The Major Soils of a Village in Northern Burkina Faso

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In the Oudalan Province of Sahelian Northern Burkina Faso soil investigations have been carried out in order to evaluate the sustainability of millet production with emphasis on the dynamics of soil fertility. Some results of pedological investigations carried out in 1990 are included. Three commonly occurring soil types in a village territory are examined and their genesis and fertility discussed. Analyses show that the soils are inherently low in organic matter. The level of macro-nutrients is low, soil structure is weak or unfavourable: all probably due to a combination of natural and human factors. Crop yields are generally low and cannot be raised without more intensive cultivation.

Keywords: *Burkina Faso, soil formation, soil fertility, semi-arid agriculture, nutrients.*

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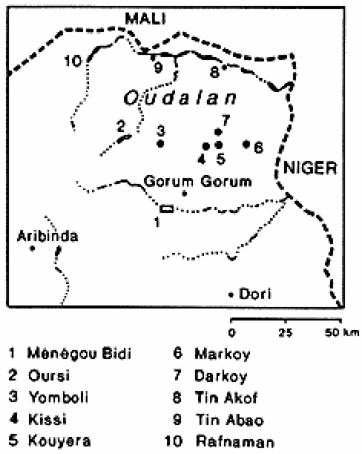

Fig. 2. The Oudalan Province and its major villages.

Since the severe drought from 1968 to 1973 the Sahelian region has attracted much attention. A combination of demographic and climatic factors are feared to have degraded the ecosystem to such an extent that a state of desertification has set in: a situation which may prove to be irreversible (Chamard & Courel, 1979; Dewispelaere & Toutain, 1976a+b; Krings, 1980; Gorse & Steeds, 1985; Grouzis, 1988).

Pastoral livestock rearing and arable farming are the principal agricultural activities in Oudalan, supporting the majority of the people (Claude et al., 1991). The farming system of the region can be characterized as dryland subsistence farming based on manual labour. Constraints to production are numerous, especially the agroclimatic conditions and the very low fertility of the soils. The extremely harsh conditions limit the choice of crops to millet (Pennisetum americanum, L.) which occupies about 90 % of the cultivated area in the region often as monoculture.

Fallow is rare and no chemical fertilizers are applied. Manure and organic wastes are applied to the degree that they are available, but because of the high cost of transport in terms of work input, they are mainly concentrated close to habitation. However, the pattern of manure distribution is subject to large variations.

The maintenance of soil fertility may be difficult under such circumstances. Continuous cultivation and monocropping lead to declining yields in the long run because of; depletion of plant nutrients, decreasing content of soil organic matter, accelerating erosion, increasing acidity,

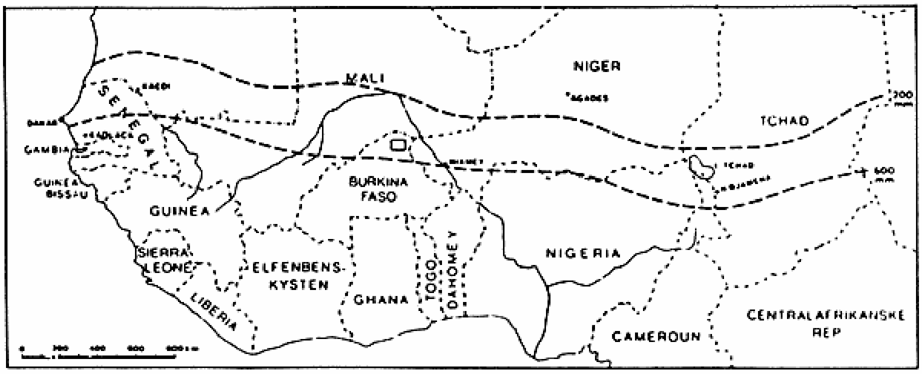

Fig. 1. Localization of Burkina Faso in West Africa. The Sahelian zone is defined as lying between the 200 and 600 mm isohyets (dashed lines). Insert frame is eqivalent to Fig. 2.

