Spatial variability and farmer resource allocation in millet production in Niger

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Proefschrift

ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van de Landbouwuniversiteit Wageningen
dr. C.M. Karssen
in het openbaar te verdedigen
op woensdag 8 september 1999
des namiddags te half twee in de Aula.

Printed by: Ponsen & Looijen bv, Wageningen
ISBN: 90-5808-079-X
Key Words: soil management, soil variability, manure application, nutrients, pearl millet, Niger

Gandah, M. 1999. Spatial variability and farmer resource allocation in millet production in Niger

Ph.D. thesis, Wageningen Agricultural University, Laboratory of Soil Science and Geology, P O Box 37, 6700 AA Wageningen, The Netherlands.

Propositions

1. Soil physical and chemical characteristics taken individually do not adequately explain observed yield differences using common linear regression analysis.
   This thesis

2. Traditional farmer practices in the Sahel can be improved by increasing the area treated during corralling, thus reducing the manure application rate and increasing manure use efficiency.
   This thesis

3. Prospects for improving crop production in the region of Tchigo Tagui should be focused on two landscape units, the plateau and the undulating terraces. The plateau would, however, require more investment in terms of labor and transportation means to transfer nutrients.
   This thesis

4. Most farmers in the Sahelian Tchigo Tagui region have their own innovative approach to low fertility management. Rather than amending the soil at high cost, they plant millet and *Hibiscus sabdariffa* (a high value crop with low fertility needs) in alternating rows. Such farmer approaches should be studied more closely.
   This thesis

5. Against common researcher-recommended management practices, farmers in the semi-arid Sahel increase within-field variability to maximize output, output stability or resource use efficiency, and to avoid total crop failure during years with extreme weather conditions. What is "uncommon" for researchers should become "common" in the future.
   Almekinders, C.J.M., L.O. Fresco, and P.C. Struik 1995. The need to study and manage variation in agro-ecosystems. Netherlands Journal of Agricultural Science. 43:127-142

6. The concept of precision agriculture extends beyond the field, the farm and the region. Efficiency of resource-use also has a planetary dimension. Transferring excess nutrients from farms in developed countries to poor soils in developing countries also represents a form of precision agriculture, which should be investigated further.

7. Understanding existing land use strategies and indigenous knowledge possessed by farmers is crucial in the development of sustainable resource management strategies. The first priority of agricultural scientists should be to assimilate this type of knowledge.
   Chokor, B.A. 1994. Land degradation assessment by small scale traditional African farmers and implications for sustainable conservation management. Geoforum 2: 145-154.

8. Quantitative estimates of nutrient flows across the landscape are essential for identifying sustainable land use strategies.
   (Powell, J.M., S. Fernadez-Rivera, P. Hiernaux, and M.D. Turner. 1996. Agricultural Systems 52: 143-170)

9. Finding technical solutions to agricultural production problems in the Sahel is insufficient: the solutions also have to be economically feasible and socially acceptable.

10. The land is poor and produces too little to feed the people; we have to choose between over-cropping and over-grazing to survive while waiting for remedies too expensive to use. *Oumarou Boubé, farmer and herder at Tchigo Tagui, western Niger.* This statement illustrates the failure so-far of agricultural research to significantly improve agricultural production in rain-fed farming in the Sahel.

11. The best research is to give fertilizer to the farmers to improve their soil and a pair of bulls to plow and transport their crop.
    Elhaj Boubacar Saley, 86 year old farmer at Tchigo Tagui

12. Structural adjustment policies and so-called free trade are two major foes of Sahelian farmers: they make foreign inputs inaccessible while limiting their entry in the international market.

13. "Sustainability" is in danger of becoming an overused buzzword, all too often only employed to attract funds.

14. Students at agricultural universities should be required to cultivate their own piece of land.

Propositions relating to the thesis
"Spatial variability and farmer resource allocation in millet production in Niger ".
Mohamadou Gandah, Wageningen, 8 September 1999.

Dédicace

To my late father Djibo Gandah
To my mother Hajia Salamatou
To my wife Kadi and children Zeinabou, Hadiza, Moustapha, and Habibou for their patience and support, and
To all the farmers of Tchigo Tagui and Katanga for their help and participation in gathering data for this thesis.

Acknowledgements

First I would like to be grateful to Almighty Allah who has given the strength and well being to complete this work.

I am thankful to Prof. Johan Bouma and Dr. Joost Brouwer for their continuous support, permanent supervision and contribution throughout my program both in Niger and in The Netherlands. I am grateful for their openness and patience. My appreciation to Dr Alfred Stein for his guidance and advice in geostatistics, statistical analyses, and review of chapters. My thanks to Mr Tjerk Kuster and Dr. Jan Willem van Groenigen for their help in data collection at Tchigo Tagui during their visit to Niger.

The research work used as a topic for this thesis was carried out under the supervision of the Desert Margin Program at the ICRISAT Sahelian Center, Sadoré, Niger. My gratitude to Dr. William Albert Payne who contributed his time and guidance in the early stages of this research, and who will always be a good friend. My appreciation to Dr Niek van Duivenbooden for correcting and contributing to several chapters of this thesis and for his supervision of my work at ICRISAT. Many thanks to Dr Fernandez Salvador-Rivera, Dr Pierre Hiernaux, and Dr Timothy O. Williams for helping with the ILRI database and for their useful comments. Finally, I acknowledge the help of field and laboratory technicians both at INRAN and ICRISAT, particularly Issa Oumarou, Seydou Maiga, Hassane Ousmane. Thea van Hummel assisted with the final preparation of the camera-ready copy. The field research has been funded by the World Bank Project PNRA at INRAN and supported by The Ecoregional Fund DMP/ORU, ICRISAT Niger.

Contents

I Spatial variability characterization in space and time

II Management of nutrient and crops in a farmer's fields

III Large scale soil management and farmers' knowledge

List of Abbreviations

DAS: Days after sowing

DMP: Desert Margin Program

DGIS: Directoraat Generaal Internationale Samenwerking

FAO: Food and Agriculture Organization of the United Nations

GIS: Geographical Information System

ICRISAT: International Crops Research Institute for the Semi-Arid Tropics

ILRI: International Livestock Research Institute

INRAN: Institut National de Recherches Agronomiques du Niger

MUSCLUS: Multi-Scale Land Use System

ORSTOM: Institut Français de Recherche Scientifique pour le Développement *en Coopération*

ORU: Optimizing Resources Use

USDA: United States Department of Agriculture

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Chapter 1

General introduction

Niger is a landlocked country of the Sahel, with an area of 1.267 million km^2, of which 50 000 km^2 is arable land and 100 000 km^2 grazing land. Population growth is high at more than 3% per annum with 6.9 million inhabitants in 1990 and a projection of 9.5 million by the year 2000 (FAO,1998).

Food production in Niger depends largely on rainfed agriculture which only takes place in the southern quarter of the country. The rainy season starts in May-June and ends in October-September. The length of the growing period, 75 to 120 days, is highly dependent upon when the rains begin, which varies from year to year (Sivakumar, 1993). Rainfall distribution during the growing season is highly unpredictable and includes frequent seasonal droughts. When occurring during the sensitive stage of crop flowering and grain filling these water deficits can cause severe damage to crops (De Rouw and Winkel, 1998). The beginning of the planting season is also characterized by other weather events, such as dust storms and high winds, causing seedling burial and heterogeneous crop stands.

The major cereal grown by farmers in Niger is millet, yielding an average 350 kg ha^{-1} year^{-1} over the past 9 years (FAO,1998). It is commonly planted in a mixed-cropping system with cowpea, groundnut or another legume. Soils used for dry land agriculture are deep and sandy, with silt and clay contents below 15% and infiltration capacity reaching 30 cm hour^{-1} (Hartmann and Gandah, 1982). Low available soil water of 4 to 15% (Gandah, 1988) requires farmers to plant soon after a rain to avoid low seed germination. Notwithstanding excessive infiltration rates, micro-topography and surface sealing cause local preferential water redistribution. Measured run-off from micro-high field areas represents about 60% of total rain followed by concentration of water in low areas reaching 340% of rainfall (Gaze *et al.*, 1997). Similar occurrences at a landscape scale were measured in western

Niger by Rockström (1997), with 11, 9, and 6% of the annual rainfall being lost in run-off from upper, mid, and bottom slope of a millet field. Soil nutrient content, in terms of phosphorus and nitrogen, is low in all soil types used for rainfed agriculture in the region (Bationo and Mokwunye, 1991). Low soil pH and CEC, high aluminum content, and low soil organic matter content indicate the level of land degradation. All these chemical and physical properties are highly variable even within field. Their influence on millet grain yield has been investigated in western Niger (Buerkert *et al.*, 1995; Manu *et al.*, 1996; Stein *et al.* 1997).

Considering these constraints to crop productivity in Niger, it is important to improve land quality to satisfy the food needs of the increasing population. Improvement of soil chemical and physical properties cannot be achieved at large scale or in a short time due to technological and economic reasons. Continuous mono-cropping of cereals with little use of legumes has made the system impoverished and difficult to improve. Research done by the Institut National de Recherches Agronomiques du Niger (INRAN) and the International Crop Research Institute for Semi-Arid Tropics (ICRISAT) has shown that average grain yields above 1000 kg ha^{-1} can be achieved when adequate nutrients are applied. However, fertilizer rates of 22.5 kg ha^{-1} of P_2O_5 and 46 kg ha^{-1} of N, recommended by extension, are well above the actual average of 5 kg ha^{-1} of fertilizer applied on dry and irrigated land. Lack of adoption of modern nutrient management methods is due to social and economic constraints limiting farmers' access to modern technologies.

As a consequence, crop production strategies have mostly remained traditional in every aspect of management, which is based on crop and livestock interactions and on the experience of the farmers. The farming systems in Niger rely on permanent land cultivation with decreasing fallow duration and low input of nutrients particularly. Use of livestock for manure application through corralling, as done by Fulani farmers or through manure transport to fields, has been one of the successful methods of soil fertility management. However, amounts of produced manure deposited in the fields are insufficient because of poor pasture quality, loss of pasture land through conversion to agricultural land, and the low number of cattle per area of cropped land (Ayantunde, 1998).

Within this context, the scientific research for this thesis was carried out in four localities in western Niger in 1995, 1996, and 1997. The overall aim was to investigate traditional land management in millet cropping in western Niger, as influenced by highly variable soil and weather conditions. Experiments were carried out to define alternative types of management based on thorough knowledge of existing production systems in the region. The main objectives of this study were:

1) to test a hill scoring technique for characterizing within field soil and crop yield variability in 3 localities of western Niger
2) to identify soil properties explaining yield variability in space and time
3) to compare the effects on millet yield of site specific management of manure and fallow in a Fulani farmer's field
4) to compare management systems used by farmers in four different landscape positions
5) to describe farmers' methods of land evaluation and management options based on farmers' expert knowledge of the environment.

The structure of the thesis follows the list of main objectives.

Chapters 2 and 3 deal with within-field soil and millet yield variability, respectively, at three sites during a season and among two consecutive seasons. Soil factors responsible for the variability and a simple low cost method of measuring millet growth variability are discussed. Changes in yield variability within sites and between sites and between years are also compared.

Chapter 4 examines management practices of an individual Fulani household, based mostly on manure application through corralling and on fallow. Produced grain and straw, as well as soil nutrient contents, are used to compare site specific management practices.

Chapter 5 discusses management at the landscape scale. Twenty households, with their respective fields located at various distances from the villages and on different landscape positions, were surveyed and their nutrient management was described. Effects of management on millet yields as influenced by distance, landscape position and availability of manure are distinguished.

Finally, chapter 6 focuses on farmers' knowledge in land management decision making. Soil, plant and weather factors and their use in ethnopedology are discussed. Possible contributions of farmers' knowledge to agricultural research are put forward, both in terms of defining alternative forms of research and of effective extension of obtained research results to farmers.

Chapter 2

Use of a scoring technique to assess the effect of field variability on yield of pearl millet grown on three Alfisols in Niger[1]

Abstract

Within-field spatial variability of pearl millet was studied at three different sites on Alfisols in Niger. Grain yields in fields on a North-South gradient were 8-383, 2-1343, 7-815 kg ha^{-1}, with a coefficient of variation (*CV*) of 61, 55, and 53%, respectively. Variability was explained by soil chemical factors for only 5 to 28%. A simple method of scoring millet growth of individual hills a few weeks before harvest was tested for measuring yield variability in a field as an alternative for expensive soil chemical analyses. The median score value explained 25, 67, and 8% of the variability for the same gradient. As a verification step, map pattern comparisons of millet grain and straw yields with median score values gave low taxonomic distances (0.01-1.7), indicating significant similarities in variability. The hill scoring method is an appropriate tool to identify millet grain and straw yield variability.

Keywords: pearl millet, spatial variability, scoring technique, Alfisols, Niger

2.1. Introduction

Spatial variability of crop growth within fields is a prominent feature in the Sudano-Sahelian zone of West Africa. Soil physical differences and highly variable soil fertility patterns within fields are not homogenized by chemical

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[1] Published as: Gandah, M., J. Bouma, J. Brouwer and N. van Duivenbooden. 1998. Use of a scoring technique to assess the effect of field variability on yield of pearl millet grown on three Alfisols in Niger. *Netherlands Journal of Agricultural Sciences.* 46: 39-51.

fertilization or tillage to the same extent as in more mechanized and capitalized types of agriculture in the developed world. Brouwer *et al.* (1993) concluded that in traditional land use systems, where high risks are involved in crop production, field variability may be an asset in avoiding complete crop failure. They hypothesized that water was more limiting in higher and drier areas of the field in years of low rainfall and nutrients more limiting in lower and more leached areas when rainfall was high. This variability poses problems in agronomic experiments, and cannot be fully explained on the basis of available data (Wendt, 1986; Wendt *et al.*, 1993; Buerkert *et al.*, 1995). Variability is often observed in patterns of soil and plant characteristics. The patterns may occur in single or interrelated patches in the field. Relations between different management practices and yields are difficult to document because the implicit statistical assumption that conditions within treatment blocks are homogeneous is not met. Management measures are, however, applied uniformly over a field and occurrence of internal variability implies that the effect of such measures is bound to be reduced as different spots require different treatment. The observed variability can form the basis for site-specific management in which management is varied over the field, but this requires much additional information and technology (Bouma *et al.*, 1996). These are generally not available in West Africa partly because the means required to document spatial variability can not be incorporated in research projects.

Therefore, a research has started to develop a methodology on how to use efficiently this within-field variability in a crop production system with limited resources. The objectives of this study are to document spatial variability, to explain it on the basis of different parameters, and to test an alternative hill scoring technique in estimating yield variability within a field.

2.2. Materials and methods

At three research stations in western Niger on Alfisols (sandy soils with a slight increase in clay content from 3 to 7% with depth), four fields were planted with pearl millet *(Pennisetum glaucum L.)* during the rainy season of

1995. The sites at Ouallam, Sadoré, and Tara, are located along a North-South axis, i.e. normally with an increasing rainfall gradient.

At each site, the local millet variety was planted at a density of 1 x 1 m (i.e. 10,000 hills ha^{-1}). In accordance with local practices, no fertilizer or organic matter was applied nor was any land preparation carried out but the removal of shrubs and old millet plants from the 1994 crop season. At Tara, although farmers traditionally plow their land, no plowing was done to allow comparison with the other sites. Weeding of the fields was done with a hand hoe, and millet was thinned to three plants per hill during the first weeding. Within each field, with sizes of 2275 and 2700 m^2 (Ouallam), 6750 m^2 (Sadoré) and 2125 m^2 (Tara), 5 x 5 m plots were laid out without alleys (Figure 1). At Ouallam, millet was planted on June 25. Hill scoring was done at 85 days after sowing (DAS), and the crop was manually harvested at 115 DAS. For Sadoré, the dates were, June 20, 67 DAS, and 115 DAS, and for Tara, June 17, 75 DAS and 110 DAS. Dry weight of all plant components per plot were obtained after air-drying for 2-3 weeks, and samples were oven-dried for moisture correction. Other observations included the number of hills and heads harvested, daily rainfall and the location of old shrubs, termites and ants mounds, and flooded areas.

Soil samples were taken after harvest in a 10 x 10 m grid at grid points, and additionally in each of the four 5 x 5 m plots surrounding a grid point in 5 selected locations (Figure 2.1). This implied for Sadoré 20 soil samples and corresponding yields from the sampled plots, and 63 soil samples at grid points, each having the average yield from the four surrounding plots. Soil samples were taken at 0-10, 10-20, and 20-40 cm depth for three reasons. Firstly, 80 to 90% of millet roots occur in the 0-40 cm layer which explains most of the soil chemical effects on millet yield. Secondly, most of the changes in soil nutrients occur in this 0-40 cm layer (A. Bationo, pers. comm. 1997) or even in the 0-20 cm layer (Geiger *et al.*, 1992).

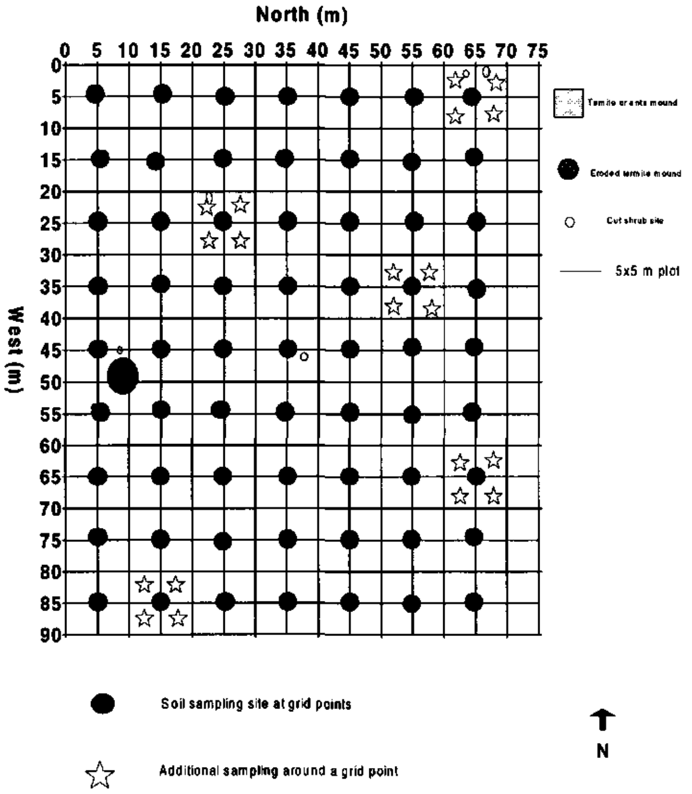

Figure 2.1. Special features and soil sampling sites in experiment field 8D at Sadoré

Finally, the amounts of nitrogen under the given conditions at larger depth are rather insignificant. Soil samples were analyzed for pH-H_2O, ECEC (Ca, Mg, Na, K, Al, and H), P_{Bray1}, C, and texture (Van Reeuwijk, 1993). Soil and plant data were analyzed with SPSS-6.01 (Anonymous, 1988) and Surfer (Anonymous, 1995).

A topographic survey of each field was made after harvest. A level was used, and an elevation reading was taken at the corners of the plots. A topographic map was made for each site from these measurements.

2.2.1 Hill scoring technique

The hill scoring technique measures variability in crop growth within a field at a certain moment in time. The technique, developed by Buerkert *et al.* (1995), scores the development stage of the plant in a hill which reflects the reaction of the plant to its environment (soil, weather, pests, and human action). In a non-fertilized, uniformly-planted and maintained field, crop growth is affected by soil and weather, the latter being considered uniform in fields of the size used in the experiment (c.f. Sivakumar and Hatfield, 1990). Hence, growth can be related to soil physical, chemical, and topographic characteristics.

The scoring is done in three steps (Buerkert *et al.*, 1995): a) touring the field to get a general appreciation of hill development, b) setting a scale of hill vigor with maximally nine classes: 1 = very poor to 7 = best development, and c) the actual scoring of rows. In this study, the technique was adapted in two ways: the scale ranged from 0 (no plant present) to 8 (best development), and individual hills were scored to allow geo-statistical analysis (coordinates: x, y, and z: the score).

2.2.2 Spatial variability analysis

Spatial variability is analyzed in two ways. Firstly, a global analysis of non-georeferenced data is conducted, using means, and coefficients of variations, followed by stepwise regression to relate yield with measured soil and plant factors.

Secondly, a map pattern comparison (MPC) technique is used (Davis, 1986). This technique was adapted; block kriging (Stein *et al.*, 1997) and a pattern analysis based on Van Uffelen *et al.* (1997) were performed to compare quantitatively the three maps (yield, straw, and median hill score) created with Surfer (Ver. 6.01). The patterns in the maps were compared and expressed as the taxonomic distance (*d*), low value indicating similarity, and a high values a large difference. To obtain that value, various steps are required using geo-statistical packages (Deutsch and Journel, 1992; Heuvelink, 1993) and routines written in Interactive Data Language (IDL, Ver. 3.61a). The ranges of the two maps may be considerably different, the standard normal value (*Z*) of the factors is used at the nodes of a grid mesh. *Z* is calculated as :

$$z_{n,\,xy} = \frac{v_{n,\,xy} - \overline{v}_n}{s_n} \tag{1}$$

where, v_n = measured value; $\overline{v}_n$ = the average of v_n, and s_n = standard deviations of v_n in the pattern *n*.

The comparison of patterns can only be done for a sample area of a limited size or window with identical positions in the two maps. After making the comparison, the window is subsequently moved to a new lateral position while keeping 80% of the area in the former windows and adding 20% new area in the case of a 5 x 5 m window. For each window, a polynomial regression is fitted to obtain a *Z* for the window. This is calculated by:

$$\begin{aligned} Z_{win,xy} = {} & b_{n,0} + b_{n,1} \cdot x_{win} + b_{n,2} \cdot y_{win} + b_{n,3} \cdot x^2_{win} + b_{n,4} \cdot y^2_{win} + b_{n,5} \cdot xy_{win} + \\ & b_{n,6} \cdot x^3_{win} + b_{n,7} \cdot y^3_{win} + b_{n,8} \cdot x^2y_{win} + b_{n,9} \cdot xy^2_{win} \end{aligned} \tag{2}$$

where, $b_{n,0\text{-}9}$ = regression coefficients obtained by the least square regression method of pattern n in the window; x and y = coordinates.

The taxonomic distance (*d*), can now be calculated on the basis of the regression coefficients from Equation 2:

$$d = \sqrt{\sum_{i=0}^{p-1} \frac{\left(b_{1,i} - b_{2,i}\right)^2}{p}} \tag{3}$$

where, $b_{1,i}$ = regression coefficients for map 1; $b_{2,i}$ = regression coefficients for map 2; p = level of polynomial regression.

Since the size of the window has an influence on the effect of the coefficients in Equation 2, a weight is applied to *d*, so that Equation 3 becomes:

$$dw = \sqrt{\sum_{i=0}^{p-1} \frac{\left(w_i \left(b_{1,i} - b_{2,i}\right)^2\right)}{\sum_{i=0}^{p-1} w_i}} \tag{4}$$

where, w = weight applied equal to the range along the z-axis for the polynomial term *i* and function of window size and mesh distance.

The calculated d_w values and the coordinates of the center of the windows are used to obtain the taxonomic distance maps. Two types of taxonomic maps are made: median score-grain yield (d_{wmg}), and median score-straw yield (d_{wms}). No method for setting a threshold level of d was found in the literature. A d_w value of zero for two windows means identical pattern, but there is no set value for opposite patterns. It is proposed here to use the median d_w as a threshold value of each map to identify patterns with high dissimilarity shown in light gray representing d_w values higher than median.

2.3. Results and discussion

In 1995, total rainfall was 100 mm above average at Ouallam and Sadoré. The Tara site showed a severe deficit with about 350 mm less than the ten years average (Table 2.1), in analyzing rainfall data, the number of rainy days is a factor, implying the best rainfall distribution in Tara.

The Alfisols at all three sites are classified as coarse kaolinitic Psammentic Ustalfs (Anonymous, 1994). At Ouallam and Sadoré, they are Psammentic Paleustalfs (West *et al.*, 1984) with a profile deeper than 6 meters. At Tara, the soil depth is shallower. The sandy soils differ in physical and chemical characteristics (Table 2.2), but all are slightly acidic and are very low in carbon, phosphorus, and a low effective cation exchange capacity.

Grain production within each field was highly variable as indicated by high coefficients of variation (*CV*) above 50 % at all sites (Table 2.3). For straw, the *CV* is in the same order of magnitude.

Table 2.1. Rainfall characteristics at the three research sites in Niger.

Site	Average 1985-1994	Total rainfall in 1995	Useful rain in 1995 (planting to harvest)	No of rainy days*
Ouallam	468.8	574.4	546.2	27
Sadoré	563.3	663.7	557.2	32
Tara	818.9	469.3	417.5	40

* Rainfall > 0.8 mm

Table 2.2. Soil characteristics of the three sites (average values 0-10 cm soil).

	Ouallam		Sadoré	Tara
	Field 1	Field 2*		
pH_{water}	5.6	5.2	5.9	5.6
Texture -Sand (%)				
-Silt (%)	93.0	92.2	89.8	82.0
-Clay (%)	3.2	3.7	4.5	14.2
	3.8	4.1	5.7	3.8
Carbon (%)	0.14	0.10	0.20	0.25
P ($mg\ kg^{-1}$)	0.8	3.8^{+}	4.0	0.22
K ($meq.\ 100g^{-1}$)	0.04	0.50	0.10	0.08
ECEC ($meq.\ 100g^{-1}$)	0.73	0.70	0.81	1.00
Number of plots	91	108	270	85

$^{+}$ field used previously for millet seed production and left under fallow for 3 years.

