Long-term topsoil changes under pearl millet production in the Sahel

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Abstract

In the Sahel, cultivated soils are commonly described as low fertility and acid sands. The fertility maintenance for pearl millet cultivation, the dominant source of food, relies either on fallowing or on manure application. The restoration of fertility under fallow is linked with increases in soil organic matter. A second amendment is dust that is wind blown from the Sahara, and for this, the tree and shrub-covered fallow land constitutes a considerable clay + silt trap. This study investigates the impacts on soils and yields resulting from the gradual shortening of fallow periods and the increasing use of manure to replace the fallow. Observations were conducted on farm (9 fields under a fallow system, and 5 fields under a manure system) over four years. Soil organic matter (0-20 cm) declined from 3.69 g kg^{-1} under long fallow management (>15 years) to 2.31 g/kg under short fallows (3-5 years), while the clay + silt fraction reduced from 107 g kg^{-1} under long fallows to 57 g kg^{-1} soils under short fallows. On manured fields (>10 years), soil organic matter (OM) stabilized at 2.97 g kg^{-1} soil. Short periods of fallow with no inputs resulted in topsoils that were very poor in N (long fallows 183 mg N kg^{-1}, short fallows 117 mg N kg^{-1}) with very low CEC (long fallows 1.04 cmol$_c$ kg^{-1}, short fallows 0.71 cmol$_c$ kg^{-1}).

Fallow managed fields had a pronounced micro relief (8-9 cm) related to trees and shrubs on steep-sided crusted micro hills generating runoff. In manured fields, the micro relief was mainly composed of aeolian micro dunes favouring infiltration due to the trapping of sand by dung, herbs and millet stubble. Grain production was approximately 400 kg ha^{-1} in long fallow fields and manured fields alike, but only 200 kg ha^{-1} under short fallows. With time, cultivated soils lose part of their clay-silt content from the topsoil through wind erosion which is enhanced by manual cultivation. Loss of fine particles results in less surface crusting and gradually, the entire field surface becomes highly permeable and eventually results in sandy skeletal soils that are entirely unproductive without constant inputs of manure. Farmers state that this transformation takes approximately 40 years. Losses of fine earth can only be achieved by the trapping of dust during long term fallowing. Manuring allows prolonged cultivation while it stabilises soil O.M. but it does not stop the loss of fine earth by wind erosion.

Introduction

In the African Sahel, between the 400 and 700 isohyets, people subsist on pearl millet, the only profitable crop. Agriculture and husbandry are often linked in this semi-arid region. However, both crops and livestock productions suffer from a combination of low soil fertility and scarce and unpredictable rains. Most soils in the Sahel are derived from acidic or aeolian parent materials which are poor in clay and nutrients, especially N and P (Bationo & Mokwunye, 1991). Almost all nutrients are found in the soil organic matter, a fraction that is also very low. The decline in nutrient status during cultivation is an inevitable consequence of clearing and is reinforced by the effects of cultivation (Ahn, 1970 p. 244; Feller & Beare, 1997). The ongoing physical land degradation in the Sahelian zone of West Africa, sealing, crusting, hardsetting of soils and the long-term reduction in amount of diversity of the natural vegetation, is enhanced by population growth and a marked drier climate since the 1970s (Sivakumar, 1992; Valentin, 1995).

Cultivation clears the soil and leaves the soil surface almost bare. Due to the heavy rains, the soil undergoes serious structural deterioration. The impacts of the drops separate the fine soil particles and the organic matter from the sand, and the soil pores get clogged. This makes the sandy soils of the Sahel very liable to surface crusting (Ambouta et al., 1996). Soil surface crusting reduces the infiltration rate, and thus triggers runoff and erosion. It constitutes a serious

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constraint for cultivation in dry areas (Casenave & Valentin, 1992). However, wind erosion is probably a greater constraint. Land clearing reduces the soil protection provided by the standing vegetation and the litter (Bielders et al., 2000). Moreover, any soil tillage breaks the surface crusts, and the detached material can be easily carried away by the wind during the storms (Valentin, 1995). The protection of the soil surface is improved by the presence of stable aggregates at the soil surface, which obviously resist better to the impact of the raindrops (Feller et al., 1989). It is also improved by any object, crop residue, dung or vegetation fragment lying on the soil, as they absorb the energy of the rains (Collinet & Valentin, 1985) and trap wind-blown particles during the storms (De Rouw & Rajot, 2004b).