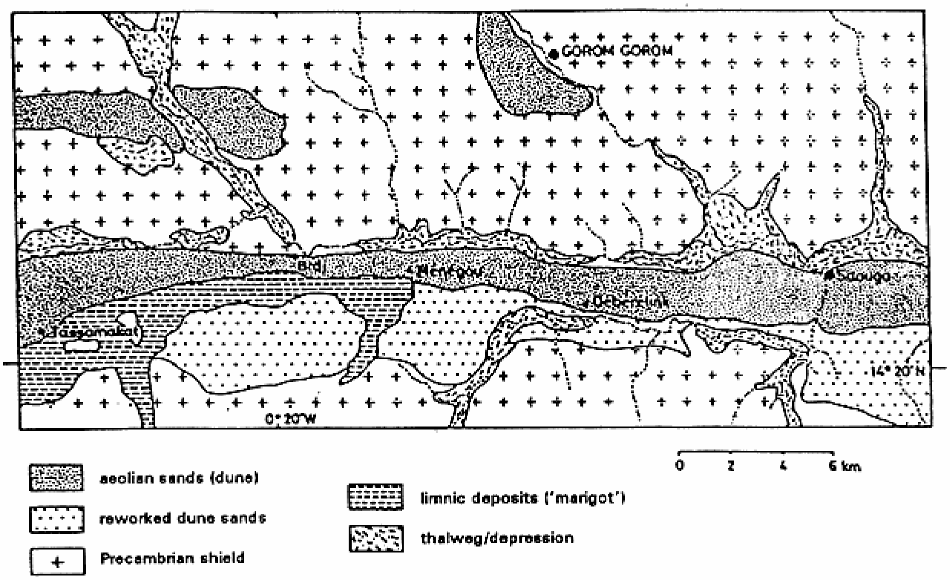

Fig. 3. Geological map of the study area. (Chamard and Courel, 1979).

deterioration of soil structure, increasing soil density, compaction, increasing problems with weeds, pests and diseases (Heathcote, 1969; Richard, 1967; Charreau & Fauck, 1970; Jones, 1971; Morel & Quantin, 1972; Siband, 1972; Lal & Stewart, 1989; Aina, 1979; Essiet, 1990; Olu Obi, 1989; Burgos-Leon et al., 1980).

The term 'soil degradation' is appropriate to describe changes of soil properties brought about by the above-mentioned processes. The result is a loss in productivity, which implies that the sustainability of the agricultural system is not ensured on the basis of the present landuse.

STUDY AREA

The study area (Figs. 1 and 2) is located around the Peuhl/Songhai village, Bidi, (14°20'N, 0°20'W) in the Oudalan Province of Northern Burkina Faso, which belongs to the Sahelian climatic zone. This climate, which is governed by the movement of the ITCZ, is semi-arid tropical and characterized by two contrasting seasons; a long, dry season with prevailing NE Harmattan winds lasting from October/November to May/June, followed by a short, wet season with SW monsoon winds. Climatic data from Gorom-Gorom, 12 km NE of Bidi (Chevallier et al., 1985), show an average annual temperature of 29.3 °C. Average annual rainfall based on the period 1956-81, amounts to 462 mm, of which 35 % falls in August, but generally rainfall is irregular and unpredictable due to randomness of convective storms (Nicholson, 1983). Average annual potential evapotranspiration using the Penman equation is around 3000 mm year^{-1} (Cocheme & Franquin, 1967) and almost constant from one year to another. The soil temperature regime and soil moisture regime according to Soil Taxonomy (Soil Survey Staff, 1975) are iso-hyperthermic and aridic ustic (Van Wambeke, 1982). The start and duration of the growing season is governed by rainfall, generally starting in mid-July and lasting about 70 days (BUNASOL, 1990). The landscape is characterized by an advanced stage of planation due to a long pedological and geomorphological evolution, which has produced lateritic duricrusts (Boulet, 1970). The Precambrian bedrock underlies 2/3 of the province, and in the study area syntectonic granite and migmatite predominate (Hottin & Ouedraogo, 1975). During the Quaternary, the region has experienced several climatic oscillations, and aeolian activity during dry periods has formed at least two distinct dune systems superimposed on the pediplain (Boulet, 1978; Nicholson, 1981; Courel, 1977). In the region, four distinct geomorphic elements can be distinguished; dune systems, pediplains, thalwegs and depressions, and rock outcrops.

The village Bidi represents a typical agro-physical unit in Oudalan. Like many other villages, Bidi is situated on the northern front of a huge protruding dune band ("l'erg recent") which stretches for more than 120 km in an E-W direction. To the south, it borders a depression ("marigot"), and to the north, though separated by a narrow depression, to a pediplain on the Precambrian bedrock, see Fig. 3. Millet is cultivated on all landscape elements.