The regression of yield on the most important soil factors showed only weak association (Table 2.4). Moreover, they were different for each site. At Ouallam, similar to Tara, soil factors explained 5 to 13% of yield variability, whereas at Sadoré, this was somewhat higher. This confirms that soil chemical properties do not properly explain grain yields in this type of agricultural production systems where the content of key elements is below the minimum level required for a good millet crop (Stein *et al.*, 1997). The variability is further influenced by bare spots (erosion crusts or old termite mounds) and micro-topographical differences affecting water redistribution and consequently grain yield (Gaze, 1996). The rainfall concentration factor (i.e. infiltration/rainfall), ranging from 0.3 to 3.4 in Gaze's experiments, had a considerable influence on yields in semi-arid conditions as it modified micro-site water and probably nutrient balances. Crop weeding operations did not mix the top soil layer deeply enough to eliminate this micro-relief as it was still present at the end of the cropping season.

Table 2.3. Millet yields (kg ha^{-1}) and harvest index at the three sites in Niger, 1995.

Sites		Ouallam		Sadoré	Tara
Factors		Field 1	Field 2		
Grain	mean	110	125	379	332
	SD	65	80	208	177
	CV (%)	59	64	55	53
	Min.	8	13	2	7
	Max.	313	383	1343	815
Straw	mean	915	602	1097	744
	SD	642	396	654	358
	CV (%)	70	66	60	48
	Min.	80	80	74	104
	Max.	2800	2000	4440	1900
TDM	mean	1025	726	1709	1319
	SD	680	462	956	580
	CV (%)	66	63	56	44
	Min.	104	96	80	254
	Max.	2927	2333	6080	2920
HI	mean	0.12	0.16	0.22	0.26
	SD	0.05	0.05	0.04	0.19
	CV (%)	41	31	18	73
	Min.	0.02	0.06	0.02	0.03
	Max.	0.30	0.30	0.32	0.55
Number of plots		91	108	270	85

TDM: total dry matter HI: harvest index

When straw yield was correlated with grain yield, only two out of the four fields studied had an acceptable fit, with the best relationship at Sadoré. When the number of millet heads and hills at harvest are also included in the regression model for this site, R^2 increases to 90% (not shown). Major disadvantages of this regression method, such as straw yield is only available after harvest and requires an oven, makes it unfit for an a-priori yield estimation. Moreover, a severe lack of fit could be obtained when damage to millet ears (from ear worm, birds, etc.) occurs just before harvest.

Table 2.4. Linear regression models of millet grain yield (kg ha^{-1}) with soil and plant factors measured at the three sites in Niger in 1995.

Factors in model	Ouallam Field 1	Ouallam Field2	Sadoré	Tara
soil	802.5Mg+39.6 R^2=0.06	524.3C-178.4ECEC+186.1 R^2=0.13	384Ca-805.9Al-64.5PH+683.4 R^2=0.28	952.7-110.1PH R^2=0.05
plant	0.62S+58.3 R^2=0.25	0.16S+27.8 R^2=0.64	0.29S+62.6 R^2=0.81	0.28S+121.3 R^2=0.32
score	24.7MED-10.3 R^2=0.24	25.8MED-12.4 R^2=0.26	133.9MED -16 R^2=67	37.2MED+236.9 R^2=0.08
soil and plant	3330Na+0.08S-0.22 R^2=0.35	1967.7Na+0.16S+4.41 R^2=0.65	981.4H - 569.2Al+0.27S+60 R^2=0.83	402.9P - 327.7Mg + 0.3S + 75.2 R^2=0.49
soil+plant+ score	3106Na+0.06S+12.4MED R^2=0.38	1806.3Na+0.12S+9.32MED-18.65 R^2=0.55	838.9H+36.7MED +0.21S-505Al+19.9 R^2=0.85	0.3S-327.7Mg + 402.9P +75. R^2=0.41

ECEC=effective cation exchange capacity ; Ca=calcium; Al=aluminum; Mg=magnesium; Na=sodium; H=hydrogen; meq. $100g^{-1}$ P=phosphorus in mg kg^{-1} ; PH=pH; C=carbon in %; S=straw yield (kg ha^{-1}); MED=median score.

2.3.1 Hill scoring technique

Plant scoring at the three sites showed a normal population of hill scores with mean almost equal to the median (Table 2.5). Having obtained the same standard error of the mean and about the same *CV* at the two fields in Ouallam, this confirms the uniform variability found in the previous analysis. The mean value of 5 should not be used in a straight-forward comparison with the other two sites since, the scoring scales used here were shifted down due to poor growth. For all three sites, the *CV* is between 44 and 86% indicating a high variability in hill growth. Hill scoring gives also the variability in the number of successful hills in the field. At Sadoré, for instance, the average number of cropped hills in the 270 plots was 8,888 ha^{-1} (i.e. 89% of planted hills) with a range of 3,600 to 10,000 hills ha^{-1}.

At Ouallam and Tara, the average was 93%. These average values exceed the threshold value of 6,000 hills ha^{-1} above which fertilizer input can produce an optimum return (Bationo *et al.*, 1992), indicating that there is room for improvement in management.

The regression analysis of median score with grain yield (Table 2.4), although with lower R^2 values than with straw yield, presented an improvement when compared with those with soil parameters. In a follow up study, three periods of scoring were used during the growing season to establish the best period for relating grain yield and median score.

Table 2.5. Descriptive statistics of millet hill scores at the three sites in Niger in 1995.

Statistics	Ouallam		Sadoré	Tara
	Field 1	Field 2		
Mean	4.63	4.97	2.93	2.63
Stand. Error	0.05	0.04	0.02	0.05
Median	5	5	3	3
SD	2.05	2.02	1.78	2.26
CV(%)	44	40	61	86

2.3.2 Spatial variability analyses

The MPC technique comparing score and grain yield resulted at Ouallam in higher d_{wmg} values for field 1 than field 2 (Table 2.6), most likely being explained by a more uniform micro-topography in field 2. Within each of the two fields there, the range of d_{wmg} and d_{wms} was about the same, while at Sadoré they were identical. Figures 2.2c (map of d_{wmg}) and 2.2d (map of d_{wms}) show the dissimilarity between the scoring and biomass production indicated in light shading.

Table 2.6. Characteristics of comparing scoring and plant components at the three sites in Niger.

		Ouallam		Sadoré	Tara
		field 1	field 2		
Range					
d_{wmg}	Min	0.12	0.02	0.03	0.01
	Max	1.72	0.70	0.64	1.12
d_{wms}	Min	0.11	0.03	0.03	0.04
	Max	1.76	0.71	0.63	1.12
Maps compared (in % of field area with high pattern dissimilarity)					
Grain yield and median score		43	46	35	43.6
Straw yield and median score		42	59	36	43.5

This dissimilarity has been quantified also for the other sites (Table 2.6) showing that Sadoré has the lowest value. Using Figure 2.1, it can be derived that the mismatch occurs in spots with an eroded termite mound, a cut down shrub site, an active termite mound and a low area with water run-on. At Ouallam, the dissimilarity is caused by medium size shrubs in the field. At Tara, the equal percentage of field with dissimilarity for straw and grain yields can be explained by the recently cleared nature of the field. These spots with high *d* can then be further investigated to identify their occurrence at the same location with time. The method whereby scoring was carried out at about 45 days before harvest need to be validated. In a follow up study, scoring was done three times during the growing season to establish the best period.

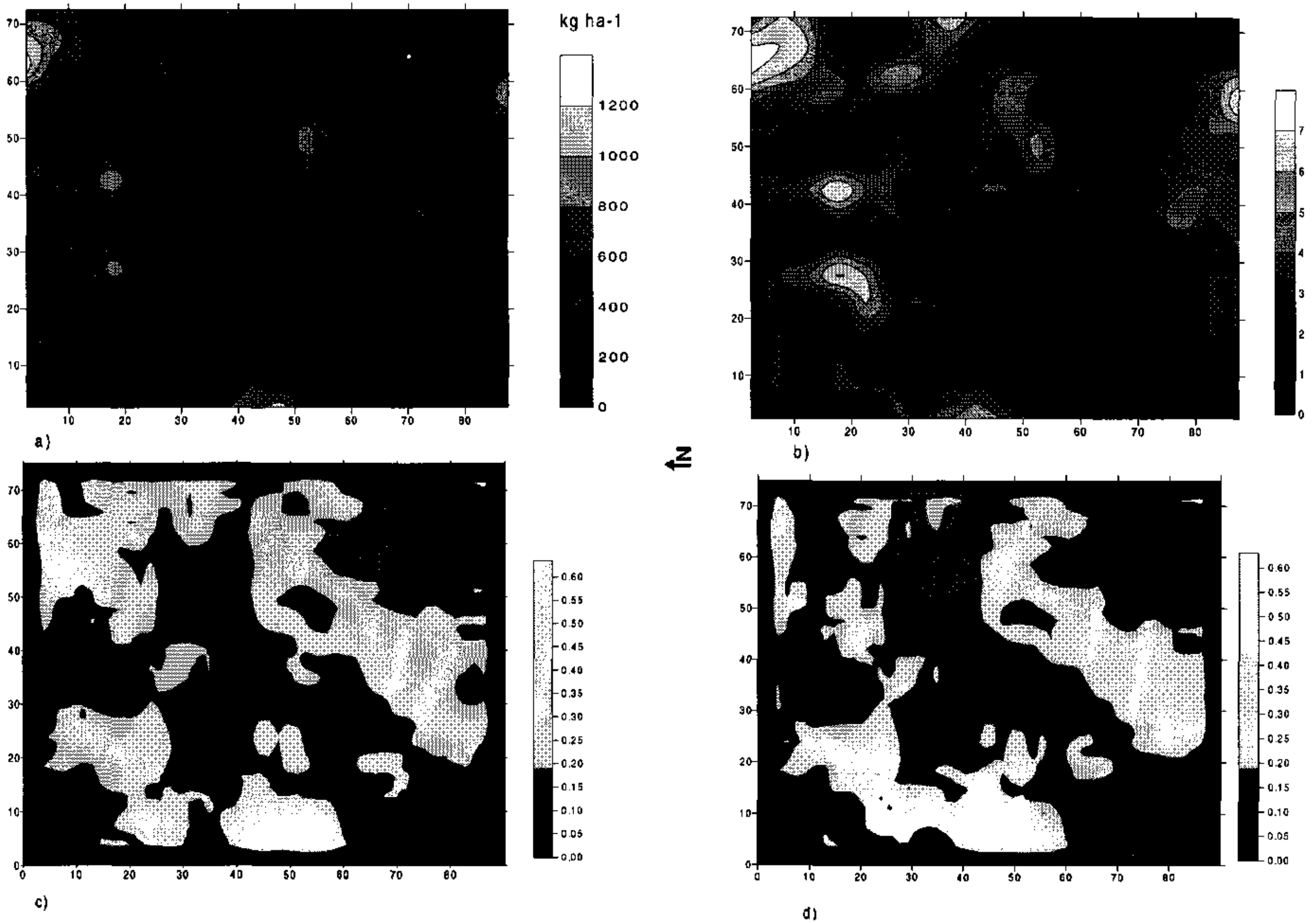

Figure 2.2. Maps of a) grain yield, b) median score, c) taxonomic distance d_{wmg} and d) taxonomic distance d_{wms} at Sadoré

2.4. Conclusions

The hill scoring technique gives an insight in the within field variability which is further quantified through the MPC technique. The latter confirms largely the variability estimated by the former, so that the hill scoring technique can be considered as a relatively good method. From this study on variability of millet yields it is concluded that, at the three sites in western Niger, variability was large within a site, and also between the sites. The soil physical and chemical characteristics taken individually do not explain adequately the observed yield differences by a common linear regression analysis.

The use of hill scoring method proved to be cheap way to measure growth variability in fields. Median scores correlated with millet yields were better than with soil factors when done at millet heading stage (about 45 days before harvest) in 1995. The technique can be used to quantify field variability and may help to design site specific soil management schemes at low costs, but further testing is required before recommendations for farmers can be designed.

Chapter 3

Dynamics of spatial variability of millet growth and yields at three sites in Niger, west Africa and implications for precision agriculture research.[1]

Abstract

This paper focuses on refinement of a simple scoring technique to make estimates of millet yield. Estimates are intended to be used for defining application rates of manure in the context of low-tech precision agriculture. Yields from 1995 and 1996 at three locations were related to scoring, soil data and elevation. Kriging was used to interpolate point data to areas. Several procedures for pattern comparison were applied. Because scoring data were available at a much higher density than yield data a sensitivity analysis was made to compare scoring and yield. Correlations between scoring and yield ranged from 0.42 to 0.91. During a separate experiment the optimal time for scoring turned out to be approximately three months after seeding for the native varieties of 120 days, but two months is convenient for farmers to locally apply chemical fertilizer. R^2 values ranging from 0.15 to 0.60 were observed for soil data and yield, subject to local conditions and changes in weather. We conclude that scoring is a cheap and reliable procedure to identify field patterns which can form the basis for precision agriculture.

Keywords: variability, precision agriculture, soil management.

3.1. Introduction

Crop production in the Semi Arid Tropics (SAT) of West Africa called the Sahel is dependent on highly variable weather and soil conditions. The beginning of the planting season, as well as distribution and amounts of rainfall are irregular

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[1] Submitted as: Gandah, M., A. Stein, J. Brouwer, and J. Bouma. Dynamics of spatial variability of millet growth and yields at three sites in Niger, west Africa and implications for precision agriculture research. *Agricultural Systems.*

(Sivakumar *et al.* 1993). The major cereal crop for the region is millet, which production zone is increasingly moving to drier areas originally used as pasture land (ICRISAT, FAO, 1996). Soils were cropped for decades without proper nutrient renewal, leading to nutrient mining and poor land. Consequently, high variability of crop growth and yield within fields is typical in these production systems. In the past ten years, researchers have studied it to identify its causes in experimental plots and in farmers fields. Almekinders et al. (1995) used the term agrodiversity for variation in agro-systems as a result of abiotic environmental variation, biotic environmental variation, and the interaction between the two. This variability is found at various scales. We will distinguish between within field variation and variation between fields.

Within field variation is observed in plant growth at a scale varying from 1 or 2 meters to tens of meters. The processes by which yield variability occurs are observed as soon as seedlings emerge. Sand blasting and burial of young seedlings are responsible for high levels of variability in early millet stands in Niger. To protect against sand movement, Klaij and Hoogmoed (1993) proposed a technique of ridging. This improved crop stands, but required additional labor and tools. Buerkert (1995) observed 18% higher soil mechanical resistance in low productivity areas compared to high productivity areas. Later in the season, chemical and physical soil factors including soil moisture can singly or jointly cause large within field yield variation. In fields in Western Niger, coefficients of variation of yields are above 50%, and poor correlations between soil properties and grain yields have been found (Brouwer and Bouma 1997; Gandah *et al.*, 1998). Wendt (1986) on the other hand, on similar Ustalfs in Western Niger, found that poor millet growth correlated well with a pH below 5 and aluminum and hydrogen saturation rates of the exchange complex of more than 45%. With low buffering capacity and low nutrient content of these soils, a small change in the soil nutrients status can cause large changes in plant growth.

Variation between fields and, at a higher scale, between geomorphological units, can be caused by factors such as moisture redistribution and differences in chemical fertility. Another cause is variation in management by different farmers depending on the scale of observation.

In recent studies, it was observed that crop growth patterns correlate well with soil properties patterns but not linearly and differently with years (Stein *et al.*, 1997).

These growth patterns, though, are generally available only after harvest, whereas in precision agriculture some preliminary yield estimate can be useful for targeted application of scarce manure and fertilizer. Yield patterns, however, may vary during successive years. For farming practices, it is important to know at an early stage the amount and pattern of yield that a farmer may expect. For that reason, attention recently focused on scoring (Buerkert, 1997). Scoring patterns are easily obtainable during the growing season. In this study, patterns of scored plant yield and soil factors are quantified. Because millet can be scored on an individual hill basis, up-scaling procedures are useful to relate these to soil and yield patterns.

The objectives of this study were to: (i) characterize the variability in crop growth (expressed by measured hill scores), yield (grain), and soil characteristics within and between three sites and two years in Niger, and (ii) explore implications for precision agriculture. In a separate experiment we analyzed the optimal time for scoring and all this served to evaluate the efficiency of scoring as a tool to predict the stability of poor crop growth areas for use in precision agriculture practices among years.

3.2. Materials and methods

3.2.1 Experimental sites and sampling procedures

During the rainy seasons of 1995 and 1996, experimental fields at Ouallam, Sadoré and Tara (Figure 3.1) were selected in Western Niger and planted with a millet crop (*Pennisetum typhoides*). These three sites are located in a North/South gradient which also represents a rainfall gradient from dry to wet. At Ouallam, 2 fields of sizes 2275 and 2700 m^2 were selected. At Sadoré and Tara, field sizes were 6750 and 2125 m^2, respectively. To evaluate time of scoring, a further test site was selected at Tchigo Tagui, 75 km NE of the capital Niamey. There, 20 on-farm fields with sizes ranging from 1 to 10 ha were used. Plots with a size of 5 x 5 m were laid out inside the fields, without dividing alleys. At each site, the local millet variety adapted to the local soil type was planted. Planting density was 1x 1m (25 hills per plot) and stands were thinned to three plants per hill during the first weeding.

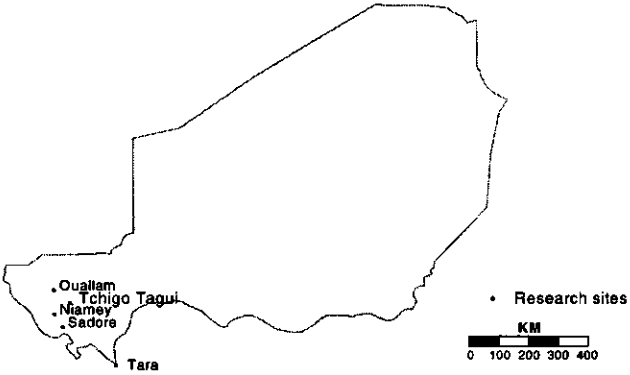

Figure 3.1. Location of experiment sites in Western Niger.

Table 3.1 gives the field activities at each site. At Tchigo Tagui, 3 plots of 10 x 10 m in size were laid in each field. Planting was done by farmers in rows and without a uniform distance between rows and between hills, as it is common in farmers' fields. Millet was manually harvested at maturity. The millet heads from each plot were air dried during two weeks before threshing. The remaining millet straw was harvested and dried in the field during 2 to 3 weeks before weighing. Final weight was obtained by correcting for moisture, using oven dried samples. Grain yield, the number of hills, the number of harvested heads, and the head yield per plot were measured. To comply with local practices restricted by inputs, no fertilizer or organic matter was applied nor was there any land preparation other than the removal of shrubs and old millet plants from the previous crop. At Tara, by tradition, farmers plow their land before planting as the soil is more structured and the longer season favors this practice. In this experiment, the field was not plowed during both years to allow better comparison with the other sites. When necessary, weeding was done manually with a hoe.

To study the relation between measured plant data and soil properties, a soil survey was done in each field after harvest in 1995 using a 0.08 m diameter auger. Sampling depths of 0-0.10 m, 0.10-0.20 m, and 0.20-0.40 m were chosen because 80-90% of millet roots occur within these depths. Moreover, changes in the amount of soil nutrients are predominantly found in the 0-0.40 m soil layer (Bationo, *pers. comm.*, 1997). Finally, the top layer explains most of the soil chemical influence on millet yield although roots are found deeper, up to 1.50 m and beyond (Hafner *et al.*1993; Geiger *et al.* 1992). The soils at all three sites were Psammentic Paleustalfs (Wilding and Daniels, 1989)

Table 3.1. Cultural practices and annual rainfall in the 3 sites

Sites		Planting	Scoring	Harvest	Annual Rainfall (mm)	Number of rain days	Rainfall in Jul & Aug (mm)
Ouallam	1995	June 25	Sept. 18	Oct. 17	574.4	27	441
	1996	June 7	Aug. 26-27	Oct. 27	500.8	26	270
Sadoré	1995	June 20	Aug. 24-25	Oct. 13	469.3	38	295
	1996	June 3	Aug. 20-21	Oct 15	485.4	30	338
Tara	1995	June 17	Aug. 30-31	Oct 5	663.7	32	418
	1996	June 3	Aug. 22-23	Sept. 16	699.6	44	227

The soil samples were taken at 10 x 10 m grid nodes, but also at the center of a limited number of the plots. At Sadoré for example, 63 samples were taken at grid points representing one soil sample for four yield data; another 20 samples were taken at the center of 20 plots giving each a pair of soil and yield data (Figure 3.2). In total, more than 600 soil samples were analyzed for pH, effective cation exchange capacity ECEC (calcium, magnesium, sodium, potassium, aluminum, and hydrogen), available phosphorus (PBray1), organic carbon, and texture, according to the standard procedures used at ICRISAT Sahelian Center (Van Reeuwijk, 1993).

Old shrubs sites, termite mounds, and waterlogged areas were identified in the fields and mapped (Figure 3.2). Elevation readings were taken with a level at the four corners of each 5 x 5 m plot and used also to obtain a detrended elevation to characterize the micro-topography. After heavy rains, the plots where water ponding occurs for few hours were identified.

Daily rainfall was recorded at all three sites (Table 3.1). The rainfall did not show the long term North-South gradient as Ouallam received more rain than Sadoré over fewer wet days. Tara, in the South had the highest rainfall for both years and the highest number of wet days in 1996.

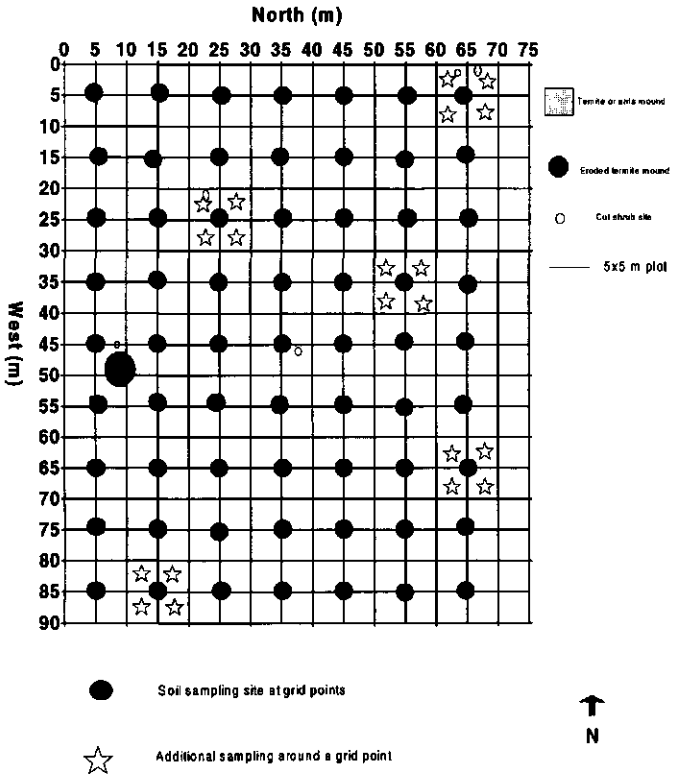

Figure 3.2. Example of plot layout in experimental sites, Sadoré

3.2.2 Scoring

Scoring is a simple low-tech method that was used in this study to measure spatial variability in crop growth during the growing season. Scoring is based on the observation that, at a given time, the millet hills present various development stages due to the reaction of the plant to its environment and to the variability in that environment (soil, climate, pests, and human action). In a field that has been uniformly planted, without any fertility management practices, development of crop will be influenced most by soil and climate. The latter is considered to be uniform over fields of the size used in this experiment. With this hypothesis and no observed pest damage, variability in millet growth should be then be explained by variation in soil physical, chemical, and topographical characteristics.

Scoring is done by touring each field and visually evaluating the development of millet hills or hills vigor (Buerkert, 1995). A scale of hill vigor is set, being an estimate of the above ground development on the basis of a combination of plant height and biomass. Scoring assigns class values to the performance of plants in individual hills. Classes of hill development have been identified with an increasing step size ranging from 0 (no millet plant present) to 8 (best millet hill in the field). Reference hills are tagged to allow comparison during scoring. The same scale has been used at all sites, although a score of 8 at Tara in 1995 for example corresponds with a hill development higher than the same score at Ouallam. Collected data are then geo-referenced by the x and y coordinates of each hill. At all sites, hill scoring in 1996 was done at about the same number of days after sowing as in 1995. At Tchigo Tagui, the scoring was done the same way as in the other 3 sites, but here at three dates: July 3-5, August 7-8, and Sept 3-4 1997.

3.2.3 Scales of observation

Multi-scale measurements of field variability make it possible to consider a range of exploratory factors. The choice of scale is based upon the simplicity of the measurement and its labor and financial cost. In this study, scales of measurement varied from the individual hill via the plot, aggregated 100 m^2 plots, to the entire fields. Previous studies only looked at row scale and above (Buerkert, 1995). Easily obtained data such as scoring were measured at a fine scale (1 x 1 m). Yields were measured at the plot scale to save labor costs. Soil was sampled at the aggregated plot scale to limit the considerable cost of sample analysis For a comparison between two patterns one has to decide upon a matching scale. As this is commonly done, the coarsest scale of the two is used, and detailed data at the finest scale may serve to evaluate effects of spatial variability.

3.2.4 Pattern comparison

To quantitatively compare observed yield patterns with scoring data and with measured soil properties, we applied various procedures.

1) A global analysis by means of data descriptive statistics and stepwise regression to explain millet grain yield with measured soil properties and scoring. The statistical package SPSS ver 7.5 (Anonymous,1988) was used for the statistical analyses.

