Netherlands Journal of Agricultural Science 43 (1995) 375-389

Farmers' knowledge and management of spatial soil and crop growth variability in Niger, West Africa

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Received 16 June 1995; accepted 5 November 1995

Abstract

Managing soil micro-variability and subsequent crop growth in the West African Sahel is a major challenge to farmers and researchers. A household survey, combined with an extensive literature search of baseline studies, complemented on-station research on spatial soil and crop growth variability with a farmer's viewpoint. Farmers explained spatial variability in crop growth in terms of differences in soil types, soil fertility and degradation, as well as their cultivation and management practices. Farmers counteract spatial crop growth variability by within-field fallow; kraaling; spot applications of manure, crop residues and household waste; by intentionally moving their settlements; and by exploiting the micro-environmental differences around specific tree and shrub species. However, these strategies also enforce the spatial crop growth variability. The accuracy of farmers' comprehensive knowledge of agriculture, soil, animal husbandry and agro-forestry was confirmed by compartmentalized on-farm and on-station studies conducted in the same region, although explanations of farmers and researchers were not always the same. Farmers are aware of soil fertility management technologies, either coming from outside or developed within the farming community, but are often unable to translate these into action on a large scale. This is due to insufficient resources and socio-economic as well as institutional constraints such as cattle ownership, land tenure, labour requirements and prices of inputs. Implications for agricultural research and technology generation are discussed.

Keywords: indigenous knowledge, local fertility management, West Africa, millet, *Pennisetum glaucum* (L.) R. Br., crop growth variability

Introduction

One of the striking observations about cropping pearl millet (*Pennisetum glaucum* (L.) R. Br.) on the sandy soils in the Sahel is the spatial variability in crop growth. This is characterised by patches of good and poor millet growth in close proximity (Brouwer *et al.*, 1993). The phenomenon of spatial variability has also come to the attention of researchers in Niger (e.g. Brouwer *et al.*, 1993; Herrmann *et al.*, 1994). Most studies describe the spatial soil and crop growth variability in terms of physical and chemical soil properties (Manu *et al.*, 1990; Geiger *et al.*, 1992). One cause for the crop growth variability is the soil micro-variability which Brouwer *et al.* (1993) defined as: '... variability over relatively short distances (approximately 2–50 m), with differences in soil properties which do affect hydrological behaviour and plant growth...' Spatial variability in research experiments leads to high coefficients of variation during statistical analyses which makes the interpretation of results difficult (Buerkert, 1995; Chase *et al.*, 1989). Also, results from on-station research suggest that the effects of soil micro-variability on millet growth in agricultural experiments can be counteracted by the adaptation of plot size, fertilizer application and by *ex post* blocking (Buerkert, 1995).

Much remains unknown about the actual causes of spatial variability within farmers' fields, and about the best way to deal with it or if one should counteract it. Particularly in the vicinities of trees such as *Faidherbia albida* Del., Syn. *Acacia albida* Del., it can be advantageous to exploit soil and environmental differences (Geiger *et al.*, 1992; Williams, 1992). Brouwer *et al.* (1993) suggested that spatial variability stabilises yields and reduces production risks for subsistence farmers under conditions characterised by poor, erratic rainfall and inherently low soil fertility. Farmers' techniques to counteract spatial variability, such as the use of fallow and manure, are limited by rapid population growth, increasing livestock numbers and reductions in grazing land (McIntire *et al.*, 1992).

Farmers' current strategies coping with spatial variability are undocumented for Niger. This case study complements on-going technical oriented on-station and on-farm research on spatial crop growth and soil micro-variability by determining the viewpoint of farmers. The main objective was to learn about farmers' knowledge, their perceptions and strategies for managing crop growth and soil micro-variability, and to estimate the potential of their strategies for sustaining soil fertility and millet production. The study combined a field survey with a literature search of baseline studies carried out in the region.

Survey methodology

A survey, based on the Rapid Rural Appraisal concept (Carruther & Chambers, 1981) was conducted from June through October 1992 with 29 farmers in two villages. In the village of Djiakindi, 60 km southeast of Niger's capital, Niamey, 20 farmers who had participated in another study (Baidu-Forson *et al.*, 1994) were surveyed. To complement an on-farm experiment on soil micro-variability, nine farmers were selected in the village of Sadoré, 45 km southeast of Niamey. Djiakindi is located in the most populated district of Tillabéri State, Kollo. In 1988, a census estimated a total of 1,227 people in 138 households (Anonymous, 1991). Sadoré, in Say District of Tillabéri State, had a population of 680 people in 90 households in 1988. Rainfall in the region is restricted from May to September with an annual long-term average of 550 mm.

The study was carried out in two phases. First, a pre-survey was conducted to become familiar with farmers' responses. The actual field survey, which used an open guideline interview, followed farmers' reasoning to understand their perceptions and relate these to their explanations and ideas. The main topics of these in-depth interviews, which were conducted on the field, were farmers' perception of soil and crop growth differences, reasons for those differences and what, why, and when farmers do something about it. The use of millet crop residues as a means for increasing crop productivity was mentioned by farmers and has been examined by researchers. Therefore, the ways households use crop residues were assessed. Interviews were conducted in Djerma/French with the help of an experienced translator. Published literature is used to discuss farmers' responses.

