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Resource conservation strategies in agro-ecosystems of semi-arid West Africa

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Countries of semi-arid West Africa are experiencing growing populations, expansion of cultivated land and intensification of crop and livestock production an ever-increasing burden on the region's limited natural resources, consequently increasing degradation rates. A broad range of technologies combating degradation currently exist. This paper presents and discusses both traditional techniques as well as modern techniques which are derived from the traditional ones. Various methods of mulching and application of manure or mineral fertilizers are used to maintain or increase soil fertility. The use of mulch as well as various methods of integrating shrubs, trees and herbaceous vegetation into the cultivation systems are the technologies currently used to decrease the effects of wind erosion. Similarly, water erosion can be prevented with lines of stones, mulch and grasses. The most promising methods which impede decreasing natural vegetation are promotion of natural regeneration and to some extent the implementation of agricultural parks. In contrast, community-based management of grazing land or forested areas are difficult to establish.

Most conservation strategies are limited by the availability of mulch, fertilizer or manure to fertilize fields or to protect sufficient land areas from wind and water erosion. Household constraints of individual farmers also play a crucial role in increasing such protection. Great efforts are needed to distribute the knowledge of the various conservation strategies throughout the different regions of semi-arid West Africa, and to develop new technologies, preferably with farmers' participation, to enable adoption. As degradation continues and populations increase, this must be accomplished in the near future in order to hinder devastation of land resources.

Keywords: degradation; natural vegetation; soil fertility; Sahel; traditional conservation methods; wind and water erosion

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Introduction

Semi-arid West Africa, also called Sahelian West Africa or Sahel covers the area from Senegal to Chad receiving about 250–500 mm summer rainfall (Fig. 1). These rainfall boundaries for the Sahel may vary with different authors within the 150–600 mm isohyets (see Wickens, 1997). In general, the Sahel is described as the zone between the Sahara and the Sudanian zone. The vegetation is characterized by semi-desert grassland, thorn shrub and wooded grassland dominated by *Acacia* spp. (White, 1983).

Resource use has a long tradition in semi-arid West Africa. The influence of man on the savannas can be traced back as long as 9000 years (Anhuf, 1995). Available land was no constraint for agricultural activities until the mid-20th century. However, today the growing population of Senegal, Mauritania, Mali, Burkina Faso, Niger and Chad, countries with areas within the semi-arid zone of West Africa, led to a drastic expansion of cultivated land over the last two decades (World Resource Institute, 1998). Even marginal, relatively unfertile land is presently being cultivated. This expansion led mainly to the reduction of pasture land used for extensive grazing, the consequences being an increase in grazing pressure on remaining pastures. Or alternatively, livestock keepers became restricted to more arid regions where no rain-fed agriculture is possible, at least during the cropping season. In general, livestock numbers increased since 1950 (LeHouérou, 1996), with extreme breakdowns in Mali and Niger during the droughts of the 1970s and early 1980s (Sturm, 1999). Although overall agricultural production had increased in the last years, it was insufficient to feed the growing population. In some countries, e.g. Mali and Niger, yields per hectare even decreased (World Resource Institute, 1998) indicating a general decline in soil fertility in the West African Sahel.

At present, many factors contribute to the development of resource depletion in semi-arid West Africa. Besides factors such as climatic change and population growth, human impact on natural resources plays a crucial role. Mainly, socio-economic constraints of households have led to inadequate management of natural resources. Appropriate land management is often of secondary importance for the individual farmers, who need to feed their family. Thus, soils and natural vegetation are over-used, favouring a short-term gain. Farmers can seldom afford investments in technologies to overcome these constraints due to the financial situation or lack of available credits. Support by extension services is either insufficient or simply non-existent due to the overall bad economic situation in all West African countries.

This paper presents a summary of recent findings about human and non-human factors which led to the depletion or destruction of resources. Secondly, it discusses different methods for resource conservation in the Sahelian environment of West African countries. Emphasis will be given to low-cost conservation methods which are already successfully applied in one of the countries or which proved to be suitable for adoption by the farmers.