Dust trapping is particularly important in the Sahel. In contrast with the local soils, which tend to be acid and highly weathered, the dust from the Sahara exhibits appreciable quantities of water-soluble and exchangeable cations (Hermann, 1996). About 25% of the dust-load consists of clay, silt and organic matter, the rest being very fine sand (Möberg et al., 1991). Though dust constitutes an important long-term factor of nutrient renewal for these soils, and though dust is supposed to help maintain soil fertility, the actual quantities involved are difficult to assess. Estimations of annual dust input in Southwest Niger varies widely, depending on method and scale: 0.9 t ha^{-1} (Buerkert & Hiernaux, 1998), 6.8 t ha^{-1} (Chappell et al., 1998), and 1.9 t ha^{-1} (Herrmann et al., 1994). When open buckets are used to measure dust deposition, only the airborne material that falls down vertically like rain is trapped. However, dust accumulates on vertical obstacles, thus tree- and shrub-covered fallows that constitute a considerable dust-trap. An appropriate method to determine the complementary dust input due to tree and shrub trapping would be to wash the dust from the vegetation and to estimate the leaf area. Though the sedimentation of dust is evident and the chief processes of soil restoration and soil losses is well documented, there is a need to investigate how pearl millet cultivation respond to this.

Most farmers in the Sahel are too poor to use external inputs (Powell et al., 1996). Subsequently, the long-term success of pearl millet cultivation depends on the recycling of nutrients in the topsoil. In practice this means either by manuring or fallowing. Model-based farm studies integrating livestock, pasture and cropland components suggest that the continuous cultivation of soils in the Sahel can be achieved by manure application, even if low quantities are applied (Harris, 1999; Abdoulaye & Lowenberg-de Boer, 2000; Buerkert & Hiernaux, 1998; Bielders et al., 2002). Minimum dung inputs observed in farmers' fields are 1.3 t ha^{-1} every two or three years (Powell & Williams, 1993) and 1.1 t ha^{-1} $year^{-1}$ (De Rouw & Rajot, 2004a). No such farm studies are available for fallowing. This study focuses on the changes in top soil due to long-term cultivation of soils and aims to relate well-known processes of soil restoration and degradation to farming practices.

Materials and Methods

Study area

The study area is located 60km east of Niamey , Niger, near the village of Banizoumbou (13º31′N, 2º39′E). The village territory, approximately 80 km², was exploited by 84 farms with an average number of 10 persons per farm. Part of the best land had been cultivated for about 150 years in alternation with periods of bush fallow. By 1990 this type of cultivation has spread over 70% of the village territory, the remaining 30% being marginal land or unfit for cultivation yet suitable for pasture (Loireau, 1998). In 1978, cultivation with regular manure application started and this practice was used at the time of the study over about 10-15% of the annually cropped area. Only 15% of the farms had more than 10 domestic animals (zebus, goats and sheep), the others had less or no livestock. However, exchange contracts were often made between farmers and nomadic herders about the manuring of fields. In the dry season, animals are left free at night in the field to let the dung and urine fall on the soil surface and decompose in situ. In the day-time these herds move to permanent pasture or fallow land. This labour-extensive practice is widespread in the Sahel (Landais & Lhoste, 1993; De Rouw & Rajot, 2004a).

The climate is hot and dry most of the year. The mean annual rainfall is 550 mm, the rains falling between June and September. The four years of experiments (1993-1996) were near average as far as total rainfall was concerned (total rainfall: 461, 642, 509 and 523 mm) but the distribution of the rain events varied largely between years and sites.

