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Fertility management and landscape position: farmers' use of nutrient sources in western Niger and possible improvements

M. Gandah[1,*], J. Brouwer[2], P. Hiernaux[3] and N. Van Duivenbooden[4]
[1]INRAN, B.P. 429, Niamey, Niger; [2]Brouwer Envir. & Agric. Consultancy, Wildekamp 32, 6721 JD Bennekom, The Netherlands; [3]International Livestock Research Institute, ICRISAT Sahelian Centre, B.P. 12404, Niamey, Niger; [4]ICRISAT Sahelian Centre, B.P. 12404, Niamey, Niger; [*]Author for correspondence

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Abstract

Poor millet growth and yields in Niger are commonly attributed to rainfall deficits and low soil nutrient content. Land management by local farmers is done as a function of soil types, crops, and available resources. Farmer management practices in millet fields located on four different landscape positions were studied in a village in western Niger located near the 600 mm isohyet. Average distance from homestead to field was 980 m, with fields in the valley bottom much closer (average 225 m) and fields on the plateau much further (average 2300 m). Farmers considered the valley and plateau fields slightly more fertile than the other fields, but rainfall infiltration on plateau fields is often relatively poor. Nitrogen and phosphorus contents in the soil were highest on the less intensively cropped plateaus. More than 50% of the fields did not receive any applied nutrients other than during livestock grazing of leftover stover. Manure application was done through corralling in only four of the fields studied (20%), out of which three were farmed by Fulani using their own herds for manuring. There was no significant effect of landscape unit on yield, though yields in the valley and on the upper slope were slightly higher than average. Millet grain yields, soil carbon and soil phosphorus decreased significantly with distance from the living quarters. This may be because manuring usually takes place close to home (average distance in 1997 <200 m). Manure application increased millet grain production from 126 kg ha^{-1} to 316 kg ha^{-1} in 1997. Manuring yielded more than 1000 kg ha^{-1} in 1996, when rainfall was much more favourable. Fallowed fields yielded an average 143 kg ha^{-1} of millet grain in 1997, with fallow taking place an average of 1640 m from the homestead. Another soil fertility management practice included use of millet threshing residues in fields adjacent to the village. There was no chemical fertilizer application. Any improvement to the system will require the solution of existing constraints limiting the integration of livestock and crops and/or limiting the input of external sources of nutrients in Niger. These limitations can include lack of land to allow fallowing practices and/or grazing; local non-availability of mineral fertiliser; lack of capital to buy fertiliser, due in part to low millet prices; lack of means of transport for inputs; but also lack of means for pest control and lack of labour for sowing, weeding and thinning. Initial improvements may be made by making more efficient use of the available manure, through much lighter and slightly more frequent manuring of much larger areas.

Introduction

Crop production in the Sahel is mainly based on rainfed production of cereals such as millet and sorghum. The rainy season generally lasts only three to four months (June/July–September), and over the past 35 yr annual rainfall has decreased throughout the region (Sivakumar et al. 1993). Water deficits quite often occur during the most sensitive stages of millet development: plant emergence and the time from heading to grain filling (De Rouw and Winkel 1998). Such water stress is significantly affected by local field conditions. On plateaus of Western Niger, the development of the vegetation in a distinct 'tiger bush pattern' (alternating bare areas and vegetated strips on plateau) is a result of run-off and run-on, related to surface sealing on the bare areas and good infiltration under the vegetated strips due to localised biological activity (e.g. Chase 1986). In adjacent agricultural lands, similar redistribution of water in the field was linked to both soil surface sealing and soil micro-topography. Gaze et al. (1997) showed on sandy soils of Western Niger that as a result of surface sealing and surface redistribution, infiltration in a field varied from 30% to 340% of rainfall. At 8–10% the available water holding capacity of the soils is generally rather limited.

In addition to water problems, nutrients also limit crop production. Land used for rainfed production of cereals is generally poor in terms of chemical elements (Bationo et al. 1989). Brouwer and Powell (1998) showed that topography, through influencing infiltration, also affected nutrient losses: greater infiltration in depressions led to significantly greater leaching of manure to below 1.5 m.

Agronomic research in the Sahel during the past 35 years has had little effect at the farm level. Farmers still use their local crop varieties. They rarely use improved varieties due to the costs involved in purchasing them, their unavailability when needed, and their non-adaptation to local cropping practices. Farmer nutrient management is subject to the same limitations. The main constraints are the high cost of chemical fertilizer, the low price paid for millet, and application rates and methods that do not fit local practices. The lack of transport to the village and to the field can also be a complicating factor.

Geomorphology has a great effect on fertility and land use in Western Niger. The landscape has been formed in Miocene sedimentary deposits called the Continental Terminal (Gavaud 1966; Wilding and Daniels 1989). Within these deposits laterite layers were formed, which in many areas now occur as ironstone caps on the highest parts of the landscape, varying in thickness from a few centimeters to several meters (Figure 1). Very thin layers of wind-blown sand were deposited on top of these ironstone plateaus during very dry periods of the Quaternary, and were mixed in with the slightly more loamy material *in situ*, probably through biological action. Soil depth above the laterite is usually less than 0.5 m, but permits the growth of tiger bush and occasionally some crop production.