Resource destructive factors

Climate change

One factor which strongly influences vegetation and crop growth is precipitation, especially in semi-arid environments such as the Sahel, where inter- and intra-annual rainfall variability holds great importance for the development of plants (see also Tucker *et al.*, 1991). Two types of climatic changes can be distinguished for the Sahel: natural long-term fluctuations which have altered vegetation over the last centuries (Lézine, 1989; LeHouérou, 1997) and short-term changes like the droughts of the

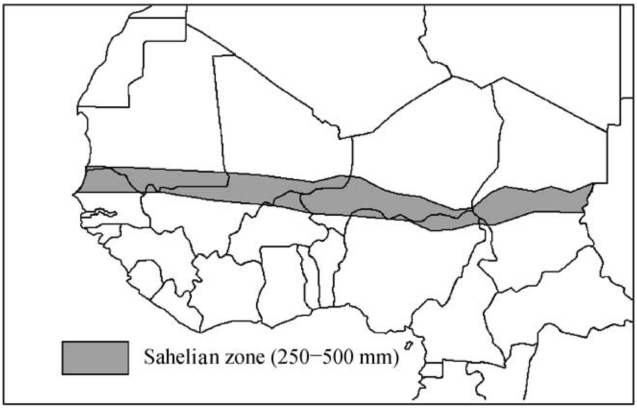

Figure 1. Sahelian zone in West Africa based on mean annual rainfall 1961–1990.

1970s and early 1980s. Studies from Niger and Sudan have shown that in recent years, rainfall has tended to decrease (Akthar-Schuster, 1995; Graef, 1999). In Sahelian Niger, this is reflected in a southward shift of vegetation zones (Wezel *et al.*, 1999). Climatic fluctuations along with vegetation changes always existed, but in the last few decades human mismanagement of the land played a major role (LeHouérou, 1996).

Wind and water erosion

Low to moderate wind erosion affects one-third of the Sahel and about 1%, corresponding to about 6 million ha, are strongly or extremely affected (Middleton & Thomas, 1997). Loss of topsoil material leads to a loss of soil fertility because most nutrients are stored within the first few centimetres. One single convective storm can result in a loss of nutrients from an unprotected field that exceeds the total annual input by dust (Sterk *et al.*, 1996). Similarly, soil nutrients and whole soil layers can be lost by water erosion which is mainly caused by high rainfall intensities. This is especially found on land with sparse vegetation cover or bare surfaces. Loss of nutrients caused by wind and water erosion may have negative aspects at the source area, but sink areas can also profit from deposited material, if not buried too deep.

Human impact

The degree of human impact on resources is strongly related to population numbers. In the West African Sahel, natural resources are limited for the smaller population numbers, compared with more humid regions south of the Sahel. In the West African Sahelian countries, populations increased 2·6–4·2 fold from 1950 to 1998 (World Resource Institute, 1998; Fig. 2), thus imposing a high pressure on the different natural resources.

Expansion of agricultural land

Clearing of land for new fields is one of the most obvious negative impacts on natural vegetation. In total, cropland has been found to have increased substantially during the last two decades (Fig. 3). Because of the ever-increasing population numbers, the expansion of cropland could not prevent a reduction of 7–24% in cropland per capita in the West African Sahelian countries, except for Mali which had a slight increase