Yields vary in time and space, but average yields are in the order of 200 kg ha^{-1}.

METHODS

During a survey in October 1990 a number of soil profiles were examined on each of the landscape elements. The soil profiles were described and classified according to FAO (1990), being the most applicable system in the field. In addition, soils were classified according to the French CPCS system (CPCS, 1967) as all existing soil surveys in the area have been made on the basis of either this system or the similar ORSTOM system, the latter specially designed for present and former French-speaking overseas territories. The National Soil Bureau of Burkina Faso (BUNASOL) has adopted the basic principles of these system.

The soils were sampled on the basis of genetic horizons. Fine earth analysis was carried out at the laboratory of the National Institute of Animals and Science, Denmark, and at the laboratory of BUNASOL, Ouagadougou, using the following methods:

Particle size distribution was determined by sieve and pipette methods; Organic carbon content was determined by combustion in a LECO induction furnace (profile 1 and 2) and by wet dichromat oxidation (profile 3) (Walkley & Black, 1934); Total nitrogen was determined by Kjeldahl digestion; Total phosphorus was determined spectrophotometrically by the Murphey & Riley method (1962) after heating the soil to 550 °C and extraction with 12N sulfuric acid (profile 1 and 2) and by the Murphey & Riley method (1962) after digestion in a mixture of sulfuric acid and salicylic acid in the presence of H_2O_2 using selenium as a catalyst (profile 3); Exchangeable bases were extracted with neutral 1N NH_4OAc. Calcium and magnesium were determined by flame absorption spectrophotometry; potassium and sodium were determined by flame emission spectrophotometry; Exchangeable acidity was determined by the m-nitrophenol method (Piper, 1944); The cation exchange capacity was calculated as the sum of adsorbed cations and the exchangeable acidity; pH was determined potentiometrically in a 1:2.5 soil/0.01M $CaCl_2$ suspension and in a 1:2.5 soil/water suspension; Free Fe was extracted by dithionite-citrate-bicarbonate (Mehra & Jackson, 1960); Electrical conductivity was measured in a 1:2.5 (profile 3) and 1:9 soil water suspension (profile 1 and 2); Available phosphorus was determined by the sodium bicarbonate method (Olsen et al., 1952); Available potassium was determined by flame emission spectrophotometry after extraction with 0.5M NH_4OAc.

RESULTS

Dune area: Arenosols

The dune, on which the village is situated, is an inland, transverse asymmetrical ridge deposited in a relatively dry period 20,000 - 12,000 years BP ("erg recent"), but probably reworked in subsequent dry periods. Easily workable and freely drained, the dune is well suited to growing millet. The most common soil types on the dune are Arenosols.

Profile 1

Classification FAO : Haplic Arenosol
Classification CPCS : Sol brun-rouge subaride peu differencies
Map sheet : Feuille ND-30-XVIII 1:200,000 Burkina Faso
Location : Bidi, village in Oudalan province of Burkina Faso, 12 km SV of Gorom
Date of examination : 90-10-23
Elevation : 270 m
Land form : Dune
i) Physiographic position : slope
ii) Surrounding land form : rolling
iii) Microtopography : nil
Slope at profile site : 5-10°
Land-use and vegetation : Dryland agriculture, exclusively millet, stalks left on the field.
Climate : Dry, semi-arid tropic, wet month 2.0-4.5, dry month 7.5-10 month, mean annual rainfall 450 mm, estimated mean annual PET 2800 mm.
Parent material : Aeolian quartzitic sand
Drainage : Excessively drainedMoisture condition in profile : Very dry in upper part, a little moist below 100 cm, depth of ground-water table unknown
Rock outcrops : None
Evidence of erosion : Rill erosion, wind erosion/deposition in dry season
Presence of salt or alkali : None
Human influence : Household waste applied in the area.