Next to the plateaus are found steep (often more than 20%) upper slopes, with high erosion potential due to water running off the plateau edge. Below this are found deep, gently undulating terraces, covered by coversands of the same origin as the thin deposits of sand on the plateaus. It is here that most of the millet fields are located. The lowest landscape positions are formed by valleys proper or valley bottoms, also just referred to as valleys (see Figure 1). These valley bottoms contain drainage channels of varying importance. Soil types according to the USDA Soil Taxonomy (Soil Survey Staff 1996) range from Petroferric Dystropepts and Petroferric Haplustults on the plateaus, to Psammentic Paleustalfs and Haplustalfs on the slopes, and Ustipsamments in the valleys (Wilding and Daniels 1989).

Crop production in each landscape position depends on physical and chemical properties of the soils, but also on the location of the field in relation to the village or housing site and the general resources available to the farmer. As a result of the lack of impact of scientific research, traditional crop production systems still rely almost exclusively on crop residues and manure for soil fertility management. Usually after harvest of the heads, part of the millet straw is removed for daily use as fuel, as construction material for e.g. hedges, or as fodder. The unused stover remains in the fields.

Plateaus and occasional fallow land constitute most of the pastures available to livestock, but during the dry season the crop residues in the fields are also fed on. Those parts of the stover still on the field after grazing are decomposed through biological activity by e.g. termites (Makhfousse et al. 1999). During the dry season animals are also camped on the millet fields in night time corrals, leaving behind their manure and urine as fertiliser. Directly around the villages, household refuse, millet threshing residues and some small ruminant manure can contribute to the improvement of soil fertility. This integration of livestock and cropping returns an estimated 53 to 57% of the daily manure and urine production to the grazing grounds; the remainder goes to the cropping areas (Schlecht et al. 1995; Mamadou Sangare 1999, personal communication). However, this system is not functioning as in the past because of pressure on the land due to human population increase, because of a reduction in fallow and pasture land and in available manure, and because of increasingly unreliable rainfall (including more frequent extreme rainfall events).

Based on this analysis of the situation in western Niger, and on what was known about various villages, the village of Tchigo Tagui some 75 km east of Niamey was selected as a representative site to investigate the relationship between use of livestock

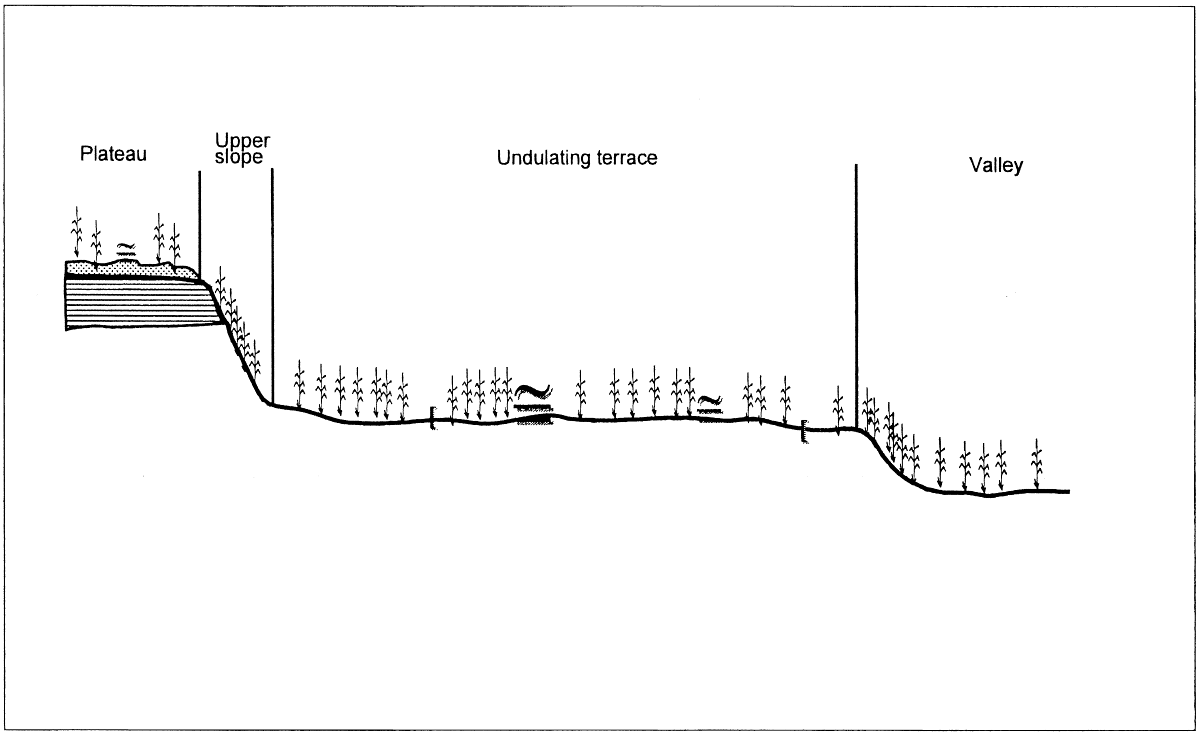

Figure 1. Landscape positions in the region of Tchigo Tagui, western Niger (schematic and not to scale). Horizontal hatching under plateau indicates ironstone cap; ≅ indicates localised occurrence of trees.

manure or other management practices and crop production on soils of four landscape positions. The village has been the subject of livestock and socio-economic studies by ILRI (the International Livestock Research Institute) since the late 1980s. The research carried out in farmer's fields and reported on here focused on the following objectives:

1. Compare nutrient management by farmers according to landscape positions and the effects of management on millet grain yields and soil nutrient contents
2. Investigate the specific use of the limited available manure in the fields in various parts of the landscape
3. Find prospects for fields located on plateaus or far away from the village to improve their fertility status.