Results and discussion

Description of farming systems

The mixed-farming systems (crop production and pastoral activities) are based on family labour and low cash budgets which are largely depleted by hiring labour. The subsistence-oriented rainfed agriculture is dominated by millet and to a lesser extent by sorghum (*Sorghum bicolor* L.), both of which are usually associated with cowpea (*Vigna unguiculata* (L.) Walp.). Cash income is earned through off-farm activities. The most dominant activities being crafts, trade and seasonal migration (Table 1),

Table 1. Characteristics of household heads and farming systems in Djiakindi and Sadoré, 1992.

Characteristic	Percentage
Ethnic group	
– Fulani	69
– Djerma/Songhaï	17
– Others	14
Origin of household head	
– survey villages	55
– immigrated	45
Principal residence outside village during the rainy season	48
Land tenure	
– Field ownership	15
– Borrowed without payment	85
Agricultural activities	
– Number of farmers cultivating less than three fields[1]	88
– Use of fallow entire fields	7
within–field fallow	58
– Use of hired labour for cropping	55
– Livestock ownership	72
Off-Farm activities	
– Involvement in off-farm activities[2]	65
– Temporary migration of household head in the past	41
presently	7

[1] Households possess several fields.

[2] Fisherman, tailor, merchant and vendor, livestock merchant, emigrant to coast, traditional healer, village chief, pensioner, rental bulky chart, part-time labourer (at ICRISAT or temporary road construction).

particularly to coastal countries such as Ghana (17%), Benin (11%) and Nigeria (7%). All cropping activities are done manually. Most household heads exploited a maximum of three fields and 72% owned sheep, goats and cattle (Table 1). Animal traction is limited to its use for bulky carts. Hay from pulses and grasses enrich the millet stover diet of livestock in the dry season. Of the household heads surveyed, about 85% belonged to the Fulani and Djerma/Songhaï ethnic groups (Table 1) and about half were born in the surveyed villages. Others, mainly Fulani nomads, settled after droughts in the seventies decimated their herds.

Farmers' knowledge on spatial crop growth variability

Farmers gave several reasons to explain the spatial variability in their fields (Table 2). Besides differences in soil types and inherent fertility, farmers related millet growth variability to soil degradation and their own cultivation and management practices.

Native patchiness. Although a most important soil feature to all farmers was a surface layer of sand, farmers mentioned three soil types which they differentiated by colour and texture: the *labu cheri*, *labu bi* and the *labu kwarey* (*labu* means 'soil' or 'sand', *cheri* means 'red', *bi* means 'black' and *kwarey* means 'white' in the local Djerma language). Farmers relate the soil colour particularly to the presence of organic material. The most well-known and widespread soil type is the *labu cheri*. About 40% of those surveyed considered this reddish, sandy soil without much organic material to have moderate fertility. Despite the general classification of soils as a *labu cheri*, almost 30% of the farmers mentioned that some *labu cheri* soils give higher yields, demand a more intensive cultivation with the traditional long-handled hoe, and are more fertile than other *labu cheri* soils. Based on remarks of farmers, West *et al.* (1984), who classified a *labu cheri* as a *psammentic Paleustalf* sandy, siliceous, isohyperthermic according to the U.S. soil taxonomic system, collected samples from four different *labu cheri* soils and confirmed farmers' observations of inherent variations within this soil type. Due to the gradations in fertility, farmers cultivate these micro-environments differently by using other plant densities, crops or intercropping combinations whenever possible, which was also reported by Taylor-Powell (1991). Geiger & Manu (1993) concluded that the management of microsites with different production potentials within a field can be adapted to their specific conditions as these sites react differently to inputs such as fertilizers. The *labu bi* and the *labu kwarey* were known to farmers from other regions. The black *labu bi* contains more organic material and was evaluated by about 40% of the farmers to be more fertile than the *labu cheri*. The *labu kwarey*, the soil with the lowest amount of organic material, was thought to be very infertile. Because the knowledge of both soil types did not come from their own experience, farmers responses are not reported here. Since farmers' knowledge on soil types is based mainly on experience and observations, the analytical methods used by research could complement this knowledge and help farmers exploit the 'good' and 'bad' producing spots better.

Table 2. Perception, explanation and management of crop growth variability according to farmers.

Perception	Explanation	Confirmed by studies and experiments
Patchiness	Differences in soil types: *labu chirey*, *labu bi* and *labu kwarey*	West *et al.*, 1984
Topographical features of soil surface: micro-highs (high productivity) and micro-lows (low productivity)	Different susceptibility to wind erosion and vegetation density result in differences in surface sand layers	Geiger & Manu, 1993
Distance to certain trees:		
Annona senegalensis, *Guiera senegalensis*	Certain bushes stimulate millet growth	Geiger & Manu, 1993
Balanites aegyptiaca, *Sclerocarya birrea*	Certain bushes depress millet growth	Not available
Distance to *Faidherbia albida*	Stimulating effect on millet growth underneath this species	Sall, 1992; Vandenbeldt & Williams, 1992
Farmers' management practices: timely sowing and weeding	Delay in execution of agricultural activities depending on rainfall and labour capacity reduce millet growth	Sivakumar, 1992 (sowing); McIntire *et al.*, 1989 (weeding)
Management techniques	Explanation	Confirmed by studies and experiments
1. fallow	Due to land and population pressure only within-field fallow	Taylor-Powell, 1991
2. localised fertilising strategies:		
– manure (direct, kraaling)	– Transfer of fertility by livestock; different manure quality depending on feed quality	– McIntire *et al.*, 1992; Powell & Ikpe, 1992; Powell & Williams, 1993
– millet crop residues and use of organic material	– Applications on spots with low productivity give high marginal net returns; many alternative uses with high opportunity costs	– Buerkert, 1995; Gavian 1992; Lamers *et al.*, 1995
– deliberately moving compounds	– High concentration of organic material	– Buerkert, 1995
3. mineral fertilizer	Sparsely used since too expensive. When used then on spots with high organic matter	Buerkert, 1995