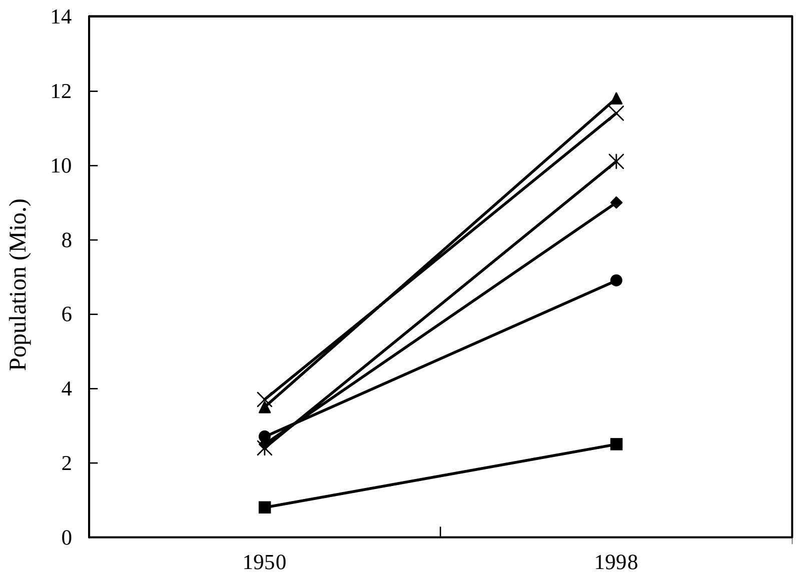

Figure 2. Population increase from 1950 to 1998 in Sahelian West African countries (*Source*: World Resource Institute, 1998). (—◆—) Senegal; (—■—) Mauretania; (—▲—) Mali; (—✕—) Burkiana Faso; (—✳—) Niger; (—●—) Chad.

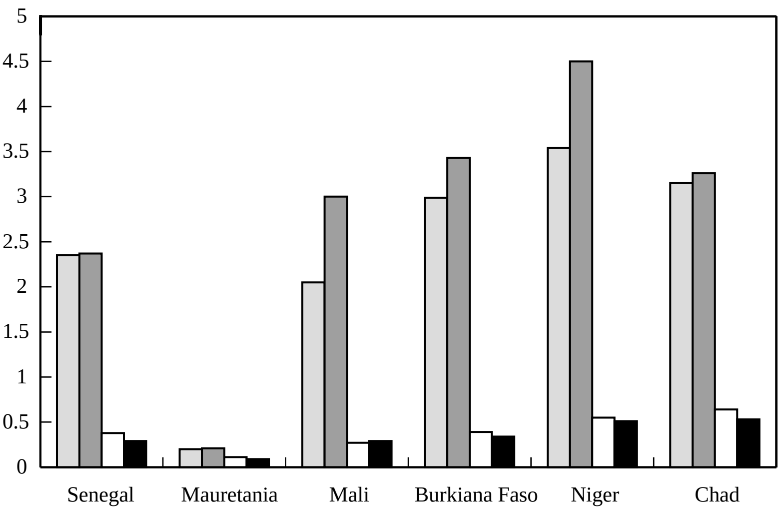

Figure 3. Increase of total cropland and cropland per capita from 1984 to 1994 in Sahelian West African countries (*Source*: World Resource Institute, 1998). (▩) Total cropland 1984 (in Mio. ha); (▢) Total cropland 1994 (in Mio. ha); (□) cropland per capita 1984 (in ha); (■) cropland per capita 1994 (in ha).

(World Resource Institute, 1998). The consequence in some regions is that trees and shrubs are completely cut down and the area is burnt for land preparation. In other regions of the West African Sahel, at least some woody vegetation is left uncut in the fields.

Wood consumption

Along with the expansion of cropped land, the need of fire and construction wood for the rural population has led to an immense reduction of trees and shrubs in the Sahel (Breman & Kessler, 1995; Fontès & Guinko, 1995). In 1995, traditional fuel use of wood and charcoal in Senegal was lowest with 56% of total energy use, in Burkina Faso it reached 93% (World Bank, 1998). In the past, only dead wood was collected as fire wood. Today, green wood is also cut down, often by commercial traders. In Niger, decreasing numbers of woody species and degradation of forest areas is not primarily caused by the rural population, but mostly a consequence of commercial cutting, often with the help of corrupted forest officers (Thomson, 1987; Neef, 1999). In Senegal, cutting of trees for charcoal production was found to be the main factor, along with impact of droughts, which led to the disappearance of several tree species (Bergeret & Ribot, 1990).

Exploitation of natural vegetation

Besides fire wood, a broad spectrum of natural plants is collected for food, medicinal purposes or hand tools (Bergeret & Ribot, 1990; Guinko & Pasgo, 1992; Maydell, 1992; Gakou *et al.*, 1994; Kéré, 1998). Many households rely on these plant resources for income generation and food supply (see also Wezel & Haigis, 2000). Over-use of certain tree species has already degraded former tree savannas to shrub/grass savannas, or when tree/shrub species disappeared, land subsequently transformed to bare land.