Materials and methods

Choice of sites

In this experiment, 20 fields were selected from the larger database collected by ILRI in the area surrounding Tchigo Tagui, east of Niamey in western Niger (Figure 2). The choice of fields was based on several factors:

- geomorphologic position,
- farmer's evaluation of the actual soil fertility status,
- distance from village,
- the history of the field, when available,
- and the willingness of the farmers to participate in the experiment.

The first three criteria were the major variables used in selecting a field. Table 1 summarizes the classification of the 20 fields whose relative positions are shown in Figure 3. The distribution of the fields in the landscape showed that seven fields were located on the plateau, three on the upper slope, eight on the undulating terrace, and two in the valley proper. This represents quite well the area occupied by the different landscape units in the region of the village, with the plateau occupying 25.2%, the upper slope 11.8%, the undulating terraces 54.3% and the valley bottoms 8.7% of the total area. Four of the fields were adjacent to the villages, eight were between 400 and 2000 m from the village of the user (generally also the owner),

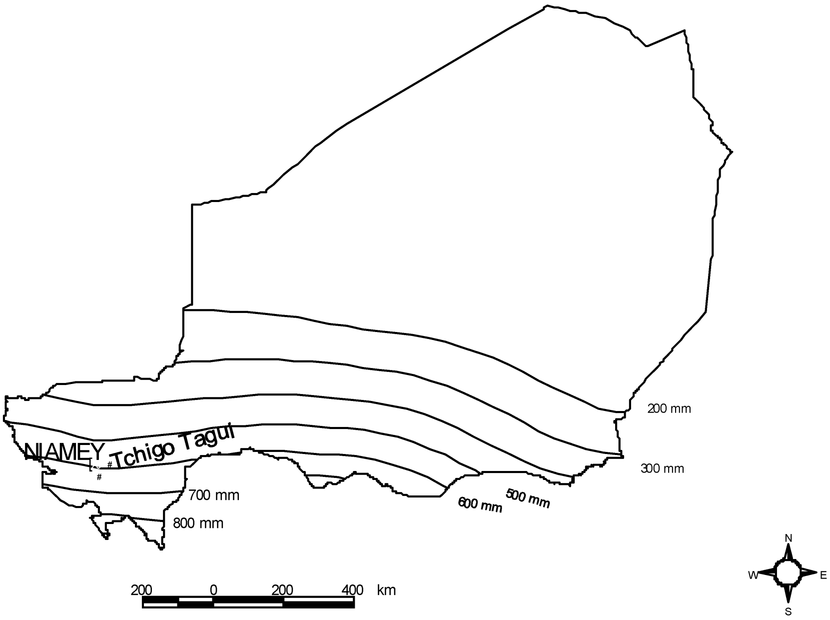

Figure 2. Map of Niger and the location of Tchigo Tagui.

and the remaining fields were located between 2000 and 4000 m away. In the last group, fields 6 and 20 were actually owned by farmers living in another village more than 15 km away. Field size varied between 1.6 and 26 ha.

Soil fertility

Soil fertility management practices found in (parts of) the selected fields were summarized in classes described as follows:

M0	manure applied to the plot in 1997
M1	manure applied to the plot in 1996
M4	manure applied to the plot 4 yr previously (in 1993)
M6	manure applied to the plot 6 or more years previously
F0	plot was under fallow less than one year previously
F2	plot was under fallow 2 yr previously (in 1995)
T0	plot was a threshing ground less than one year previously
T2	plot was a threshing ground 2 yr previously
T3	plot was a threshing ground 3 yr previously

Field measurements

In each of the 20 selected fields, 3 plots were delineated. The plots were 10 × 10 m and placed at three different locations. Slope gradient and fertility status were used in deciding where to place the plots. Where the field was on a clear slope, the plots were placed at the top, mid and bottom positions. In fields that were more or less flat, plots were placed according to practices affecting soil fertility (fallow, manure). When manure was applied to part of the field during the year of the study, one plot was installed in the fertilized area. Single soil samples were taken with an auger at the center of each plot at 0–0.10, 0.10–0.20, 0.20–0.40, and 1.0–1.20 m depths before planting in June and after harvest in October. The samples were air dried and analyzed for pH in water, carbon content, total nitrogen, and Bray-1 available phosphorus using standard procedures as described by Van Reeuwijk (1993). Texture was determined in four fractions: clay, silt, fine and coarse sand. The results presented in various tables refer to the sampling of June.

The top soil (0–0.05 m) of each plot was sampled for bulk density using a 100 cm^3 steel core. Five samples were taken, in the center of the plot and at the four corners. The samples were oven dried at 105 °C for 24 h and weighed. Five profile pits were dug: one pit on each of the four landscape units except the plateau, where two pits were used because the soil color and depths varied considerably. Profiles were described and classified according to the USDA Soil Taxonomy classification system. Where manure had been applied to a field, a 1 × 1 m iron frame was used to estimate the application rate. The frame was placed at random at three different locations and the manure inside the frame was collected, air dried, and weighed.

Table 1. Classification of the 20 fields according to landscape position and distance from village (sorted on distance).

Field number	Landscape position[1]	Fertility level as estimated by farmer[2]	Distance (m from village)	Field area (ha)
8[+]	S	A	50	13.0
10	T	P	50	3.13
13	V	A/F	50	26.17
16[+]	P	F	50	3.12
17	V	A	400	2.06
5	T	A	600	13.73
19[+]	T	A	600	6.25
18	T	P	800	5.56
2	S	P	1000	8.88
9	S	P	1100	7.25
11	P	A	1100	15.17
12	P	P	1900	5.31
4	T	A	2000	1.62
3	S	A	2200	11.78
14	T	P	2200	8.15
20	P	P	2200	3.84
7	T	F	2300	4.66
1	P	A	3500	2.93
15	P	F	3500	6.16
6	P	F	3800	9.31

[+]Farmers concerned owned their own livestock for manuring. [1]Landscape position: plateau (P), upper slope (S), undulating terrace (T), and valley (V) (Figure 1). [2]Fertility level as estimated by the farmer: poor (P), average (A) and fertile (F).