Topographical features of the soil surface. Almost 70% of the interviewed farmers also allocated crop growth differences to micro-topographical features in their fields. The micro-highs (or *fandu* in Djerma) are the fertile parts with a thick sand layer surface, whereas 55% consider the micro-lows (*gorou*) to be less fertile due to a thinner sand layer surface. Typically, *fandus* have a more dense natural and planted vegetation than *gorous*. Farmers explained that barriers, such as natural vegetation but also dead twigs, branches, tree stumps and crop residues, capture wind-blown soil components. Through termites or hoeing, the organic material is mixed with the top soil layer. This augments the soil fertility of the *fandus* and enhances the vegetation growth.

Geiger & Manu (1993), who studied millet yields and soil characteristics in transects in farmers' fields, showed the relationship between soil fertility and micro-elevations. Millet grain yields on sites with micro-highs were 120% higher than on sites without micro-highs. Brouwer *et al.* (1993) confirmed farmers' observations of relatively high and fertile areas and relatively low and leached spots within the same field. In an on-station experiment they found that two months before the onset of the rainy season the residual soil water level of micro-highs was 17% lower than that of micro-lows. The authors concluded that aside from differences in fertility, the different soil water level influences millet growth and yields, particularly on a sandy soil in a year with poorly distributed rainfall. Moreover, the uneven and unequal distribution of water and nutrient resources within a field is beneficial to farmers and helps reduce yield fluctuations (Brouwer *et al.*, 1993). In the present survey farmers did not mention hydrological aspects of micro-highs and micro-lows, but stressed the fertility aspects and the different susceptibility of the micro-elevations to erosion.

Field topography and soil degradation. According to 48% of the farmers, field topography and decreasing soil fertility are two interacting factors leading to patches with poor and good millet growth. A low soil fertility or inadequate rainfall decreases the stover production. This leads to a reduced surface cover making the top soil, particularly in *gorous*, more susceptible to wind erosion. A vicious circle starts when the erosion process continues, soil fertility decreases and yield reductions render the soil more susceptible to wind erosion. If the erosion process is not restrained, the *gorous* will eventually be covered by a thin surface crust which impedes water infiltration. This spot is called *gangani*. When the erosion process continues further, the *gangani* expands in size and farmers call it a *tanka*.

The farmers' observation that loose sand is blown from micro-lows to micro-highs within the same field was also confirmed by research (Taylor-Powell, 1991). A detailed survey classified the micro-lows as eroded surfaces caused by sheet erosion and a *gangani* as an exposed B_t horizon after the removal of the A horizon (Taylor-Powell, 1991). Hoogmoed & Stroosnijder (1984) affirmed that the Sahelian sandy soils are very sensitive to crust formation and that crusting impairs water infiltration. The special terms in the Djerma language indicating the different stages of eroded surfaces illustrate that farmers are familiar with wind erosion and its effects. Although farmers stated that wind erosion mainly occurs during the 'Harmattan' season, Michels (1994) found that wind erosion during this entire 3-month period did not exceed the erosion that took place during one storm event in the rainy season.

Trees and bushes. According to 45% of those interviewed, certain trees and bushes also caused crop growth variability. Farmers pointed out millet plants, in close proximity to trimmed bushes such as *Guiera senegalensis* J.F. Gmel and *Annona senegalensis* Pers., which were darker green and taller than the millet in the surrounding area. In contrast, species such as *Balanites aegyptiaca* (L.) Del. and *Sclerocarya birrea* (A. Rich.) Hochst. depress millet growth. Apart from these smaller trees and bushes, 55% of the farmers emphasised the growth enhancing features of *F. albida*, and they ascribed this improvement to the presence of manure. Since shade suppresses millet growth and because *F. albida* loses its leaves during the rainy season, the reduced shading during the growing period was judged to be advantageous. Farmers maintained, weeded and protected useful tree species, especially on remote bush fields located at further distances from settlements or villages. Yet, none of the surveyed farmers had ever planted trees.

Geiger & Manu (1993) showed that the better producing micro-highs in farmers' fields were associated particularly with the presence of *G. senegalenis*, *Combretum glutinosum* Perr. ex DC. or *Piliostigma reticulatum* (DC.) Hochst. Research results confirmed yield increases underneath *F. albida*, but explanations were different than those of farmers. According to farmers, animals attracted by the palatable pods and leaves deposit manure underneath *F. albida* trees while grazing, resting and seeking shade during the hot dry season. Research showed that millet grain yields with *F. albida* windbreaks increased in average by 17%, but this increase could not be attributed to manure as it was excluded from these experiments (Michels, 1994). Sall (1992) reviewed several *F. albida* studies and concluded that underneath this species total soil carbon and nitrogen content was increased by 40–100%, and biological activity increased two to five-times. He also concluded that the litter drop combined with the biological activity increased the soil fertility, although the nitrogen content in *F. albida* leaves were not higher than those of other local species in Niger (Lamers *et al.*, 1994). The assumption that the soil fertility increase was caused by a higher capacity of *F. albida* to fix nitrogen than other trees, was not always confirmed. Schulze *et al.* (1991), for example, found that *F. albida* had the lowest nitrogen fixation among 22 Mimosaceae. Vandenbeldt & Williams (1992) added that soil temperatures underneath *F. albida* were closer to the optimum for millet growth and development than in their surroundings. This allowed plants underneath to exploit the higher fertility related to this species. The results of research so far are not consistent enough to support or develop a definite explanation of the better millet growth underneath *F. albida*.