Fallow and permanent cropping

For many decades the fallow cultivation system was the traditional cropping system in semi-arid West Africa. Regeneration of cultivated land was achieved by fallow periods. In past decades this was a valid option, but in recent years fallow periods decreased to an extent, that soil fertility no longer is able to be restored (Cissoko, 1993; Floret *et al.*, 1993; Hahn-Hadjali & Thiombiano, in press). In Niger, fallow periods in former times was normally 15 years or longer, nowadays it is reduced to less than 5 years (Wezel & Boecker, 1998), to an average of 2 years, or as found for one village, fallow period disappeared totally (Haigis, 2000). This is a crucial development because at least 15 years of fallow are necessary for a significant increase in soil organic matter (Wezel, 1998).

Grazing

In the Sahel, grazing areas usually comprise natural pasture, fallow land and harvested cropland. Natural pasture is in most cases common property and its use is managed through traditional user rights, while fallow land and post-harvest cropland can only be used in mutual agreement with the land owner (Scoones, 1994; Rath, 1999). Sedentary and transhumant livestock systems compete for the grazing resources. Sedentary livestock systems are bound to the small grazing patches around the village, consisting mainly of harvested cropland and fallow during the dry season, while during the rainy season herders guide the animals to remote natural pasture. In sedentary systems, grazing intensity is generally high due to the low mobility of the village herd. Overgrazing occurs frequently in the vicinity of villages, water points and livestock tracks, and influences plant species composition. More than a third of the species encountered in old Sahelian fallow land appeared sensitive to heavy grazing (Hiernaux, 1998). However, the majority of species were either fostered by grazing, indifferent or tolerant to grazing. In contrast to the sedentary system, transhumant herders are very mobile and change almost daily the grazing area, subject to availability and quality of water and pasture (Jahnke, 1982; Colin de Verdière, 1995; Schareika *et al.*, 2000). The transhumant system makes very efficient use even of very remote rangeland. The system's high mobility ensures a sufficient recovery of grazed areas which in turn ensures the sustainability of the rangeland.

With the encroachment of cropland in traditional pastoral zones, the picture of resilient and balanced rangeland ecology has turned upside down. The increasing use of rangelands as cropland has led to the loss of good grazing areas as well as to rising conflicts between sedentary farmers and itinerant herdsmen. The contraction of the pastoral zone limits the mobility of transhumant herders and it has led to overgrazing and degradation of communal grazing lands in some parts of the region, with the final consequence of decreasing productivity of the livestock system (Colin de Verdière, 1995; Mohamed-Saleem & Fitzhugh, 1995).

Resource conservation strategies

A number of resource conservation strategies can be found in semi-arid West Africa. Either they were developed by local farmers themselves already in past times, so-called indigenous conservation strategies, or together with projects and extension services over the last few years. Most of the conservation techniques are multi-factor techniques, developed to combat different degradation factors at the same time such as the decrease of soil fertility caused by wind and water erosion. In the following, the techniques will be discussed along with the respective primary degradation factor. An overview of the techniques is presented in Table 1.

Soil fertility

Decreasing soil fertility is one of the major constraints for agricultural production in the West African Sahel. Inherently poor sandy soils are found in many regions, which become depleted after a few years when permanently cultivated. The situation on loamy or clayey soils is better in general. A commonly applied method to reduce soil fertility decline is mulching. Leaving crop residues on the fields minimizes the export of nutrients via harvested crops or even imports nutrients when using mulch material produced elsewhere. Mulching increases not only nutrient and organic matter content of soils, but also reduces soil erosion, enhances water conservation and increases water infiltration (Michels, 1994; Sterk & Spaan, 1997; Léonard & Rajot, 1998). Depending on the amount of crop residues applied (500–2000 kg ha^{-1}), yields were 31–106% higher compared with unmulched areas (Bationo & Mokwunye, 1991; Buerkert, 1995; Muehlig-Versen *et al.*, 1998). However, crop residues are limited because they are used for other purposes such as building material, as fuel and as fodder during the dry season and often the recommended amounts of 2000 kg ha^{-1} are not very realistic. Thus, farmers mostly apply higher amounts of crop residues only to areas with very low soil fertility (Lamers & Feil, 1995; Haigis & Heidhues, 1998). Alternatively, other mulch material can be used. In Burkina Faso, higher yields were achieved with mulch material from the natural growing grass *Loudetia togoensis* (Hien *et al.*, 1998). This traditional technique is used mainly for mulching smaller field areas, often in combination with mulch from tree branches (Slingerland & Masdewel, 1996). In Niger, the grass *Andropogon gayanus* is used for mulching (Lamers & Feil, 1995). Interestingly, not only material from grasses is used as mulch, but also traditionally branches of trees and shrubs (Haigis & Heidhues, 1998). In Burkina Faso, mulch from planted *Azadirachta indica* and *Albizia lebbeck* trees (Tilander, 1993) and in