Crop production was entirely rainfed. Pearl millet was cultivated on every field, the fields being usually very large (minimum and maximum area of individual fields 4 and 30 ha, respectively). The crop was sown in hills and generally two weeding rounds were required. Weeding was performed using the “hilaire”, a shallow cultivating hoe that not only cuts the roots of the weeds but, more importantly, breaks the superficial crusts to allow the rains to infiltrate. All tillage operations (cultivation, clearing, sowing, thinning, weeding) were entirely made by hand and no chemical fertilizers were applied. Thick aeolian sand deposits, up to 9 m thick, were the preferred areas for cultivation, provided the slopes were less than 4%. These deposits were uniformly sandy, from 91% sand, 6% silt and 3% clay in the topsoil upper slope to 90% sand, 6% silt and 4% clay downslope. The organic matter content in the topsoil was very low, but slightly higher downslope (0.27%) than upslope (0.23%) (D'Herbès & Valentin, 1997). These cultivated soils are classified as Psammentic or Cambic Arenosols (FAO).

Sites and cropping systems

A survey among 60 farms gave four cropping systems depending on the farmers' access to arable land and manure.

Fallow system – long cycles. Farmers with land but no access to manure cultivate the same field for about 10 years then let it lie fallow for more than 15 years (four fields).

Manure system – new fields. Farmers with land and access to manure open up new fields and apply small quantities of manure each year thus cultivating the same site for over 15 years (four fields).

Fallow system – short cycles. Farmers with little land and no access to manure cultivate the same plot for short periods, 4-6 years, after which a fallow period is necessary of 3-5 years (four fields).

Manure system – old fields. Farmers with little land but access to manure recuperate impoverished land that they make productive by annual manure application (three fields).

It should be kept in mind that all fields are under the pressure of population increase, resulting in two long-term trends: (1) The gradual shortening of the fallow period, i.e. fields of the Fallow system – long cycle will progressively pass into the group Fallow system – short cycle. (2) Manure replacing the fallow, i.e. some fields of the Fallow system will evolve into field of the Manure system.

Plot size and other observations

Pearl millet stands can be extremely variable over short distances. Part of this variability is organized along the slope (Rockström & de Rouw, 1997). In order to capture this variability, the plots were arranged in transects of 100 m*5 m running down the slope. However, some variability appeared at random in the fields. This was mainly due to contrasting soil surface features ranging from highly permeable micro dunes to almost impermeable crusts. The size of the plots was adjusted to the scale of these heterogeneities (5*5 m).

Some transects were studied for four years (3 fields), others for two years (9 fields), and some for only one year (3 fields). The general description of each field (n = 15) included the area, the slope and the history of the site, with an estimate of the family's access to manure, workforce and land. Annual records for each field (n = 33) included the daily rainfall and the cropping practices. Annual records of each plot (n = 1,320) included: (1) in the first week after sowing: cover by dung and crusts (typology after Valentin & Bresson, 1992), maximum height and origin of micro relief (between 5 and 50 cm), and the meso relief (over 50 cm, mainly gullies); (2) at harvest: number of woody plants, grain yield and total aboveground biomass of the crop. Fresh biomass was weight in the field and a sample was taken and ovendried (24H 70ºC) for dry weight determination.

Soil sampling and analysis

Topsoil (0-20 cm) samples were taken at harvest. As the analysis of every plot each year was too costly, two compromises were made: (1) as transects ran down the slope and the soil texture was known to slightly increase downslope, samples of two adjacent plots were mixed, up to a maximum of four plots in case they looked homogeneous; (2) When the soil conditions were different in adjacent plots (*e.g.* a gully or sand fan) the soil samples were analysed separately. As a result, the number of soil samples analysed per field varied between a minimum of 10 in transects with a relatively uniform soil surface, to a maximum of 14 in transects with heterogeneous soil surface. In order to get a representative set of data, both the mean and the standard deviation of each variable were weighed by the number of plots mixed in the soil sample.