Spacing of cultivation and management practices. Farmers' cultivation and management practices themselves contribute to crop growth variations. According to all farmers, differences in the dates of (re)sowing, thinning and weeding were considered to influence millet growth and development. A delay in weeding particularly reduces yields. When farmers realise that they cannot weed in time they prefer to abandon a field and continue with a second weeding on the remaining, more prosperous looking millet fields.

The main causes of growth variability due to management and cultivation practices are the lack of labour, insufficient resources to hire additional man-power during peak labour periods, and their response to irregular rainfall. Delayed planting reduces the water available to crops and increases the risk of partial or total crop failure (Sivakumar, 1992). Farmers usually sow more fields than they can weed and every day of delay in weeding reduced millet yields by 10–30 kg ha^{-1} (McIntire *et al.*, 1989).

Farmers' techniques for managing soil fertility and soil degradation

Spatial growth variability is also caused by the management strategies of farmers for counteracting both a decline in soil fertility and an increase in soil degradation. Since farmers regarded soil fertility and soil degradation as two interacting factors, they address them both through one strategy which is to increase soil fertility by using fallow and animal manure (Table 3). In addition, farmers consciously moved their huts or applied organic material. Most farmers mentioned using fallow and manure, but only under favourable socio-economic conditions, such as the access to sufficient land, the ownership of cattle and the availability of cash. Consequently, farmers discriminated between fields on which they apply different strategies. Family fields (cultivated by all household members) have a higher priority than individual fields (usually worked by individual members of the household), and fields in the vicinity of settlements get more attention than bush fields. Land tenure, primarily based on land use without payment (Table 1), also influences fertilising strategies. Neef *et al.* (1995) concluded that without the assurance of profiting from their investments in soil fertility strategies, farmers are hesitant to invest. However, this should be taken with caution because a guarantee of individual ownership does not automatically mean that soil improvement measures are implemented (Napier, 1992). The low reputation of agricultural work, low returns to the additional invested labour, and also, more profitable off-farm activities are important issues when discussing the limited application of local knowledge.

Fallow. Farmers said that a fallow of 7–10 years after 3–5 years of cropping is becoming less and less feasible since the increasing population pressure is forcing them to shorten or even abandon this practice. Instead of allowing entire fields to lay fallow, more than half of the surveyed farmers (Table 1) currently fallow only parts of their field (within-field fallow). In the past decade, about one-third did not practice fallow but all farmers still use special terms for indicating the years after the clearance of fallow. A field in the first year after fallow is called a *sakara* and 48% of the farmers predicted that millet yields in this year will be modest. Farmers blamed the compact soil structure which hinders the penetration of roots and their growth. The traditional practice of zero-tillage land clearing, which is based on cutting and burning the fallow vegetation, cannot loosen the compact soil. Yet, 24% of the farmers claimed that a very intensive tilling or weeding could increase yields even during the *sakara*. A field in the second year after clearing a fallow, *lalibanda*, gives the expected yield increase due to previous weedings. Farmers explained that weeding softens the soil, helps decompose the accumulated organic matter and enhances root growth. Yields in the *Kuari-kuari*, the third year after fallow, may still be satisfying depending on the duration of the fallow. Currently, fallow periods are 3–6 years which seldom allows for more than 5 years of cultivation, at least not without the use of other means of improving soil fertility.

The development of yields after fallow was confirmed by Nabos (1966), yet population growth, a decrease in livestock numbers from droughts in the seventies and eighties, and a reduction in grazing land have limited the application of traditional soil fertility management strategies on a 7–10 ha farm, the average farm size in Western Niger (McIntire *et al.*, 1989). The increase in the partitioning of land has destabilised the balance between fallow and crop land, and although within-field fallow increases spatial variability (Taylor-Powell, 1991) it allows a regeneration of soil fertility on a small scale.

Manure. Farmers know of the growth stimulating effects of manure, but sufficient quantities are not available for manuring all fields and this lack of resources has generated a sophisticated manuring system. In the first place, due to feed deficiencies and insufficient numbers of livestock for manuring, the surveyed farmers systematically move the kraal where the cattle stay overnight (*Kanandi*) from one low productivity spot to another. Particularly the main family field is manured through kraaling, whereas on more remote fields kraaling is only practiced when fertility problems cannot be solved by other means. Secondly, farmers distinguished between the quality of cattle manure produced throughout the year. During the rainy season, cattle feed consists of herbaceous plants, grasses and browses provoking a liquid manure which easily mixes with the sandy soil. Rapid decomposition of this manure leads to an immediate benefit for crops. Livestock have free access to fields until millet tillers. After tillering access is denied because the plant becomes a palatable feed. Kraaling during the cold season is less efficient, according to farmers, because the compact faeces dries out quickly. This delays decomposition, reduces the amount of nutrients available to crops and leads to only modest yield increases. Farmers observed the smallest yield increases with kraaling during the hot season, from February to April, because animal feed is insufficient and the nutrients from this faeces is not directly available for crops. Even farmers without cattle (18%) may manure their fields, while at the same time clearing them of crop residues, through contracts with nomadic herdsmen. These leave their herds on the field in exchange for one bundle of un-threshed millet every 3–4 days. Because farmers realised that fallowing will grow virtually impossible in the future, their long-term problem solving strategy is to use manure. Hence, due to manure deficiencies, most farmers seek to enlarge or (re)establish a herd.