Niger mulch from natural growing *Guiera senegalensis* shrubs (Wezel & Böcker, 1999) positively influenced crop yields, e.g. in Niger from 68% to 94% compared to the control. Mulch from the exotic tree species *Azadirachta* and *Albizia* is only available in areas where sufficient trees are planted. In contrast, *Guiera senegalensis* is widely distributed as it is the most abundant indigenous shrub in fallow sites and millet fields in south-west Niger. However, mulch material is also limited due to the fact that rural populations use this shrub for firewood, for construction as well as assigning it a medicinal use. Applying shrub mulch together with herbaceous mulch is a traditional method used by farmers in Niger to fertilize unfertile areas on their fields or for rehabilitation of denuded soils (Mabrouk *et al.*, 1998).

In general, sufficient mulch material for application to whole fields and in high quantities is seldom available. Thus, mulching should be preferably used in combination with other fertilization techniques such as manure or mineral fertilizer to maintain or increase soil fertility.

Fertilization and rehabilitation of lateritic or degraded soils can be achieved by an improved traditional method of planting pits (called za or tassa) (Ouedraogo & Kaboré, 1996; Wedum *et al.*, 1996). For this, small holes are dug out with a hoe to capture runoff water. Before the first rains, the farmers add a small amount of manure to each pit to cultivate different crops. This traditional method from Burkina Faso and Mali was successfully introduced by development projects in Niger at the beginning of the 1990s (Hassan, 1996; Mabrouk *et al.*, 1998; Sterk & Haigis, 1998; Hassane *et al.*, 2000). Similar to the planting pits, half-moons (demi-lunes) were also used to rehabilitate degraded soils (Hassane *et al.*, 2000). Half-moons have a size of 3–4 m to harvest higher amounts of water. As in the case of planting pits, manure is applied before cultivation to improve soil fertility.

Fertilization of sandy or loamy soils by means of mineral fertilizers is well-known as effective in increasing crop yields (Bationo & Mokwunye, 1991; Buerkert, 1995; Lamers & Feil, 1995), but enough quantities of fertilizer are seldom available for the households as they simply cannot afford it. A more effective method of fertilization is the application of animal manure to enhance soil organic matter content, thereby increasing nutrient retention capability and stability of soils (Pieri, 1989). In contrast to inorganic fertilizer, animal manure is widely available, although not every farmer has the possibility or means to manure all of his fields (Neef, 1998). Farmers in Burkina Faso and Niger apply manure either during the dry season by corralling livestock overnight on the fields or by manually spreading manure transported from the village (Knierim, 1991; Lamers & Feil, 1995). Here, herding contracts play an important role for accumulation of organic matter in the fields to increase millet yields (Mabrouk *et al.*, 1998; Neef, 1998). These contracts are made between pastoralists and farmers and commits the herders to keep their cattle for 3–4 nights on a field in return for money or food from the farmers. Fields fertilized with a herding contract receive 5–13 times more manure than average village land (Hiernaux *et al.*, 1998).

Moving settlements of cattle owners living outside the village every 2–3 years to improve soil fertility is reported from Niger (Buerkert, 1995). But, compact surfaces of hut locations have to be broken up or corralled.

Soil regeneration by means of fallows has become almost impossible in Sahelian West Africa (see above). Thus, farmers in Niger changed their management strategies from leaving whole fields uncultivated to so-called ‘in-field fallows’ in order to restore or maintain at least partly the soil fertility (Lamers & Feil, 1995; Haigis, 2000).