Soil analyses included pH-water, total carbon, particle size distribution (<2 µm, 2-20 µm >20 µm), N-tot, P-Bray and P-tot. The cations Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} were determined using the ammonium acetate method, H^{+} and Al^{3+} were determined using 1 M KCl. The effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable bases and exchangeable acidity. Zebu dung was collected from the soil surface in May 1994, where it had dried in situ. Preliminary analysis of the data.

Data gathered over three or four years from the same transect were analysed to determine whether they showed a trend with time. None of the soil variables demonstrated such a trend. For example, the organic matter content did not decline as the number of years of cultivation increased from the third to the sixth year. Instead, all the data from a given field tended to remain clustered. The variables “height of micro relief”, “proportion of permeable surface”, “number of woody plants ha^{-1}”, “grain yield” and “crop residue” were also unrelated to the year of cultivation. Hence, a single data set per field was enough. In order to facilitate the comparison among fields of the fallow system, the data analysed were those of the third year of cultivation after clearing. For the manured fields, the data were those of the last available year.

Results

Analysis of topsoil

In farming systems with no chemical fertilizers applied, organic matter and clay are determinant for the cation exchange capacity of the soil and therefore the key elements to appreciate the nutrient status of the soil. Organic matter and clay + silt contents were very low in all samples (Figure 1). These values are typical of the Sahelian sandy soils cultivated with pearl millet. In fields where fertility maintenance relies exclusively on fallowing, the topsoils of long fallow fields were different from those of short fallow fields by their higher clay + silt content, and to a lesser degree by their slightly higher organic matter content. Fields where manure was applied were split in two groups, the “old” fields being sandier than the “new” fields.

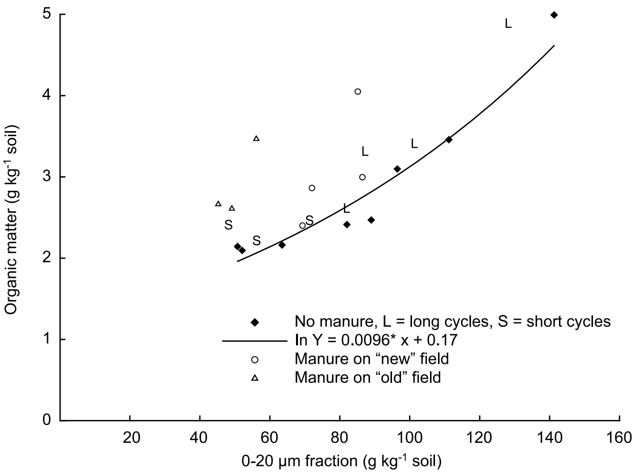

Figure 1. Organic matter content and soil particles <20 µm content of topsoil (0-20 cm) of pearl millet fields, fertility management by long or short-term fallowing, with or without manure input, Banizoumbou, Niger

Soil organic matter was not different in the two groups, probably because the quantities of manure applied yearly were equally low across all the fields.

The well-known relationship between organic matter and clay + silt contents is usually interpreted as an indication of land degradation, because uncultivated soils exhibit the highest values, over cultivated soils the lowest and normally managed soils intermediate values. The difference with the literature is that the values observed in the study area were much lower. Data from fields after long and short fallow periods were located on a continuum because transitions from long to short fallow cycles occur. The reduction of fallow periods and the accumulation of rotations resulted in a gradual decline in soil organic matter from 3.7 g kg^{-1} under long fallow management to 2.3 gkg^{-1} under short fallow, while the clay + silt content decreased from 107 g kg^{-1} under long fallows to 57 gkg^{-1} soils under short fallows. Thus, the solid line in Figure 1 describes the loss in soil particles <20 µm and in soil organic matter as cultivation becomes more frequent.

In fields where manure is applied, the most frequently cultivated sites were also the poorest in soil particles <20 µm, but the organic matter content was not different. Thus manure application seems to make up for some of the organic matter reduction enforced by cultivation, but manure application cannot prevent the topsoil from becoming sandier with frequent cultivation.

Table 1 shows the chemical analyses of the soil samples and zebu dung, the principal input. These results confirm the overall very low fertility of millet fields. Rotation of short fallow and cultivation without manure application resulted in the poorest topsoils in N, P and exchangeable cations.