Description of horizons;

A1 0-20 cm :	*Reddish yellow (7.5 YR 6/8 D) fine sand; several shallow bands with dark organic material; very weak crumb structure, soft consistency; clear, smooth boundary*
C1/B 20-50 cm :	*Reddish yellow (7.5 YR 6/8 M) fine sand; structureless/very weak; no in-ped porosity, very soft consistence; diffuse, smooth boundary*
C2 50-130 cm :	*Reddish yellow (7.5 YR 6/8 M) fine sand; structureless/very weak; no in-ped porosity, very friable consistence.*

The Arenosol is developed in unconsolidated, fine aeolian, quartzitic sands with the dominant particle sizes within the 50-250 μm range. The soil has small amounts of clay throughout the profile. Silt is almost absent. XRD-analysis has shown that the dominant mineral of the silt and sand fractions is quartz. The clays of the aeolian material are mainly kaolinite, with a small amount of vermiculite. Profile development is weak due to a combination of; young age, lack of weatherable minerals, and/or slow soil formation because of the dry climate. Moreover, the continuous shifting of the sand impairs soil formation until the dune is colonized by vegetation and held in place. The predominantly red to orange colours are thought to come from platelets of kaolinite which are covered by submicroscopic particles of hematite (El-Baz, 1986), presumably a residual from eroded lateritic soils. A more advanced stage of soil formation requires a more complete vegetative cover allowing for the incorporation of organic matter and the initiation of biogeochemical processes.

The cohesion of the soil matrix is weak due to a low SOM content and the quartz/low activity clay skeleton. The CEC values are correspondingly very low, and may even be considerably overvalued when measured at pH 8.2 due to the predominance of variable charge surfaces. This implies a severe degree of infertility, meaning that the soil is not able to meet even modest nutrient requirements. Furthermore, conventional fertilizer application may cause nutrient imbalance due to the shortage of trace elements. Likewise, the response to irrigation is minimal when nutrient contents are at such a low level (FAO, 1979). The soil is moderately acid and, as it is poorly buffered, it is sensitive to further acidification, e.g. through base removal with harvested products.

Pediplain: sodium-affected soils

Areas on the pediplain are also used for millet cultivation, and in recent years more land on the plain has been brought into cultivation (Reenberg & Rasmussen, 1992). However, a much higher work input is needed in the process of preparing and sowing the fields on the pediplain which is due to the high clay content of the soils. The pediplain area of the village is the 'bas glacis' of Michel (1959, 1969) on which pedogenesis is still active. On the higher terrain the ancient Quaternary lateritic duricrust permits no further soil development. Pediplains are old continental landforms produced by a gradual vertical and/or lateral lowering of the surfaces. An evaluation of the soil processes is very difficult because of erosion

horizon	cm depth	% of < 2 mm					
		Cl < 2μm	FSi 2-20μm	CSi 20-50μm	FSa 50-250μm	CSa 250-2000μm	OM
A	0-20	3.0	0.5	0.8	55.3	40.0	0.40
C1/B	20-50	3.6	0.5	1.8	69.8	24.1	0.20
C2	50-	2.6	0.5	0.7	71.5	24.6	0.10

horizon	cm depth	%			ppm			
		Carbon	Nitrogen	C/N	Total-P	P ($NaHCO_3$)	K (NH_4OAc)	Fe_{DCB}
A	0-20	0.22	0.022	10	81	2	-	2914
C1/B	20-50	0.09	0.013	7	172	47	62	3829
C2	50-	0.04	0.007	6	47	4	67	3210

horizon	cm depth	cmol(+) kg^{-1}							%			Lt
		CEC pH 8.2	Ca^{++}	Mg^{++}	K^+	Na^+	Sum of bases	Exchan. acidity	Bas. sat.	pH H_2O	pH $CaCl_2$	EC 1:9
A	0-20	2.62	0.87	0.28	0.16	0.01	1.32	1.3	50	6.4	-	0.23
C1/B	20-50	3.05	0.45	0.14	0.15	0.01	0.75	2.3	25	5.5	4.3	0.09
C2	50-	1.82	0.32	0.14	0.15	0.01	1.82	1.2	34	6.0	4.7	0.06

Table 1. Analytical data Arenosol.