Wind erosion

There are two variables which predominantly mitigate the negative impact of wind erosion: the degree of vegetation cover to protect soils and obstacles to reduce wind

Table 1. *Resource conservation strategies in Sahelian West Africa*

Degradation factor	Techniques	Traditional conservation strategy	Low-cost technique	Other degradation factor which are affected	Constraint of described technique	Reference
Decreased soil fertility	Crop residues broadcast	×	×	Reduced wind and water erosion	Other uses of crop residues	Bationo & Mokwunye (1991), Buerkert (1995), Muehlig-Versen *et al.* (1998), Haigis & Heidhues (1998)
	Crop residues on small spots	×	×	Reduced wind and water erosion	Only for small areas	Lamers & Feil (1995), Haigis & Heidhues (1998)
	Grass mulch	×	×	Reduced wind and water erosion	Only for small areas	Lamers & Feil (1995), Slingerland & Masdewel (1996), Hien *et al.* (1998)
	Tree mulch	×	×	Reduced wind and water erosion	Other use of trees	Tilander (1993), Haigis & Heidhues (1998)
	Shrub mulch	×	×	Reduced wind and water erosion	Other uses of shrubs	Haigis & Heidhues (1998), Wezel & Böcker (1999)
	Shrub and herbaceous mulch	×	×	Reduced wind and water erosion	Only for small areas	Slingerland & Masdewel (1996), Mabrouk *et al.* (1998)
	Planting pits: small holes with manure	×	×	Re-vegetation	Labour intensive	Ouedraogo & Kaboré (1996), Wedum *et al.* (1996), Hasan (1996), Rinaudo (1996), Mabrouk *et al.* (1998), Hassane *et al.* (2000)
	Half-moons			Re-vegetation	Very labour intensive	Hassane *et al.* (2000)

	Manure (direct, corralling)	×	×		Need of own livestock	Knierim (1991), Lamers & Feil (1995),
	Manure (herding contracts)	×			Cost intensive for poor farmers	Mabrouk *et al.* (1998), Neef (1998)
	Moving compounds	×				Buerkert (1995)
	Mineral fertilizer				Cost intensive	Bationo & Mokwunye (1991), Buerkert (1995), Lamers & Feil (1995)
	Fallow	×	×	Reduced wind and water erosion, re-vegetation	General decline of fallow periods	Cissoko (1993), Floret *et al.* (1993), Wezel (1998)
	In-field fallow	×	×	Reduced wind and water erosion, re-vegetation	Only on limited areas	Lamers & Feil (1995), Haigis (2000)
Wind erosion	Crop residues	×	×	Soil fertility, reduced water erosion	Other uses of crop residues	Michels (1994), Sterk & Spaan (1997)
	Wind breaks			Reduced water erosion	Unsure economic benefits	Michels (1994), Michels *et al.* (1998)
	Banded fallow vegetation		×	Reduced water erosion	Did not increase crop yields	Banzhaf (1988)
	Grass strips		×	Reduced water erosion	Did not increase crop yields	Renard & Vandenbeldt (1990), Michels *et al.* (1998)
	Disperse growing natural shrubs		×	Increased soil fertility	Land tenure	Wezel (2000)
Water erosion	Grass strips	×	×	Reduced wind erosion	Protection from intensive grazing	Kassogué *et al.* (1996), Slingerland & Masdewel (1996)
	Mulch lines	×	×	Reduced wind erosion	Other uses of mulch material, not effective on clayey soils	Kassogué *et al.* (1996), Slingerland & Masdewel (1996)

Table 1. *(Continued.)*

Degradation factor	Techniques	Traditional conservation strategy	Low-cost technique	Other degradation factor which are affected	Constraint of described technique	Reference
	Stone lines and bunds	×			Labour intensive	Kassogué *et al.* (1996), Slingerland & Masdewel (1996)
	Stone walls	×			Labour intensive	Kassogué *et al.* (1996)
	Terraces	×			Labour intensive	Kassogué *et al.* (1996)
Decreased vegetation cover	Natural regeneration		×	Reduced wind and water erosion, increased soil fertility	Traditional practice of clean fields	Taylor & Rands (1992), Rinaudo (1996), Sterk & Haigis (1998), Joet *et al.*, (1998)
	Re-vegetation of bare soils with mulch	×	×	Reduced wind and water erosion, increased soil fertility	Only on smaller areas	Chase & Boudouresque (1987), Kessler *et al.* (1998), Sterk & Haigis (1998)
	Establishment of woody species on bare soils with wood and stone lines along the contour	×		Reduced wind and water erosion	Labour intensive	Kessler *et al.* (1998)
	Land rehabilitation with light grazing		×	Reduced wind and water erosion	Grazing pressure has to be controlled	Kessler *et al.* (1998)
	Agricultural parks	×	×	Reduced wind erosion, increased soil fertility	Only few selected species with limited vegetation cover	Krings (1991), Sturm (1998)