Micro relief and soil surface

In the absence of tillage other than the breaking of the surface crusts, the micro relief is always natural. The micro relief can be microdunes (favouring infiltration) or crusted micro heights and lows (generating runoff). Both kinds of micro relief were found in every millet field, but the repartition between infiltrating and impermeable micro relief was strongly correlated with cropping practices (Table 2).

In manured fields, the micro relief was mainly made of microdunes formed around any obstacle littering the soil surface. Their maximum height (up to 8 cm) depended on the degree these obstacles could trap aeolian sand. In fields of the fallow system, the

Table 1. Analytical data from topsoil (0-20 cm) of pearl millet fields, Banizoumbou, Niger, according to cropping system

Cropping system	pH-H_2O	pH - KCl	0-20 µm g kg^{-1}	O.M.	N-tot	P-tot	P-Bray	Exchangeable cations $cmol_{(+)}$ kg^{-1}						Cation exchange capacity
								K	Ca	Mg	Na	H	AI	
Fallow system – long cycles 10 yrs cult/>15 yrs fallow	5.0	4.0	107	3.7	183	49	2.5	0.06	0.51	0.17	0.04	0.10	0.16	1.04
Fallow system – short cycles 4-6 yrs cult/3-5 yrs fallow	5.2	4.2	57	2.3	117	33	2.0	0.04	0.31	0.13	0.02	0.08	0.15	0.71
Manure system – "new" field	5.4	4.4	77	2.8	153	40	1.9	0.11	0.43	0.19	0.03	0.05	0.06	0.78
Manure system – "old" field	5.5	4.4	54	3.0	156	40	3.0	0.09	0.40	0.18	0.02	0.07	0.08	0.83
Significance														
P< 0.1 = ***; 0.5<P<0.1 = **	**	***	***	ns	ns	**	ns	***	ns	ns	ns	**	**	ns
Dung [1]	7.4 [2]			470	1,400	174		18.7	51.5	15.0	1.23	0.00	0.00	86

[1] Zebu dung, collected from the soil surface in may 1994 where it had dried in situ
[2] 1 part dung to 4 parts of water

Table 2. Mean maximum micro relief and soil surface characteristics according to cropping system, Banizoumbou Niger. Observations in 25 m^2 plots, 5-15 days after the sowing of pearl millet

Cropping System	Micro Relief (cm)	% Related to						
		Crusted areas (generating runoff)			Sandy areas (favouring infiltration)			
		Tree or shrub	Other	Total surface	Millet stumps	Dung	Other	Total surface
Fallow system – long cycles 10 yrs cult/>15 yrs fallow	8.8	51	13	64%	16	1	19	36%
Fallow system – short cycles 4-6 yrs cult/3-5 yrs fallow	7.6	54	4	58%	17	0	25	42%
Manure system – "new" field	4.4	7	8	15%	60	16	9	85%
Manure system – "old" field	5.7	36	1	37%	33	21	9	63%

micro relief was mostly related to trees and shrubs. The micro mounts were highest in fields cleared after a long fallow period because trees and shrubs were oldest. Each individual or cluster of trees and shrubs stood on its own steep-sided pedestal, often over 15 cm high. Fallow-managed fields carried an average of 700 (long cycles) and 480 (short cycles) woody plants ha^{-1}. Manured "new" fields had an average densities of 340 woody plantsha $^{-1}$ but manured "old" fields carried only 80 plantsha $^{-1}$. Being relicts of the fallow vegetation, these plants managed to grow over successive cultivation periods, but woody plants tend to disappear with frequent cultivation. They also disappear gradually from manured fields, possibly because of heavy grazing.