Nabos (1966) concluded that manuring is the most desirable fertilisation method for millet and Ikpe *et al.* (1994) estimated yield increases of 40% at rates of 1,500 kg manure ha^{-1} compared to a bare control. Powell & Williams (1993) confirmed that the manure production in the wet season was higher and richer in mineral nutrients than manure produced during the dry season. The fact that farmers pay nomadic herdsmen for manure is an additional indication of the importance farmers assign to it. McIntire *et al.* (1992) and Powell & Ikpe (1992) showed that farmers make efficient use of livestock for transferring fertility through manure from one area to another. Yet, even though it was confirmed that manure efficiently increases millet production, a rise in livestock numbers as desired by farmers is detrimental to the already overgrazed range lands (McIntire *et al.*, 1992). Given the importance of livestock for the mixed farming systems and the lack of feed, the use of fodder trees, weeds and crop residues should be considered to improve both the quality and quantity of feed in the West African Sahel. Millet breeders are well-advised to consider the nutritional characteristics of millet stover for livestock production.

Moving settlements. Cattle owners living outside the village (48%) deliberately moved their huts every 2–3 years to improve production on spots with a low productivity. Farmers stated that household refuse, chaff, bran and other waste, increase soil fertility. On the other hand, former hut locations and termite mounts can only be rehabilitated through kraaling or breaking up the compact surface. A recent aerial survey illustrated that even after 4–5 years the effects of deliberately moving settlements were clearly visible on millet growth and development (Buerkert, 1995). The former interior of huts, often swept or paved with mud bricks, could be identified as infertile spots. Moving huts augments micro-variability by increasing the differences in productivity around and within the former settlements. Little research has been conducted on the effects of moving settlements, but obviously such an efficient strategy can only be applied on a small scale. Agricultural research should be encouraged to study how the composting of household waste could improve the strategy of moving settlements.

Mulching with organic material. Crop residues are also used to increase millet production and to conserve soil, but about 40% of the farmers appreciated crop residues more as a means of capturing air-blown material than for enriching the soil directly (Table 3). The stover catches soil particles and then soil fauna, especially termites, decompose the stover and this, particularly, increases grain yields. Manuring or kraaling was mentioned by almost 65% as being better than crop residues for increasing yields, but a combination of crop residues and manure was most beneficial because manure stimulates stover decomposition. Nigerien households have many uses for crop residues, all of which influence their income directly or indirectly (Figure 1). These many uses limit its availability for mulching. Farmers also use twigs, branches and organic material from old huts, such as *Andropogon gayanus*, to mulch and improve the crusty *gangani*s and *tanka*s. One-third of the farmers had carried village refuse to their fields to improve low productivity spots (Table 3).

Powell & Ikpe (1992) showed that millet crop residues initially immobilise soil nitrogen and this causes a nitrogen deficiency during early millet growth. Mixing the straw with animal manure is a remedy against this kind of nitrogen immobilisation. This might explain farmers' preferences for using crop residues to rehabilitate crusty

Table 3. Knowledge and application of soil fertility management techniques by farmers.

Soil fertility management strategy	Known by farmers	Applied by farmers	Active collection of material for application	Only use of present material	Use of own and hired animals
	%			%	
1. Fallow	79	83	–	–	–
2. Use of organic material					
– Crop residues	58	82	29	53	–
– Household refuses	90	69	27	42	–
– Manure	83	59	21	38	–
– Kraaling	90	73	–	–	73[1]
3. Moving of settlements	62	83	–	–	–