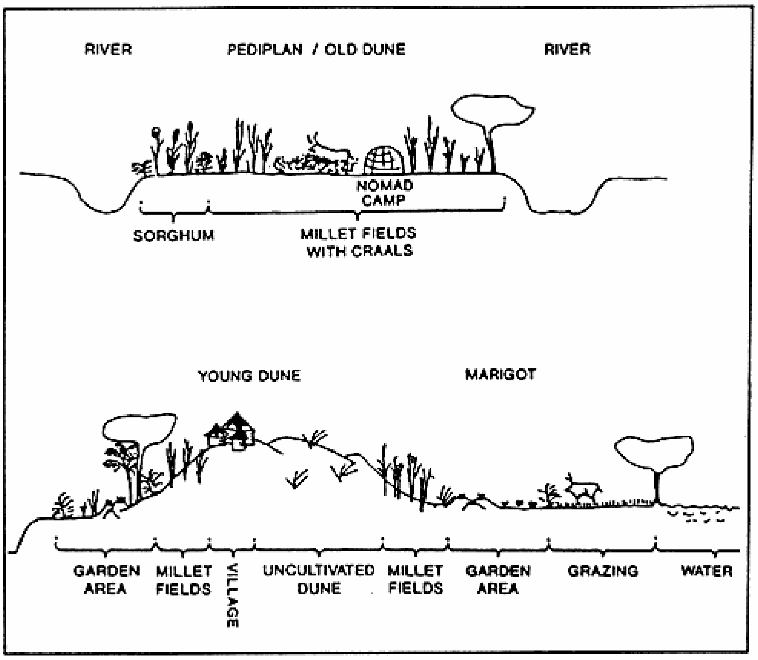

Fig. 4. Schematic cross-section showing the agricultural system in Bidi. (Reenberg & Rasmussen, 1992).

and climatic changes. The climate of sub-Saharan Africa has fluctuated seen from a geological perspective, and the soils on the old landforms have therefore been exposed to conditions which were both more humid and more arid than today. Thus soils are mostly polygenetic, and some present soil properties reflect processes operating under conditions in the past. A combination of high age and even a slight inclination of the pediplains has affected the soils laterally, especially in the more humid regions, giving rise to catenas termed 'monotonic toposequences' with weak lateral systematic variations and 'contrasted toposequences' with high lateral systematic variations (Boulet, 1978; Boulet & Paquet, 1972).

On the plain, soil materials are colluvial and red sandy clay loams in situ weathered derived from granite and migmatite. However, most soils reveal a strong textural contrast - a duplex character (Nortcote, 1971) - exhibiting sandy topsoils.

Profile 2
Classification FAO : Orthic Solonetz
Classification CPCS : Sol a alcali lessive
Map sheet : Feuille ND-30-XVIII 1:200,000 Burkina Faso
Location : Bidi, village in Oudalan province of Burkina Faso, 12 km SV of Gorom
Date of examination : 90-10-24
Elevation : 260 m
Land form : Pediplain
i) Physiographic position : lower end of plain
ii) Surrounding land form : flat
iii) Microtopography : nil
Slope at profile site : 0-1°
Land-use and vegetation : Dryland agriculture, exclusively millet, stalks left on the field.
Climate : Dry, semi-arid tropic, wet month 2.0-4.5, dry month 7.5-10.0, AAR 450 mm, estimated mean annual PET 2800 mm.
Parent material : Colluvium derived from granitic rocks
Drainage : Imperfectly to poorly drained
Moisture condition in profile : Very dry in upper part, a little moist below 100 cm, depth of groundwater table unknown
Rock outcrops : Less than 2 % bedrock exposed
Evidence of erosion : Sheet erosion, wind erosion/deposition in dry season
Presence of salt or alkali : Soil affected by alkalization.

Description of horizons;

A1 0-15 cm :	*Reddish yellow (7.5 YR 6/6 D) sand; very weak, thin, platy structure, soft consistence; clear, smooth boundary*
E 15-32 cm :	*Reddish yellow (7.5 YR 6/8 D) loamy sand; few, fine, faint reddish yellow mottles (5 YR 6/8 D); weak, coarse, angular blocky structure, very hard consistence; patchy, thin cutans on some ped faces and in root channels of clay with iron oxides and hydroxides; very few, angular,*

weathered, granitic gravel; abrupt, smooth boundary

B1tgn 32-120 cm :Reddish yellow (7.5 YR 6/8 M) sandy clay loam mixed with sand; few, fine, faint reddish yellow mottles (5 YR 6/8 M); strong, very coarse, prismatic structure, extremely firm consistence; broken, moderately thick cutans on some ped faces and in root channels of clay with iron oxides and hydroxides; few, very fine, continuous, tubular pores, vertical oriented within peds; very few, angular, weathered, granitic gravel; very few, small, soft, spherical, black iron-manganese nodules; gradual, smooth boundary

B2tgn 120- cm : Not described, but similar to horizon above.