2) The taxonomic distance method (Davis, 1986). In this case, plot grain yield and median score were interpolated using ordinary kriging towards a 40 x 52 grid necessary in taxonomic distance procedure. The grid files were then analyzed with the taxonomic distance method to compare patterns found in the maps (Van Uffelen et al. 1997). This method compares the standardized values at the nodes of a grid mesh. The standardized values are calculated as:

$$z_{\pi,xy} = \frac{v_{\pi,xy} - \bar{v}_{\pi}}{s_{\pi}} \qquad (1)$$

with $\bar{v}_{\pi}$ and s_{π} are the average and standard deviations of the original values in a pattern π. Pattern comparison is done moving a window of a fixed size across the field and comparing corresponding portions of the two patterns. An optimal window size of 25 nodes was determined in this study and has been used to analyze the data for the three sites. A polynomial regression is fitted to each of the two patterns in the form of:

$$Z = b_{\pi,0} + b_{\pi,1} \cdot x + b_{\pi,2} \cdot y + b_{\pi,3} \cdot x^2 + b_{\pi,4} \cdot y^2 + b_{\pi,5} \cdot xy + b_{\pi,6} \cdot x^3 + b_{\pi,7} \cdot y^3 + b_{\pi,8} \cdot x^2 y + b_{\pi,9} \cdot xy^2 \qquad (2)$$

A third degree polynomial is sufficient to detect the most important changes (Van Uffelen et al. 1997). Coefficients $b_{\pi,0}$ to $b_{\pi,9}$ are obtained by a least square regression fit of the pattern π within the window. Two sets of coefficients for two patterns are compared by way of the taxonomic distance *d* (Davis, 1986) defined as:

$$d = \sqrt{\sum_{i=0}^{p-1} \frac{\left(b_{1,i} - b_{2,i}\right)^2}{p}} \qquad (3)$$

where *p* is the number of polynomials (p=10) and the first indices 1and 2 denote the two patterns being compared. The result is stored as similarities between the 2 patterns, and the window is moved to a new position while keeping points from the former windows (20 points out of 25).

A weighted equivalent applies a weight to the taxonomic distance with w_i equal to the range along the z-axis of the polynomial term i (Verhagen, 1997)

$$d_w = \sqrt{\sum_{i=0}^{p-1} \frac{\left(w_i\left(b_{1,i} - b_{2,i}\right)^2\right)}{\sum_{i=0}^{p-1} w_i}} \tag{4}$$

Taxonomic distance maps are drawn to show similarities and dissimilarities between yield and scoring maps.

3) Cross-correlograms were used to analyze lagged patterns, i.e. to compare shift in patterns (Stein *et al.*, 1997). The cross-correlogram between two patterns i and j is defined as

$$\rho_{ij}(h) = \frac{C_{ij}(h)}{\sqrt{\sigma_{i_{-h}}^2 . \sigma_{j_{+h}}^2}} \in [-1,+1] \tag{5}$$

where $C_{ij}(h)$ is the covariance function (Cressie, 1993) and $\sigma_{i_{-h}}^2$ and $\sigma_{j_{+h}}^2$ are the variance of the ith and the jth variable, respectively, for those points involved in calculating $C_{ij}(h)$.

From the patterns obtained for the numerous soil and plant data (all soil chemical and physical characteristics, plant grain yields, scores, and micro-topography), only those included in the regression models in Table 3.1 were considered in the cross-correlation analysis. For the yield x soil cross-correlation functions, a 95% confidence interval was determined using tabulated values for the correlation coefficient.

3.2.5 Sensitivity analysis

A sensitivity analysis of modeling the relation between scoring and yield was done by calculating the plot specific mean m_P and the standard deviation s_P of the 25 scoring measurements. A random, plot-specific value was drawn from the normal distribution with parameters m_P and S_P. This was done for all plots. With values thus obtained, the cross-correlation function was re-calculated. The procedure of drawing random values and re-estimating the cross-correlation function was repeated 200 times. At each lag distance the interval between the 3rd and the 197th cross correlation value served as the 95% confidence interval.

3.3. Results and discussion

3.3.1 Descriptive statistics of the sites yield data

Descriptive statistics are given in Table 3.2. Mean yields were low at all sites for both years except Tara with 531 kg ha^{-1} harvested in 1996. The yields obtained at Tara in 1996 were probably due to delayed nutrient release as the field was fallowed prior to 1995. Ouallam maintained an average yield below the threshold level of 250 kg ha^{-1} during both years, indicating the marginal state of this site for agriculture. Standard deviations were in general lower at Ouallam than at the two other sites for both years. This site has low and stable yields. Scores at Ouallam, Sadoré, and Tara had a distribution close to normal in 1995 and at Sadoré and Tara also, in 1996. Plots at Ouallam showed a skewed distribution to the left in 1996. The 2 plots in Ouallam showed a symmetric distribution in 1995, and a skewed to the right distribution in 1996 (Table 3.2). These differences between the two years may have resulted from the rainfall amounts received in July and August, with 1995 showing a relatively good rainfall distribution over time, producing more uniform crop growth and subsequent grain yields.

In 1996, results of stepwise regression of soil factors and detrended elevation are given in Table 3.3 for the 3 sites. At Ouallam, the most important explanatory variables for both fields combined are pH_{40}, Al_{40}, H_{20}, Na_{40}, and Mg_{40} in 1995. In 1996, the variables included in the model were K_{10}, Al_{10} and the texture properties Csa_{20} and $Clay_{40}$. In Sadoré, the explanatory variables with the highest significance were Al_{10}, Elev, and $Clay_{10}$ in 1995, and the chemical variables Al_{10}, K_{40}, Mg_{40} and P_{20} in 1996 . At Tara, no explanatory variable was included in the model at the 10% level for 1995 although the site was under fallow for 4 years, whereas in 1996, it included P_{20}.

As in previous studies, the coefficient of determination (R^2) is about 30-40%, except at Ouallam, field 1 (Table 3.3). The soil factors included in the models vary with the year considered, but Al, H, pH are more common to both years. Correlation between yield and mean score for the two years varies between 0.01 and 0.91

Table 3.2. Statistics of grain yields and scoring in 1995 and 1996 at the three experiment sites.

Sites	Grain yield (kg ha^{-1}) 1995			Grain yield (kg ha^{-1}) 1996			Score values 1995			Score values 1996			Correlation yield x mean score 1995	Correlation yield x mean score 1996
	μ	σ	Skew	μ	σ	Skew	μ	σ	Skew	μ	σ	Skew	R^2	R^2
Ouallam														
Field 1	109	72	0.90	141	133	0.98	4.6	2.05	-.61	1.7	1.92	.93	-0.013	0.91
Field 2	125	80	1.15	83	111	1.96	4.9	2.05	-.78	1.1	1.63	1.71	0.51	0.87
Sadoré	379	208	1.11	301	177	1.1	2.9	1.78	0.44	2.5	1.52	.59	0.89	0.88
Tara	332	177	0.59	531	197	0.9	2.6	2.26	0.41	4.7	1.50	-.53	0.44	0.42

μ = mean σ = standard deviation, Skew = skewness

(Table 3.2) with the best relationship for years with poor yields due to poor but uniform crop growth. A exception for 1995 in Field 1 was a result of a weeding done too late.

Table 3.3. Regression of millet yields and soil chemical and physical factors at Ouallam, Sadoré and Tara.

Sites		Regression equation	Significance	Coefficient
Ouallam	Field 1	$\text{Grain}_{95} = 685.4 - 99.1\text{pH}_{40} - 473\text{H}_{20} + 1556\text{Mg}_{40}$	$P = 0.01$	$R^2 = 0.49$
		$\text{Grain}_{96} = 614.84 - 47\text{CLAY}_{40} - 4972\text{K}_{10}$	$P = 0.01$	$R^2 = 0.60$
	Field 2	$\text{Grain}_{95} = 284 - 4159\text{Na}_{40} - 212\text{Al}_{40}$	$P = 0.04$	$R^2 = 0.43$
		$\text{Grain}_{96} = -66.8 - 6.6\text{Csa}_{20} - 164\text{Al}_{10}$	$P = 0.04$	$R^2 = 0.46$
Sadoré		$\text{Grain}_{95} = 394 - 509\text{Al}_{10} + 279\text{Elev} + 14\text{Clay}_{10}$	$P = 0.03$	$R^2 = 0.33$
		$\text{Grain}_{96} = 456 - 488\text{Al}_{10} - 62\text{P}_{20} + 1653\text{K}_{40} - 632\text{Mg}_{40}$	$P = 0.00$	$R^2 = 0.35$
Tara		Grain_{95} = no relationship obtained with variables used		
		$\text{Grain}_{96} = 360 + 820\ \text{P}_{20}$	$P = 0.04$	$R^2 = 0.15$

Al = aluminum, C = carbon, Ca = calcium, Elev = detrended elevation, H = hydrogen, pH = soil pH, P = phosphorus, Csa = coarse sand, K = potassium, Mg = magnesium; subscripts $_{10}$ = 0-0.1 m, $_{20}$ = 0.1-0.2 m, $_{40}$ = 0.2-0.4 m below the soil surface; $_{95}$ and $_{96}$ = 1995 and 1996, respectively.

The range of absolute micro-elevation was divided into 5 classes at Sadoré. The result shows clear differences in yields between classes 1 and 5, but not between the intermediate classes 2 to 4 (Table 3.4). This indicates that at Sadoré, a difference in elevation of 1.2 m causes a significant yield difference, but this is also possible between less different elevation classes, such as between classes 1 and 3 to 4. Ponding of water on plots has also an effect on grain yield (Table 3.4). For ponded plots, yield was reduced by 50%.

Table 3.4. Grains yields as a function of elevation classes and observed water logging at Sadoré

Elevation (m)/ Moisture status	Elevation class	Grain yield (1995 and 1996) (kg ha^{-1})
> 240.30	1	965.9*a*
239.90-240.30	2	427.38*b*
239.50-239.90	3	405.4*b*
239.10-239.50	4	328.31*bc*
238.70-239.10	5	202.81*c*
No ponding		356.90*a*
Ponding		182.30*b*

a, b, c, : mean grain yields followed by the same letter are not significantly different at 5% significance level

3.3.2 Time of scoring

At Tchigo Tagui (western Niger), the best time to score hills was tested. Variability of *hill scores* expressed as *coefficient of variation* (*CV*), correlation coefficient, and R^2 are given in Table 3.5. An increase in variability with time occurs, as plants grow with more variation between hills. The relationship between grain yield and mean score expressed by the correlation coefficient indicates that the third scoring date is the best time of scoring because at this time the highest R^2 value is observed. Implications for precision farming vary according to the objectives:

- if the aim is to apply corrective treatments during the season (for example chemical fertilizer application), the second date of scoring will be preferred;
- if the goal is to predict grain yields and to obtain field information to apply *corrective measures the following cropping season*, then the third *scoring* date will be preferred.

Table 3.5. Variation of millet hill scores and correlation with grain yield in 60 plots at Tchigo Tagui.

Level of scoring	DAS	*CV* (%)	R^2
First scoring	30	36.2	0.12
Second scoring	64	51.5	0.25
Third scoring	91	44.27	0.54

DAS = days after sowing *CV = coefficient of variation*

3.3.3 Taxonomic distance

Taxonomic distance maps comparing grain yields and median score are plotted (Figure 3.3a-h). Dark shading shows the field areas with a good pattern-similarity between yield and score. The percentage of field area with similar patterns is given in Table 3.6. The procedure slightly overestimates the similar patterns, as there is a band around the edges always identified as similar due to the edge effect of the procedure used.

Table 3.6. Summary of taxonomic distance maps: percentage of field area with good correlation between yield and scores.

Sites		Field area covered by similar patter (%)	
		1995	1996
Ouallam	Field 1	57	56
	Field 2	54	57.2
Sadoré		65	63.5
Tara		56.4	56.2

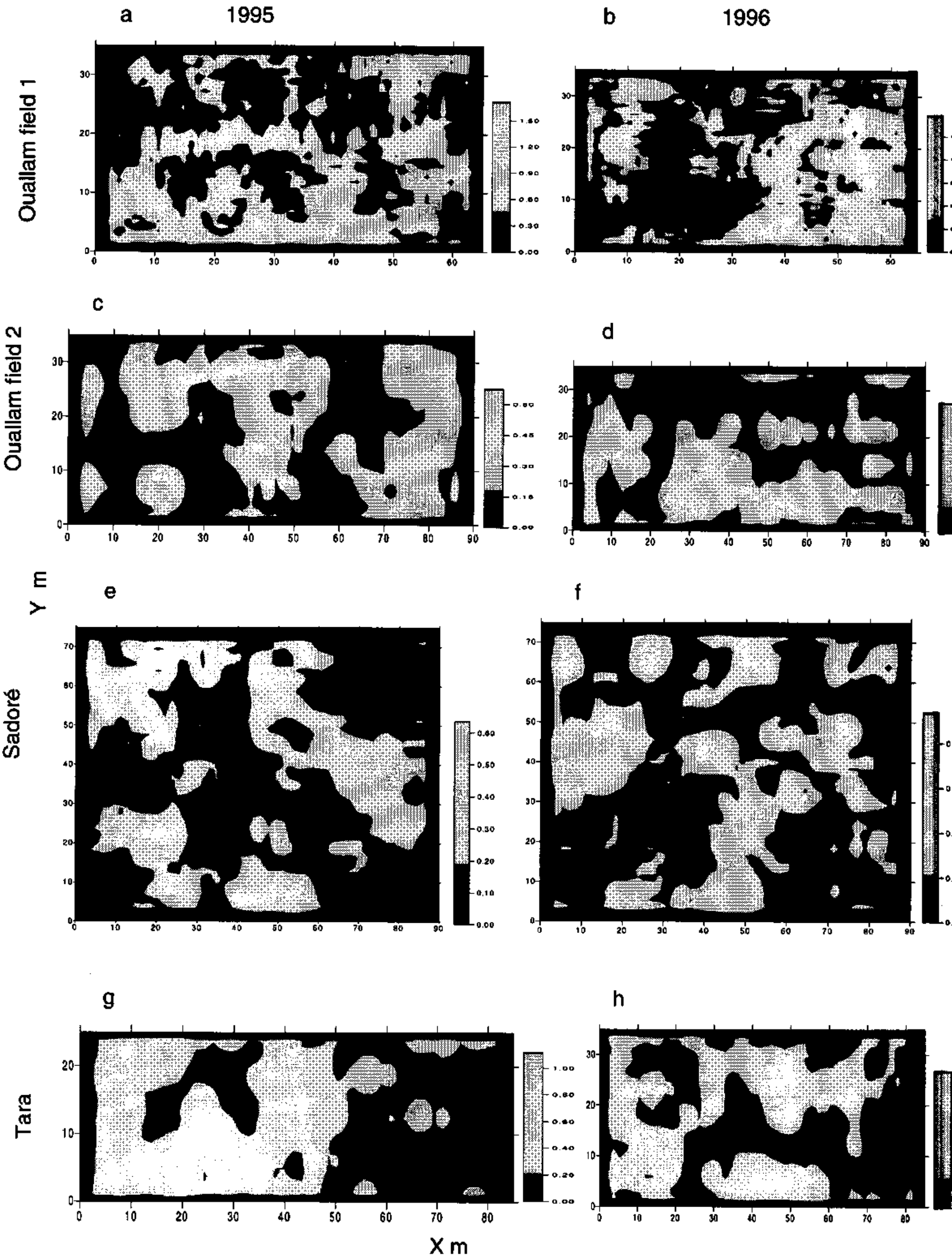

Figure 3.3 Taxonomic distance for grain yield and score

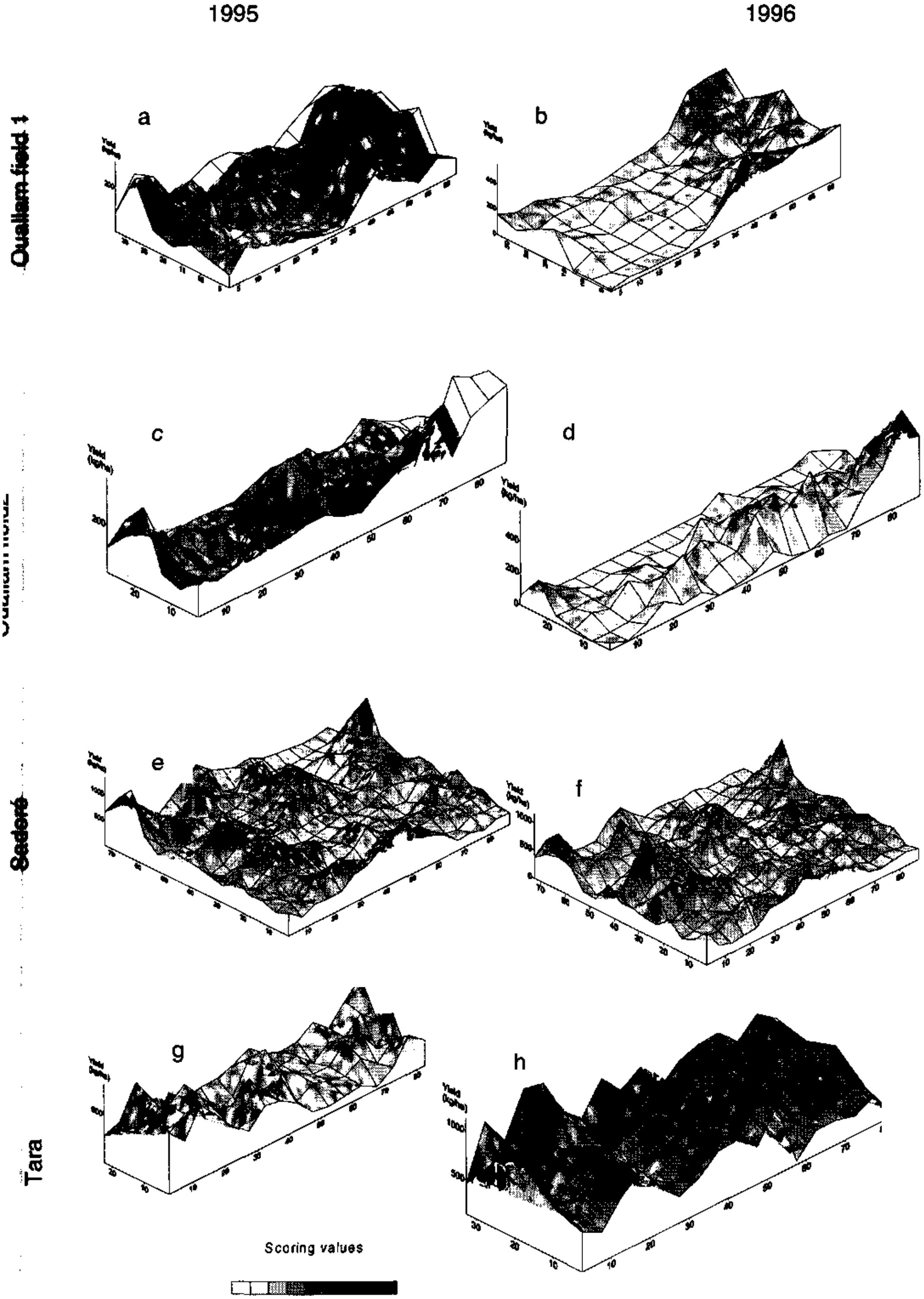

Figure 3.4. Yield and scoring maps for Ouallam, Sadoré, and Tara

The highest similarity percentage was observed at Sadoré. This same concordance of yield and score is illustrated in Figure 3.4a-h where high yields correspond with high scores.

3.3.4 Cross-correlation

Cross-correlation analysis of grain yield with soil factors and detrended elevation are presented in Figure 3.5(a-g).

At Ouallam, a negative correlation between $grain_{95}$ and pH_{40} (and H_{20}) in field 1 was significant only at very small distances, whereas a positive correlation with Mg_{40} was significant up to approximately 20 m. In 1996, $Clay_{40}$ was significantly correlated with grain up to 20 m. It shows that clay is strongly related, contrary as for Sadoré, under the weather conditions of 1996. It could be a major determining factor in yield variation with implications for precision agriculture. Also, differences occur as a consequence to differences in rainfall distribution during the critical months of July and August (Table 3.1). In field 2, in 1995, a significant negative correlation between grain and Na_{40} exists for distances up to 21 m. Notice as well the negative, but not significant correlation with Al_{40}. In 1996, however, Al_{10} shows a significant positive correlation at shorter distances with grain yield. Although it cannot be explained on soil chemical considerations, it is possible that rainfall was the most limiting factor. Any management practice related to Al of the soil should therefore be subject to the occurring weather conditions.

At Sadoré, $grain_{95}$ is spatially correlated at distances up to 15 m with both Elev and with Al_{10}, although correlation with Elev is positive, and with Al_{10} is negative. This emphasizes the high Al values in low areas in the field. A deviating correlation occurs for $Clay_{10}$, showing significance beyond 10 m. Both could have been caused by erosion as described previously, where the highest yields are obtained at some distance from places with high clay contents, due to local crusting (Stein *et al.* 1997). Further, $grain_{96}$ is highly correlated for short distances (up to 10-15 m) with both K_{40} and Al_{10} (negatively) and with K_{40} (positively). Also cross-correlation with Mg_{40} is significant, but for different distances (beyond 10m). Differences in distribution of rainfall probably have caused these differences in variables. A selection of chemical variables in much more important in conditions of much more frequent rain (1996). As in previous studies (Stein *et al.* 1997), the importance of erosion in explaining grain yield variation in this area is important in 1995, whereas in 1996 no such effect appears to exist.

For the southern site Tara, in 1996, the single soil element correlated with grain yield was P_{20}. It is successively positively and negatively correlated at various distances but never significant. The variation is therefore too erratic to show any spatial structure and the field was under fallow for several years previously. It may need to be cropped for some years to develop some type of distinct pattern.

3.3.5 Sensitivity analysis

The sensitivity analysis of the scoring method produced plots of the cross-correlation between grain yield and mean score for all three sites and two years. The 95% confidence interval of the 200 random sample plots and the actual data are indicated in Figure 3.6(a-h). In Ouallam, field 1, cross-correlation fits within the confidence interval and decreases with distance, with no correlation beyond 20 m in 1995. In 1996, the same declining trend with distance is observed, but with much less variability. In field 2, cross-correlation is very broad at shorter distances, and decreases to zero at about 15 m. At Sadoré, the two years had a similar trend of a good correlation over a short distance, with no correlation for distances exceeding 15 m. For Tara, there is a high degree of scattering at short distances in both years, although the shapes are different for the two years.