[1] 15% of the surveyed farmers hired animals and 58% used their own animals

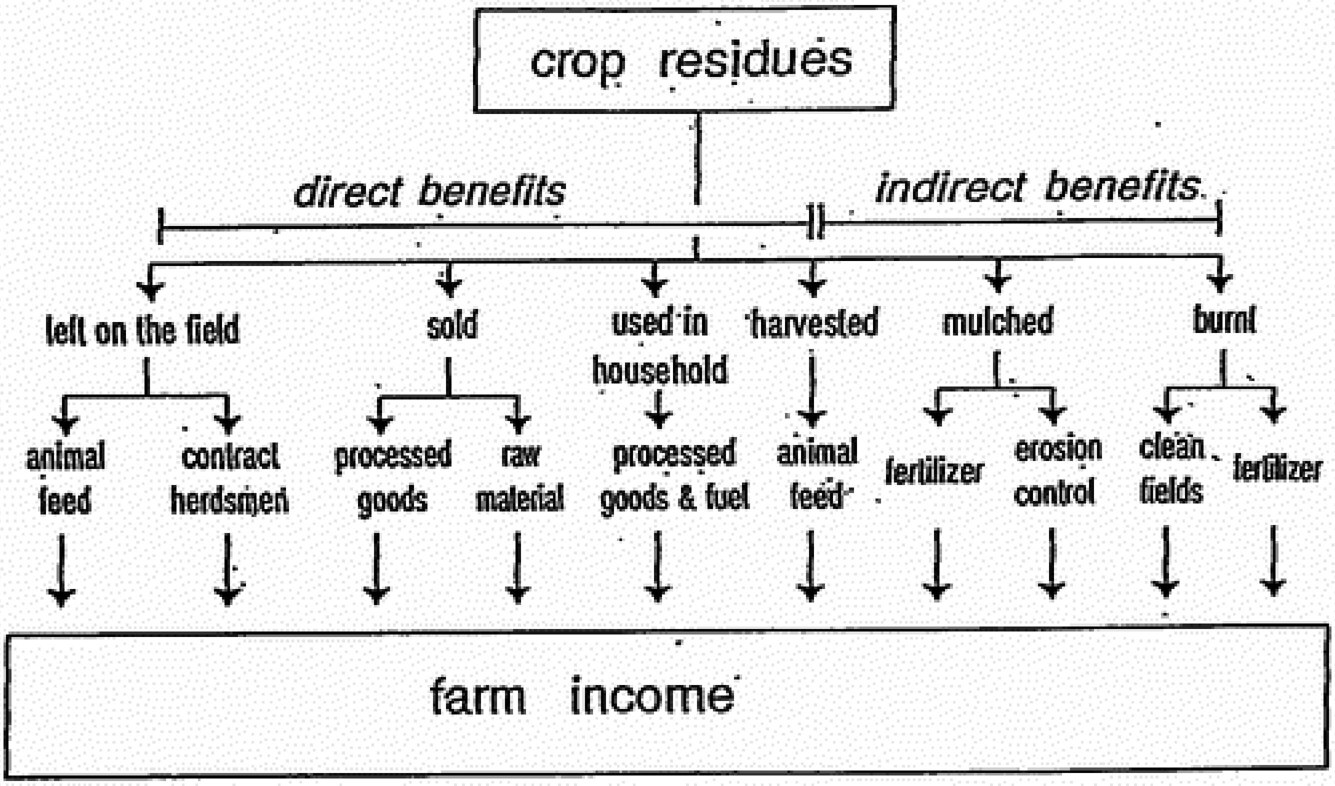

Figure 1. Direct and indirect effects of crop residue uses on farmers' income.

spots and not initially to increase millet production. Chase & Boudouresque (1987) proved that a mulch of branches improved crusty spots even within the same year of application and, thus, confirmed that farmers effectively exploit the wind erosion process to restore low productivity spots.

The increase in population and livestock has created a growing demand for crop residues which, accordingly, has increased in value (Baidu-Forson, 1994). Whereas McIntire *et al.* (1992) postulated that feeding crop residue to livestock is its most economical use in the long run, Lamers & Bruentrup (1996) concluded that a multipurpose use of crop residues, as currently practiced by farmers, is the most profitable use in the short run. By linear programming techniques, it was shown that the profitability of farmers' concentrated use of crop residues on spots with a low productivity, was higher than that of broadcast applications which did not differentiate between low and high productivity spots (Lamers *et al.*, forthcoming). Due to a low production level of crop residues and its many uses, farmers do not have many alternatives to a concentrated use of crop residues on low productivity spots.

Farmers in many developing countries have generated their own techniques for maintaining the fertility of their soils such as mulching, cover cropping, incorporation of organic matter, animal manure, crop rotation, leguminous crops and herding strategies (Hailu & Runge-Metzger, 1992). Although the authors correctly stressed that, in general, the existence of these indigenous practices does not prove that they are effective in establishing sustainable agro-ecosystems, it does show farmers awareness of problems and possible solutions. Economic evaluations of traditional techniques are seldom available, although they could indicate future development paths for these techniques and should be included in future research activities.

Buerkert (1995) showed that millet dry matter production increased through an application of the ashes of burnt millet crop residues in the same year of burning. This was not mentioned by the surveyed farmers although burning is commonly practiced. Farmers considered burning not as a fertilising strategy but a management practice to obtain a clean field. Lamers & Bruentrup (1996) confirmed that a soil mulch of crop residues hampers agricultural operations, such as weeding, because weed growth increases due to a crop residue mulch. In addition, millet residues may host eggs of the stem borer *Coniesta (Acigona) ignefusalis* which hatch by the first rains. Burning old millet stalks prior to the rainy season is a recommended treatment against this pest (Maïga & Issa, 1988).

Although none of the farmers used mineral fertilizers in the survey year, in their experience the response of millet to fertilizers was extremely variable, or as one Haussa farmer stated, 'Babu rua, taki banza' –'without water (rainfall), fertilizers are useless'. In Sahelian regions receiving less than 800 mm rainfall, there is an extremely variable response of millet to mineral fertilizers (Deuson & Sanders, 1988). The experience of farmers that at a low soil fertility mineral and organic fertilizers work best together, was also confirmed by Bationo *et al.* (1995).

Implications for agricultural research and technology generation

In the last decade, several technologies based on low external inputs have been developed to increase soil fertility and reduce soil degradation in small-scale farming systems in the West African Sahel. Researchers have studied the use of locally available millet crop residues and animal manure, both of which increase yields. However, the presence of these materials on the farm does not make them automatically available for soil sustaining practices, as their opportunity costs are high (Lamers & Bruentrup, 1996). The ability of smallholders to apply a soil mulch of crop residues with higher quantities than can be reproduced is very low, particularly since they are continually short of resources, and this brings the long-term sustainability of this recommendation into question (Feil *et al.*, 1995). Many technologies have been developed, but few innovations proved to be economically superior to farmers' current technologies and their adoption is therefore modest (Deuson & Sanders, 1988). Without access to inputs such as cash, manure or hired labour, little can be done to improve sustainability and systems will eventually deteriorate. Knowledge, either coming from outside or developed within the farming community, has to be combined with sufficient resources.