The three samples from each plot were later mixed and a composite sub-sample was taken for laboratory analysis (carbon, dry matter, total nitrogen and total phosphorus).

Three weeks after planting the millet, the number of hills planted in each plot were recorded. At harvest in October, the number of millet hills and heads harvested, as well as the straw produced per plot were

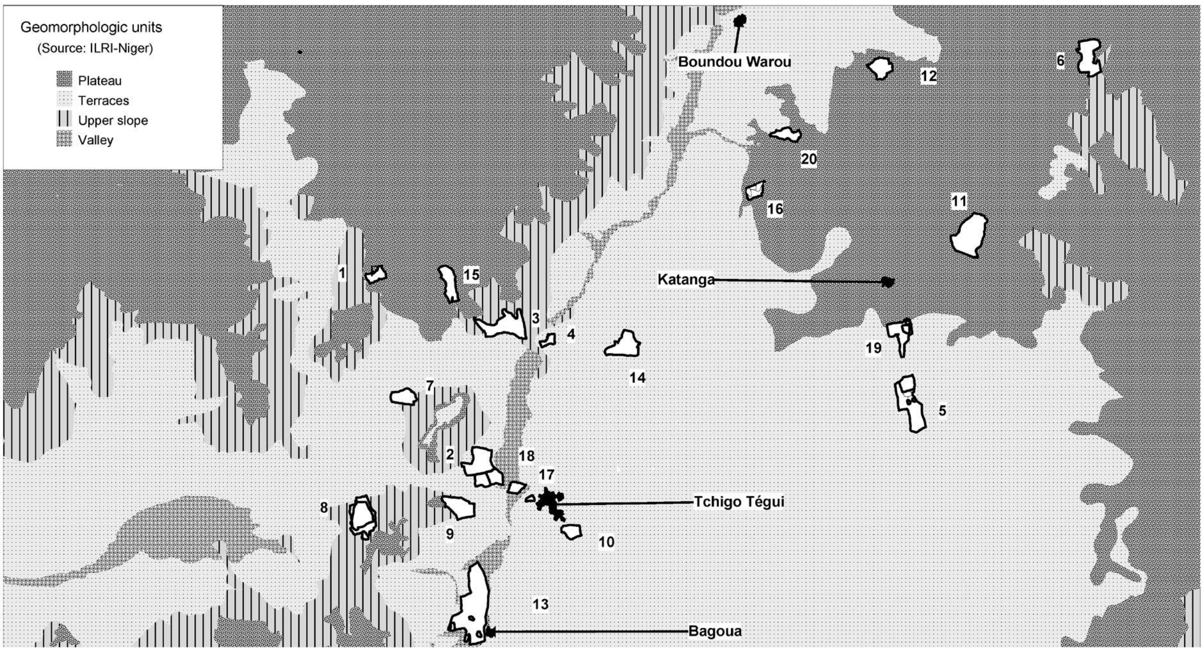

Figure 3. Map of the Tchigo Tagui region with landscape positions and selected research fields. The distance between the villages of Tchigo Tagui and Bagoua equals 1.8 km.

measured. The straw weight from each plot was corrected for moisture content using an oven dried sub-sample. The millet heads were air dried in the sun for 2 weeks and threshed to obtain the grain weight per plot. In each field, the manure application sites were mapped using a GPS after a differential correction was done.

Results and discussion

Field location in the landscape

The average distance of the fields from the homestead was 980 m. The two fields in the valley bottom were on average closest to the farm house: only 225 m (range 50–400 m; Table 1). The distance to both undulating terrace fields and upper slope fields varied greatly but was similar for the two landscape units: range for both from 50 m to just over 2000 m, average distance 1250 m for the terrace fields, 1100 m for the upper slope fields. Plateau fields were generally furthest away at 2300 m (range 50–3800 m). Overall, farmers considered their valley and plateau fields to be most fertile (slightly above average), and their upper slope fields least fertile (halfway between poor and average). Undulating terrace fields were on the whole considered to be of just below average fertility. There was no clear correlation between farmers' evaluation of field fertility and distance to the field.

Soil physical and chemical properties and landscape position

Mean soil physical properties of the topsoil in four landscape positions are shown in Table 2. The bulk density showed quite small but consistent differences between the four landscape positions: topsoils on the plateau had the lowest bulk density (1.53 Mg m^{-3}), while the undulating terrace had the highest (1.57 Mg m^{-3}). More importantly, the clay content of the plateau soil was significantly higher than in all the other landscape positions: 6.2% against less than 4%. On the plateau, the clay size fraction would be predominantly kaolinite from the parent material, very fine quartz, and very fine iron oxide from the laterite (Legger and van der Aa 1994). Part of it is also clay from dust deposition: according to Herrmann (1996), 50% of clay size particles in harmattan dust is kaolinite. Silt content was highest in the valley and plateau soils (Table 2).

Clay and silt fractions are critical for soil surface sealing. The high clay and silt contents on the plateau result in water ponding in micro-low areas of the plateau, or being lost via runoff to the upper slope and down to the valley via erosion fans or gullies (Figure 1). Similarly, about 12–13% of the annual rainfall ran off from upper slope positions in another village in the same region (Rockström and Valentin 1996).