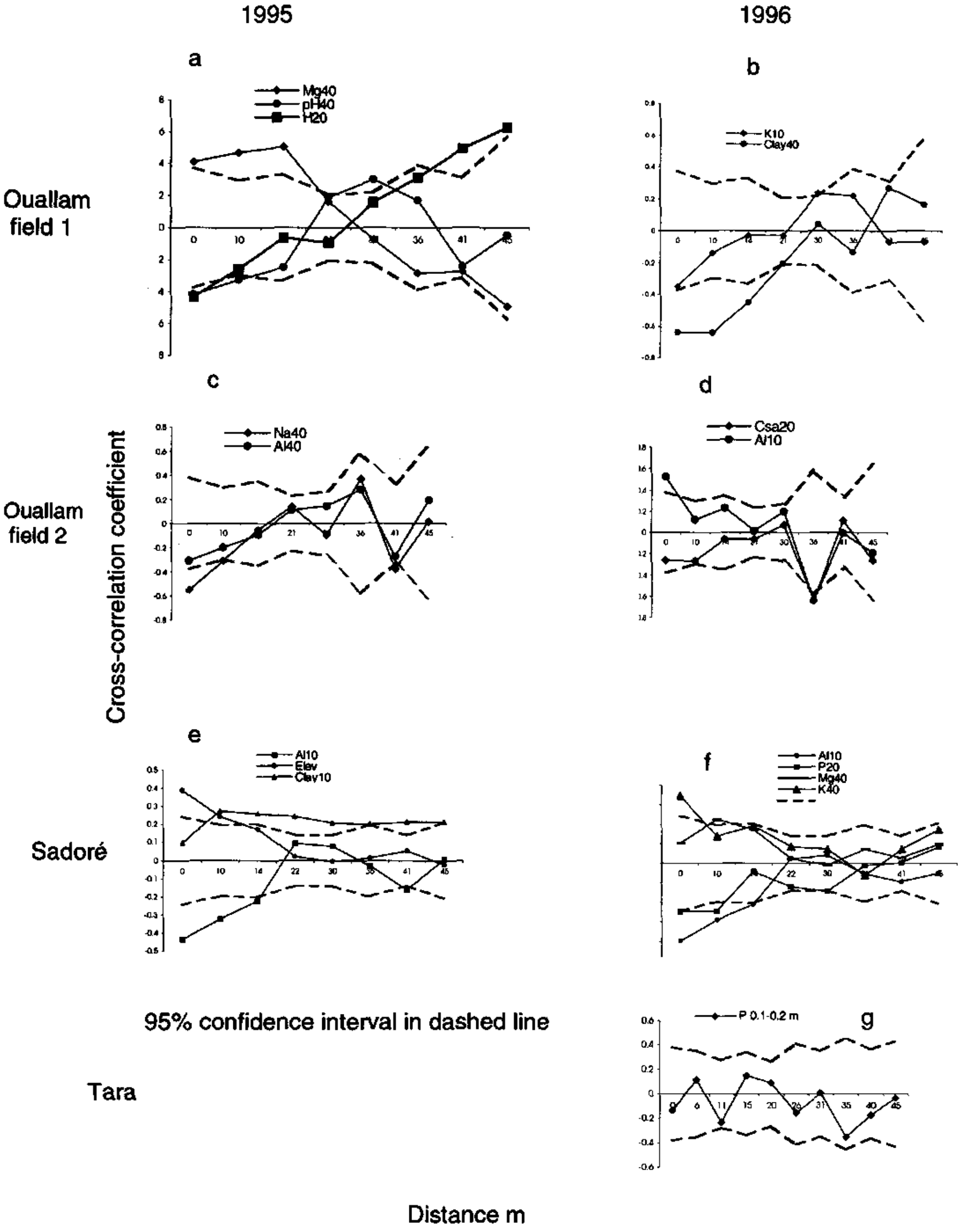

Figure 3.5: Cross-correlation curves between grain yield and soil factors

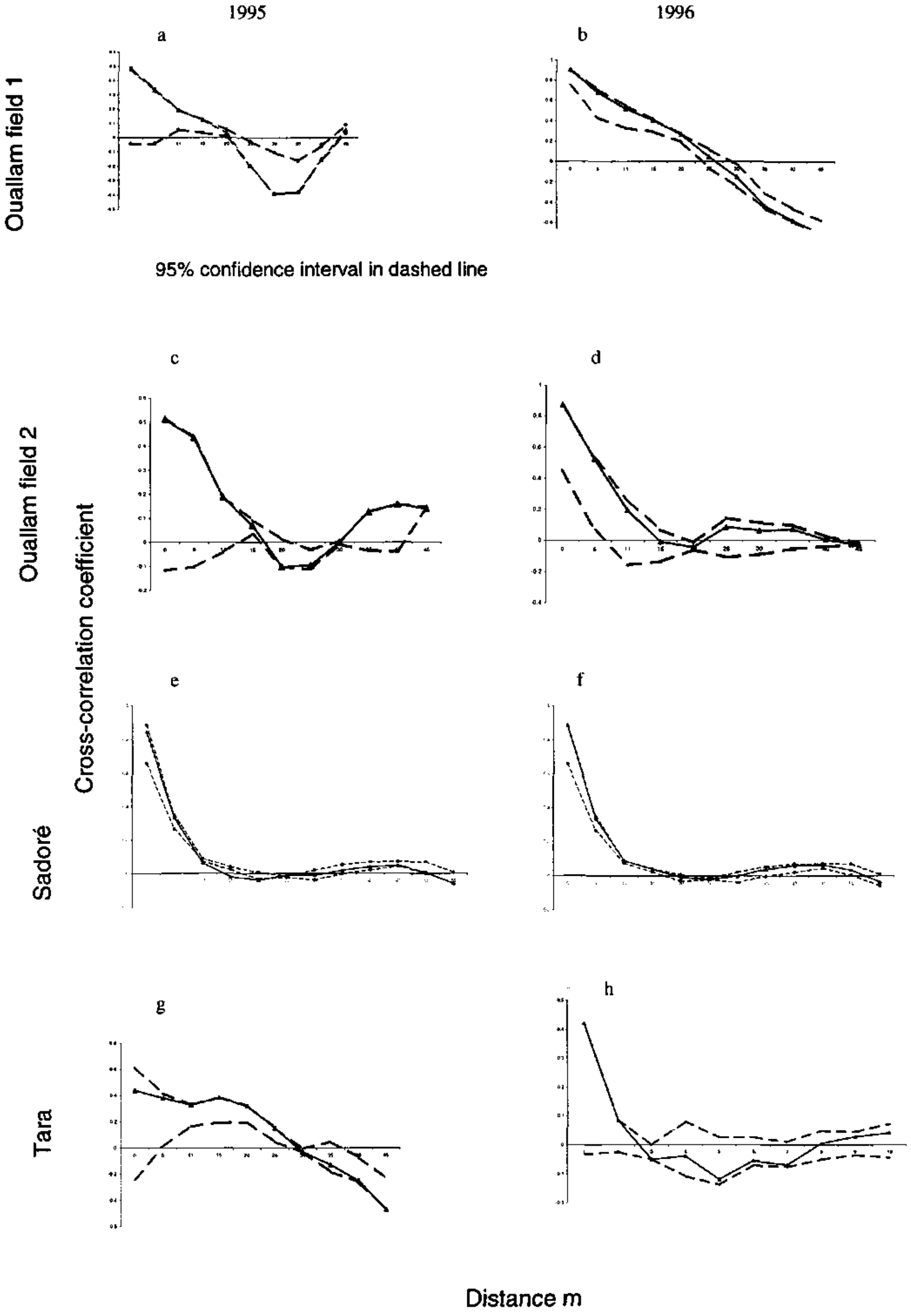

Figure 3.6. Sensitivity analysis of scoring data

3.4. Conclusions

From this study, we conclude that soil variables correlate differently with millet grain yield depending on the site and year. Soil pH, H, and Al, basic indicators of soil acidity are all included in the regression models at Ouallam and Sadoré during both years. For the Southern Tara site, P was the single nutrient well correlated with yield. Micro-topography was important in the final yield at Sadoré where it caused 50% yield decrease due to water ponding. The patterns of ponded areas varied from 50 to 150 m^2 which represent units large enough for precision agriculture treatments. For research, this information is also useful in deciding in the layout of experimental plots. Cross-correlations between soil and topography variables usually extend to distances up to 10-15 m. This value may therefore serve as a guidance for differences in management: uniform inorganic nutrients and manure amounts may apply to areas of this size, whereas modifications may be necessary beyond such distances. The 60 DAS scoring time, with a correlation between score and yield of 0.5, can be used as the best time to perform precision farming involving such as application of mineral fertilizer. However, the 90 DAS should be considered in the context of West African agriculture where manure and other sources of nutrients are gathered during the long dry season and applied to the fields just before planting the crops. This second alternative gives a better prediction of gain yield and provides information on field areas where corrective measures can be used the following cropping season.

Chapter 4

Optimal allocation of limited nutrients to fields of a Fulani farmer's household in a village in Niger, West Africa.[1]

Abstract

Soils used for rainfed cereal production in Niger are sandy, deficient in major nutrients (N and P), and also low in organic matter content. Scarce rainfall with an unpredictable distribution in space and time makes crop and nutrient management difficult. Observations were made in 1996 and 1997 on management by a Fulani household, based on manure application through corralling and on use of fallow. Field corralling of cattle left between 1500 and 17000 kg ha^{-1} of manure on limited areas of the fields. Millet grain yields were increased from 500 kg ha^{-1} in areas manured six or more years ago to 1100 kg ha^{-1} in recently manured areas. Drought during the growing season of 1997 limited the effects of manure application on grain and straw yields. Carbon and nitrogen levels were higher at depths below 0.20 m in sites where manure was applied four to five years ago (M4) while pH and phosphorus were higher in 0-0.10 m of the soil profile in practices where manure was applied less than a year ago (M0). Looking back, nutrient management in 1997 could have been improved by reducing the locally very high manure rates in order to fertilize a two or three times larger area and consequently improve yields over a larger area and reduce risks of nutrient leaching and crop damage from droughts.

Keywords: soil management, manure, pearl millet, nutrient application efficiency, Sahel

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[1] Submitted as: Gandah, M., J. Bouma, J. Brouwer, P. Hiernaux and N. Van Duivenbooden. Optimal allocation of limited nutrients to fields of a Fulani farmer's household in a village in Niger, West Africa. *Agriculture, Ecosystems & Environment*

4.1. Introduction

Food production in the Sahel is essentially based on rainfed agriculture. The major crops are millet (*Pennisetum typhoides*, sorghum (*Sorghum bicolor*), cowpea (*Vigna unguiculata*), and in wetter parts of the region maize (*Zea mais).* Interaction between crop production and livestock has existed since ancient times and was based on mutual benefits, including the use of crop residues as livestock fodder and the use of manure to improve and maintain soil fertility.

Rainfed agriculture in this region depends on two major factors: rainfall and soil fertility. Annual rainfall in Niger has been relatively low during most of the past 35 years (Sivakumar *et al.*, 1993). However, both the total amount and the rainfall distribution during the season are important in obtaining a successful crop. Studies in the region have shown that 300 mm of rainfall, when well distributed, can be sufficient to produce a good millet crop (Gandah, 1988).

Soil fertility, has also been identified to be quite low in Niger (Manu *et al.* 1992), and highly variable within and between fields. Soil pH and exchangeable acidity were highly related to productive and unproductive parts of studies in western Niger (Manu *et al.*, 1996; Wendt, 1986). Phosphorus has been found to be the most important single nutrient for millet in this environment (Bationo and Mokwunye, 1991).

Inherent fertility management of these degraded soils that have been cropped for years depends heavily on annual inputs and outputs of nutrients. Outputs for fields have been estimated to be, on average, 15 kg ha^{-1} of N, 2 kg ha^{-1} of P, and 15 kg ha^{-1} of K for 440 kg of millet grain and about 1860 kg of straw (Buerkert and Hiernaux, 1998). Other outputs include losses by wind and water erosion, and leaching of nitrogen and phosphorus.

Nutrient inputs to the soil include rain and wind borne dust, and chemical and organic elements applied by farmers. Herrmann (1996) found that, in SW Niger, 62 to186 g m^{-2} of solids was deposited on the soil surface annually from the atmosphere, equivalent to an average nutrient deposition of 16-33 kg ha^{-1} year^{-1} of C, 1.0-4.0 kg ha^{-1} year^{-1} of N, and 0.4-1.0 kg ha^{-1} year^{-1} of P. Potassium, calcium, and magnesium were other major elements contained in the dust, averaging 13.8, 7.8, and 5.4 kg ha^{-1} year^{-1} , respectively. Trees and shrubs also contribute indirectly to restoring soil fertility, through further sand and dust collection, decomposition of litter, and in certain cases fixation of nitrogen. These mechanisms combined permit to maintain a minimum soil fertility level that can sustain the low average annual grain yields observed in the region of 350 kg ha^{-1} $year^{-1}$, provided that other measures like fallow are applied (SEDES, 1987).

Nutrient management by farmers themselves includes use of livestock for nutrient cycling and transfer to agricultural land. Two approaches are used. The first consists of gathering manure and other residues and transporting them to the field where they are spread just before the first rains. A cart is needed to move the manure, and the number of draught animals available is usually limited. The second method is by corralling. Corralling is a simple practice whereby, upon return from pasture in the evening, livestock are camped for the night in a limited area of the field, for days or even months. Feces and urine are deposited during 8 to 10 hours every night. Corralling can be done during both the growing season and dry season. During the growing season, corrals can only be established near pathways to pastures and a fence is needed to avoid damage to the crops. Research by ILRI in West Africa has shown that livestock recycles about 50% of organic matter (OM), 85% of P, and 48% of N intake via the feces (Hiernaux *et al.*, 1997). In the study region, based on the cropped area and livestock population ratio, the estimated recycling will amount to an annual average application on the cropped land of 1.2 kg ha^{-1} N and 0.16 kg ha^{-1} P (Hiernaux *et al.*, 1997). These figures are similar to values given by Stoorvogel and Smaling (1994) for the Sahel. Although these averages appear small, field corralling and manure transport from the village, and application to specific parts of the fields only, can result in large quantities of nutrients being applied locally, up to 3-14 t ha^{-1} of manure, equivalent to 43-199 kg ha^{-1} of N and 4.8-22.4 kg ha^{-1} P. Such large quantities may cause significant losses of nutrients through leaching (Brouwer and Powell, 1993).

To estimate the most efficient manure application rates and to avoid losses, nutrient inputs and outputs need to be monitored and compared. In the normal thinking process of a farmer, this is done very roughly by a backward analysis of the inputs and outcome of a cropping season, followed by adjustments for the next season (Bouma, 1997). In this study, this monitoring and comparison of nutrient balances are done in detail to see whether it is possible to fine-tune nutrient management beyond traditional farmer's practices. Farmer interviews and field research were used to test the following hypotheses:

- Different fertility management practices by a Fulani household produce different soil nutrient contents in his fields;
- Effects of fertility management and soil nutrient contents on crops vary from one year to the next due to weather conditions;
- A posteriori (backward looking) analysis after the growing season can help to design alternative and more efficient nutrient application practices.

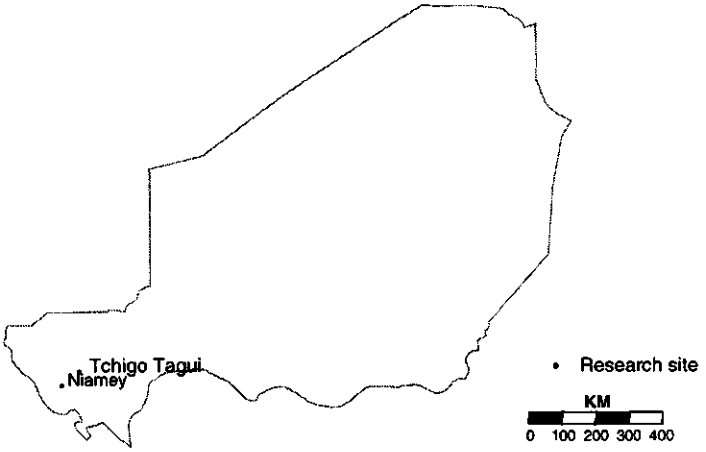


Figure 4.1. Location of research site in Western Niger

4.2. Materials and methods

4.2.1 Site selection and description

The study was carried out in Western Niger, in the village of Tchigo Tagui at 75 km east of the capital city Niamey (Figure 4.1). From a data base compiled by ILRI-Niger in the context of a long-term study on livestock and agriculture interactions, a household and its cropping fields were selected in 1996 on the basis of ownership of livestock and practice of site specific manure management. The household consisted of a Fulani farmer and his family of 21 people. The household owned 2 fields obtained through rent: field 1 is where the household lived and field 2 is a field located about 600 m away from the first one. The farmer owned 23 heads of cattle and 12 small ruminants (sheep and goats), kept year around in the vicinity of the village. Livestock was corralled in the two fields according to a schedule set up by the farmer. Occasionally, the herd migrated to better pasture land during the dry season. The farmer did not own a cart and did not transport manure to the fields by other means.

A survey of the household included:

- the livestock owned and its management
- the fertility management for different parts of the field (manure, chemical fertilizer, crop and household residues, fallow, crop rotation or crop association, etc.), and erosion control measures if any
- the age of the fields and their cropping history;
- the size of the fields, distance from the village and distance between fields
- the ownership of the land
- the available transportation means
- the family composition (sex, age, family relationships) and activities during and after the cropping season (agriculture, livestock raising, handcrafts, merchants, migration to bigger towns or to foreign countries, etc.)
- the social status

The fields boundaries were precisely mapped in May 1996 with a Trimble GPS after a differential correction using a base station located at the ICRISAT Sahelian Center, Sadoré about 130 km away. Within each field, all the site specific management activities performed by the farmer, as far back as he could remember and locate them in the field, were recorded. The field areas used for each specific management were mapped with the GPS. Discussions with the farmer revealed that the choice of a corralling site is based on his assessment of the soil nutrient status, but also on where the compound is located. Corralling is generally done near the compound as a protection against theft. Actual field activity information (sowing, weeding, harvesting, etc.) was gathered during 1996 and 1997.

4.2.2 Characterization of management classes

During the survey in 1996, seven management classes were identified and labeled as follows, where M defines manure application by corralling and F defines fallow:

M0: less than one year since the last manure application
M1: one year since the last manure application
M2: 2 to 3 years since the last manure application
M4: 4 to 5 years since the last manure application
M6: 6 years or more since the last manure application
F0: less than one year since the last fallow
F1: 1 year since the last fallow

4.2.3 Soil and plant data measurements

The soils of the fields were Psammentic Ustalfs with more than 90% sand and little clay and silt (Table 4.1). In the two fields, 38 observational plots of 5 x 5 m each were marked out to cover all the management classes and provide replicates. At planting in July, soil was sampled in each plot at 0-0.10, 0.10-0.20, 0.20-0.40 m depths for chemical and physical analyses: pH, available phosphorus (P_{Bray1}), total nitrogen (N), organic carbon (OC) and texture. The analyses were done according to the standard methods at ICRISAT (Van Reeuwijk, 1993). In plots where manure had been applied and where it was visible on the ground, the amounts of manure were estimated. Sampling was done with a 1x1 m wire frame placed at random at 3 locations in each plot, and the manure found inside was collected, dried, weighed. Later, a composite manure sample from the 3 locations was analyzed for dry matter content and nutrients. Crop data were collected per plot and included the number of hills harvested, head number, total head weight, grain and straw yields.

Table 4.1. Soil texture at four depths in household fields (*n*=9).

Soil depth (m)	Means Clay (*s.d*)	silt (*s.d*)	Fine sand (*s.d*)	Coarse sand (*s.d*)
0-0.10	2.6 (1.3)	3.5 (1.1)	50.3 (3.4)	41.5 (4.2)
0.10-0.20	3.6 (1.1)	3.2 (1.3)	49.7 (5.3)	41.5 (6.0)
0.20-0.40	4.8 (0.9)	3.2 (1.0)	47.6 (4.7)	43.5 (5.0)
1.0-1.20	4.8 (2.9)	2.2 (1.9)	46.6 (3.6)	43.3 (4.0)

In 1997, a data collection scheme different from 1996 was used because the fields used in 1996 were included in 1997 in a much broader study (See Chapter 5). Field measurements were done at a less detailed scale. The same fields were used but because of an extra year of management having passed, additional management units were identified in the two fields in consultation with the farmer, and classified using the same criteria as in 1996. Only three plots of 10x10 m were delineated in each field, in some case corresponding to plot sites used in 1996.

Soil was sampled this year at four depths: 0-0.10, 0.10-0.20 m, 0.20-0.40 m, and 1-1.20 m. The additional depth of 1-1.20 m was included to document possible nutrient leaching in case of high infiltration in high manure rates. The soil was sampled at two different times: at planting time in June and at harvest in October. Soil analysis was done the same way as in 1996. Where present, manure was sampled using the same method as in 1996. Millet plant data measured in 1997 included number of harvested hills, head weight, and grain and straw yields. Rainfall from a nearby weather station was recorded during both years.

The soil, yields and other crop data were analyzed statistically (Oneway *ANOVA*, *T*-test) to evaluate the various effects management classes on soil fertility factors.

4.3. Results and discussions

4.3.1 Fertility management

The management classes observed in 1996 were M0, M1, M4, M6, and F0, with M6 being predominant (Table 4.2). As indicated in materials and methods, soil fertility status and housing site influenced the choice of corralling site. This is the case for M0 in Field 1 in 1997, which was M6 the previous year (Figure 4.2b). This site was fertilized in 1988-1989 and again in 1997 because it is located near the compound. Other more remote parts of the field which had not received any manure for a much longer period of time were not treated. In order to cover the entire field progressively, the compound was moved to a new location every two years and the corrals every year. In the same field (Figure 4.2b), an additional M1 management, not referred to in Figure 4.3a, was a wet season corralling done by the farmer in an area which has not been planted. In Field 2, the new management units added in 1997 included an old fallow site cleared and sown with millet (F0) and two corral sites

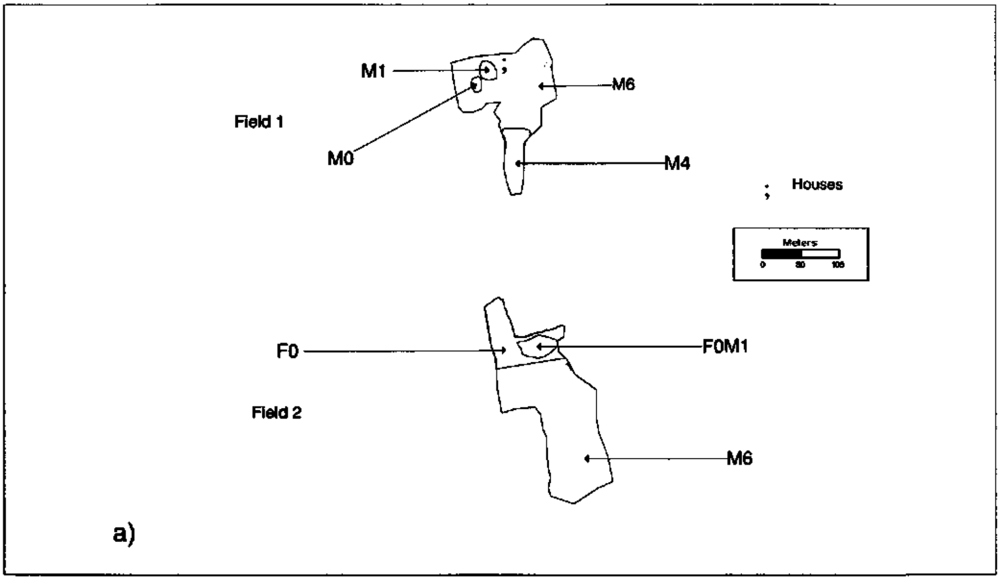
(M0). Recently applied manure (M0-M1) represented at most 20% of the total area of Field 1 and only 2% of Field 2 in 1996 and 1997 (Table 4.2).

Table 4.2. Field area covered by the management classes and numbers of observation plots.

Management class	n (5x5m) 1996	n (10x10m) 1997	Area covered (ha) Field 1 1996	Field 1 1997	Field 2 1996	Field 2 1997
M0	14	1	0.131	0.760		0.289
M1		1	0.237	0.419*		
M2				0.237		
M4	6		1.126	1.126		
M6	12	2	4.721	3.673	8.273	7.984
F0	6	1			2.560	2.900
F1		1				2.560
Total	38	6	6.215	6.215	10.833	13.733

* including corralling done in the field during the cropping season of 1996

About one hectare of crop land was fertilized with manure the 1996-1997 dry season, compared to 0.131 ha during the 1995-1996 dry season. The low figure for 1995-1996 was caused by the corralling of the animals in 0.56 ha of fallow land (F0) about to be reused that year in field 2, forming sub-unit (F0M1) (Figure 4.2a). This technique was used by the farmer to shorten fallow duration from the usual four years to two years. In Field 2, the fallow land put into cultivation in 1996 was two years old, while the fallow land cultivated in 1997 was three years old.



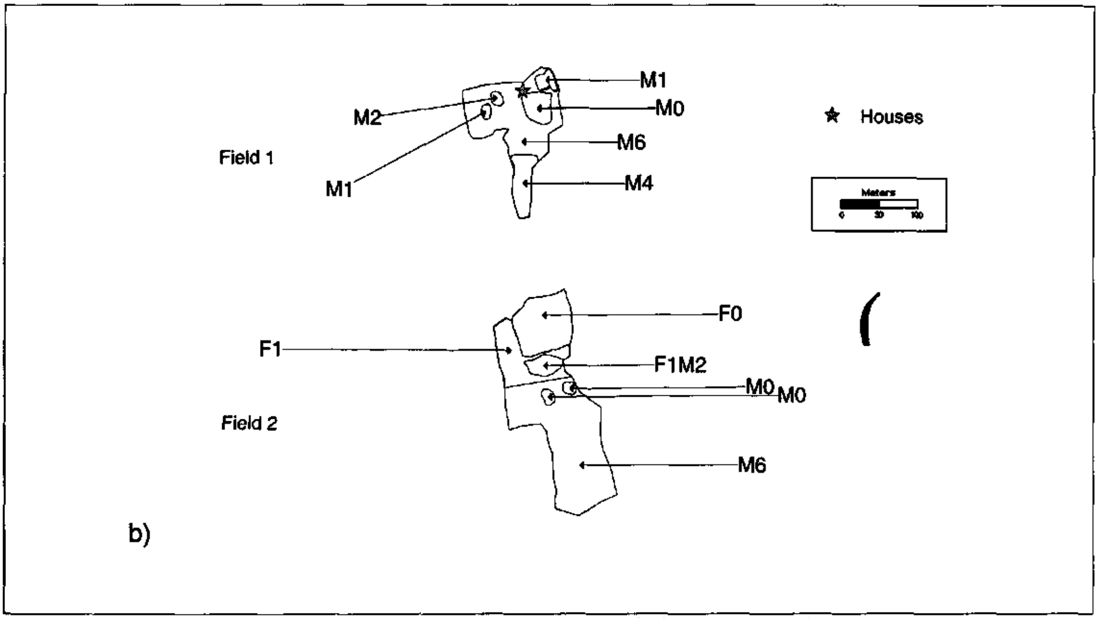


Figure 4.2. Fields and site management at start of a) 1996 and b) 1997

4.3.2 Effects on soil nutrient contents and yields

The effects of management on soil chemical properties were compared in 1996. The amounts of manure applied in MO and M1 treatments as well as the dry matter (DM), organic matter (OM), nitrogen (N) and phosphorus (P) contents are summarized in table 4.3. Due to inclusion of sand in the manure, organic matter varied between 41 and 80% of the manure samples. Phosphorus content was 0.12-0.20% of organic matter, and nitrogen content 1.0-1.6%.

Table 4.3. Manure rates and amounts of nutrients applied (kg ha^{-1}) in MO and M1 practices in fields 1 and 2 calculated from manure analyses

Practice	MO (1996)	M1 (1997)	MO (1997)	MO (1997)
Factor	Field 1	Field 1*	Field 1	Field 2
Manure rate	3528	1514	17,502	6883
Dry matter	3410	1438	16570	6609
Organic matter	1981	846.8	11222	3354
Phosphorus	5.35	2.0	29.8	11.2
Nitrogen	53.5	18.0	256.8	85.2

* amount remaining on the ground from 1996 MO

Between 2 and 30 kg ha^{-1} P and 18 to 257 kg ha^{-1} N were applied to specific areas of the fields through corralling. In addition, an estimated average 315 kg ha^{-1} of stover from the previous crop supplied an input of 0.154 kg ha^{-1} N and 0.010 kg ha^{-1} P (Hiernaux *et al.*, 1997), negligible in comparison with the inputs through manure. Table 4.4 show soil management effects on soil nutrient content in 1996. Among all management schemes found in the two fields, M4 had the highest carbon contents for both the 0.10-0.20 m and 0.20-0.40 m depths. This is an indication of downward movement of nutrients in the soil profile over the years, as a result of high rates of manure application, as reported also by Brouwer and Powell (1993, 1998).

M0 had the highest nitrogen level but not significantly different from M4 and M6 in the top 0-0.10 m of the soil. From 0.10 to 0.40m depth, nitrogen content in M4 was higher than the other practices and this supports the relatively rapid downward movement of nitrogen prior to breakdown and removal from the root zone.

Table 4.4. Comparison of significant mean nutrient contents in the soil under different management practices in 1996, (Oneway *ANOVA*).