There is no doubt of the importance of pro-active base-line research, but past research on experimental stations has focused more on increasing the technical efficiency of innovations and less attention was paid to the applicability and feasibility of these techniques for farmers. There is often a conflict between conservation, or reducing soil degradation, and production by improving soil fertility techniques. In making land-use decisions, farm households need to consider both the agro-ecological features and economics. Research should take this into consideration during the design of experiments. Moreover, since past research has determined the technical potentials and limits of innovations, future research should examine practical intermediate solutions which reduce the competition between production and conservation. Since farmers decide what and how to produce, more research should be conducted on-farm and in collaboration with farmers.

Although knowledge on soil fertility management is wide-spread among farmers, its application depends, to a large extend, on their socio-economic situation, their problem awareness, perceptions and priority-setting. For the most part, compartmentalised research to increase soil fertility and decrease soil degradation has resulted in a recommendation of an isolated technology without considering the complex framework of the farming systems or the interaction of a technology with the existing system. Farmers could guide researchers towards a system thinking which not only means considering a farm instead of a single field, but also corpping systems instead one single commodity. It is not enough to know the increase in yield or the decrease in soil loss, if the economic and social significance of potential techniques and innovations are unknown. Research recommendations must be flexible enough to deal with the diversity and variability of the farming community, since they often need to be tailored to the conditions of the different groups that form the farming community. Technical oriented research should be encouraged, more than ever, to include these aspects.

Acknowledgements

This study was supported by the Deutsche Forschungsgemeinschaft via the Special Research Programme 308. The authors thank Mrs. J. Kidd for editing their English and two anonymous reviewers for their skilful and supporting comments.

References

Anonymous, 1991. Recensement général de la population 1988. Répertoire National des villages du Niger. République du Niger, Ministère du Plan, Bureau Central de Recensement, Niamey, 300 pp.

Baidu-Forson, J., 1994. Uses and economic value of crop residues and herbaceous plants to rural households in western Niger. Resource Management Program. Progress Report n° 5. International Crops Research Institute for the Semi-Arid Tropics, Niamey, 20 pp.

Baidu-Forson, J., C. Renard, N. Deuro, C. Reddy & M. Kadi, 1994. Evaluation agro-économique de nouveaux systèmes de production en milieu paysan au Niger. Programme d'Exploitation des Ressources. Compte rendu des travaux, n° 5. International Crops Research Institute for the Semi-Arid Tropics, Niamey, 22 pp.

Bationo A., A. Buerkert, M.P. Sedogo, B.C. Christianson & A.U. Mokwunye, 1995. A critical review of crop residue-use as soil amendment in the West African semi-arid tropics. In: J.M. Powell, S. Fernández-Rivera, T.O. Williams & C. Renard (Eds.), Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa. Volume II: Technical Papers. International Livestock Centre for Africa, Addis Ababa, pp. 305–322.

Brouwer, J., L.K. Fussell & 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.

Buerkert, A., 1995. Effects of Crop Residues, Phosphorus, and Spatial Soil Variability on Yield and Nutrient Uptake of Pearl Millet (*Pennisetum glaucum* L.) in Southwest Niger. Ulrich Grauer Verlag, Stuttgart, 272 pp.

Carruther, I. & R. Chambers, 1981. Rapid appraisal for rural development. *Agriculture Administration* 8:407–422.

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

Chase, R.G., J.W. Wendt & L.R. Hossner, 1989. A study of crop growth variability in sandy Sahelian soils. In: C. Renard, R.J. Vandenbeldt & J.F. Parr (Eds.), Soil, crop and water management systems for rainfed agriculture in the Sudano-Sahelian Zone. ICRISAT Sahelian Center, Niamey, pp. 229–240.

Deuson R. & J.H. Sanders, 1988. Technology development and agricultural policy in the Sahel-Burkina Faso and Niger. In: P.W. Unger, T.V. Sneed, W.R. Jordan & R. Jensen (Eds.), Challenges in Dryland Agriculture – A global Perspective. Texas Agricultural Experiment Station, Amarillo/Bushland, Texas, pp. 610–612.

Feil, P.R., J.P.A. Lamers & L. Herrmann, 1995. Knowledge transfer in the field: Solving crop residue problems in Niger. *Journal of Technology Transfer* 20(1):31–41.

Gavian, S., 1992. Manure and crop residue management strategies used by farmers in selected regions of the Tillabéri department, Niger. ILCA Niger Research Report, 92/1, 71 pp.

Geiger, S.C. & A. Manu, 1993. Soil surface characteristics and variability in the growth of millet in the plateau and valley region of Western Niger. *Agriculture, Ecosystems and Environment* 45:203–211.

Geiger, S.C., R.J Vandenbeldt & A. Manu, 1992. Pre-existing soil fertility and the variable growth of *Faidherbia albida*. In: R.J. Vandenbeldt (Ed.), *Faidherbia albida* in West African semi-arid tropics. ICRISAT Sahelian Center, Niamey, pp. 121–125.

Hailu, Z. & A. Runge-Metzger, 1992. Sustainability of Land Use Systems. The potential of indigenous measures for the maintenance of soil productivity in Sub-Sahara African agriculture. Tropical Agroecology 7. Weikersheim, Margraf, 168 pp.