Tree planting	Reduced wind and water erosion, increased soil fertility	Very limited success	LeHouérou (1989), Kerkhof (1990), Orr (1995), Wickens (1997)
Community-based forest management	Reduced wind and water erosion	Villages need institutional and legislative support; many socio-economic issues have to be considered	Peltier *et al.* (1995), Kessler *et al.* (1998)
Conservation of natural vegetation	Reduced wind and water erosion, increased soil fertility	Very limited because of land tenure and use rights	Neef (1999)
Management of communal grazing land	Reduced wind and water erosion	Very limited; many socio-economic issues have to be considered	Wickens (1997), Kessler *et al.* (1998)

velocity. On a local scale most soil material, is transported from bare areas to vegetated areas, especially at the onset of the rainy season with heavy convective storms (Sterk *et al.*, 1996). This means that nutrients are not generally lost but locally redistributed provided that enough fallows or protected areas exist. Here, application of mulch material, in addition to its fertilization effect, is effective in trapping wind-blown topsoil material. Sterk & Spaan (1997) found a reduction of total mass transport by 42% and 64% with 1000 and 1500 kg ha^{-1} of crop residue mulch, respectively. Michels (1994) measured a decreased sand flux of 46% with 2000 kg ha^{-1} of crop residues, whereas it was insignificant for 500 kg ha^{-1}. Nevertheless, mulching with crop residues for erosion control is economically feasible only under certain conditions, as labour for weeding is often more constraining than land (Lamers, 1995). In order to maintain a sufficient cover of natural vegetation on fallow land, in areas with intensive grazing, grazing pressure needs to be reduced on fields or on rangelands until the next rainy season. This task proves to be a difficult one as after harvesting, almost all land is traditionally open for communal grazing.

Wind speed has shown to be reduced by windbreaks (Michels, 1994), bands of fallow vegetation (Banzhaf, 1988), grass strips (Renard & Vandenbeldt, 1990) or disperse growing trees (Kainkwa & Stigter, 1994). However, windbreaks are difficult to establish because direct economic benefits for farmers are not ensured (Michels *et al.*, 1998). Also the vegetation bands do not increase millet production and will not thus be adopted by the farmers. In contrast, comparison of areas with shrubs and areas without shrubs in farmer's field in Niger showed that the integration of scattered shrubs into millet production was one of the few technical options that increased gross margin of households and was found to be appropriate for implementation in the villages (Haigis *et al.*, 1999). The disperse growing shrubs were also shown to be able to trap nutrient-rich topsoil material within fields and from nearby unprotected fields (Wezel, 2000; Wezel *et al.*, 2000). In southern Niger, most of the peasants promoting regeneration of natural woody species on their fields benefited from sufficient wood production for their household and increasing sustainable crop yields after 2–3 years (Taylor & Rands, 1992; see also Joet *et al.*, 1998). Also long-term experiences with farmer managed natural regeneration of woody species showed higher adoption rates than conventional erosion control measures (Rinaudo, 1996).

A severe constraint to the introduction of anti-erosion measures can be land tenure. In Mali, conservation techniques on borrowed land were often not applied, as benefits could not be harvested by the tenant (Kassogué *et al.*, 1996). In Niger, the security of tenure and user rights of tenant farmers, women and sedentary livestock keepers are limited both by customary land right systems and state legislation and thus impeded the use of conservation methods (Neef, 1999).

