.36 cmol kg^{-1} in DE1 to 1.73 cmol kg^{-1} in DE3 and to 2.05 cmol kg^{-1} in DE4, with a rate of decrease of about 0.17-0.46 $\text{cmol kg}^{-1} \text{ year}^{-1}$.

Table 5: Evolution of soil characteristics under different land use/cover

Land use/ Cover	Depth 20-40 cm						
	Ca^{2+}	Mg^{2+}	K^+	Na^+	SB	BS	CEC
DE1	6.36	1.89	0.49	0.10	8.8	80	11.0
DE2*	2.70	0.92	0.36	0.10	4.1	52	7.8
DE3**	1.73	0.71	0.23	0.08	2.7	50	5.5
DE4***	2.05	0.73	0.19	0.13	3.1	61	5.1

The results in Mg^{2+} content showed the same trends compared with those of Ca^{2+} (Tables 4 and 5). The Mg^{2+} content was 2.27 cmol kg^{-1} at 0-20 cm depth compared with 1.89 cmol kg^{-1} at 20-40 cm depth. Temporal changes in Mg^{2+} concentration were significant. The Mg^{2+} concentration decreased at the rate of 0.06-0.11 $\text{cmol kg}^{-1} \text{ year}^{-1}$ for the 0-20 cm depth and about 0.05-0.11 $\text{cmol kg}^{-1} \text{ year}^{-1}$ for the 20-40 cm depth. The rate of decline of the Mg^{2+} concentration was similar in both depths and was about one-quarter of that of the Ca^{2+} concentration.

The K^+ data show significant differences with respect to depth and cultivation time. The K^+ concentration was 0.82 cmol kg^{-1} at 0-20 cm depth compared with 0.49 cmol kg^{-1} at 20-40 cm depth, a difference of about 40% in woodland. The K^+ content decreased significantly with cultivation. The rate of decline was about 0.023-0.054 $\text{cmol kg}^{-1} \text{ year}^{-1}$ for 0-20 cm depth and about 0.012-0.026 $\text{cmol kg}^{-1} \text{ year}^{-1}$ for 20-40 cm depth.

The data in Tables 4 and 5 show significant differences in CEC with respect to land use/ cover and cultivation time. On the other hand, there was not difference between CEC in the two depths (e.g. 11.4 cmol kg^{-1} at 0-20 cm depth and 11.0 cmol kg^{-1} at 20-40 cm depth) under woodland conditions. There was a definite trend of decrease in CEC with cultivation at both depths. The CEC value at 0-20 cm depth decreased from 11.4 cmol kg^{-1} in DE1 to 6.7 cmol kg^{-1} in DE3 and to 5.0 cmol kg^{-1} in DE4, with a rate of decrease of 0.26-0.47 $\text{cmol kg}^{-1} \text{ year}^{-1}$. Similarly, the value of CEC at 20-40 cm depth decreased from 11.0 cmol kg^{-1} in DE1 to 5.5 cmol kg^{-1} in DE3 and to 5.1 cmol kg^{-1} in DE4, with a rate of decrease of 0.24-0.55 $\text{cmol kg}^{-1} \text{ year}^{-1}$.

4. Conclusion

The results show that the loss in clay and silt contents, which was of about the same magnitude as the gain in sand content, was probably due to erosion and illuviation. The gravel content increased on the surface with the cultivation duration. The decline of pH did not lead to soil acidification after 25 years cultivation. However, the pH became slightly acid at 20-40 cm depth. The temporal changes in TSN were similar to those of SOC content with a rate of decrease of about 0.05 to 0.08 % year⁻¹ for the 0-20 cm depth (SOC) and at the rate of 0.004 to 0.008 % year⁻¹ for TSN at the same depth. In general, the C:N ratio decreased with cultivation time at a rate of about 0.02 to 0.08 units year⁻¹ for both depths. After 10 or 25 years cultivation, available phosphorus increased due to the regular application of phosphatic fertilisers for cotton. The Ca²⁺, Mg²⁺ and K⁺ contents show significant differences between woodland or Savanna and cultivated soils. The rate of decline of Mg²⁺ concentration was similar in both depths and was about one-quarter of that of Ca²⁺ concentration. There was a definite trend of decrease in CEC with cultivation at both depths. These results confirm soil depletion of N and K in the study area through permanent maize/cotton cultivation inspite of regular application of N P K-fertilizers. The following studies will be to understand the extent and the degree of this soil degradation in the region.