Herrmann, L., A. Hebel & K. Stahr, 1994. Influence of microvariability in sandy Sahelian soils on millet growth. *Zeitschrift für Pflanzenernährung und Bodenkunde* 157:111–115.

Hoogmoed, W.B. & L. Stroosnijder, 1984. Crust formation on sandy soils in the Sahel. I. Rainfall and infiltration. *Soil and Tillage Research* 4:5–23.

Ikpe, F.N., J.M. Powell & N.O. Isirimah, 1994. Primary tillage and nutrient cycling in mixed farming systems of semi-arid West Africa. ORSTOM, Réseau Erosion, no. 14, pp. 410–437.

Lamers, J.P.A., K. Michels & R.J. Vandenbeldt, 1994. Trees and Windbreaks in the Sahel. Establishment, growth, nutritive and calorific values. *Agroforestry Systems* 26(3):171–184.

Lamers, J.P.A & M. Bruentrup, 1996. Comparative advantage of single and multipurpose uses of millet stover in Niger. *Agricultural Systems* 50:273–285.

Lamers, J.P.A., M. Bruentrup & A. Buerkert, forthcoming. The profitability of traditional and innovative mulching techniques of millet crop residues in West Africa. Submitted to *Agricultural Economics*.

Maïga, S. & H. Issa, 1988. Les principaux insectes nuisibles aux cultures pluviales. In Reddy, K.C., A. Berrada et A. Bonkoula (Eds.), Manuel de l'expérimentation en plein champ, à l'usagedes cadres de développement agricole, 1ère édition. Institute National de Recherches Agronomiques du Niger (INRAN), Niamey, pp. 47–68.

Manu, A., S.C. Geiger, A. Berrada & J. Scott-Wendt, 1990. Microvariabilité dans le Sahel: un aperçu général. In: A. Berrada, I. Mahaman & M. Gandah (Eds.), Actes du séminaire national sur l'aménagement des sols, la conservation de l'eau et la fertilisation (Tahoua), Institute National de Recherches Agronomiques du Niger (INRAN), Niamey, pp. 117–128.

McIntire, J., J. Hopkins, J.P.A. Lamers & L.K. Fussell, 1989. The millet system of western Niger. I Crop production. ILCA, Addis Ababa, Ethiopia, (unpublished).

McIntire J., D. Bourzat & P. Pingali, 1992. Crop-livestock interaction in Sub-Saharan Africa. World Bank Regional and Sectoral Studies. The World Bank, Washington D.C., 246 pp.

Michels, K., 1994. Wind Erosion in the Southern Sahelian Zone. Extent, Control, and Effects on Millet Production. Ulrich Grauer Verlag, Stuttgart, 99 pp.

Nabos, J., 1966. Present state of research work on improved varieties and cultivation methods of millet and sorghum in Niger. *Journal African Soils* 11(1/2):365–381.

Napier, T.L., 1992. Property rights and adoption of soil and water conservation practices. In: Arsyad, S., Istiqlal, A., Sheng, T. & W. Moldenhauer (Eds.), Conservation policies for sustainable hillslope farming, pp. 193–201

Neef, A., J. Haigis & F. Heidhues, 1995. Impact of institutional and legal pluralism on the introduction of anti-erosion measures – the case of Niger. In: B. Buerkert, M.v. Oppen & B. Allison (Eds.), Wind Erosion in West Africa: The Problem and its Control. December 5–7, 1994, Stuttgart-Hohenheim, Germany. (In press).

Powell, J.M. & F. Ikpe, 1992. Fertiliser factories. Nutrient recycling through livestock. *ILEIA Newsletter* 8(3):13–14.

Powell, J.M. & T.O. Williams, 1993. Livestock, nutrient cycling and sustainable agriculture in the West African Sahel. *IIED Gatekeepers Series* No. SA37, 15 pp.

Sall, P. N., 1992. Site effects of *Acacia albida* Del. In: R.J. Vandenbeldt (Ed.), *Faidherbia albida* in West African semi-arid tropics. ICRISAT Sahelian Center, Niamey, pp. 103–105.

Schulze, E.D., G. Gebauer, H. Ziegler & O.L. Lange, 1991. Estimates of nitrogen fixation by trees on an aridity gradient in Namibia. *Oecologia* 88:451–455.

Sivakumar, M.V.K., 1992. Climate change and implications for agriculture in Niger. *Climatic Change* 20:297–312.

Taylor-Powell, E. 1991. Integrated management of agricultural watersheds: land tenure and indigenous knowledge of soil and crop management. TropSoils bulletin 91–04. Dep. of Soils and Crop Sci., Texas A&M Univ., College Station, 30 pp.

Vandenbeldt, R.J. & J.H. Williams, 1992. The effect of soil surface temperature on the growth of millet in relation to the effect of *Faidherbia albida* trees. *Agricultural and Forest Meteorology* 60:93–100.

West, L., L.P. Wilding, J.K. Landeck and F.G. Calhoun 1984. Soil Survey of the ICRISAT Sahelian Center, Niger, West Africa. Texas A&M University: Soil and Crop Sciences Department/ TropSoils, 66 pp.

Williams, J.H., 1992. The agro-ecological significance of *Faidherbia albida*. In: R.J. Vandenbeldt (Ed.), *Faidherbia albida* in West African semi-arid tropics. ICRISAT Sahelian Center, Niamey, pp. 127–129.