Generally, the higher the micro relief, the more the soil is protected against erosion because with increased surface roughness, the water stays longer on the soil surface and thus can infiltrate. This seems to account for the sand dunes, the more and the higher these sand masses were, the less signs of water erosion were observed. The opposite seems to be true for the micro mounts formed by woody plants. In contrast with the gentle slopes of the aeolian sand deposits, these slopes were steep and impermeable. Instead of favouring infiltration, they accelerated the circulation of water over the soil surface. Field cultivated after long fallow periods had the highest micro relief and the largest amount of crusted surface, also showed evidence of much superficial water movement: gullies, sand fans, depositional crusts and eroded areas were frequent. By contrast, in fields where microdunes were highest and occupied most of the cropped surface, i.e. in manured fields, these indications of water erosion were scarce.

Pearl millet production

Sowing requires little effort in terms of time and sowing seed, compared to weeding and thinning. At the onset of the rains, as much land as possible is planted and later preferential choices are made as to in what part of the field crop care will continue. Most often, where crop establishment is bad, cultivation will stop. However, the transects were weeded and harvested even when the plots were regarded as hopeless by the farmers.

Table 3. Pearl millet production according to cropping system, Banizoumbou Niger. With indication of the proportion of the field abandoned after sowing because of expected low yield

Cropping system	All planted land[1]	Planted, weeded and harvested land [2]			Part of the field abandoned[2]
	Grain yield kg ha^{-1}	Grain yield kg ha^{-1}	Total biomass t ha^{-1}	Crop residu t ha^{-1}	
Fallow system – long cycles 10 yrs cult/>15 yrs fallow	301	385	1.7	1.1	25%
Fallow system – short cycles 4-6 yrs cult/3-5 yrs fallow	122	195	0.9	0.6	47%
Manure system – “new” field	339	371	1.9	1.4	10%
Manure system – “old” field	399	399	2.5	1.8	0%

[1] Cultivation continued in the experimental plots
[2] Farmers’ practice

Fields of the fallow system had large parts of abandoned land, compared to manured fields where almost the entire planted area contributed to grain yield (Table 3). In long fallow fields, unproductive areas were associated with gullies, coarse sand deposits (sand fans) and large tracts of erosion crusts. In short fallow fields, the abandoned areas were patches of extremely sandy soil, too poor to sustain production. In fields of the manure system, 90% to 100% of the sown land contributed to grain yield because gullies, sand fans were largely absent and because patches of extremely poor sand were fertilized with dung. Considering the grain production under farmer’s management, that is the yield from that part of the field where cultivation continued after sowing, then grain yields were slightly under 400 kgha $^{-1}$ in all cropping systems, except for the short fallow fields without manure input where grain yields did not exceed 200 kgha $^{-1}$ (Table 3).

Discussion and conclusion

In the Sahel ecosystem, the soil particles <20 µm of the topsoil constitute a capital on which the long-term success of pearl millet cultivation depends. This study demonstrates that this capital can be lost, because, with time, cultivated soils loose part of their clay and silt fraction from the topsoil. Though the loss of fine particles results in less surface crusting and visible products of water erosion like gullies and sand fans, and though most of the soil surface can be sown to pearl millet, the final result is the development of extremely skeletal soils. This loss constitutes a real threat to pearl millet cultivation as can be seen by the very low yield obtained in the plots that have been cultivated for a long time in alternation with short fallow periods.

Long-term processes

During fallowing, the woody vegetation is allowed to grow. Part of the vegetation that dies at the end of the rainy season is worked by the macro soil fauna and buried into the soil, thus increasing the soil organic matter content and forming more stable aggregates (Feller et al., 1989). Airborne particles accumulate on obstacles like shrubs and trees. Some of this material gets incorporated into the soil via stemflow beneath the shrubs or trees, and some is washed down to lower parts of the land (Ambouta et al., 1996). With land clearing and the cutting of the vegetation, not only the input of biomass stops but also the dust-trap disappears. While mineralization rates have gone up because of increased exposure, reduced organic matter means loss of soil structure and subsequently less stable aggregates. Repeated weeding further disrupts the aggregates and clay + silt particles are subject to erosion (Valentin, 1995; Pieri, 1989; Feller & Beare, 1997). Particles <20 µm are liberated when unstable aggregates are disrupted by raindrop impacts, they clog the pores and form crusts. Cover by crusts is highest in fields cultivated after a long period of fallow because the building material of crusts is relatively abundant, secondly during cultivation the reduction of organic matter from the topsoil is probably more rapid than the loss of fine earth. On the other hand, high organic matter content increases the structural stability of soils, preventing them from disintegrating. This makes newly cleared fields that are manured less prone to crusting. Despite the still considerable clay + silt fraction of the topsoil, the decomposed dung mixed with soil by organisms ameliorates its structure so aggregates become less sensitive to disintegration. A second argument is that the soil surface of manured fields is littered with dung, thus dung protects the soil against aggressive rains. The farmers in Banizoumbou are aware that the issue of crusting, typical of long fallow fields can be greatly reduced by the application of manure. The best option is to start applying manure even before clearing, in the last year of fallowing. In the history of land use in Banizoumbou, this was a general practice when opening new land for cultivation (Loireau, 1998) but this option is now only open to the few well-off farmers.