Regarding texture changes with depth, clay content generally increased with depth, a sign of illuviation, and silt content decreased correspondingly (data not shown). Across all the landscape positions, soil texture to a maximum of 1.5 m depth (less on the plateau) ranged from sandy to no heavier than sandy clay loam.

Of the soil chemical characteristics measured, the average soil profile carbon content of the 0–40 cm layer was highest on the plateau (0.17%) and upper slope (0.14%) (Table 3). One would expect the plateau to be poor in carbon due to the limitations for plant growth (surface sealing and run-off, etc., causing low biomass production). However, carbon may have accumulated there as a result of little tillage, little water movement in the profile of the bare areas, and/or bonding to clay materials. For nitrogen, no difference was observed except that nitrogen values on the plateau were higher than on the upper slope (Table 3). Soil available phosphorus content was highest on the plateau and significantly different from

Table 2. Mean soil physical properties of the topsoil in four landscape positions, as indicated in Figures 1 and 3.

Landscape	Bulk density (0–5 cm depth) (g cm^{-3})	Clay (0–20 cm depth) (%)	Silt (0–20 cm depth) (%)	Fine sand (0–20 cm depth) (%)	Coarse sand (0–20 cm depth) (%)
Plateau	1.53*c*	6.2*a*	5.4*a*	45.68*c*	41.0*a*
Upper slope	1.55*b*	3.9*b*	4.1*b*	52.8*b*	38.5*b*
Undulating terrace	1.57*a*	3.6*bc*	4.2*b*	51.8*b*	39.2*ab*
Valley	1.56*ab*	2.7*c*	5.7*a*	56.2*a*	34.8*c*
P	0.00	0.00	0.00	0.00	0.00

a, *b*, *c*, indicate significant differences between means. *P* = probability of differences not being significant.

Table 3. Mean nutrient content and pH of the soil profile (0–120 cm), as a function of landscape position.

Landscape	Total carbon (%)	Total nitrogen (%)	Bray-1 phosphorus (mg kg^{-1})	pH_{water}
Plateau	0.17*a*	0.008*b*	2.79*a*	5.51*a*
Upper slope	0.14*a*	0.005*a*	2.15*ab*	5.69*a*
Undulating terrace	0.11*b*	0.006*ab*	1.74*b*	5.66*a*
Valley	0.12*b*	0.006*ab*	2.3*ab*	5.23*b*
P	0.00	0.00	0.05	0.00

a, *b* indicate significant differences between means. P = probability of differences not being significant.

the contents in the undulating terraces area. Relatively high phosphorus levels on the plateau could be explained by a combination of eolian sand deposition, which contains 1 to 5 kg ha^{-1} yr^{-1} of P (Herrmann 1996), and relatively little removal of P. Low levels on the undulating terraces were probably due to nutrient mining, due to removal of P in harvested components not being balanced by various inputs. Over the whole landscape, there is no clear correlation between clay content (Table 2) and C, N or P content (Table 3). Soil pH in water was lowest in the valley soil, and there was no difference between the other three positions. A low pH in the valley is common, as nutrients are leached out of the soil due to high water infiltration. This also occurs in the soils in ancient river valleys in the region, with pH values between 4.5 and 5.5 (Wilding and Daniels 1989).

On the basis of the nutrient status observed, the plateau is a much richer environment for crop growth and may be easy to improve if its limitations can be resolved: surface sealing and run-off, limited soil depth, and distance from the village. This relative richness of the soils on the plateau of this region was also observed by Legger and van der Aa (1994). Although the plateau soils were relatively fertile, all four landscape positions were low in all major nutrients for good millet growth, and fertility improvement by farmers was necessary.

A regression analysis was carried out to examine soil nutrients and millet yields relationships with distance between fields and farmer's living site, along with landscape position. The data was scaled down using nutrient contents at 0–40 cm depth, averaged over each measured distance to site of living. The best regression valid for all nutrients, pH and yields was obtained with a power model (Table 4). Negative coefficients were obtained for yields, carbon and phosphorus to indicate a reduction with distance from living quarters. High correlation coefficients exist between millet yields and distance from the place of residence. The fact that at the same time no correlation was found between distance from place of residence and soil fertility as estimated by farmers, indicates that other factors play a role in millet production, too. Such factors can be the availability of labour to sow, thin and weed the millet at the right time; and the occurrence of millet pests and diseases. As manure application often takes place close to the homestead (see below), the relatively short-lived nature of the effects of manure application on millet yield may also play a role.

Table 4. Regression of average properties of the soil layer with most roots (0–40 cm), and crop yields, on distance to fields.

Factor	Model	R^2
Carbon	-6.32×10^{-12} distance^3 + 0.139	0.31
Nitrogen	2.62×10^{-14} distance^3 + 0.0101	0.39
Phosphorus	-1.88×10^{-10} distance^3 + 1.65	0.70
pH_{water}	3.61×10^{-11} distance^3 + 5.68	0.50
Grain	-2.02×10^{-9} distance^3 + 211.95	0.90
Straw	-2.98×10^{-7} distance^3 + 3347.8	0.97

Landscape positions and the power model for distance were also combined to explain variations in soil parameters (Table 5). R^2 values ranged from 0.13 to 0.47. We note that for phosphorus the power model holds, whereas for the other components a linear relation with distance applies. Clearly, for these variables the power behavior observed before (Table 4) is largely explained by differences in landscape position. For carbon, nitrogen and phosphorus, both landscape and distance influenced nutrient content at the 0.05 significance level. This was not the case for soil pH.