The colonisation of new land by migrants from over-populated rural areas, which initially affected small patches ten years ago, then vast areas further south and west of the study area. The destruction of vegetation by agricultural colonisation has been all the more considerable because it not only opened up new fields, but also facilitated the sale of firewood and charcoal in the towns to provide the new settlers with income while waiting for their first harvest. The increase of cultivated land of about 223% from 1978 to 1997 demonstrated this land colonisation.

Field clearings, deforestation for firewood and charcoal, bush fire and sometimes overgrazing and continuously land use can lead to land degradation, with drastic adverse changes in soil properties such as a decrease aggregation and aggregate size distribution and an increase in susceptibility to erosion (Lal, 1976). These effects contribute to an increase in bulk density, a reduction in available water-holding capacity and a decrease in macroporosity and infiltration capacity (Lal and Cummings, 1979; Alegre, et al., 1986). These effects are exacerbated by a reduction in the activity and species diversity of soil fauna, a decrease in the quantity and quality of soil organic matter content, and a possible reduction in the formation of organic-mineral complexes (Lal, 1996). Intensive burning can also alter aggregate size distribution

(Ghumam and Lal, 1989), and decrease wettability. Some of these effects of deforestation has been studied and described for Alfisols (Luvisols) and Ultisols (Acrisols) in west Africa (Lal, 1986; Lal and Ghuman, 1989, 1991; Igué and Youssouf 1995; Lal, 1996.

References

- Agboola, A.A. 1981. The effects of different soil tillage and management practices on the physical properties of soil and maize yield in a rain forest zone of Western Nigeria, *Agronomy journal*, 73, 247-251.
- Azontondé, A., 1993: Dégénération et restauration des terres de barre (sols ferrallitiques faiblement désaturés argilo-sableux) au Bénin. Cahier ORSTOM, Série Pédolog. Vol. XXVIII, n°2, pp 217-226, Paris.
- Alegre, J.C., Cassel D.K., and Bandy D.E., 1988: Effects of land clearing method on chemical properties of an Utiisol in the Amazon. *Soil Science Society of America Journal*. 52. 1283-1288
- Brabant, P. Darracq S. Egue, K. and Simonneaux V. 1996: Etat de dégradation des terres résultants des actions humaines. Collection Notice Expl. N° 112. Editions ORSTOM, Département Milieux et Activités Agricoles, Unité de recherche 34 Paris.
- Casenave, A. and Valentin, C., 1989: Les états de surface de la zone sahélienne. Influence sur l'infiltration. Collection ``Didactiques``. ORSTOM, Paris. 229p.
- Cretenet M., 1993: Rapport de mission au Bénin. Programme Coton CIRAD CA U.R. Systèmes de cultures CIRAD Montpellier France.
- D'Herbès, J.M. and Valentin C., 1997: Land surface conditions of the Niamey region: ecological and hydrological implications. *J. Hydrol.* 188-189: 18-42.
- FAO 1990: La conservation et la restauration des terres en Afrique. 120p Programme International ARC 90/4 Rome.
- Floquet A. et Mongbo R. 1998: Des paysans en mal d'alternatives. Dégénération des terres, restauration de l'espace agricole et urbanisation du bas Bénin. 190p. Weikersheim Margraf Verlag
- Gaiser, T 1993: Bedeutung der organischen Bodensubstanz für Eigenschaften und Ertragsfähigkeit von Vertisolen und Acrisolen in Süd-Benin.: Hohenheimer Bodenkundliche Hefte 12, Universität Hohenheim, Stuttgart.
- Gaiser, T., B. Fadegnon, M. Cretenet, and Ch. Gaborel 1999a: Long-term Experience on a tropical Acrisol: Evolution of soil properties and yield. pp. 153-156 In UFZ-Bericht N° 24/1999. Hrsg: Wolfgang Merbach und Martin Körschens Germany.
- Ghuman B.S., and Lal R., 1989: Soil temperature effects of biomass burning in windrows after clearing a tropical rainforest, *Field Crop Research*, 22, 1-10.