	M0	M4	M6	F0	*P* level
Factor	14	6	12	6	
Carbon 0.10-0.20 m	0.145*a*	0.200*b*	0.127*a*	0.130*a*	0.005
Carbon 0.20-0.40 m	0.145*ab*	0.153*b*	0.117*a*	0.116*a*	0.030
Nitrogen 0-0.10 m	0.0134*b*	0.0130*b*	0.0124*ab*	0.0103*a*	0.046
Nitrogen 0.10-0.20 m	0.0128*b*	0.0150*b*	0.0132*b*	0.0080*a*	0.001
Nitrogen 0.20-0.40 m	0.0124*b*	0.0143*b*	0.0125*b*	0.0078*a*	0.000
Phosphorus 0-0.10 m	7.94*b*	1.32*a*	2.32*a*	2.55*a*	0.002
pH_{water} 0-0.10m	5.90*b*	5.70*ab*	5.31*a*	5.76*ab*	0.02
pH_{water} 0.20-0.40m	5.15*a*	5.66*b*	5.29*ab*	5.18*a*	0.09

Nitrogen and Carbon in %; Phosphorus in mg kg^{-1} of soil

The highest levels of phosphorus, a less mobile element, are measured in the top soil of M0, with an average of 7.9 mg kg^{-1} of soil The average quantity of P applied there was 5.3 kg ha^{-1} in the manure alone (Table 4.3), an amount well above the rates usually applied for millet on sandy soils. Like the organic carbon, phosphorus took some time to move down to 0.40 m depth.

Soil pH level was raised to 5.9 in M0 in the top 0-0.10 m of the soil. Deeper in the soil profile (0.20-0.40 m), M4 had the highest pH of 5.6. The soil pH in M0 can be explained by the manure and urine applied to the soil during the corralling which moves down the profile. This is consistent with results obtained by Somda *et al.* (1997) in Niger where top soil pH was raised above 7.5 for more than 4 months after sheep urine application. In 1997, due to the limited number of plots used per field and a greater number of practices, not all practices were replicated enough to obtain meaningful differences.

Grain and straw yields were increased in all management classes where manure was recently applied. M0 produced the highest yield of all management practices done in 1996 in the two fields with 1100 kg ha^{-1} of grain and 3553 kg ha^{-1} of straw (Table 4.5). This yield was significantly different from yields in other management units. F0 and M4 had equal grain yields, implying that the long term effect of manure in M4 was as productive as two years of improved fallow. In 1997, yields were relatively low in M0 plots due to soil moisture deficit caused by very low rainfall in July and August.

Table 4.5. Mean yields (kg ha^{-1}) per management class in 1996 and 1997 (Oneway *ANOVA*)

Factor		Management						*P* level
	n in 1996	14		6	12	6		
	n in 1997	1	1		2	1	1	
		M0	M1	M4	M6	F0	F1	
Grain yield	1996	1100*b*		666*a*	485*a*	676*a*		0.000
	1997	177.5	247.7		149.7	193.5	224	
Straw yield	1996	3553*b*		1880*a*	1270*a*	1436*a*		0.000
	1997	3450	2150		1150	1100	1100	

Compared to normal fallow (F0), corralling in a fallow (F0M1), used by the farmer to save fallow time, improved most carbon and phosphorus content in the top 0-0.10 m and nitrogen in the 0.10-0.20 m of the soil profile. Grain yield was increased by about 100 kg ha^{-1} (Figure 4.3a-d) from 676 to 788 kg ha^{-1}.

A comprehensive analysis comparing the effects of manuring a long time ago (M6) to all the practices where manure was applied (M0 to M4), showed that grain and straw yields were lower in M6 in 1996, but not significantly lower in 1997 (Table 4.6). The reason for the small difference in 1997 was a 21 days drought period in

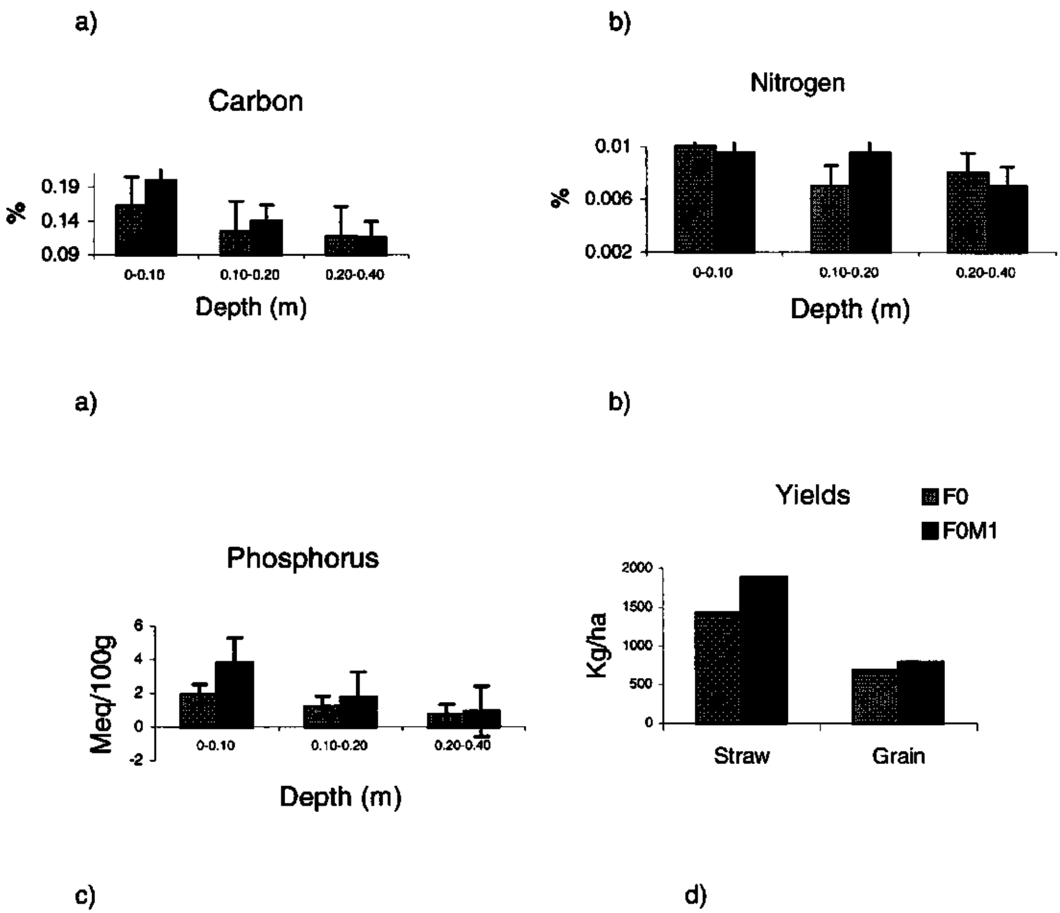


Figure 4.3. Effects of corralling, in addition to a two year fallow, on soil nutrients in 1996

August causing a water deficit observed especially in M0 (higher fertility, faster development) and early senescence of leaves. Total above ground biomass (heads and straw) produced in M0 compared to grain in M0 resulted in a low harvest index of 0.05. Straw abundance is not a total loss for the system, although farmers' primary objective is to produce grain, since it provides fodder for the cattle and the remaining litter is a source of OM, P, and N (Hiernaux *et al.*, 1997).

Table 4.6. Yield (kg ha^{-1}) comparisons between plots with recent (M0-M4) and long ago (M6) manure application (*T*-test).

Factor	Treatments	1996			1997*		
		n	Means	*P* level	*n*	Means	*P* level
Grain	Recent	16	1061.6*a*	0.00	2	212.6*a*	0.18
	Long ago	22	559.2*b*		2	149.8*a*	
Straw	Recent	16	3344.6*a*	0.00	2	2775.0*a*	0.29
	Long ago	22	1426.2*b*		2	1150.0*a*	
Rainfall (mm)			495			415	

*values for the year given as an indication due to small number of cases, *n* =number of cases used for means calculation

4.3.3 Alternative management

As a consequence of nutrient changes in the soil and the crop yields, we propose alternative suggestions to improve the management system. The sandy texture throughout the soil profile (Table 4.1) make the soil highly susceptible to deep drainage of moisture and nutrients. The rate of 3528 kg ha^{-1} applied to 2% of the area of Field1 could have been better used if applied to 6% of the field at a third of the rate used by the farmer in 1996. As indicated in Table 4.3, about half of the manure applied in 1996 in M0 was still on the soil surface a year later with reduced nutrient content. The other half had gone into the soil as nutrients for plant uptake or lost through biological activity or leaching. In 1997, 12% of the same field was fertilized at a rate of 17.5 t ha^{-1}, enough to fertilize all the field's M6 area. A similar suggestion can be made for Field 2 where the manure was applied to 2% of the field at a rate of 6883 kg ha^{-1}. It could have been applied on a larger area of M6 or probably on a much larger area of F0 to improve the fallow before the 1997 cropping season. Increasing the field area can be done by reducing the time a corral stays in one location in order to treat several locations during the course of the off season.

Both the low rainfall measured in 1997 and the very wet season recorded in 1998 with about 700 mm at this site support the application of reduced manure rates. Low rainfall will cause water deficits essentially in heavily manured plots and probably a high percentage of manure will still remain on the soil surface. On the other hand, excessive rainfall will cause leaching of nutrients below the millet root zone.

The alternatives for the farmers could be further improved if threshold levels of nutrients in the soil from nutrient-yield response curves and the economic return of applied manure were known for each management class. Moreover, up-scaling of field results to the region would result in constraints such as labor costs, balance between pasture and crop land, availability of cattle, etc. Pressure on the pastures will increase because 10-40 ha of pasture are needed to fertilize one hectare of crop land using 9 cattle during the dry season (Powell *et al*, 1996). A single sided approach will not be a long term solution to the problem of nutrient management. Use of chemical fertilizers in combination with organic nutrient sources can reduce the need for extensive pasture area and at the same time improve the capacity of these sandy soils to store more nutrients (Bekunda *et al.*,1997; Powell and Williams, 1993; Sissoko, 1998). Further research in these areas is recommended before guidelines for extension can be made.

4.4. Conclusions

Traditional soil fertility management based on the use of manure and millet stover has changed soil nutrient content in several aspects. Traditional corralling practices by Fulani farmers had improved soil nutrient status. Very recent dry season corralling (M0) has improved N and P contents in the top 0-0.10 m of the soil. Four years after manure application (M4), carbon, nitrogen and pH were still higher in 0.10-0.40 m depth of the soil profile. M0 produced an average grain yield of 1100 kg ha^{-1} under normal rainfall conditions (500 mm). However, adverse weather conditions, such as the drought of 1997, decreased the effects of manure on grain and straw yields, specially for M0 management. These traditional practices can be improved for a better efficiency in nutrient application and subsequently high yields. The suggestion is to reduce the application rates and increase the area treated. The proposal is easily applicable without modifications in the farmer's traditional system of rotating corrals and housing compounds in his fields. The duration of each corral at a given site, the variation found in the nutrient content of the fodder and manure produced during the seasons, the number and type of livestock and soil types are all variables that can be used to estimate the required amount of manure to a specific site. Easy to use combinations can be developed and used by extension services and NGO's for an application at a larger scale in the region. However, other aspects such as labor constraints, availability of grazing land and manure need to be taken into account.

Chapter 5

Soil management and landscape position: farmers' use of nutrients to design rainfed farming strategies in Western Niger[1]

Abstract

Poor millet growth and yields in Niger are caused by rainfall deficits and low soil nutrients content. Land management by local farmers is done as a function of soil types, crops, and available resources. Management practices done by farmers in millet fields located on four different landscape positions were studied in a village of western Niger. Nitrogen and phosphorus contents in the soil were higher on the less intensely cropped plateaus. More than 50 % of the fields did not receive any applied nutrients except during livestock browsing. Manure application was done through corralling in only 20 % of the fields studied, out of which 3/4 were farmed by Fulani raising livestock and living on the farm. Other management practice included fallow and use of millet residues in fields adjacent to the village. There was no chemical fertilizer application and any improvement to the system will require the solution of existing constraints limiting the integration of livestock and crops in Niger.

Keywords: management practices, landscape, manure, millet, Niger

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[1] Submitted as: Gandah, M., J. Brouwer, N. Van Duivenbooden, and P. Hiernaux. Soil management and landscape position: farmer's use of nutrients to design rainfed farming strategies in Western Niger. *Nutrient Cycling in Agroecosystems.*

5.1 Introduction

Crop production in the Sahel is mainly based on rainfed production of cereals such as millet and sorghum with legumes mainly used as inter-crop. Agriculture in the region is highly dependent on scarce and erratic rainfall that occurs during the three to four months of the growing season. For the past 35 years, annual rainfall has decreased throughout the region (Sivakumar *et al.* 1993). One of the consequences of this change in rainfall patterns is the southward movement of the 300 mm isohyet used as the limit between the agricultural and the pastoral zones of the Sahel. Rainfall distribution during the course of the season is also a very important factor. Rainfall distribution defines both the beginning and the end of the rainy season and the availability of water from planting to harvest. Quite often, water deficits occur during the most sensitive stages of millet development, that is plant emergence and the time from heading to grain filling (DeRouw and Winkel, 1998). Such water stress is significantly affected by local field conditions. On plateaus of Western Niger, Chase (1986) have found that soil surface sealing and associated water run-off were responsible for the low grass cover and the local disappearance of trees and shrubs. The development of the vegetation in a distinct "tiger bush pattern" (alternating bare areas and vegetated strips) was found to be a result of local run-on and run-off. In agricultural lands, similar redistribution of water in the field was linked to both soil surface conditions 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 of rainfall, infiltration in a field varied from 30 to 340% of rainfall. Brouwer and Powell (1998) also showed that micro-topography is an important factor for infiltration , which in turn affects nutrient losses through leaching. In addition to water problems, nutrients also limit crop production. Land used for rainfed production of cereals is generally poor both in terms of chemical elements and physical properties.

Despite long term agronomic research during the past 35 years to improve crop varieties, and to implement new management techniques involving nutrient and pest management, little effects of these efforts are found at the farmer's level in SW Niger. Farmers still use their local crop varieties and rarely use improved ones due to costs involved, unavailability when needed, and non-adaptation to local cropping practices. Farmer nutrient management is subject to the same limitations. Recommended fertilization practices by research have not been adopted. The main constraints are the high cost of chemical fertilizer, and application rates and methods that do not fit local practices. Also, distances between fields and villages and the lack of transport can be a complicating factor.

Geomorphology has a big effect on fertility and land use in Western Niger. The landscape has been formed in relatively undisturbed Miocene deposits, the Continental Terminal (Wilding and Daniels, 1989). The deposits are often covered with ironstone caps of thicknesses varying from a few centimeters to several meters. Sand deposited on top of these plateaus permits the growth of tiger bush and occasionally allows some crop production. Soil depth is usually shallow (less than 0.5 m). Next to the plateaus are found steep upper slopes with high erosion potential due to water running off the plateau edge. Below this position are found gently undulating terraces where most of the millet fields are located. The last landscape positions are occupied by valleys, containing drainage channels of varying importance. Soil types 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.

Scientific research results have had little impact on soil nutrient management in Niger, but specifically in this part of the country. Nutrient rates, methods of application and management through time and space could not be transferred by extension agents to farmers due to high costs involved for a subsistence crop like millet, inadequacy in the actual farming system and impracticability because of weather and resources availability problems. As a consequence of this, traditional crop production systems still rely on crop residues and manure for soil fertility management. Usually after harvest of grains, part of the millet straw is removed for daily use (for fuel, construction material, or fodder). The unused portion remains in the fields. Plateaus and occasional fallow land constitute most of the pastures available to the livestock. Crop residues remaining in the fields are also by the cattle for feed in a free grazing system. The leftover stover is decomposed on the soil surface through biological activity. This integration of livestock and agriculture returns an estimated 53 to 57 % of the daily manure to the grazing grounds. The remaining percentage is deposited in the corrals set up generally in fields (Schlecht *et al.*, 1995; Mamadou Sangaré ,pers. Com.). Around the villages, house refuse, millet threshing residues along with small ruminant from the village contribute to improve soil nutrient in the adjacent fields. However, this system is not functioning as in the past due to pressure on the land due to human population increase, to a reduction in livestock, fallow and pastures, and finally weather problems.

Based on this diagnostic of Western Niger, the region of Tchigo Tagui was used to investigate the relationship between use of livestock manure and other management practices on crop production on soils of four landscape positions. Studies carried out in farmers fields were 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 .

(2) Investigate the specific use of the scarcely 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 for improving their fertility status

5.2. Materials and methods

5.2.1 Choice of sites

In this experiment, 20 fields were selected from a larger data base collected

by ILRI in the area surrounding Tchigo Tagui, north east of Niamey in Western Niger (Figure 5.1). 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 3 criteria were the major variables used in selecting a field. Table 1 summarizes the classification of the 20 fields whose relative positions are sown in figures 5.2 and 5.3. The distribution of the fields in the landscape showed that 7 fields were located on the plateau, 3 on the upper slope,

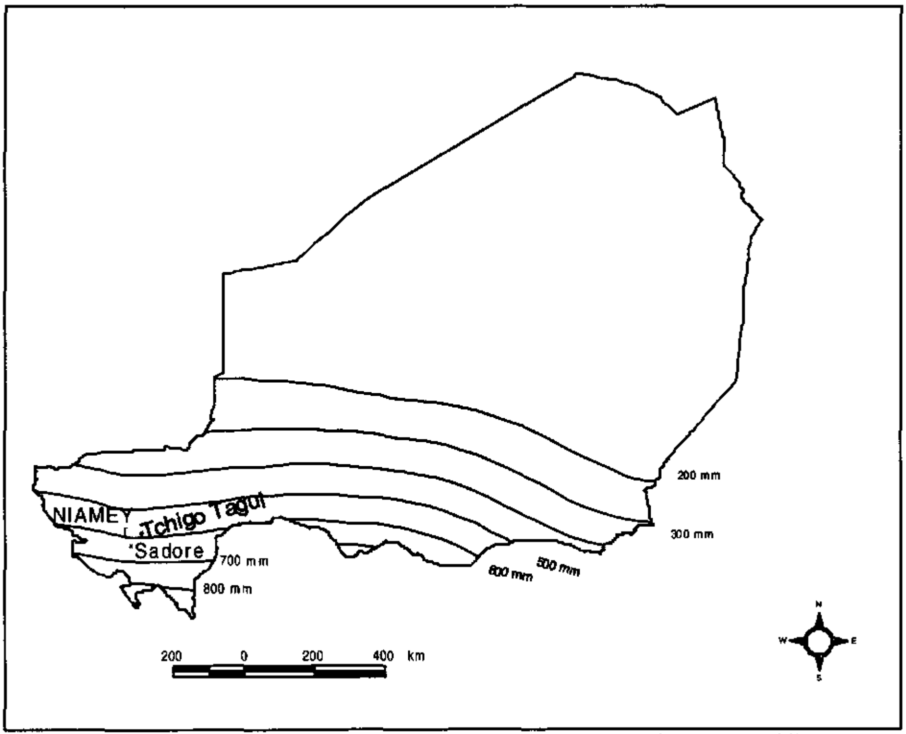

Figure 5.1. Map of Niger and the location of Tchigo Tagui, western Niger

8 on the undulating terrace, and 2 in the valley. This represents quite well the area occupied by the different landscape levels in the region of the village with the plateau occupying 25.2%, the upper slope 11.8 %, the undulating terrace 54.3% and the valley 8.7% of the total area. Two of the fields were adjacent to the village, 8 were between 400 and 2000 m from the village of the owner, and the remaining fields were located between 2000 and 4000 m. In the last group, fields 6 and 20 actually belonged to farmers living in another village more than 15 km away. Field size varied between 1.6 and 26 ha.

Management practices found in 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 years 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 years previously (in 1995)
T0: plot was a threshing ground less than one year previously
T2: plot was a threshing ground 2 years previously
T3: plot was a threshing ground 3 years previously

5.2.2 Field measurements

In each of the 20 selected fields, 3 plots were delineated. The plots were 10x10 m and placed at three different locations. Slope gradient and fertility status were used in deciding where to place the plots. On a slope, the plots were placed at the top, mid and bottom positions. When manure was applied to the field during the year of the study, one plot was installed in the fertilized area.

Soil samples were taken 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_{water}, carbon content, total nitrogen, available phosphorus. Texture was determined in four fractions:

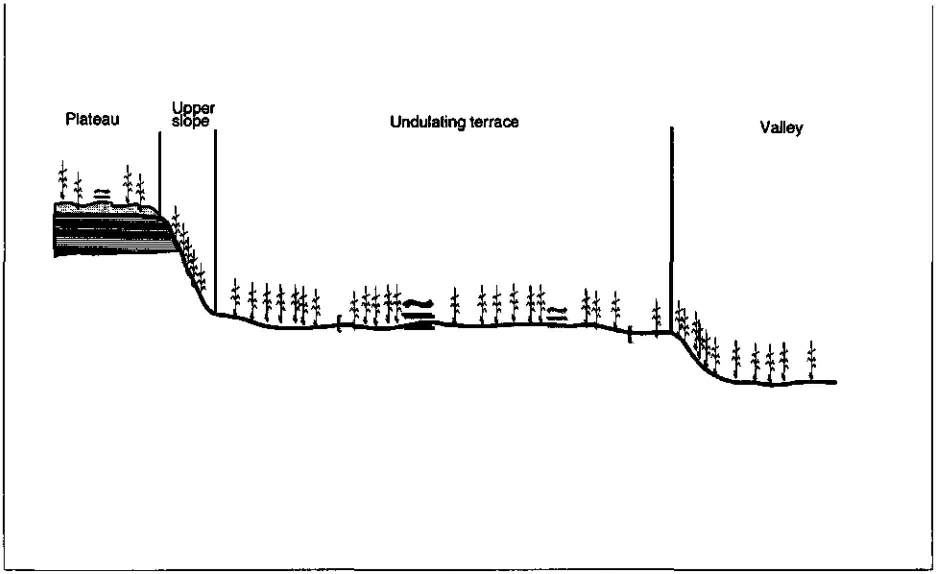

Figure 5.2. Landscape position in the region of Tchigo Tagui, western Niger.

clay, silt, fine sand and coarse sand. The top soil (0-0.05 m) of each plot was sampled for bulk density using a 100 cm^3 steel core. Five samples for bulk density were taken in the center of the plot and at the four corners. The samples were oven dried for 24 hours and weighed. Five profile pits were dug, one on each of the four geomorphology units. Only on the plateau two pits were dug because the soil color and depths varied considerably. Profiles were described and classified according to the CPS/ORSTOM and USDA systems. Samples from each profile were analyzed for pH, exchangeable bases, nitrogen, available phosphorus (Bray1), carbon, and texture (4 fractions as above). Where manure had been applied to a field, a 1x1m 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. The three samples from each plot were later mixed and a composite sub-sample was taken for laboratory analysis (dry matter, carbon, total nitrogen and total phosphorus).

Three weeks after planting the millet, the number of hills planted in each plot was recorded. At harvest in October, the number of millet hills

Table 5.1. Classification of the 20 fields according to the 3 major criteria

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

* Farmers living permanently on their farm
Landscape: plateau (P), upper slope (US), undulating terraces (UT), and valley (V) (Fig. 1)
Fertility level as estimated by the farmer: poor (P), average (A), and fertile (F)

and heads harvested, as well as the straw produced per plot were 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 Trimble GPS after a differential correction with a base station located at the ICRISAT Sahelian Center, about 135 km away.

5.3 Results and discussion

5.3.1 Field location in the landscape

Out of the 20 fields, an equal number was located on the plateau and in the undulating terraces area. The upper slope and valley area also had approximately the same, but lower number of fields. The fields farmed on the plateau had at least 0.5 m of eolian sand deposit on top of degraded laterite soil, as indicated in the profiles descriptions (Annexes).

5.3.2 Soil physical and chemical properties and landscape position

Soil types ranged between sand and sandy clay loam in texture. The clay content in the plateau soil was significantly higher than in all the other landscape positions, while the valley soils had the lowest clay content averaged over the sampling depths. On the plateau, the clay would be predominantly kaolinite and very fine quartz from the parent material (Legger and van der Aa, 1994), but also dust from atmospheric deposition (50% of clay size particle in Harmattan dust is kaolinite, Herrmann, 1996) and very fine iron oxide from the laterite material. Silt content was highest in the valley and plateau soils (Table 5.2). With respect to texture changes with depth, clay content increased with depth, a sign of illuviation, and silt content decreased correspondingly (data not shown). Clay and silt fractions are critical for soil surface sealing causing run-off of about 12 to 13% of the annual rainfall on upper slope positions in the same region (Rockström and Valentin, 1996).

Table 5.2. Mean soil physical properties on four landscape positions, as indicated in figure 3.

Landscape	Bulk density (0-5 cm depth) g cm^{-3}	Clay (%)	Silt (%)	Fine sand (%)	Coarse sand (%)
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 terraces	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*

a , b, c, indicate significant differences between means

As a consequence, much run-off occurs in fields located on the plateau and upper slope with relatively high clay content and development of structural or erosion crusts. The result is water ponding occurring in micro-low areas of the plateau or lost to the upper slope and down to the valley via erosion fans or gullies (Figure 5.2).

Soils on the plateau had the lowest bulk density (1.53 Mg m^{-3}) which was significantly different from values for the upper slope and valley (Table 5.2). The undulating terraces had the highest bulk density. The values for all landscape positions are within the range of 1.5 to 1.6 Mg m^{-3} found in the region (Rockström and Valentin, 1997). Furthermore, the changes are in the order of 0.01 to 0.04 units and would be expected to have less influence on other physical soil characteristics than texture.