Fertility management, soil nutrient status and landscape position

The data confirmed that fallow, application of threshing residues, and manuring are the main nutrient management methods used by villagers to maintain land productivity. The distribution of the management systems in the landscape (Table 6) indicated that

Table 5. Modeling soil nutrients and pH (0–40 cm) with landscape positions and distance to fields.

Factor	Source	df	Mean square	F	Sig.	R^2
Carbon	Intercept	1	0.339	7.717	0.000	0.47
	Distance	1	2.175E−02	181.458	0.002	
	Landscape	3	1.918E−02	11.649	0.000	
	Error	34	1.867E−03	10.272		
	Total	39				
Nitrogen	Intercept	1	5.680E−04	93.309	0.000	0.44
	Distance	1	5.429E−05	8.919	0.006	
	Landscape	3	3.851E−05	6.326	0.003	
	Error	24	6.087E−06			
	Total	29				
Phosphorus	Intercept	1	88.911	79.795	0.000	0.28
	Distance	1	6.345	5.694	0.021	
	Landscape	3	3.557	3.192	0.031	
	Error	52	1.114			
	Total	57				
pH_{water}	Intercept	1	584.722	3251.261	0.000	0.13
	Distance	1	5.616E−02	0.312	0.579	
	Landscape	3	0.461	2.564	0.065	
	Error	51	0.180			
	Total	56				

fallow conditions (F0 or F2) were found in two fields located on the plateau (fields 11 and 15, respectively 1100 and 3500 m from the homestead) and in three fields of the undulating terrace far away from the village (fields 2, 4 and 5 in Figure 3, respectively 1000, 2000 and 600 m from the homestead). The average distance to fallowed fields was therefore 1640 m, rather greater than the average distance to all fields of 980 m.

Manure (M0, M1, M4 or M6) was applied to parts of one field on each of the four landscape units. Except for field 13, the fields where manure was used were farmed by Fulani tribe farmers possessing several heads of cattle and living permanently on their land (fields 8, 16 and 19). The distance to manured fields was only 50 m in three cases and 600 m in the fourth; this indicates that the farmers concerned preferred to manure their home fields, or to move their huts to the fields they wanted to manure. This is a well known phenomenon, and relates to security of coralled livestock as well as travel distances.

The whole range of management classes was found on the undulating terrace, which represented the position preferred by farmers for crop production because the soil is easy to work, has less run-off and water erosion, and is suitable for many crop species (interview data, not shown). Crop residue management through application of threshing leftovers (T0, T2 and T3) was not actively applied by the farmers, except in field 10 adjacent to the village of Tchigo Tagui. In this field, the estimated treated area around each tree was about 350 m^2. Women use large trees to shade themselves during the daily millet threshing process. The owners of the field manage the residues remaining on the ground and allocate a new tree to the village women every two years. Three such sites were found

Table 6. Types and numbers of soil fertility management practices according to landscape position.

Landscape position	M0		M1		M4		M6		F0		F2		T0	T2	T3
	N	*n*	*N*	*n*	*N*	*n*	*N*	*n*	*N*	*n*	*N*	*n*		*N* = *n*	
Plateau	1	1					7	18	2	2					
Upper slope	1	1					3	8							
Undulating terrace	1	1	1	1	1	1	8	17	3	3	1	1	1	1	1
Valley	1	1					2	5							
Total	4	4	1	1	1	1	20	48	5	5	1	1			

N = number of fields with given management. *n* = number of 10 × 10 m plots used in the experiment.

in field 10. The accumulated millet heads residues are considered a useful fertility enhancing input by farmers.

The results for the effects of fertility management practices on soil nutrients are presented in Table 7. On the plateau, among the three practices found there, fallow was the best for improving carbon content, M6 best for improving phosphorus and pH. Overall significant phosphorus content on the plateau may be explained by the low cropping intensity of the plateau fields. On the upper slope, the plots manured in 1997 (M0) had the highest carbon content and there was no difference between M0 and M6 for P, N and pH. On the undulating terrace, the oldest threshing ground (T3) had the highest soil carbon content, significantly different from the fallow and M6. The fact that the threshing ground used three years previously had a higher carbon content than more recent threshing grounds, may be because the old threshing ground was used more heavily: historic intensity of use could not be established. Threshing residues applications as a whole (T0–T3) were correlated with a higher phosphorus content than all the other practices. Threshing residues, in decomposing, release appreciable amounts of carbon and phosphorus with lasting effects. For nitrogen, the most significant practices were the T2 and M0–M4 treatments. M4 was the best practice for improving soil pH in this part of the landscape.

The detailed effects of the practice using millet threshing residues to improve soil nutrients are illustrated in Table 8. The approach was effective in increasing phosphorus content with levels between 3 and 5 mg kg^{-1} and the carbon content in T3 to 0.23%. This particular well known method of managing soil fertility is limited to fields adjacent to the village, and to a field area around the selected tree for threshing millet. For manure, the global analysis using all the 20 fields masks some interesting results when individual fields are analyzed. Its effects were confirmed in a previous detailed study of fields 5 and 19 using 1996 and 1997 cropping seasons data: those results showed the M0, M1 and M4 treatments to increase phosphorus, carbon and nitrogen contents in the soil (Gandah et al. 2003).

Landscape position, nutrient management and millet yield

As a whole, millet grain yield was not statistically

Table 7. Effects of soil fertility management practices on soil nutrient contents and pH (0–40 cm) in four landscape positions.