- Ghuman B.S., and Lal R., 1991: Land clearing and use in the humid Nigeria tropics. II. Soil chemical properties, *Soil Science Society of America Journal*, 55, 184-188.
- Graef, F., 1999: Evaluation of agricultural potentials in Semi-arid SW-Niger. -A Soil and Terrain (NiSOTER) study 217p. *Hohenheimer Bodenk. Hefte*, 54. Hohenheim University Stuttgart.
- Greenland D.J., 1975: Bringing green revolution to the shifting cultivators. *Science*, 190, 841-844.
- Herrmann, L., 1996: Staubdeposition auf Böden West Africas. Eigenschaften und Herkunftsgebiete der Staäube und ihr Einfluß auf Böden und Standortseigenschaften. 236p. *Hohenheimer Bodenk. Hefte* 36 Hohenheim University
- Igué A. M., 1992: Utilisation des données pédologiques pour une agriculture durable: Cas des terres de barres au sud Bénin. *World Soil Resources Reports* n° 83 pp 109-127 Rome.
- Igué, A.M., and Youssouf I., 1995: Etude au 1:5000 de l'état de dégradation des sols de la Station de Recherche sur les cultures vivrières d'Ina. Etude N° 317 CENAP, Cotonou.
- Igué, A.M., 2000. The use of of the soil database for Land Evaluation Procedures-Case study of Central Benin. PhD thesis. University of Hohenheim, Stuttgart, Germany. 235p ISSN 0942-0754.
- Lal, R., 1987: Managing soils of sub-Sahara Africa, *Science*, 236, 1069-1076.
- Lal, R., 1976: Soil Erosion Problems on Alfisols in Southern Nigeria and their Control, IITA Monograph N° 1, IITA, Ibadan.
- Lal, R., 1996a: Deforestation and Land use effects on soil degradation and rehabilitation in Western Nigeria. I. Soil Chemical and Hydrological Properties. *Land Degradation and Development*, Vol. 7, 19-45.
- Lal R., 1996b: Deforestation and Land use effects on soil degradation and rehabilitation in Western Nigeria. II. Soil Chemical Properties. *Land Degradation and Rehabilitation*. Vol. 7, 87-98.
- Lal, R., and Kang B.T., 1982: Management of organic matter in soils of the tropics and sub-tropics, *Transactions of the 12th International Congress on Soil Science*, New Delhi, 3, 152-178.
- Lal, R., 1993: Soil erosion and conservation in West Africa. P. 7-26. In D. Pimentel (Eds) *World soil erosion and conservation*. Int Union for Conservation of Nature and Natural Resources. Switzerland.
- Lal R and Cummings D.J., 1979: Clearing a tropical forest. 1. Effects on soil and micro-climate. *Field Crops Research* 2: 91-107.
- Mama, J.V., et al 1994 : L'exploitation du bois et du charbon dans le département du Zou. PNUD-Cotonou.

- Nye P. and Greenland D.J. 1962: Soils under Shifting Cultivation, Commonwealth Agriculture Bureau, Harpenden.
- Nye P and Greenland D.J. 1964: Changes in soil properties after clearing a tropical forest, Plant Soil, 21, 101-112.
- Piéri, C., 1989: Fertilité des terres de savannes. Bilan de trente ans de la recherche et de développement agricoles au sud du Sahara. 44p. Paris, Ministère de la Coopération et du Développement, CIRAD.
- Roose, E.J. 1976: Le problème de la conservation de l'eau et du sol en République Populaire du Bénin. Mission de consultation FAO 34p. Etude N° 146, CENAP. Cotonou Bénin.
- Van Diepen, C., 1982: La dégradation des sols en Rép. Pop. du Bénin. CENAP-Cotonou.