Regarding soil chemical characteristics, carbon content was highest on the plateau (0.17%) and upper slope (0.14%) (Table 5.3). One would expect the plateau to be poor in C given its limitations for crop production. The carbon may have accumulated as a result of little soil tillage, less water movement in the profile or bonding to clay particles. For nitrogen, no significant difference was observed except that values on the plateau were higher than on the upper slope (Table 5.3).

Table 5.3. Mean nutrient content in soil averaged over all sampling depths as a function of landscape position

Landscape	Carbon (%)	Nitrogen (%)	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 terraces	0.11*b*	0.006*ab*	1.74*b*	5.66*a*
Valley	0.12*b*	0.006*ab*	2.31*ab*	5.23*b*

a, b indicate significant differences between means

Soil phosphorus content was highest on the plateau and significantly different from the amounts in the undulating terraces area. Phosphorus levels on the plateau could be explained by an increase in eolian sand deposition on the plateau after several years of cropping (farmers interview) and the measured 1 to 5 kg ha^{-1} $year^{-1}$ of P input from dust (Herrmann, 1996). Low levels on the undulating terraces probably due nutrient mining.

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 infiltration rates. This also occurs in the soils in an ancient river valley 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 could be a much richer environment for crop growth and may be easy to improve if its limitations can be resolved: surface sealing, limited depth, distance from village and runoff. This relative richness of the soils on the plateau of this region was also observed by Legger and van der Aa (1994) in the same region. Although the plateau soils are relatively fertile, all four landscape positions were deficient in all major nutrients for good millet growth and fertility improvement by farmers was necessary.

Next, a regression analysis was carried 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 content (in 0-40cm depth) averaged over each measured distance class to site of living. The best regression valid for all nutrients, pH and yields, was obtained with a power model (Table 5.4). Negative coefficients were obtained for yields, carbon and phosphorus to indicate a reduction with distance from living quarters. High correlation also exists between millet yields and distance from the place of residence.

Table 5.4. Regression of average soil factors 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

In addition, landscape positions and the power model for distance were combined to explain variations in soil parameters (Table 5.5). R^2 values changed from 0.14 to 0.47. We also 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

3) is largely explained by differences in landscape position. For carbon, nitrogen and phosphorus, both landscape and distance influenced nutrient content at 0.05 significance level. This was not the case for soil pH.

Table 5.5. Modeling soil nutrients with landscape positions and distance to fields

Factor	Source	df	Mean square	F	*P*	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	.000	0.44
	Distance	1	5.429E-05	8.919	.006	
	Landscape	3	3.851E-05	6.326	.003	
	Error	24	6.087E-06			
	Total	29				
Phosphorus	Intercept	1	88.911	79.795	.000	0.28
	Distance	1	6.345	5.694	.021	
	Landscape	3	3.557	3.192	.031	
	Error	52	1.114			
	Total	57				
pH_{water}	Intercept	1	584.722	3251.261	.000	0.13
	Distance	1	5.616E-02	.312	.579	
	Landscape	3	.461	2.564	.065	
	Error	51	.180			
	Total	56				

5.3.3 Fertility management, soil nutrient status and landscape position

The data showed that fallow, application of crop residues and manure are the main nutrient management methods used by villagers to improve land fertility. The distribution of the management systems in the landscape (Table 5.6) indicated that fallow conditions were found in 2 fields located on the plateau (fields 11and 16) and in 3 fields of the undulating terraces (fields 2, 4 and 5, cf Figure 5.3).

Manure was applied to parts of one field on each of the four landscape units. Except in field 13, all the field where manure was used were farmed by Fulani farmers possessing several heads of cattle and living on their land.

Table 5.6. Types and number of management practices according to landscape positions

Landscape	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 terraces	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 10x10 m plots used in the experiment

The whole range of management classes was found in the undulating terraces, which represented the position preferred by farmers for crop production (interview data, not shown). Crop residue management 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. Three such sites were found in the field. The accumulated millet heads residues are richer in P than the straw.

The results for the effects of practices on soil nutrients are presented in Table 5.7, averaged per landscape position and per practice within a position . On the plateau, among the three practices found there, fallow was the best for improving carbon content, M6 for phosphorus and for pH. Significant phosphorus content on the plateau could be explained by 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 third landscape position, the oldest threshing ground (T3) had the highest soil carbon content, significantly different from the fallow (F0) and M6.

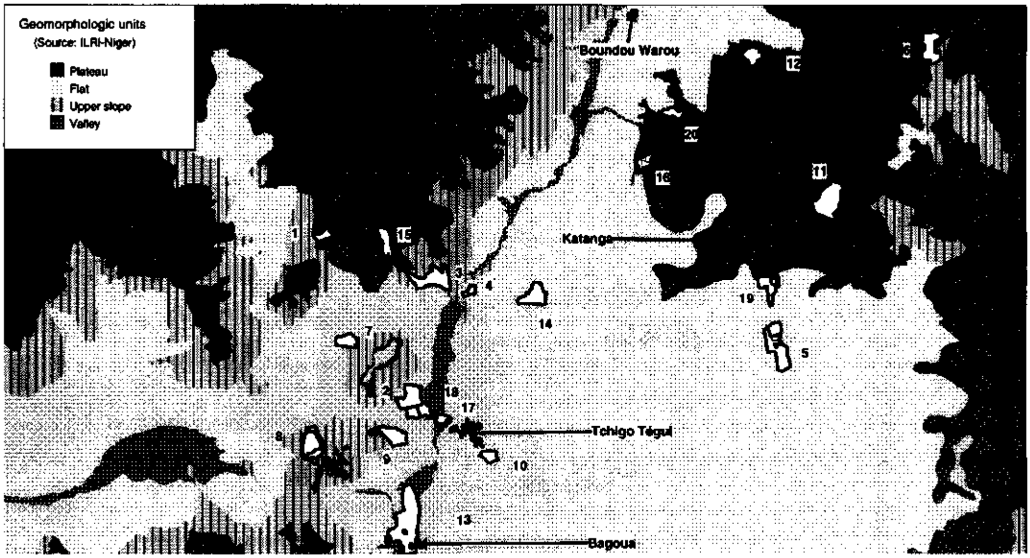

Figure 5.3. Selected study fields and geomorphology map of the Tchigo Tagui region

Threshing residues application as a whole (T0-T3) had a higher phosphorus content than all the other practices. For nitrogen, the most significant practices were T2 and M0-M4 treatments. M4 was the best practice for improving soil pH in this part of the landscape. Threshing residues, in decomposing, released appreciable amounts of carbon and phosphorus with lasting effects. Quantities applied were not measured, but are controlled by the farmer with the number of years each site was used. The detailed effects of the practice using millet threshing residues to improve soil nutrients is illustrated in Table 5.8. 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 method of managing soil fertility is only limited to fields adjacent to the village, and to a field area around the selected tree for processing millet.

Table 5.7. Effects of management practices on soil nutrient content in four landscape positions

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

a, b, c, indicate significant differences between means

For manure, the global analysis using all the 20 fields masks some interesting results which can be identified when individual fields are analyzed. Its effects were confirmed in a previous study detailed study of fields 5 and 19 using 1996 and 1997 cropping seasons data. The results for individual fields in chapter 4 show how M0, M1 and M4 treatments increase phosphorus, carbon and nitrogen contents in the soil.

Table 5.8. Effect of management practices on average soil nutrient content 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

5.3.4 Landscape position, nutrient management and millet yield

As a whole, millet grain yield was not statistically different among the soils at different positions. The largest mean yields were however obtained in the valley and on the upper slope (Table 5.9). The fields on the undulating terraces area of the landscape used most by the villagers had the lowest yields as a result of poor soils caused by continuous cropping and little application of manure rates to entire fields. Grain yields on the plateau were not higher than in the valley 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 run-off and shallowness of the soil profile. Farmers indicated that due to distance to the village, fields on the plateau are the last ones to be cared for and are quite often "abandoned". This general observation however masks specific good yield responses to manure 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 manuring an attractive practice to increase productivity. The average manure rate, found in six of the total sixty plots in the study, was 6445 kg ha^{-1} in 1997 with a range between 3000 and 17000 kg ha^{-1}. These values are high considering the low availability of manure to the farmers, and efficient management of the amounts deposited in the corrals is needed.

Table 5.9. Mean millet grain and straw yield in plots located on four landscape positions and in plots with and without manure

Yields	Plateau	Upper slope	Undulating terraces	Valley	*P*	Fields		*P*
						Manure	unmanured	
Grain (Kg ha^{-1})	131*a*	164*a*	128*a*	203*a*	0.44	316*a*	126.7*b*	0.00
Straw (kg ha^{-1})	1454*a*	2127*a*	1174*a*	2258*a*	0.29	5475*a*	1257*b*	0.00

a, b indicate significant differences between means

5.4. Conclusions

Soil fertility management on landscape positions was investigated in the region of a village in Western Niger. The number of management practices used on the plateau were limited in comparison with the terraces where farmers prefer to diversify their management alternatives. The data showed that plots under fallow had higher C, and long term cropping had higher P and pH on the plateau. On the upper slope, M0 increased P the most compared to M6. On the terraces, threshing residues gave the best soil C, P and N contents and M4 manured practice showed the highest pH. In the valley, no difference was observed between the effects of various practices on soil nutrient content. Results also showed that sixty to ninety percent of the fields did not receive manure application, fallow or localized residue application. The little manure available to a few farmers was applied to limited areas of the field with an average grain yield of 316 kg ha^{-1} in 1997 compared to 126 kg ha^{-1} for non manured plots (Table 9). Much higher yields (1000 kg ha^{-1}) were obtained the previous year in manured plots under better rainfall conditions (see Chapter 4). In comparison, fallow plots cropped with millet produced an average 143 kg ha^{-1} of grain (data not shown). The undulating terraces had all the practices found in the fields, which indicated that farmers are aware of 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, water run-off and, on average, located far away from the village. Fields located on the other landscape positions and far from the owner's place of living were given little attention in nutrient management. Prospects for improving crop production in the region of Tchigo Tagui should rely on the two primary landscape units, the plateau and the undulating terraces. The plateau would, however, require more investment such as labor and transportation means to transfer nutrients. Successful cropping of the plateau will be possible if sand cover is deep and field corralling is provided. More research is needed on the topic because the plateau is important both for the balance between livestock and crops in the region and for the villagers as a source of wood.

Chapter 6

Ethno-pedology: knowledge in land management in the region of Tchigo Tagui, western Niger.[1]

Abstract

This paper analyses farmers' use of local knowledge in the diagnostics, evaluation and management of land in a village of western Niger. Soil physical characteristics such as texture and color are used as primary soil descriptors. Fertility was evaluated using soil color, indicator plants and micro-faunal activity such as termite sites. Indigenous soil and crop management techniques were aimed at minimizing risks of crop failure, with the use of natural shrub sites for fertility, planting of low nutrient needing crops, and field corralling of cattle. Limitations of local practices were discussed along with the importance of ethno-pedology for modern agricultural research both, for the identification farmers' constraints and the transfer of results.

Keywords: farmers' knowledge, land evaluation, pearl millet, Niger

6.1 Introduction

Soil management for agriculture in the Sahel, including western Niger, is based on land evaluation as perceived by the farmers, the available resources to meet production objectives, and the weather. Low and erratic rainfall and soil deficiency in major nutrients are the main limitations for a good millet production, the staple crop in Niger. A steady decrease in the average annual rainfall over the past 20 to 30 years (Sivakumar *et al.*, 1993) has lead farmers to practice a more extensive agriculture and consequently grow crops in drier zones at the expense of pasture land.

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[1] Submitted as: Gandah, M. Ethno-pedology: knowledge in land management in the region of Tchigo Tagui, western Niger. *Journal of Environmental Management*

Selecting land to clear makes the land assessment procedure the first step for farmers in crop production. Knowledge gained from centuries of practice has resulted in a variety of ethno-pedological tools, used by them to identify, evaluate and manage land and crops in a generally harmonious manner. In the region studied, finding easily accessible new land is difficult and continuous use of old fields, either owned or rented, is a common practice. To maintain soil fertility, farmers who own cattle or can pay the cost of corralling livestock in the field may apply manure during the dry season, and sometimes during the wet season. When new fields are required, land is selected and clearing takes place one or two months before planting. Clearing consists of cutting of shrubs and for old fields also of piling up residues from previous crops. Excessive residues are burned to avoid hampering planting and weeding of the crop. When the first substantial rain occurs, crops are sown and cared for until harvest. At each step during this management path, farmers rely on their own expertise and their own environmental classification systems for making the right decision.

To classify soils, texture and color are the first characteristics used elsewhere (Ettema, 1994; Asiamah *et al.*,1997), and in western Niger, (Taylor-Powell, *et al.* 1991; Lamers *et al.*,1995; Osbahr, 1997). More precision is achieved with the use of additional soil characteristics such as surface condition, to define chemical and physical properties important for management. Qualitative and semi-quantitative criteria are used to refine soil descriptions but with less detail compared to the well structured western systems. At Fandou Béri, near our research site in western Niger, Osbahr (1997) identified four soil types based on texture and crusting as they were recognized traditionally by farmers. Taylor-Powell *et al.* (1991) noted three colors (black/dark, white, and red) used commonly by farmers to identify soils in the Hamdallaye area, in the same region. Quite often, vegetation and soil microfauna are used as additional soil investigative tools to derive land quality indicators for crop production. For example, *Zornia glochidiata* is known to indicate fertile soils, and *Eragrostis tremula* is a sign of poor soils (Osbahr,1997). Lamers *et al.* (1995) reported *Giuera senegalensis* and *Anona senegalensis* bushes as the most effective shrubs species farmers preferred for the fertile soils surrounding them.

The lack of adoption of new technologies is caused by limited availability of resources, low education and a mismatch between research results and needs of the farmer (Enyong *et al.*, 1999). To devise technologies to improve the local system of land management, farmers' knowledge and traditional practices are an asset scientific research can and should build on. To understand this indigenous knowledge base in western Niger, surveys were made in 1994, 1996 and 1997 in the surroundings of the village of Tchigo Tagui with the following objectives:

- to describe factors used by local farmers to characterize their land
- to identify the major factors and their use in land management
- to verify the scientific soundness of the local classification systems and practices, and their potential for the transfer of new technologies

6.2 Materials and methods

In 1994, a large scale survey was carried out by the International Livestock Research Institute (ILRI) in western Niger in several villages with different levels of crop-livestock associations (cf. Figure 5.1). The interviews included questions on land area, livestock, and their management by each household surveyed. Data were also recorded on household size, composition, and activities. In 1996 and 1997, twenty households were selected in the region of Tchigo Tagui (cf. Figure 5.3), and farmers were interviewed on their knowledge of soil characteristics, land evaluation, and soil and crop management. The selected farmers were diverse in age, ethnical background, and site of residence in the landscape. Two approaches were used to conduct the interviews:

a) a questionnaire with specific questions asked to the farmer, both at home and in his fields regarding:

- soil color and its use in soil fertility assessment and management
- soil texture classes and related management practices
- soil depth and its importance for crops and tillage practices
- soil moisture and its relationship with soil type and cropping practices

- landscape positions and relationships with soil types, soil erosion and nutrient content
- use of indicator plants for soil fertility assessment
- management of soil fertility using the resources available to the farmer (e.g. inputs, manure, crop residues, use of shrub sites)

b) informal discussions with individual farmers or groups of farmers during their field activities. The farmers were asked to explain the rationale for their observed management practices in their fields. These discussions were used to understand sometimes surprising changes in farming strategy following developments in the weather or in the availability of resources.

6.3 Results and discussion

6.3.1 Use of soil characteristics in soil identification and land evaluation

The questionnaires showed that two physical properties were primary descriptors of soils in the region. Soil texture was used by seventy five percent of the farmers as the first criterion for identifying soil types. Texture was not measured in a quantitative manner, but was estimated visually and by hand grading. Three major textural classes were distinguished in the region: Tassi (sand), Gangani (loamy texture with surface crusting) and Botogo (clay) (Table 6.1). The second class (Gangani) refers more to the crusting state than to the texture class. Osbahr (1997) reported a fourth class called Korobanda, which describes a sandy soil with many crust spots. From experience, farmers in Tchigo Tagui know that crusting occurs on soils with loamy texture and used the same name both for crusting and the texture class.

Soil color was used by eighty percent of the farmers as the second criterion to identify soils. The colors used were Labou bi (black or dark soils), Labou kirey (red soils), and Labou kwarey (light or white soils) (Table 6.1). No color associations were distinguished and only the most dominant color was used.

Soil depth is an accessory descriptor used only in soils found on a plateau or on upper slope positions of the landscape. Even then, it is not applied when the soil is deeper than depths to which regular field activities such as planting, weeding, and harvesting take place. In general, farmers have little perception of soil depth because most of the fields in the area are located on very deep sand deposits and to them, soil thickness is not worth mentioning when it is, in their perception, not a barrier for plant rooting.

Farmers consider soil moisture a factor of major importance for growing crops in their environment, because of recurring droughts during the season. Moisture characteristics and their relationship with soil types are well known to them. Sandy soils were considered highly permeable, loamy soils less permeable with surface run-off constraints, and clay soils were considered impermeable and subject to water ponding. They used a measuring method whereby a hole is dug in the soil after a rain and the presence of moisture to hand length depth (approximately 20 cm) indicates sufficient moisture for planting millet. This method is also used to estimate the number of days after a rain event during which millet planting is still possible without a high risk of failure due to uneven seedling emergence. For example, about 30 mm of rain will correspond to a 20 cm moist profile depth in sandy soils which is sufficient to allow millet planting for two days.

Of the four landscape positions recognized and described in Chapter 5, three were also recognized and given a name by farmers. They were locally designated as Tondobon (plateau), Tondikakassia (upper slope) and Gorou (valley) (Table 6.1). The undulating terraces were not distinguished with a name and group all the positions which do not fit the first three positions. Associations were made between landscape position, the soil types commonly found on them and crop growth limitations.

Table 6.1. Names used by farmers for soil classification at Tchigo Tagui and equivalent English terms

Color	Texture	Landscape
Labou kirey = red soil	Tassi = sand	Tondobon = plateau
Labou kwarey= white soil	Gangani = loamy soil and/or sealed surface	Tondikakassia = upper slope
		No special name for terrace
Labou bi = black soil	Botogo = clay soil	Gorou = valley

The Tondobon (plateau) is occupied by Gangani soils which develop surface crusting leading to water erosion trough run-off. Tondokakassia positions, on the upper slope, have high run-off and occasionally develop gullies. The undulating terraces are covered with deep sand and are prone to wind erosion and to millet seedling burial. Finally, Gorou (valley) areas are occupied by washed-out sand, and by clays in areas subject to long term ponding.

Soil fertility evaluation by farmers focuses on observations of plants as well as soil color. Eighty percent of the farmers, from the questionnaire survey, indicated that millet yield and plant vigor is their primary diagnostic tool to estimate soil fertility in their field. Ten percent use soil color, with dark or black (Labou bi) indicating fertile soils. Both grass and legume species were used for fertility appraisal but there is variability among farmers as to their expertise in the evaluation of weeds. Older farmers have better knowledge of plant species and how they relate to soil. Expertise depends also on ethnical background. Fulani farmers, because of their tradition of searching for the best pastures to feed livestock, have a superior knowledge of plants and where they grow as compared with Zarma farmers who know more about the soil. A list of plants used in the region to asses soil fertility is given in Table 6.2. We note here that *Acacia albida* is a tree which causes improved soil fertility from e.g. decaying leaves around it. Although it was used in the same manner as the other indicator plants, it's presence is the cause of the high fertility status, rather than a result.

Table 6.2. Soil fertility indicator plants used at Tchigo Tagui

High fertility indicators	Low fertility indicators
Cassia mimosoides	*Mitrocarpus villosus*
Zornia glochidiata	*Eragrostis tremula*
Ipomea involucrata	*Striga hermontica*
Alysicarpus ovalifolius	*Mariscus spp*
Acacia albida	*Cassia mimosoides*
Brachiaria ramosa	

6.3.2 Use of farmers' knowledge in environment management

Classification of soils by farmers and evaluation of their potential is also done in the field by farmers as a basis for their crop management (Table 6.3).

6.3.2.1 Management of soils on plateau and upper slope

The major constraint on plateaus and upper slope in the area is surface sealing and run-off. Farmers apply crop residues, and shrubs cut down during land clearing, on bare areas to trap eolian sand and organic material such as dry leaves and seeds. Soil biological activity is improved due to termites and other fauna decomposing the applied organic materials. Water infiltration into the soil increases through the created macro-porosity and soil aggregate stability is improved (see also Chase and Boudouresque, 1987).

On soils with a large proportion of strongly sealed surfaces, because of scarce residues, farmers adopt a minimum investment strategy whereby the field is planted and little labor is spent on weeding. Occasionally, women will use depressions in such soils to grow high value crops (okra, groundnut) which pay for the labor required to till the soil surface frequently to increase water infiltration. Farmers do little to control run-off water, thus causing erosion channels down-hill. They consider large scale water erosion to be beyond their individual capacity to control, and no collective work was done by the village inhabitants. An explanation for this behavior was given by Manu *et al.* (1994) at Hamdallaye in the same region: at this site, water-eroded plateaus and upper slopes were used as communal land for grazing and for wood gathering without any common responsibility to provide soil protection measures. Occasionally at Tchigo Tagui, branches are placed in small gullies in the fields to reduce water flow, but this is the only such activity.

Fertility management remains minimal because fields located on the plateau are generally located far away from the village. They present a relatively higher nutrient level than other lower landscape positions but poor physical properties increase the risk of crop failure (see Chapter 5). Finally, farmers preferably plant photosensitive millet varieties on the plateau, which use residual soil moisture and mature late in the season. Labor is then first used to harvest better yielding early varieties on the terraces and valleys after which they move on to the plateau.

Table 6.3. Use of soil and vegetation knowledge in decision making at the farm level at Tchigo Tagui, western Niger

Time	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Management activity	Field selection	Land preparation	Sowing	Normal crop care			Harvest		Soil fertility improvement off season			
Problem	1. Low soil fertility	1. Seed bed preparation 2.Pest control	1.variety selection 2. Seedling survival 3.crop nutrition	1. water erosion 2.water infiltration 3. weed/shrub competition 4. Low soil fertility					1. Low soil fertility 2. few resources			
Use of soil and vegetation knowledge to solve identified problem	1. Use of soil texture, color, and vegetation to select field areas for cropping of fallow	1.Sealed surface correction with crop and shrub residues 2.Plant and crop residues stacked or burned for nutrients release, for workability, and pest control	1. Late maturing varieties for plateau and distant fields 2. Soil moisture estimation by hand 3. denser sowing near shrub sites and termite mounds for nutrients and water	1.Place shrub branches in gullies for erosion control 2.Tillage of soil surface to improve rain infiltration 3.Preferential weeding in high potential areas and 2nd shrub pruning to limit competition to millet 4.Rainy season corralling in field to collect rich manure 5.Indicator annual plants for fertility estimation for next year's crop					1.Field livestock corralling in selected areas for site application of nutrients 2.Free browsing in fields for nutrient recycling and global application of nutrients			

6.3.2.2 Management of the undulating sandy terraces and valleys

Soils of these two landscape units are in general sandy (with the exception of a few heavier textured soils at sites where water ponding can last for months). It is the most preferred area for growing millet. Fallow is the most common soil fertility improvement technique used on these soils. However, 8 out of the 20 farmers said they do not fallow their land, while another 8 farmers will use a 4 year fallow and then crop the land for six years or more. One farmer will fallow his fields for less than 3 years, and another one will apply fallow for more than 9 years. According to the farmers, the average duration of a fallow is now 4 years for about 6 years of cropping, a decline from the normal 6 to10 years of fallow required. For farmers who do not own enough land, half of the field is put under fallow for the number of years planned and the other half is cropped. There is an ethnical difference between Fulani and Zarma in fallowing land. Fulani farmers have less fallow than Zarma because they can apply manure and economically cannot afford not to sow because they have to pay the price of renting the land. Distance from the village is the second factor influencing fallow practice by farmers. Fields located near the village are seldom left fallowed because they are inherently more fertile and/or easier to fertilize. Thus, the majority of the farmers who do not practice fallow have their fields close to the village, some cropped continuously for more than 40 years already.

Pre-cropping management of fallow includes burning of the vegetation at the onset of the growing season to reduce weed competition to the crop to be planted. Farmers' best nutrient supply is achieved by corralling of livestock in the field during the dry season and thirty percent of the farmers used it. Four out of the twenty farmers in the survey who used corralling were Fulani farmers who possess livestock and live on their farm. Only one Zarma farmer used the same practice as the Fulani because he was wealthy and owned livestock and a field adjacent to the village. Applied manure quantities varied from almost zero to more than 10 ton ha^{-1} on limited areas of the fields. Application efficiencies for the high manure rates are low (see Chapter 4) but do not seem to be a concern for the farmers. They consider remaining manure on the ground after harvest to be totally available for the crop the following year, disregarding losses due to nutrient leaching and to biological activity. Reduced livestock population in the region and costs involved in obtaining a corralling contract increasingly limit the use of this practice.

Regular land preparation also include assembling crop residues from the preceding season and shrub cuttings at specific locations (Gangani areas), where the sealed B horizon is exposed by wind or water erosion, in order to improve infiltration. The same technique is used for degraded termite mound sites. More than half of the farmers interviewed then leave the residues to decay on the soil surface, 30 % burn all the residues and 20 % burn only shrub residues. Burning is done to facilitate crop planting and to control parasites as previously stated. Alternative sources of organic matter, such as millet threshing residues, are sometimes applied in fields adjacent to the village, using very little labor (see Chapter 5). At sowing, farmers use their knowledge of field variability by planting denser hills around termite and ant mounds to efficiently use run-off water and nutrients from the mound. They will also plant millet hills at the four corners around a cut-down shrub site to use nutrients accumulated there through dust and organic matter deposition. Shrub re-growth is removed at first millet weeding time to reduce competition to the millet. These practices have been corroborated by research results on sand and dust deposition near shrub sites in fields (Herrmann, 1996), and by results on water redistribution and soil nutrient contents around termite mounds (Mando and van Rheenen, 1998).