Management		Carbon (%)	Nitrogen (%)	Phosphorus (mg kg^{-1})	pH_{water}
Plateau					
	F0	0.26*a*	0.008*a*	1.98*b*	5.21*b*
	M6	0.17*b*	0.01*a*	2.97*a*	5.57*a*
	M0	–	–	2.00*b*	5.11*b*
	P	0.05	0.44	0.02	0.01
Upper slope					
	M6	0.13*b*	0.005*a*	2.22*a*	5.76*a*
	M0	0.21*a*	0.006*a*	1.54*a*	5.48*a*
	P	0.05	0.44	0.38	0.17
Undulating terrace					
	M6	0.10*b*	0.006*b*	1.60*ab*	5.55*c*
	F0	0.12*b*	0.007*ab*	3.43*cd*	5.41*c*
	F2	0.10*b*	0.002*c*	1.62*ab*	–
	M0	–	–	1.96*abc*	6.24*ab*
	M1	–	–	0.30*a*	6.26*ab*
	M4	0.17*ab*	0.004*bc*	0.66*a*	6.50*a*
	T2	0.17*ab*	0.01*a*	4.92*d*	5.9*bc*
	T3	0.23*a*	–	4.42*d*	5.72*c*
	T0	0.18*ab*	–	3.71*cd*	5.44*c*
	P	0.00	0.00	0.00	0.00
Valley					
	M6	0.10	0.005	2.47	5.27
	M0	0.13	0.006	1.55	5.19
	P	0.20	0.70	0.34	0.51

a, *b*, *c*, indicate significant differences between means. *P* = probability of differences not being significant.

Table 8. Effect of management practices on average soil nutrient contents and pH (0-40 cm) in field 10 in 1997.

Management	n	Carbon (%)	Phosphorus (mg kg^{-1})	pH_{water}
M6	12	0.11*a*	0.82*b*	5.8*b*
T0	7	0.18*a*	3.71*a*	5.4*a*
T2	7	0.17*a*	4.92*a*	5.9*b*
T3	3	0.23*b*	4.42*a*	5.7*b*
P		0.016	0.00	0.002

a, *b*, *c*, indicate significant differences between means. *P* = probability of differences not being significant.

different between the different landscape units. Slightly higher yields were, however, obtained in the valley proper and on the upper slope (Table 9). The fields on the undulating terrace area of the landscape used most by the villagers had the lowest yields as a result of poor soils, caused by continuous cropping and low average rates of manure application to the fields. Grain yields on the plateau were not higher than in the valley bottom, in spite of the higher fertility levels found there. This is caused by other limitations of the plateau as discussed: surface sealing due to higher clay content, and consequently higher run-off and, perhaps, shallowness of the soil profile. Farmers indicated that due to the distance to the village, fields on the plateau are the last ones to be cared for: they are quite often 'abandoned', for instance when there is insufficient labour for thinning or weeding.

These general observations, however, do not bring out the good yield responses to manure (M treatments) in fields managed by Fulani farmers. The average grain yield of manured plots was 316 kg ha^{-1} compared to 126 kg ha^{-1} in the unmanured plots, which makes manure application an appealing practice to increase productivity. The fact that even yields on the manured fields were quite low is due to a combination of the very low waterholding and nutrient retention capacities of the soils, the irregularity of the rainfall, and/or the lack of pest control.

Farmers use little or no mineral fertilizer as a substitute for manure because of its high cost, non-availability locally, and the risk of crop failure due to low rainfall. In addition, the average manure rate, found in 6 of the total 60 plots of the study, was 6445 kg ha^{-1} in 1997, with a range between 3000 and 17000 kg ha^{-1}. These values are very high considering the low availability of manure to the farmers. Efficient management of the amounts deposited in the corrals is needed. Instead of buying extra manure or mineral fertiliser, the farmers may be better off manuring a much larger area at a much lower rate and slightly more frequently. In a similar vein, based on an on-station experiment, Brouwer and Powell (1998) suggested applying only 1500 kg ha^{-1} of manure and urine every three years or so.

Conclusions

Soil fertility management on different landscape positions was investigated in 1997 in fields of a village in Western Niger. The number of practices used on the plateaus was limited in comparison with the undulating terraces. The data showed that plots under fallow had higher C, and long term cropping had the highest P and pH on the plateau. On the undulating terraces, threshing residues gave the best soil C, P and N contents and the highest soil pH was found in the field plots manured four years ago (M4). In the inland valley bottoms, no difference was observed between the practices on soil nutrient content. Results also showed that 60 to 90% of the fields did not receive manure application, fallow or localized residue application. The little manure available to only some of the

Table 9. Mean millet grain and straw yield in plots located on four landscape positions and in plots with and without manure applied in the last 0–6 years.

Yields (kg ha^{-1})	Plateau	Upper slope	Undulating terrace	Valley	*P*	Fields		*P*
						Manure	Unmanured	
Grain	131*a*	164*a*	128*a*	203*a*	0.44	316*a*	126.7*b*	0.002
Straw	1454*a*	2127*a*	1174*a*	2258*a*	0.29	5475*a*	1257*b*	0.000

a, *b*, indicate significant differences between means. *P* = probability of differences not being significant.

farmers was applied to limited areas of the field with an average grain yield of only 316 kg ha^{-1} in 1997 compared to 126 kg ha^{-1} for non manured plots. Much higher yields (1000 kg ha^{-1}) were obtained the previous year in manured plots under better rainfall conditions. In comparison, fallow plots cropped with millet produced an average 143 kg ha^{-1} of grain. On the undulating terraces all the fertility maintenance practices found in the fields were present. This indicates that farmers are aware of (chemical) land degradation there and are willing to use the resources available to maintain field productivity. The study has shown that soils on the plateau are relatively rich in carbon, phosphorus and nitrogen compared to the other landscape positions. However, they are subject to surface sealing and consequently high water runoff, and thus probably more sensitive to intra-season droughts. They are also on average located far away from the village.