The studied soil has the horizon sequence A-E-B1tgn-B2tgn. The B horizon has an extremely hard prismatic structure, which is partly due to dryness. A thin surface crust, probably due to rainfall splash was observed (Casenave & Valentin, 1989; Hoogmoed, 1987). The ESP (calculated as exch. Na/CEC), pH and EC values show that the soil is weakly acid in the upper horizons and alkalized in the upper B horizon with a pH above 9, and alkalized and slightly saline in the lower B3 horizon due to soluble salts. These processes are common in arid and semi-arid regions due to low amounts of water percolating through the soil. An excess of soluble salts tends to be concentrated in the soil solution which can result in unfavourable growth conditions. If sodium becomes the dominant exchangeable base cation of the adsorption complex and the concentration of soluble salts is low, sodium may undergo hydrolysis and increase the pH, which in turn causes a nutritional imbalance and structural deterioration (Gupta & Abrol, 1989). In this particular case the excess sodium responsible for the sodification is derived

	cm	% of < 2 mm					
horizon	depth	Cl < 2μm	FSi 2-20μm	CSi 20-50um	FSa 50-250μm	CSa 250-2000μm	OM
A1	0-15	4.6	0.5	4.1	55.8	34.7	0.30
E	15-32	10.6	1.4	3.6	53.2	30.9	0.30
B1tgn	32-120	25.5	7.5	8.2	31.2	27.2	0.40
B2tgn	120-	30.5	10.4	10.5	32.8	15.4	0.40

	cm	%	%		ppm			
horizon	depth	Carbon	Nitrogen	C/N	Total-P	P ($NaHCO_3$)	K (NH_4OAc)	Fe_{DCB}
A1	0-15	0.11	0.013	8	86	6	81	5681
E	15-32	0.15	0.017	9	111	4	-	8226
B1tgn	32-120	0.25	0.018	14	127	6	102	12925
B2tgn	120-	0.21	0.018	12	171	5	152	29000

	cm	cmol(+) kg^{-1}							%				Lt
horizon	depth	CEC pH 8.2	Ca^{++}	Mg^{++}	K^+	Na^+	Sum of bases	Exchan. acdidy	Base sat.	ESP	pH H_2O	pH $CaCl_2$	EC 1:9
A1	0-15	2.60	0.90	0.39	0.20	0.01	1.50	1.1	58	0	6.6	5.6	0.09
E	15-32	4.59	1.92	0.83	0.24	0.10	9.09	1.5	67	2	6.8	5.4	0.07
B1tgn	32-120	24.81	17.07	3.71	0.26	3.57	24.61	0.2	99	14	9.4	7.7	1.76
B2tgn	120-	24.06	13.97	3.91	0.36	5.22	23.46	0.6	98	22	9.4	7.9	2.15

Table 2. Analytical data Solonetz.

from the crystalline bedrock which has inclusions of various sizes in which the granite is calco-alkaline (Hottin et Ouedraogo, 1975). Thus the occurrence of sodified soils in the area is generally patchy. The sodium-affected soils occur as a complex, comprising individuals with similar morphology but without the influence of sodium. However, lateral migration of solutes and sodium sieving in zones of preferential water flow may also take place causing the influence of sodium to be particularly high along the drainage passages, irrespective of the original source (Bocquier, 1964, 1968).

The A horizon shows almost the same texture as the Arenosol, which emphasizes that aeolian covers are not restricted to dunes. In fact, vast areas in the Sahel are covered by aeolian sand. A sandy topsoil is a common feature of savanna soils (Moss, 1968; Ahn, 1970; Jones & Wild, 1975), and apart from wind deposition it can also be caused by other factors, such as clay migration, in situ weathering at depth, termite activity, differential erosion on the surface removing the finer particles, as well as chemical destruction of clay minerals in the topsoil due to impeded drainage. However, with depth at least part of the clay enrichment may be ascribed to migration. In addition, the influx of solutes may result in 'reverse weathering' whereby clay is gradually synthesized and eventually transformed into smectite (Breeman & Brinkman, 1978): a process which in time, takes place further and further up slope. The high Fe content in the subsoil is presumably also due to an absolute accumulation.

Accordingly, topsoil CEC is low, but subsoil CEC is substantially higher. The dominant clay mineral is montmorillonite with smaller amounts of kaolinite in the top of the soil. However, as a result of the high sodium level, the beneficial effects related to the higher clay content are largely offset by the alkalization.