Only 10% of the farmers interviewed mentioned having used small amounts of urea or compound chemical fertilizer when growing millet on the sandy soils. Most farmers do not have funds to buy fertilizer, which is in addition is not available locally. Phosphate fertilizer, when used, was not broadcast but mixed with the seed at planting or placed around millet hills at a rate of about 0.5 kg per hectare of land.

Most farmers in the region have also their own innovative approach to low fertility management. Rather than amending the soil at high cost, they plant millet *Hibiscus sabdariffa* in alternating rows. Hibiscus is a multi-purpose, high value cash crop which is well adapted to poor soils. For Fulani farmers living on the farm, the rainy season is the period to corral the cattle in a fenced and un-planted area of the field to collect additional manure which would otherwise be lost on camping sites. According to farmers, wet season manure is the best both in quality and in availability, because the livestock feeds on a richer vegetation and the manure is in a semi-liquid form that facilitates its mixing with the soil. These assertions have been confirmed by research (Schlecht, 1995; Ayantunde, 1998).

Next in management is the normal crop care such as thinning and weeding. These are always performed first on field areas which farmers know have high yield potentials, e.g manured or fallowed areas. After grain harvest, part of the millet straw is removed by the farmers for use as construction material and fuel, the remaining part is left standing for the cattle to feed on and to protect the soil against wind erosion.

6.3.3 Management of within-field variability

Farmers considered within-field variability as an assurance against total crop failure. Variability of yields within fields is due to several natural causes such as micro-topography, trees and shrubs sites, and differences in soil physical and chemical properties (Brouwer and Bouma, 1997; Stein *et al.* 1997; van Groenigen *et al.*, 1998). Variability may also be induced by the farmer himself as part of his management strategy. On all soil types, patchy manure application, localized application or burning of field residues, and late weeding of low fertility areas increase final crop yield variability. Farmers prefer to have a uniform crop stand but consider it difficult to achieve this in their environment, considering the resources available and the lack of control of water and nutrient availability. They also consider it to be hazardous because of the unpredictable rainfall distribution. The aim is to minimize risks involved in crop production rather than to maximize crop production. Site specific soil management is therefore a necessity (e.g. Bouma *et al.*, 1997).

6.4 Ethno-pedology: contribution to research and limitations

6.4.1 Research and ethno-pedology

Ethno-pedology reflects a long-term adaptation of farmers to their environment and it should be used as a source to understand farmers' priorities in land management and their need for simple solutions to complex problems.

Diversity found in village communities in terms of experience, ethnical background, and resources are often a source of conflict of interest, which prevents farmers from adopting new methods or management practices. For example, technologies may be advocated for crop yield improvement such as inter-cropping millet with longer growing cowpea varieties to reduce competition for soil moisture. However, harvesting the legume late in the season will prevent livestock from returning to the fields as soon as millet is harvested to feed on residues. This is unacceptable for farmers.

Another example is greater attention being paid by research and extension to young farmers who are willing to accept changes while experienced farmers, who own the land, are less involved in technology transfer. This can create problems which can be overcome by also focusing on experienced, older farmers and their concepts.

Finally, ethno-pedology uses simple descriptors which can be combined to characterize more complex phenomena to be addressed by research. In this way, research can be focused on worthwhile topics considered important by farmers themselves, rather than follow traditional textbook approaches.

6.4.2 Limitations to the broad use of ethno-pedology

Some limitations do exist to the use of ethno-pedology for a broad region or a country wide application. Descriptors used by farmers are limited in number, in general qualitative in nature, and limited to a specific region. They will have to be adapted to be applicable to situations elsewhere. Many practices in ethno-pedology such as livestock corralling during the wet and dry season, cannot be evaluated quantitatively by the farmers except on the basis of the harvested grain. The true efficiency of the practice is not known and may be less than optimal. Another key limitation can be the confusion between causes and effects. Farmers are most sensitive to effects and take action to treat them without always understanding the causes. In all theses aspects, targeted research may help increase efficiency and sustainability of farming practices.

Furthermore, social factors are at least as important as physical factors in ethno-pedology, which makes it less applicable for different settings because social behavior will change with location. For example, there was no action taken to control erosion in this particular region, eventhough in the north central part of Niger Haussa farmers use efficient traditional methods of protection. Targeted research can help transfer technologies between different regions.

6.5 Conclusion

Overall, it can be said that farmers' classification of their environment has gained more interest in the past several years because scientists have realized that rapid improvement in agricultural production in marginal regions cannot occur only through high-input technologies. In western Niger, simple soil descriptors used by farmers such as color, soil texture, and indigenous plants to describe and evaluate the land, were found to be well adapted to their environment. Sand, loam, and clay were three major texture classes used and designated as Tassi, Gangani, and Botogo. Soil color and native plant species provided additional information on soil fertility e.g. labou bi (dark soil) and labou kwarey (white soil) for low and good fertility respectively. Targeted management practices are then applied by the farmers. When livestock is present, corralling on selected parts of fields was the preferred method of fertility management. When manure is not available, most farmers use field characteristics such as shrub sites and other natural features to select more fertile parts of a field. In this way, within-field variability is used more efficiently. Cultural diversity in the region, as experienced by the Zarma people with their knowledge of the land and the Fulani people with livestock and plants can make ethno-pedology a community-based source of knowledge available to all.

Limitations exist however when using ethno-pedology. Little expertise is available in this region to deal with soil erosion problems. The lack of quantification and the lack of distinction between cause and effect limit the general use of local expertise. Finally, ethno-pedology is a type of "gray literature" in danger of disappearing considering the present trend of rapid but non sustainable solutions to long term problems. It should be used to develop research programs and as an interface to transfer research findings to farmers in a simple format which they can understand.

Conclusions and Further Research

The research presented in this thesis was carried out in western Niger in 1995, 1996 and 1997 with additional data from surveys in the village of Tchigo Tagui in 1994. It looked at spatial variability at a number of scales, from within-field to landscape and how farmers identify and manage it while performing crop production activities. Within-field variation of soil properties and crop growth in farms is a major concern to nigerien producers who lack the resources to assess it (e.g. with soil and plant analyses), but also lack the funds to apply corrective measures. Adapting their knowledge to the crop production constraints, farmers have developed field level solutions such as site specific application of nutrients (manure and residues), use of localized natural fertility (around shrubs), and use of low risk strategies. At a higher scale, variability in crop productivity between field shows that fields near villages have a relatively better fertility, but are increasingly mined of their nutrients without any fallow. In general, farmers' practices for fertility management are based on fallow, crop residues, manure through corralling, and use of more rustic crop species. Finally at the regional scale, landscape position has been found, in various aspect, to be important for crop production in western Niger. Fields located on plateaus were, in general, too distant from villages, and less cared for by farmers due to physical constraints. Soil nutrients amounts, such as phosphorus and carbon, were higher there than down the landscape. Undulating terraces represent farmers' most preferred location in the landscape for growing millet because require less effort for clearing, cropping, and is often near the village. As a consequence, good fertility management is highly important there to limit prevent further soil degradation.

The following conclusions summarize results of research on within-field crop growth variability and farmers' soil management in western Niger:

- within-field millet yield variability is high with a factor of 10 to 30 at all sites investigated and is not only related to soil variability in nutrient content. Field micro-topography caused relatively high yields in high topographic positions. Soil surface sealing and water run-off to lower positions reduced grain yields due to low germination and water ponding at two of the sites studied.

- hill-scoring of millet plants is a cheap alternative to yield measurement for estimating field variability. It should be done at millet heading stage. Within-field millet yield variation is smaller among years at the drier northern site as compared with yields at the wetter central and southern sites.
- traditional corralling and fallowing are favorable to increase millet yield significantly in the low input crop production systems of western Niger. Millet yield doubled due to manure application with adequate rainfall. The quantities of manure locally applied in corrals is, however, high, varying between 3 and 17 tons ha^{-1}. Losses through leaching of nutrients and other processes should be expected when rates exceed 3 tons ha^{-1}. Spreading manure collected by rotating corrals more frequently could be a solution to over-manure application.
- landscape position and distance between fields and villages play a crucial role in soil fertility management. Fields located less than 1 km from villages are cropped continuously because of their relative high fertility. Fields located at 1 to 4 km from the villages are managed with little or no nutrient application. With time, it is expected that both near and distant fields will become infertile. Plateau soils are richer in nutrients such as carbon and phosphorus than those on upper slopes, terraces and valley positions because of low cropping intensity. Use of soils on the plateau is limited by distance and surface sealing causing water run-off.
- farmers use their own knowledge of soils, plants, and animals to compensate for lack of modern technologies adapted to local crop production constraints. Selective choices are made by farmers in terms of management, using shrub and crop residues on sealed surfaces, planting near shrub sites to use local fertility, and planting specific crops adapted to low nutrient or sealed soils. Strategies used by farmers are designed to minimize the risk of total crop failure due to water deficit.

For future research, we recommend:

- to use variability analysis in both research experiments and in targeted application of research results in farmers' fields in order to adapt research activities to real fields and farmers' conditions.

- to do more research on threshold levels of major soil nutrients in manured fields in order to calculate optimal manure rates and corral-rotation cycles in farmers' fields. For this, nutrient contents and their distribution and retention in the soil profile should be investigated as a function of soil type and weather conditions .

- to use farmers' knowledge and experience in land management should be used by researchers to identify real needs and constraints and to develop effective methods of transferring research results back to the farmer.

References

Almekinders C.J.M., L.O. Fresco, and P.C Struik. 1995. The need to study and manage variation in agro-ecosystems. *Netherlands Journal of Agricultural Science.* 43:127-142

Anonymous. 1988. SPSS/PC+ V2.0 Base manual. SPSS Inc., Chicago, 215 pp.

Anonymous. 1994. Keys to Soil Taxonomy. United States Department of Agriculture. Soil Conservation Service. Sixth edition. United States of America. 524 pp.

Anonymous.1995. User guide Surfer Ver 6.01. Golden Software Inc. Colorado, 600 pp.

Anonymous. 1994. Keys to Soil Taxonomy. United States Department of Agriculture. Soil Conservation Service. Sixth edition. United States of America. 524 pp.

Anonymous, 1988. SPSS/PC+ V2.0 Base manual. SPSS Inc., Chicago IL, USA, 215 pp.

Asiamah, R.D. , J.K. Senayah, T. Adjei-Gyapong, and O.C. Spaargaren. 1997. Ethno-pedology surveys in the semi-arid savanna zone of northern Ghana. Report 97/04. SRI-ISRIC Wageningen, The Netherlands. 38 p.

Ayantunde, A. 1998. Influence of grazing regimes on cattle nutrition and performance and vegetation dynamics in Sahelian range lands. PhD Thesis. Wageningen Agricultural University. 179 p.

Bationo, A. and A.U. Mokwunye. 1991. Alleviating soil fertility constraints to increased crop production in West Africa: the experience in the Sahel. *Fertilizer Research* 29: 95-115.

Bationo, A., C.B. Christiansen, W.E. Baethgen and A.U. Mokwunye, 1992. A farm level evaluation of nitrogen and phosphorus fertilizer use and planting density for pearl millet production in Niger. *Fertilizer Research* 31: 175-184.

Bouma, J., J. Verhagen, J. Brouwer and J.M. Powell, 1996. Using systems approaches for targeting site specific management on field level. In: M.J. Kropff, P.S. Teng, P.K. Aggerwal, J. Bouma, B.A.M. Bouman, J.W. Jones, & H.H. Van Laar (Eds). Applications of Systems Approaches at the Field Level. Kluwer Academic Press, Dordrecht, pp. 25-36.

Bouma, J. 1997. General reflections. *In:* Precision Agriculture: spatial and temporal variability of environmental quality. CIBA Foundation Symposium 210. John Wiley & Sons Ltd. 251 p.

Brouwer, J., L.K. Fussel and L. Herrmann. 1993. Soil and crop growth micro-variability in the West African semi-arid tropics: a possible risk reducing factor for subsistence farmers. *Agriculture, Ecosystems and Environment* 45: 229-238.

Brouwer, J., and J.M. Powell. 1993. Soil aspects of nutrient cycling in manure application experiment in Niger. *In:* J.M. Powell, S. Fernadez-Rivera, T.O. Williams and C. Renard (Eds): *Livestock and sustainable nutrient cycling in mixed farming systems of Sub-Saharan Africa Vol. II: Technical Papers.* pp 211-226.

Brouwer, J. and Bouma, J. 1997. Soil and crop growth variability in the Sahel: Highlights of research (1990-1995) at ICRISAT Sahelian Center. Information Bulletin No. 49. ICRISAT, Patancheru 502 324, Andhra Pradesh, India. 42 p.

Brouwer, J., and J.M. Powell. 1998. Increasing nutrient use efficiency in West African agriculture: the impact of micro-topography on nutrient leaching from cattle and sheep manure. *Agriculture, Ecosystems & Environment* 71: 229-239.

Buerkert, A., R.D. Stern, and H. Marschner. 1995. Post stratification clarifies treatment effects on pearl millet growth in the Sahel. *Agronomy Journal.* 87:752-761.

Buerkert A., and P. Hiernaux. 1998. Nutrients in the West African Sudano-Sahelian zone: losses, transfers and role of external inputs. Z. Pflanzenernahr. Bodenk., 161: 365-383.

Buerkert, A., R.D. Stern, and H. Marschner. 1995. Post stratification clarifies treatment effects on millet growth in the Sahel. *Agron. J.* 87:752-761.

Chase, R.G. 1986. TropSoils collaborative water conservation research in Niger. In: Ted J. Davis,(Ed.) Development of rainfed agriculture under arid and semiarid conditions : proceedings of the Sixth Agriculture Sector Symposium. Washington, D.C. World Bank, 1986. p. 265-290.

Chase, R. and E. Boudouresque. 1987. Methods to stimulate plant regrowth on bare Sahelian forest soils in the region of Niamey, Niger. *Agriculture, Ecosystems & Environment* 18: 211-221.

Cressie, N.A.C. 1993. Statistics for spatial data. Wiley, New York.

Davis, C.1986. Statistics and data analysis in geology. Second edition . John Wiley, New York, 550 pp.

De Rouw, A. and T. Winkel. 1998. Drought avoidance by asynchronous flowering in pearl millet stands cultivated on-farm and on-station in Niger. *Experimental Agriculture* 34: 19-39.

Deutsch, C.and A.G. Journel. 1992. GSLIB Geostatistical software library and user's guide. Oxford University Press, New York, 340 pp.

Enyong, L.A., S.K. Debrah, and A. Bationo. 1999. Farmer' perception and attitudes towards introduced soil-fertility enhancing technologies in western Africa. *Nutrient Cycling in Agroecosystems.* 53: 177-187.

Ettema, C. H. 1994. Indigenous soil classifications: what are their structure and function, and how do they compare with scientific soil classifications. Report. 10p.

Fao.1998. The state of food and agriculture. FAO, Rome Italy. 396 p.

Gandah M. 1988. Response of pearl millet [Pennisetum americanum L. (Schum)] to soil moisture in one agro-ecological zone of Niger, West Africa. MSc. Thesis. Texas A&M university College Station Tx. 133 p.

Gandah, M., Bouma J., Brouwer J. and Van Duivenbooden N. 1998. Use of a scoring technique to assess the effect of field variability on yield of pearl millet grown on three Alfisols in Niger. *Netherlands Journal of Agricultural Science.* 4:39-51

Gandah, M., J. Bouma, J. Brouwer, P. Hiernaux and N. van Duivenbooden. 1999. Optimal allocation of limited nutrients to fields of a Fulani farmer's household in a village in Niger, West Africa. (submitted to *Agriculture, Ecosystems & Environment Journal*).

Gandah, M., J. Brouwer, N. Van Duivenbooden, and P. Hiernaux. 1999. Soil management and landscape position: farmer's use of nutrients to design rainfed farming strategies in Western Niger. (This thesis).

Gaze, S.R. 1996. Water balance of farmer-managed millet and fallow savannah on sandy soils in South West Niger. PhD thesis. Department of soil science, University of Reading, Reading, 268 pp.

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

Geiger, S.C., A. Manu and A. Bationo. 1992. Changes in a sandy Sahelian soil following crop residue and fertilizer additions. *Soil Science Society of America Journal* 56: 172-177.

Hartmann, R., and M. Gandah. 1982. Hydrodynamic characterization of a sand dune soil in Niger. Med. Fac. Landbouww. Rijksuni. Gent. p. 1195-1204.

Heuvelink, G.B.M., 1993. WLSFIT manual. University of Amsterdam, Amsterdam,

Herrmann, L. *1996. Straubdeposition auf b d̄en West Afrikas.* Eigenschaften und herkunftsgebiete der st≅ube und ihr einflub auf boden und standortseigenschaften. Phd thesis. Universitat Hohenheim, Stuttgart, Germany 239 p.

Hiernaux, P., S. Fernadez-Rivera, E. Schletcht, M.D. Turner, and T.O. Williams. 1997. Livestock-mediated nutrient transfers in Sahelian agro-ecosystems. ILRI Report, Niamey, Niger. 9 p.

ICRISAT, FAO. 1996. The world of sorghum and millet economies. Facts, trends and outlook. 68 p.

Lamers, J.P.A., and P.R. Feil. 1995. Farmers' knowledge and management of spatial soil and crop growth variability in Niger, west Africa. *Netherlands Journal of Agricultural Science.* 43: 375-389.

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

Mando, A, and T. van Rheenen. 1998. Termites and agricultural production in the Sahel: from enemy to friend? *Netherlands Journal of Agricultural Science.* 46:77-85.

Manu, A., A. Bationo, and S.C. Geiger. 1991. Fertility status of selected millet producing soils of West Africa with emphasis on phosphorus. *Soil Science Journal,* 152: 315-320.

Manu, A., T.L Thurow, A.S.R Juo., I. Zanguina, M Gandah, and I. Mahamane. 1994. Sustainable Land Management in the Sahel: a case study of an agricultural watershed at Hamdallaye, Niger. TropSoils/TAMU Bulletin No. 94-01.

Manu, A., A.A. Pfordresher, S.C. Geiger, L.P. Wilding, and L.R. Hossner. 1996. Soil parameters related to crop growth variability in Western Niger, West Africa. *Soil Science Society of America Journal* 60(1): 283-288.

McIntire, J., J. Hopkins, J. Lamers and L.K. Fussel. 1989. The millet system in western Niger. Internal report. ILCA, Addis Abeba, Ethiopia.

Osbar, H. 1997. Indigenous knowledge, fallow systems and indicator species: a case study of Fandou Béri, southwestern Niger. MSc Thesis, University College of London. UK. 81 p.

Powell, J.M., S. Fernadez-Rivera, P. Hiernaux and M.D. Turner. 1996. Nutrient cycling in integrated range land/crop land systems of the Sahel. *Agricultural Systems*, 52: 143-170.

Powell, J.M., and T.O. Williams. 1993. Livestock, nutrient cycling and sustainable agriculture in West African Sahel. IIED Gatekeeper Series 37. 15p.

Rocktröm, J., C. Valentin. 1997. 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. Agricultural Water Management. 33: 183-210.

Rockström, J. 1997. On-farm agrohydrology analysis of the Sahelian yield crisis: rainfall partitioning soil nutrients and water use efficiency of pearl millet. PhD. thesis. Department of Systems Ecology. Stockholm University, Sweden. 192 p.

Schlecht, E. 1995. The influence of different levels of supplementation on feed intake and nutrient retention of grazing zebu cattle in the Sahelian agro-pastoral systems. Phd thesis, University of Hohenheim, Germany. 200p.

Schlecht, E., F. Malher, M. Sangaré, A. Susenbeth, and K. Becker. 1995. Quantitative and qualitative estimation nutrient intake and fecal excretion of Zebu cattle grazing natural pasture in semi-arid Mali. pp 85-97. *In*: Powell JM, Fernandez-Rivera S., Williams TO and Renard C. (eds) Livestock and Sustainable Nutrient Cycling in Mixed Farming Sytems of sub-saharan Africa held in Addis Ababa 22-26 Nov 1993, ILCA, Addis Ababa, Ethiopia, 568p.

SEDES. 1987. Etude du secteur agricole du Niger. Bilan diagnostique. Phase 1. SEDES Paris.

Sissoko, K. 1998. Et demain l'agriculture. Options techniques et mesures politiques pour un développement agricole durable en Afrique subsaharienne. Cas du cercle de Koutiala en zone sud du Mali. Thesis dissertation. Wageningen Agricultural University, Wageningen The Netherlands. 184 p.

Sivakumar, M.V.K., A. Maidoukia, and R.D. Stem. 1993. Agrometeorology of West Africa : Niger. ICRISAT Information Bulletin No. 5. ICRISAT Patancheru, Andhra Pradesh 502324, India. 108 p.

Sivakumar, M.V.K. and J.L. Hatfield, 1990. Spatial variability of rainfall at an experimental station in Niger, West Africa. *Theoretical applied climatology* 42: 33-39.

Somda-Z.C., J.M. Powell, and A. Bationo. 1997. Soil pH and nitrogen changes following cattle and sheep urine deposition. Communications in *Soil Science and Plant Analysis* 28: 15-16, 1253-1268.

Stein, A, J. Brouwer, and J. Bouma. 1997. Methods of comparing spatial variability patterns of millet and soil data. *Soil Science Society of America Journal* 63: 861-870.

Stoorvogel, J. and E.M.A Smailing. 1994. Assessment of soil nutrient depletion in Sub-Saharan Africa: 1983-2000. Vol. 1. Main Report. The Winand Staring Centre, Wageningen. The Netherlands. 137 p.

Taylor-Powell, E., A. Manu, S.C. Geiger, M. Ouattara, and A.S.R. Juo. 1991. Integrated management of agricultural watersheds: Land tenure and indigenous knowledge of soil and crop management. TropSoils Bulletin 91-04 North Carolina State University, Raleigh. USA

Van Groenigen, J. W., M. Gandah and J. Bouma, 1998. Soil sampling strategies for precision agriculture research under Sahelian conditions. Submitted to Soil Science Society of America Journal.

Van Reeuwijk, L.P., 1993. Procedures for soil analysis. Technical Paper No. 9. ISRIC, Wageningen, 100 pp.

Van Uffelen C.G.R., J. Verhagen and J. Bouma. 1997. Comparison of simulated crop yield patterns for site specific management. *Agricultural Systems* 54: 207-222.

Verhagen, J. 1997. Spatial soil variability as a guiding principle in nitrogen management. Ph.D. thesis. Wageningen Agricultural University. 109 p.

Wendt, J.W. 1986. Pearl millet (*Pennisetum typhoides*) response to soil variability in sandy ustalfs near Niamey, Niger, West Africa. MSc thesis. Texas A&M University, Texas, 87 pp.

Wendt, J.W., A. Berrada, M.G. Gaoh and G.G. Schultze, 1993. Phosphorus sorption characteristics of productive and unproductive Niger soils. *Soil Science Society of America Journal* 57: 766-773.

West L.T., L.P. Wilding, J.K. Landeck, and F.G. Calhoun. 1984. Soil survey of ICRISAT Sahelian Center, Niger, West Africa. Soil and Crop Science Dept. / Tropsoils. Texas A&M University, Texas, 66 pp.

Wilding, L.P. and R. Daniels. 1989. Soil-geomorphic relationships in the vicinity of Niamey, Niger. Tropsoils Bulletin No. 89-01. North Carolina State University, NC 27695-7113.

Summary

The Sahel of West Africa is the agro-ecological zone located between 12° and 16°N, with an annual rainfall of between 300 and 1000 mm. Crops are grown in a subsistence type of agriculture during the 75 to 125 days growing period between May and September. Major crops are millet, sorghum, cowpea, and groundnut, sown usually in mixed-cropping. Crop production suffers from frequent droughts and poor soil fertility, which cause low yields and repeated food shortages. Traditional farming, in the western part of Niger, relies on the use of livestock to combat soil nutrient deficiencies, and other risk minimizing strategies, to produce an average 350 kg ha^{-1} $year^{-1}$of millet grain. This is the context within which this research was conducted in four localities in western Niger in 1995, 1996, and 1997. The overall aim was to investigate soil and crop variability at various scales and the rightness of traditional land management in millet cropping subject to extremely variable weather conditions. The main objectives were:

1) to test and refine the hill scoring technique for characterizing within field soil and crop yield variability in 3 localities of western Niger
2) to identify soil properties explaining yield variability in space and time
3) to evaluate the effects on millet yield of site specific management of manure and fallow in a Fulani farmer's field
4) to compare management systems used by farmers in four different landscape positions
5) to describe farmers methods of land evaluation and management options, based on farmers' expert knowledge of the environment

Within-field soil and crop variability are discussed in chapters 2 and 3. Grain and straw yields varied considerably within-field at each of the three sites, and also between sites and between years. In 1996, grain yields varied from 8-383 kg ha^{-1}, 2-1343 kg ha^{-1}, and 7-815 kg ha^{-1} at the three sites along a 400 km

N-S gradient. The coefficient of variation at the three sites was 61, 55, and 53% respectively. Only 5 to 28% of the yield variability could be explained by soil chemical properties. Other factors such as micro-topography and water redistribution also made yields vary over short distances according to several studies in the region. A millet hill scoring method was tested and refined to obtain yield estimates before crop harvest. Scoring studies have remained at the row or plot level as opposed to the individual hill level. The method was simple and was able to explain up to 67% of the yield variation. Yield variation between years was least at the drier northern site with poorer soil and yields. Variation in yields among years was most closely correlated with soil pH and Al in the northern and central sites, whereas P was the best in explaining grain yield differences in the southern site.