Fields located on the other landscape positions and far from the village were given little attention in nutrient management, except those owned by Fulani tribe farmers who live on their land. Fallow as a fertility management practice generally occurred quite far away from the homestead (average distance 1640 m), and manuring (average distance $<$200 m) and threshing residue application (50 m) quite close to the homestead or village.

Prospects for improving crop production in the region of Tchigo Tagui should rely on the two primary landscape units, the plateaus and the undulating terraces. The plateau would, however, require more investment in labor and transportation means to transfer nutrients, or in wells to allow local settlement. Successful cropping of the plateaus with the Fulani nutrient management practices will be possible if soil cover is deep and field corralling is provided. The plateaus are, however, also used for crop production, as range land, and for wood gathering; any increased use for crops should take into account these other land uses.

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References

Bationo A., Mokwunye U. and Christianson C.B. 1989. Gestion de la fertilité des sols sableux au Niger: un aperçu de quelques résultats de recherche de l'IFDC/ICRISAT. In: Berrada A., Mahaman I. and Gandah M. (eds), Les actes du séminaire national sur l'aménagement des sols, la conservation de l'eau, la fertilisation. Séminaire organisé par l'INRAN et le Programme Engrais Nigérien. 20 au 24 Février 1989 à Tahoua, République du Niger, pp. 177–194.

Brouwer J. and Powell J.M. 1998. Increasing nutrient use efficiency in West-African agriculture: the impact of micro-topography on nutrient leaching from cattle and sheep manure. Agric. Ecosyst. Environ. 71: 229–239.

Chase R.G. 1986. TropSoils collaborative water conservation research in Niger. In: Davis T.J. (ed.), Development of Rainfed Agriculture under Arid and Semiarid Conditions: Proceedings of the Sixth Agriculture Sector Symposium. World Bank, Washington, DC, pp. 265–290.

De Rouw A. and Winkel T. 1998. Drought avoidance by asynchronous flowering in pearl millet stands cultivated on-farm and on-station in Niger. Exp. Agric. 34: 19–30.

Gandah M., Brouwer J., Hiernaux P. and van Duivenbooden N. 2003. Strategies to optimize allocation of limited nutrients to sandy soils of the Sahel: a case study from Niger, west Africa. Agric. Ecosyst. Environ. 94: 311–319.

Gavaud M. 1966. Etude pédologique du Niger Occidental. Rapport général Tome II. Monographie des sols. Première partie. Centre ORSTOM de Hann, Dakar, 248 pp.

Gaze S.R., Simmonds L.P., Brouwer J. and Bouma J. 1997. Measurement of surface redistribution of rainfall and modeling its effect on water balance calculations for a millet field on sandy soil in Niger. J. Hydrol. 188–189: 267–284.

Herrmann L. 1996. Straubdeposition auf Böden West Afrikas. Eigenschaften und Herkunftsgebiete der Stäube und ihr Einflub auf Boden und Standortseigenschaften, Ph.D. Thesis, Universität Hohenheim, Stuttgart, Germany, 239 pp.

Legger D. and van der Aa M. 1994. Soils of the West Central Site, Niger. HAPEX-Sahel 1992. Department of Soil Science and Geology, Wageningen Agricultural University, Wageningen, The Netherlands, 31 pp.

Makhfousse S., Agbogba C. and Russel-Smith A. 1999. Abondance et diversité des termites dans les jachères Sahéliennes. Effet des termites et autres microfaunes du sol sur l'infiltration de l'eau. In: Floret C. and Pontanier R. (eds), La jachère en Afrique tropicale: roles, aménagement, alternatives. Vol. 1. John Libbey Eurotext, Paris, pp. 242–249.

Rockström J. and Valentin C. 1996. Hillslope dynamics of on-farm generation of surface water flow: The case of rain-fed cultivation of pearl millet on sandy soil in the Sahel. Agric. Water Manage. 33: 183–210.

Sivakumar M.V.K., Maidoukia A. and Stern R.D. 1993. Agrometeorology of West Africa: Niger. ICRISAT Information Bulletin No. 5. ICRISAT, Patancheru, India, 108 pp.

Schlecht E., Malher F., Sangaré M., Susenbeth A. and Becker K. 1995. Quantitative and qualitative estimation of nutrient intake

and fecal excretion of Zébu cattle grazing natural pasture in semi-arid Mali. In: Powell J.M., Fernandez-Rivera S., Williams T.O. and Renard C. (eds), Livestock and Sustainable Nutrient Cycling in Mixed Farming Sytems of Sub-saharan Africa, Proceedings of a conference held in Addis Ababa, 22–26 November 1993. ILCA, Addis Ababa, Ethiopia, pp. 85–97.
Soil Survey Staff 1996. Key to Soil Taxonomy. 7th edn. USDA, Washington, DC.
Van Reeuwijk L.P. 1993. Procedures for soil analysis. Technical Paper No. 9. ISRIC, Wageningen, The Netherlands, 100 pp.
Wilding L.P. and Daniels R. 1989. Soil-geomorphic Relationships in the Vicinity of Niamey, Niger. TropSoils Bulletin 89-01 SM-CRSP. North Carolina State University, Raleigh, NC, 34 pp.