Thalwegs and the depression: associations of Cambisols, Luvisols and Fluvisols

The depression, which extends along the northern dune front, has been cultivated over a long period. Part of the area is periodically inundated during the wet season. Soil textures vary from sands to heavy grey clays, indicating relatively poor drainage. Some sites have a faint gilgai relief. However, the extreme clayey soil are not suited for millet cultivation due to waterlogging. The description and analytical data from a common soil type used for millet is shown below.

Profile 3
Classification FAO : Vertic Cambisol
Classification CPCS : Sol bruns subarides vertiques sur materiau argileux issu de granites.

Map sheet : Feuille ND-30-XVIII 1:200,000 Burkina Faso
Location : Bidi, village in Oudalan province of Burkina Faso, 12 km SV of Gorom
Date of examination : 90-10-24
Elevation : 255 m
Land form : Depression
i) Physiographic position : lower end of plain
ii) Surrounding land form : flat
iii) Microtopography : Faint gilgai
Slope at profile site : 0-1°
Land-use and vegetation : Dryland agriculture, exclusively millet, stalks left on the field.
Climate : Dry, semi-arid tropic, wet month 2.0-4.5, dry month 7.5-10.0, AAR 450 mm, estimated mean annual PET 2800 mm.
Parent material : Granitic rocks
Drainage : Imperfectly to poorly drained
Moisture condition in profile : Very dry in upper part, a little moist below 100 cm, depth of groundwater table unknown
Rock outcrops : Less than 2 % bedrock exposed
Evidence of erosion : Wind erosion/deposition in dry season
Presence of salt or alkali : None observed.

Description of soil;

A1 0-10 cm :	*Dull yellow orange (10 YR 6/4 D) sand; very weak, subangular blocky structure; abrupt smooth boundary*
B1t 10-18 cm :	*Dull yellow brown (10 YR 5/3 D) loamy sand; weak, coarse angular blocky structure, abrupt, smooth boundary*
B2t 18-50 cm :	*Yellowish brown (10 YR 5/4 D) sandy clay loam; very strong coarse angular blocky structure, extremely firm consistence;*
C/R 50-110 cm :	*Yellowish brown (10 YR 5/4 D) sandy clay loam; strong, coarse angular blocky structure, bedrock and weathered granite gravel.*

The soil is of sedentary origin. The matrix is paler than that observed on the plain, indicating poorer drainage. The topsoil texture is sandy and there is a gradual increase in clay with depth due to in situ weathering and migration. Fine silt is lacking but the content of coarse silt is high. Soil structure is angularly blocky. The soil has a medium CEC with pH in the neutral range which secures a optimal availability of important nutrients. At this particular site, the granitic bedrock was encountered at a depth of 110 cm, but was absent at most other sites, contributing to a highly non-systematic variation in soil properties. This has been reported to be common in the tropics and leads to uneven crop yields over short distances especially under inadequate management (Moorman & Kang, 1978).

DISCUSSION

In the semi-arid tropics, the nature and amount of soil organic matter is closely related to soil fertility (Jones &

horizon	cm depth	% of < 2 mm Cl < 2μm	FSi 2-20μm	CSi 20-50μm	FSa 50-250μm	CSa 250-2000μm	OM
A1	0-10	4.8	0.5	3.7	61.3	29.2	0.52
B1wt	10-18	10.5	0.0	5.5	60.3	23.5	0.33
B2wt	18-50	12.0	1.0	10.2	48.2	28.2	0.40
C/R	50-110	16.0	1.3	5.2	50.3	27.1	0.16

horizon	cm depth	% Carbon	% Nitrogen	C/N	% $CaCO_3$	ppm Total-P	ppm P ($NaHCO_3$)	ppm K (NH_4OAc)	ppm Fe_{DCB}
A1	0-10	0.30	0.030	10	0.00	83	6	102	2200
B1wt	10-18	0.19	0.013	15	0.00	53	2	249	3200
B2wt	18-50	0.23	0.011	21	0.00	53	1	244	4400
C/R	50-110	0.09	0.011	8	0.01	38	0	293	3600

horizon	cm depth	cmol(+) kg^{-1} CEC pH 8.2	Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Sum of bases	Exchan. acidity	% Base sat.	pH H_2O	pH $CaCl_2$	dS m^{-1} EC 1:2.5
A1	0-10	3.40	1.56	0.66	0.27	0.01	2.50	0.9	74	7.0	6.0	0.04
B1wt	10-18	5.61	2.72	0.99	0.70	0.00	4.44	1.2	79	7.0	5.8	0.04
B2wt	18-50	7.48	3.99	1.37	0.69	0.03	6.08	1.4	81	7.1	5.9	0.06
C/R	50-110	8.97	5.24	1.70	0.85	0.08	7.87	1.1	88	7.5	6.6	0.06

Table 3. Analytical data Vertic Cambisol.