Chapter 4 deals with land management at the individual household level. Soil and crop management were investigated in two fields owned by a Fulani household. Management practices created man-made variability in the fields. Soil nutrient contents were improved in patches through the use of field corralling of livestock and fallow. Quantities of manure applied at specific sites varied from 1500 to 17000 kg ha^{-1}. Corralling increased yields from 500 to 1100 kg ha^{-1}, but amounts of manure applied were too high in some spots and losses were likely to occur through leaching. Nutrients and pH changes in the soil profile were found to change appreciably over time following the application of manure or of fallow. Based on the results obtained, an improvement in the farmer's management can be achieved by spreading manure to an area 3 to 5 times larger than the area actually used.

Chapter 5 focuses on farmers' land management practices according to landscape position. Contrary to common belief, soils on the plateau were richer than soils on other landscape positions, which were cropped continuously and had a sandier texture. Plateaus, however, showed limitations such as low infiltration of rainfall and were located relatively far away from villages. Fields on undulating terraces and valleys had the highest number of different management practices, among which the use of livestock corralling and fallow were the most important.

Chapter 6 considers social aspects of soil management, through the use of ethno-pedology by farmers in ordinary cropping activities. Farmers' knowledge of the land, plants and weather is described as well as the use of this knowledge by farmers in millet production. Simple soil descriptors such as texture, color, surface condition and indicator plants have been used by farmers to evaluate the land. Management practices rely on local knowledge regarding variability in soil fertility and water availability as a guide to implement crop management decisions and to design risk reducing strategies. These compensate in part for the lack of external inputs. The value of ethno-pedology for modern research is that it can serve to better identify farmers' needs and, as a result, improve research quality and the effective communication of results obtained. However, limitations in the use of ethno-pedology exist and they include its inability to quantify factors and the confusion between causes and effects for processes not well understood by farmers.

Samenvatting

De Sahel van West Afrika is de ecologische zone tussen 12º en 16º NB, met een jaarlijkse regenval varierend tussen 300 en 1000 mm. Gewassen worden verbouwd in zelfvoorzieningslandbouw met een groeiperiode van 75 tot 125 dagen tussen mei en september. De belangrijkste gewassen zijn parelgierst, sorghum, cowpea en aardnoot, meestal gezaaid in gemengde gewassystemen. De gewasproductie lijdt onder vaak voorkomende droogteperiodes en onvruchtbare bodems, die geringe oogsten en herhaaldelijke voedseltekorten veroorzaken. De traditionele landbouw in het westen van Niger drijft op het gebruik van vee, en op andere risico-beperkende strategiNen, om gebrek aan bodemvruchtbaarheid te bestrijden en gemiddeld 350 kg ha^{-1} jaar^{-1} te produceren. In deze context werd het huidige onderzoek uitgevoerd op vier plaatsen in west Niger, in 1995, 1996 en 1997. Het algemene doel was de variabiliteit van bodem en gewasgroei op verschillende schalen te onderzoeken, alsook de juistheid van het traditionele landgebruik in een parelgierst gewassysteem dat bloot staat aan extreem variabele weersomstandigheden. Daarbij ging het om:

1) het testen en verfijnen van een techniek om de gewasgroei per individueel plantgat te beoordelen, met als doel de karakterisering van de bodem- en gewasgroeivariabiliteit binnen velden op drie plaatsen in west Niger.
2) het identificeren van bodemeigenschappen die de ruimtelijke en tijdelijke variatie in gewasopbrengst kunnen verklaren
3) het evalueren van de effecten op parelgierstopbrengst van plaats-specifiek gebruik door een Fulani boer, binnen een veld, van mest en braaklegging
4) het vergelijken van de beheerssystemen van boeren op vier verschillende plaatsen in het landschap
5) het beschrijven van boerenmethoden van landevaluatie, en van beheerskeuzes gebaseerd op de gespecialiseerde kennis van de boer zelf

Variabiliteit in bodem- en gewasgroei binnen een veld worden in hoofdstukken 2 en 3 besproken. Graan- en stro-opbrengst varieerden aanzienlijk binnen de velden op ieder van de drie lokaties, alsook van lokatie tot lokatie en van jaar tot jaar. In 1996 varieerde de graanopbrengsten op de drie lokaties langs een N-Z gradient van 400 km lengte respectievelijk van 8-383 kg ha^{-1}, 2-1343 kg ha^{-1}, and 7-815 kg ha^{-1}. De coëfficienten van variatie op de drie lokaties waren respectievelijk 61, 55 en 53%. Slechts 5 tot 28% van de variatie in opbrengst kon verklaard worden uit bodemchemische eigenschappen. Andere factoren zoals micro-topografie en herverdeling van water zorgden ook voor variatie in de opbrengst over korte afstanden. Een techniek om de gewasgroei per individueel gierstplantgat te beoordelen werd beproefd en verfijnd, ten einde de opbrengst al voor de oogst te kunnen schatten. Eerdere studies die gebruik maakten van deze methode hadden zich beperkt tot het schaalniveau van een hele rij of een heel proefveldje, in plaats van individuele plantgaten. De methode was eenvoudig en kon tot 67% van de variatie in opbrengst verklaren. De variatie van jaar tot jaar in de opbrengst was het kleinst op de drogere noordelijke lokatie, met zijn arme gronden en lage opbrengsten. De variatie in opbrengst was over de jaren heen het best gecorreleerd met bodem pH en Al op de noordelijke en centrale lokaties, terwijl op de zuidelijke lokatie de graanopbrengst het best verklaard werd door het P-gehalte van de bodem.

Hoofdstuk 4 behandelt landbeheer op het niveau van een enkel huishouden. Bodem- en gewasbeheer werden onderzocht in twee velden van een Fulani huishouden. Door beheersmaatregelen werd anthropogene variabiliteit gecreeerd in de velden. Het nutriëntengehalte werd pleksgewijs verbeterd door het laten overnachten van vee op de velden, en door braaklegging. De hoeveelheden mest die toegediend werden op bepaalde plekken varieerden van 1500 tot 17000 kg ha^{-1}. Door het overnachten van het vee werd de opbrengst verhoogd van 500 tot 1100 kg ha^{-1}, maar de hoeveelheden toegevoegde mest waren op sommige plekken te groot en een gedeelte van de mest spoelde waarschijnlijk uit. Nutriëntengehaltes en pH van het bodemprofiel bleken in de loop der tijd aanzienlijk te veranderen na toedoening van mest of braaklegging. Op basis van de gemeten resultaten kan het beheer verbeterd worden door de mest uit te spreiden over een 3 tot 5 keer groter gebied dan dat wat werkelijk gebruikt werd.

Hoofdstuk 5 richt zich op boerenbeheersmaatregelen in verhouding tot de positie in het landschap. In tegenstelling tot de gangbare overtuiging waren de bodems op het plateau vruchtbaarder dan bodems op andere posities in het landschap, waar doorlopend gewassen verbouwd worden en de bodems zandiger zijn. De plateaus hadden echter ook hun beperkingen, zoals geringe infiltratie van de regenval. Bovendien lagen ze relatief ver van de dorpen. Velden op golvende terrassen en in valleien vertoonden het hoogste aantal verschillende beheersmaatregelen, waarbij het laten overnachten van vee op de velden en braaklegging het belangrijkst waren.

In hoofdstuk 6 worden de sociale aspecten van bodembeheer beschouwd, via het gebruik van bodemkundige volkskennis ('ethno-pedologie') door boeren tijdens hun dagelijkse activiteiten. Boerenkennis van land, planten en weer wordt beschreven, alsmede het gebruik van deze kennis door boeren bij hun normale teeltactiviteiten. Eenvoudige bodemeigenschappen zoals textuur, kleur, opppervlakte-eigenschappen en indicator plantensoorten worden door boeren gebruikt voor landevaluatie. Beheersmaatregelen hangen af van plaatselijke kennis van variabiliteit in bodemvruchtbaarheid en waterbeschikbaarheid, als leidraad bij het nemen van beslissingen ten aanzien van de teelt en van het uitstippelen van risico-beperkende strategieen. De laatste compenseren ten dele het gebrek aan toevoegingen van buitenaf. De waarde van ethno-pedologie voor modern onderzoek ligt in de betere identificatie van de behoeften van boeren, en als resultaat daarvan in verbetering van de onderzoekskwaliteit en van het overdragen van de resultaten van dat onderzoek. Het gebruik van ethno-pedologie heeft echter ook zijn beperkingen, waaronder het gebrek aan quantificering en de verwarring over oorzaken en effecten van processen die boeren niet goed begrijpen.

Résumé

Le Sahel d'Afrique de l'ouest est la zone agro-écologique situé entre 12° et 16°N avec une pluviométrie annuelle de 300 à 1000 mm. Une agriculture de subsistance y est pratiquée pendant les 75 à 125 jours de culture entre les mois de Mai et Septembre. Les principales cultures sont le mil, le sorgho, le niébé, et l' arachide plantées généralement en association. La production des cultures souffre de sécheresses périodiques et de la pauvreté des sols entrainant des rendements très bas et des déficits alimentaires. L'agriculture traditionelle, dans l'Ouest du Niger, est basée sur l'utilisation du bétail pour combattre les déficits en éléments nutritifs dans le sol, et sur d'autres stratégies de minimisation des risques, pour produire en moyenne 350 kg ha^{-1} an^{-1} de mil. C'est dans ce context que cette recherche a été menée dans quatre localités de l'Ouest du Niger, en 1995, 1996, et 1997. L'objectif global était d'investiguer la gestion traditionelle des terres dans un systeme à base mil dans des conditions de sol et de climat très variables. Les principaux objectifs étaient:

1) d'utiliser une technique de notation pour caractériser la variabilité intra-parcelle du sol et du rendement du mil au niveau du champs dans trois localités du Niger
2) d'identifier des propriétés du sol explicant cette variabilité dans l'espace et dans le temps
3) de comparer les effects d'une gestion localisée du fumier et de la jachère sur le rendement du mil dans un champ de paysan Peulh
4) de comparer les systèmes de gestion utilisés par les paysans sur quatre unités du paysage
5) de décrire les méthodes paysannes d'évaluation et les options de gestion des terres, basées sur les connaissances paysannes du milieu.

La variabilité intra-champs du sol et des cultures est discutée dans les chapitres 2 et 3. Les rendements grain et paille on variés fortement à l'intérieur des parcelles au niveau de chacun des 3 sites, mais aussi entre les années. En

1996, les rendements en grain ont varié de 8-383 kg ha^{-1}, 2-1343 kg ha^{-1}, et 7-815 kg ha^{-1} au niveau des 3 sites se trouvant sur un gradient N-S de 400 km. Le coefficient de variation du rendement au niveau de chacun des sites était de 61, 55, et 53%. Seulement 5 à 28% de la variabilité du rendement pouvait être expliquée par les propriétés chimiques du sol, indiquant que d'autres facteurs tels que la micro-topographie et la redistribution de l'eau interviennent aussi comme lindiquent plusieurs études faites dans la région. Une méthode de notation des poquets de mil avait été testée pour estimer le rendement avant la récolte. La méthode était simple et pouvait expliquer jusqu'à 67% de la variation du rendement. La variabilité du rendement entre les années était moindre au niveau du site Nord peu pluvieux et ayant des sols plus pauvres que les deux autres sites. La variation des rendement entre années était plus correlée avec le pH et Al au niveau des sites Nord et central, alors que P était l'élément le mieux correlé avec le rendement grain pour le site du Sud.

Le chapitre 4 examine la gestion des terres au niveau d'une famille. La gestion des terres et des cultures a été étudiée dans deux champs cultivés par une famille de paysans Peulhs. Leurs méthodes de gestion ont crée une variabilité induite par l'homme dans les champs. Les teneurs en éléments nutritifs du sol ont été améliorées gr>ce à l'utilisation du parcage et la pratique de la jachère. Les quantités de fumier appliquées varient entre 1500 et 17000 kg ha^{-1}. Le parcage a efficacement augmenté le rendement grains du mil de 500 à 1100 kg ha^{-1} , mais les quantités de fumier apportées étaient trop élevées à certains endroits et des pertes pourraient arriver par lessivage. Les changements observés ont variés de manière appréciable suite à l'apport de fumier ou de la jachère.

Le chapitre 5 développe les pratiques paysannes en matière de gestion des terres selon la position geomorphologique. Contrairement à ce qu'on pouvait penser, les sols sur le plateau étaient plus riches que les sols situés sur les autres positions du paysage, qui eux, étaient cultivés en permanance et étaient

de texture plus sableuse. Cependant, le plateau présente des limitations tels qu'une infiltration faible des eaux de pluie, et se trouvent relativement éloignés des villages. Les champs situés sur le replat et dans les vallées présentent le plus grand nombre de pratiques différentes de gestion, parmi lesquelles les plus importantes étaient l'utilisation du parcage et de la jachère.

Le chapitre 6 décrit les aspects sociaux de la gestion des terres à travers l'utilisation de l'ethno-pédologie dans leurs pratiques agricoles. Les connaissances paysannes de la terre, des plantes et du climat ont été décrites et ont été liées à la production du mil. Des descripteurs simples tels que la texture, la couleur et les conditions de surface du sol, de mΛme que les plantes indicatrices étaient utilisés par les paysans pour évaluer la terre. Les pratiques de gestion se basent sur l'utilisation de propriétés spécifiques du terrain (sites d'arbustes par exemple), et sur des stratégies tendant à limiter les risques, pour compenser le manque de d'intrants externes. L'importance de l'ethno-pédologie pour la recherche moderne se trouve dans le fait qu'elle peut etre utilisée pour mieux identifier les besoins des paysans, et par conséquent, améliorer la qualité de la recherche et assurer un transfer effectif des résultats obtenus. Cependant, des limitations existent quand à l'utilisation de l'ethno-pédologie, qui sont entre autre son manque de quantification de certains facteurs et la confusion qui est faite entre les causes et les effets quand les processus impliqués ne sont pas bien connus.

Curriculum Vitae

Mohamadou Gandah was born in Yéni (Niger) on August 31st 1952. He completed secondary school in 1971 at the Lycée National de Niamey. From 1971 to 1974, he studied biology at the Université de Dakar (Sénégal). From 1976 to 1978, he attended Western Illinois University (USA), where he obtained a BSc degree in agronomy. From 1978 to 1985, he worked for the Institut National de Recherches Agronomiques du Niger (INRAN) in charge of the soil physics and water use section. From 1986, he attended Texas A&M University, College Station (USA) where he obtained an MSc degree in soil science in 1988. From 1988 to 1995, he held scientific and administrative positions at INRAN as head of soil physics and water use section, head of irrigation section, and head of the department of ecological research. From 1995 to 1999, he was granted a PhD sandwich scholarship by Wageningen Agricultural University. He is married and father of 2 girls and 2 boys.

ANNEXE

Description of soil profiles in the four landscape units around Tchigo Tagui

Profile location: field 16 (Boubé Seydou)
Soil classification CPS/ORSTOM : sol ferrugineux peu lessivé
Site name : Tchero
Date of description : 16/05/98
Geomorphology : Sand dune (Plateau)
Substratum : sand
Slope : 1%
Relief : slightly undulated
Soil moisture : moist from the surface
Vegetation : millet field, few combretum bushes

Morphologic description of the profile :

0-23 cm : dark brown (7.5YR5/6) when moist; loamy sand; massive structure; friable when moist; very fine and fine pores; many fine and very fine roots; distinct transition

23-38 cm: dark brown (7.5 YR4/6) when moist; sandy loam; massive structure; friable when moist; few very fine and fine pores; numerous fine and very fine roots; gradual transition

38-57 cm: reddish yellow (5YR6/8) when moist; sandy loam; massive structure; friable consistence when moist; few fine and very fine pores; numerous very fine roots; gradual transition

57-83 cm: red (2.5 YR5/8) when moist; sandy loam; massive structure; friable consistence when moist; few fine and very fine pores; few very fine roots; diffuse transition.

83-105 cm: red (2.5 YR4/8) when moist; sandy loam to loamy sand; massive structure; friable consistence when moist; few fine and very fine pores; very rare roots; diffuse transition.

105-153 cm: light red (2.5 YR 6/8) when moist; loamy sand; massive structure; friable consistence when moist; few very fine pores to non apparent porosity; some very fine roots.

Remarks: some pieces of charcoal in the 4th horizon.

Depth (cm)	pHw	pHkcl	P_{Bray1} mg kg^{-1}	C %	N	Na	K	Ca méq/100 g	Mg	CEC
0-23	5.4	4.6	2.22	0.26		0.01	0.01	0.65	0.11	0.8
23-38	5.02	4.42	1.39	0.15		0.01	0.06	0.55	0.24	1.1
38-57	5.11	4.5	0.9	0.09		0.01	0.03	0.6	0.11	0.7
57-83	5.25	4.75	0	0.09		0.01	0.08	0.1	0.06	1.5
83-105	5.46	4.68	0.45	0.38		0.02	0.05	0.2	0.1	1.05
105-153	5.27	4.55	0			0.02	0.02	0.35	0.21	1.1

Profile location: Field 15 (Seydou Moussa)
Soil classification CPS/ORSTOM : sol ferrugineux lessivé
Site name : Tchero
Geomorphology : plateau
Slope : 1%
Soil moisture : moist from the second Horizon
Date of description : 16/05/98
Substratum : sand
Relief : nearly flat
Vegetation : millet field, Eragrostis tremula, in patches, Adropogon gayanus, Calotropis procera, Guiera senegalensis Mitracarpus villosus.

Morphologic description of the profile :

0-20 cm : dark brown (7.5YR5/6) dry and (7.5YR 4/6) when moist; loamy sand; massive structure; tender consistence when dry; few very fine pores; many fine and very fine roots; distinct transition.

20-34 cm: yellowish red (5 YR 5/6) when moist; sandy loam; massive structure; friable when moist; few very fine and fine pores; many fine and very fine roots; gradual transition.

38-50 cm: yellowish red (5YR 4/6) when moist; sandy loam; massive structure; friable consistence when moist; numerous fine and very fine pores; few very fine roots; gradual transition.

50-66 cm: red (2.5 YR 5/6) when moist; sandy to loamy sand; massive structure; friable consistence when moist; numerous fine and very fine pores; few very fine roots; diffuse transition.

66-91cm: red (2.5 YR 5/8) when moist; sand to loamy sand; massive non well developed structure; friable consistence when moist; few very fine pores; few very fine roots; diffuse transition.

91-137 cm: light red (2.5 YR 6/8) when moist; sand to loamy sand; massive structure; friable consistence when moist; few very fine pores; rare very fine roots.
Remarks:

Depth (cm)	pHw	pHkcl	P_{Bray1} mg kg^{-1}	C %	N	Na	K	Ca méq/100 g	Mg	CEC
0-20	6.2	5.63	2.86	0.09		0.01	0.11	2.05	0.53	0.55
20-34	5.6	4.71	1.63	0.09		0.01	0.1	0.15	0.11	2.3
34-50	5.45	4.56	1.39	0.15		0.01	0.07	1.1	0.15	3.9
50-66	5.23	4.39	1.14	0.15		0.01	0.04	0.95	0.16	1.1
66-91	5.33	4.58	1.04	0.15		0.01	0.02	0.9	0.08	2.1
91-137	5.42	4.29	1.39	0.09		0.01	0.13	1	0.15	0.85

Profile location: Field 13 (Boubacar Saley)
Soil classification CPS/ORSTOM : sol ferrugineux peu lessivé
Site name : Bagoua
Date of description : 14/05/98
Geomorphology : inter dunes depression (Valley)
Substratum : sand
Slope : 2%
Relief : undulated
Soil moisture status: *dry in all the profile*
Vegetation : *millet field,* Eragrostis tremula, Guiera senegalensis

Morphologic description of the profile :

0-20 cm : yellowish brown (10YR5/8) dry and yellowish brown to dark yellow brown (10YR 4/8) when moist; sand; massive non well developed structure; tender consistence when dry; few very fine pores; few very fine roots; distinct transition.

20-33 cm: brownish yellow (10 YR 6/6) when moist and yellowish brown (10YR 5/6) when moist; loamy sand; massive non well developed structure; tender consistence when dry; numerous very fine and fine pores; few fine and very fine roots; gradual transition.

33-55 cm: dark brown (7.5YR 5/8) when dry and same color when moist; loamy sand; massive non well developed structure; friable consistence when dry; numerous fine, very fine, and medium size pores and some large pores; few very fine roots; diffuse transition.

55-77 cm: reddish yellow (7.5 YR 6/8) when dry and same color when moist; loamy sand; massive non developed structure; friable consistence when dry; numerous very fine, fine and medium size pores; few very fine roots; diffuse transition.

77-99 cm: reddish yellow (7.5 YR 7/8) when dry and same color when moist (7.5YR6/8); sand to loamy sand; massive non well developed structure; tender consistence when dry; few very fine pores; rare very fine roots; diffuse transition.

99-116 cm: reddish yellow (7.5 YR 7/6) when dry and same color when moist (7.5YR7/6); sand; massive non developed structure; tender consistence when dry; few very fine pores; some very fine roots.

116-157 cm: yellow (10YR8/6) when dry and same color when moist (10YR7/8); sand; massive non developed structure; tender consistence when dry; few very fine pores; some very fine roots.

Remarks: *some biological activity holes in the 2nd, 3rd, 4th, and slightly in the 5th* horizon.

Depth (cm)	pHw	pHkcl	P_{Bray1} mg kg^{-1}	C %	N	Na	K	Ca méq/100 g	Mg	CEC
0-20	5.75	4.86	2.37	0.2		0.02	0.14	0.55	0.16	0.75
20-33	5.38	4.54	1.34	0.2		0.02	0.07	0.7	0.19	0.85
33-55	5.22	4.67	0.99	0.09		0.01	0.05	0.95	0.17	0.95
55-77	5.35	4.77	0.6	0.09		0.02	0.05	0.65	0.14	0.85
77-99	5.37	4.82	0.94	0.09		0.01	0.06	0.85	0.13	0.7
99-116	5.32	4.49	0.94	0.09		0.01	0.04	0.4	0.11	0.55
116-157	5.54	4.63	0.9	0.03		0.01	0.02	1.25	0.13	0.9

Profile location: Field 12 (Habibou Djibo)
Soil classification CPS/ORSTOM : sol ferrugineux lessivé gravillonnaire
Site name : Boundouwarou **Date of description** : 15/05/98
Geomorphology : sand covered glacis (Plateau) **Substratum** : continuous laterite cap
Slope : 0.5% **Relief** : flat
Soil moisture status: moist starting from 2nd horizon **Vegetation** : Guiera senegalensis, Combretum micranthum, Maerua crassifolia

Morphologic description of the profile :

0-13 cm: brown (7.5YR5/4) when dry and brown to dark brown (7.5YR 4/4) when moist; sandy loam; compact non well developed structure; tender consistence when dry; numerous fine and very fine pores; many very fine roots; distinct transition.

13-25 cm: brown to dark brown (7.5 YR 4/4) when moist; sandy loam; compact non well developed structure; friable consistence when moist; numerous very fine and fine pores; few very fine roots; gradual transition.

25-44 cm: yellowish red (5YR 5/6) when moist; sandy loam; massive and compact non well developed structure; friable consistence when moist; numerous fine, very fine, and medium size pores; few very fine roots; distinct transition.

44-71 cm: yellowish red (5YR 5/8) when moist; sandy loam with 80% of coarse materials; non apparent porosity; few very fine, and medium size roots.

71 cm: continuous laterite pan

Depth (cm)	pHw	pHkcl	P_{Bray1} mg kg^{-1}	C %	N	Na	K	Ca méq/100 g	Mg	CEC
0-13	5.16	4.19	8.55	0.09		0.02	0.13	2.45	0.49	2.1
13-25	5.09	4.33	1.97	0.2		0.01	0.05	0.3	0.09	2
25-44	5.04	4.22	1.39	0.15		0.01	0.05	0.45	0.12	2.25

Profile location: Field 19 (Oumarou Boubé)
Soil classification CPS/ORSTOM : *sol ferrugineux peu lessivé*
Site name: Guecemaka **Date of description** : 15/05/98
Geomorphology: sand dune summit (Terrace) **Substratum** : sand
Slope: 1-2% **Relief**: slightly undulated
Soil moisture : moist from the surface (rain of April 30th 1998) **Vegetation**: planted millet field

Morphologic description of the profile :

0-18 cm: brown to dark brown (7.5YR4/4) when moist; sand; massive non well developed structure; friable consistence when moist; numerous very fine pores; many fine and very fine roots; distinct transition.

18-30 cm: dark brown (7.5 YR 5/6) when moist; loamy sand; massive non well developed structure; friable consistence when moist; few very fine pores; numerous fine and very fine roots; gradual transition.

30-47 cm: yellowish red (5YR 4/6) when moist; loamy sand; massive non well developed structure; friable consistence when moist; few very fine pores; numerous fine and very fine roots; diffuse transition.

47-72 cm: red (2.5 YR 4/8) when moist; sand; massive non developed structure; friable consistence when moist; few very fine pores; numerous very fine roots; diffuse transition.

72-99 cm: red (2.5 YR 5/8) when moist; sand; massive non well developed structure; friable consistence when moist; few very fine pores; some very fine roots; diffuse transition.

99-150 cm: reddish yellow (5 YR 6/8) when moist; sand; massive non developed structure; friable consistence when moist; rare very fine pores with non apparent porosity; some very fine roots.

Remarks: some clay pots debris and charcoal elements in the 3rd horizon

Depth (cm)	pHw	pHkcl	P_{Bray1} mg kg^{-1}	C %	N	Na	K	Ca méq/100 g	Mg	CEC
0-18	6.06	5.25	3.35	0.2		0.01	0.11	1.4	0.26	0.65
18-30	5.71	4.84	1.44	0.15		0.01	0.06	0.4	0.13	0.8
30-47	5.66	4.73	1.48	0.15		0.02	0.11			1.05
47-72	5.05	4.31	1.19	0.2		0.02	0.1			0.95
72-99	5.39	4.53	1.19	0.09		0.02	0.03			0.75
99-150	5.44	4.62	0.85	0.09		0.02	0.03			0.75