Rajot (2001), by studying a field and an adjacent fallow during the same storm event, demonstrated that vegetated sites accumulated dust whereas cultivated fields lost dust. Wind erosion from fallowed land was always very limited, but it could be very large from the millet fields. He assessed that the mass budget of wind erosion (erosion versus deposition) at the scale of a village territory was positive in Banizoumbou, about 150 kgha $^{-1}$year $^{-1}$ and calculated that a further clearing for cultivation of only 6% of presently vegetated land would lead to a budget of zero (Rajot, 2001). Both the above-mentioned studies and our data show that the dominant process driving the fallow system is wind erosion. The loss of fine particles is enhanced by manual cultivation and the subsequent loss of fertility can only be restored by the trapping of dust during a long-term fallowing. Manure can only partly replace the fallow as a means of sustaining fertility. Dung application can supply the necessary nutrients to provide an average of 400 kg of grain yield/ha^{-1}. Under the current forms of manuring, visible traces of runoff and water erosion disappear and the soil organic matter content stabilises at a low level. However, the clay + silt content of the topsoil keeps declining with time.

Time span

How much time is needed to reach such losses of clay, silt and organic matter and to change a relatively productive skeletal soil, into an unproductive soil without the constant application of manure? As this is a long-term process, no direct measurements are available.

Ga-koudi, department of Maradi, Central Niger has similar climate and soils but the pressure on arable land is much higher than in Banizoumbou (Micheau, 1994; Wango, 1995; Dosso et al., 1996). Two types of soils are cultivated with pearl millet, one called Jigawa, a very sandy soil (typical value 55 gkg $^{-1}$ of <20 μm) and the other Hako, a less sandy soil (typical value 81 gkg $^{-1}$ of <20 μm). Local farmers reported that the Jigawa soils, located close to the village, were formally Hako, and they estimated that the transformation took about 40 years of cultivation (Dosso et al., 1996). They further ascertained that the reverse was possible under long term fallowing. Hako soils are regularly returned to fallow for short periods and seldom manured. They produce an average grain yields of 250 kgha $^{-1}$, similar to those obtained in Banizoumbou under short cycles. All the manure is applied on the Jigawa soils, where the average yields reach about 300 kgha $^{-1}$ (Dosso et al., 1996). In Ga-koudi, the practice of long-term fallowing has disappeared. Most of pearl millet production depends entirely nowadays on the yearly application of manure. However, dung is becoming increasingly scarce because fallow land, formerly used as pasture, has been cleared for cultivation.

A second estimate comes from Banizoumbou farmers. Farmers crop long season pearl millet land races called Somno (120-130 days) exclusively in long fallow fields because they consider that Somno requires a heavier soil, and they plant the short season Heinkirey land races (90-100 days) in the other fields. Farmers observe that after cropping the same field for a certain period (generally over 40 years) they must shift from long- to short-season cultivars because the topsoil becomes sandier.

The use of long-season varieties has become less and less frequent with time. The growing popularity of short-season land races should be attributed to the spread of very sandy topsoils and this is due to the gradual loss of the clay + silt fraction by wind erosion from cultivated soils, losses that are no longer compensated by long-term fallowing.

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