Wild, 1975; Jones, 1971, 1976; de Ridder & van Keulen, 1990): the positive effects being chemical, physical and biological in nature, and intrinsically linked to the nitrogen and phosphorus levels in soils. These are the plant nutrients most likely to become in short supply in semi-arid soils. Contrary to what is often thought, the absence of these elements rather than water, often limit plant production in semi-arid soils, except in the northern Sahel where the lack of water is more limiting (Penning de Vries & Djiteye, 1982; Breman & de Wit, 1983).

As shown by the analysis, the examined soils have very low organic matter contents with an isohumic distribution (Duchaufour, 1982), presumably due to the in situ decomposition of roots which provides the main input of organic matter during cultivation. N and P contents are also low.

Most of the N in soils is bound by the organic matter, and readily available N in the form of NH_4^+ and NO_3^- is released by mineralization and humification processes. The supply is greatly influenced by microbial activity, and repeated mineralization flushes - 'the Birch effect' - (Birch, 1958) have been observed after rainfall events. This provides the main part of the nitrogen for the millet.

The low amounts of phosphorus in the soils accords well with the physical environment. In the absence of fertilizers the main source of phosphate in soils is the parent material. As soil parent materials in West Africa are mainly derived from rocks with granitic mineralogy, phosphorus contents are naturally low. Moreover, the high age of the soils also accounts for the low P contents (Walker & Syers, 1975; Smeck, 1985; West, 1991). Even in soils with considerable quantities of total phosphate, deficiencies occur because of phosphates reacting with soil components leading to the formation of insoluble

compounds largely unusable to plants (Sanyal & De Datta, 1991).

In addition to providing nutrients, soil organic matter affect the fertility through the ability of the humified part to retain cationic plant nutrients. It has a positive effect on soil physics by increasing the water-holding capacity and infiltration, and improving the diffusion of gasses through the soil. The buffer capacity increases as well.

However, low contents of organic matter are a characteristic of well-drained savanna soils (Jones, 1971; Bocquier & Maignien, 1963) and are attributable to several interacting natural factors; low biomass production due to low rainfall, repeated wetting and drying, elevated temperatures promoting mineralization, and low organic matter stabilization due to sandy parent material (Stott & Martin, 1989).

The environmental conditions in the study area all point to a low natural soil organic matter level which may even be lowered by cultivation because of the decreased effectiveness of organic recycling and enhanced mineralization (Fauck et al., 1969; Siband, 1972). Furthermore, the "opening of soil" by the use of the hoe and the clearing of vegetation, leaves the soil in a state susceptible to wind and water erosion that may carry away topsoil rich in organic matter.

Conservation measures are thus important in order to maintain soil fertility. Fallowing could contribute to a gradual increase in soil fertility by raising the level of organic matter (Nye & Greenland, 1959), but the physical environment is not well suited to a recovery. The application of manure and effective recycling of organic residues would also improve the fertility (Parr et al., 1989; Quilfen & Milleville, 1983; Pichot et al., 1974), but biomass production is low, and some remains of the millet stalks after harvest are used as livestock fodder or for household purposes. Consequently, there seems to be no other means of improving soil fertility apart from intensifying cultivation using inorganic fertilizers. High yields cannot be obtained if the nutrient demands of crops are only to be met by the mineralization of the labile organic matter fraction.

As regards soil degradation, in particular organic matter and nutrient depletion, it is difficult to ascribe the present soil status to either a natural or cultural impact without knowledge of the past status. Degradative processes are counteracted by restorative processes and management, and only by computing the balances between input and output is it possible to substantiate long-term trends.

CONCLUSION

It can be concluded that the soils constituting the basis of the agricultural production in Bidi village have a very low fertility due to a combination of natural and human factors. The sandy dune soils are; inherently low in important nutrients and soil organic matter, poorly buffered, poorly structured and susceptible to erosion. The heavier soils of the pediplain seem to offer better opportunities in terms of important nutrients but some of these are alkalized, and their consistency is hard. Other major constraints are crusting and erosion. The soils in the depression, which are not too clayey, are in a more favourable situation. They have medium CEC values and are not affected by acidity or alkalinity.

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