Water erosion

Water erosion occurs usually on sloping fields. Many techniques aim to minimize the effects of water erosion by reducing the velocity of the water runoff. In Mali, farmers traditionally build stone lines and bunds along the contour of the field, reinforcing them with earth (Kassogué *et al.*, 1996). On steep rocky hills, gravely slopes and stream beds, low stone walls to retain earth and hold back water can be established. The stone bunds were introduced to Burkina Faso in the 1980s (Slingerland & Masdewel, 1996) as well as to Niger in recent years. However, in many regions of the West African Sahel, stone lines, bunds or walls are problematic in their installation as stone material is usually limited except in those regions where laterite plateaux occur nearby. Another traditional technique in Mali reduces sheet and gully erosion through so-called trash lines or grass barriers (Kassogué *et al.*, 1996). Along field contours, millet and sorghum stalks as well as branches of trees are applied as trash lines. Along gullies and ravines, growing of grass is encouraged. Mulching and grass strips against water and wind erosion are also traditionally practised in Burkina Faso (Slingerland & Masdewel, 1996).

Vegetation

The degree of natural vegetation cover plays an important role in decreasing or inhibiting the loss of topsoil by wind and water erosion. Moreover, natural vegetation is a vital resource for consumption, medicines or other purposes of the rural population as well as being a source of feed resource of the livestock.

To re-vegetate bare soils, hand tillage and mulching has been shown to be effective in stimulating plant re-growth, especially important for self-establishment of trees (Chase & Boudouresque, 1987; Kessler *et al.*, 1998). Alignments of dead wood and small stones along the contour of the land also showed to be beneficial in the regeneration of woody vegetation (Kessler *et al.*, 1998). Branches from trees and shrubs are used by farmers in Niger on bare, crusted spots on fields for soil structure regeneration (Sterk & Haigis, 1998). Application of mulch supports the restoration of natural vegetation, because mulch stimulates the activities of termites, which effectively break up the soil crusts (Mando, 1997). Besides mulching, light grazing can also be beneficial for land rehabilitation (Kessler *et al.*, 1998) as livestock is useful for opening up crusted soils (Hiernaux, 1992 cited in Kessler *et al.*, 1998).

Attempts at reforestation in the West African Sahel have not met with any long-term success, even when indigenous species were planted. Exceptions were only reported from trials with *Acacia senegal* and *A. tortilis* in Senegal (LeHouérou, 1989). Other projects in Mali, Burkina Faso and Niger showed that large-scale planting of trees was financially non-profitable, thus the approach changed to regeneration of spontaneous woody vegetation (Kerkhof, 1990). Reforestation in the Sahel does not appear impossible, but extremely difficult and needs to be long-term oriented (Wickens, 1997). Thus, it is very important to manage the still existing forested areas, a goal which can be achieved by community-based forest management, as an example from Niger shows (Peltier *et al.*, 1995). But, management plans of natural forests often needs revision as the role of fire and grazing, as well as the planting and cutting patterns of woody species was not considered sufficiently (Orr, 1995).

The technique to re-establish natural shrub and tree species in fields has already been discussed above (Taylor & Rands, 1992). It has become a standard practice in many villages, although many initial hurdles such as strong social pressure against innovation, the traditional image of being a clean farmer, one who completely cleans its farm of non-crop species, theft of trees for wood or perceived crop yield reduction due to competition, had to be endured until farmers recognized the various benefits (Rinaudo, 1996). A management system which was developed in the past, is the so-called agricultural parks, areas where trees are protected or promoted on fields and fallow land for fruit production and soil fertility management (Krings, 1991; Sturm, 1998).

In general, maintenance of vegetation cover, sufficient to protect the soil against erosion, is a serious problem as vegetation is used in many ways by both man and livestock. Management of trees and shrubs is extremely complicated as customary and state land tenure as well as user rights are often contradictory or discourage the conservation of the woody vegetation (Neef, 1999). On community land, unregulated individual use of natural vegetation and subsequent degradation is frequently reported. In Sahelian Burkina Faso for example, the bush is considered by the people as an unending resource, only dependent on the amount of rainfall, and therefore any traditional strategies for its conservation have not been developed (Knierim, 1991; Krogh & Paarup-Laursen, 1997). In a project for the rehabilitation of sylvopastoral land in Burkina Faso, community-based management was increasingly neglected, and after a 5-year period exploitation levels reverted back to normal (Kessler *et al.*, 1998). This was attributed to socio-economic issues, including insufficient insights into the norms and values attributed by the villagers to such low-potential sylvopastoral lands. Although certain ethnic groups have quite sophisticated pastoral management techniques, where they consider the seasonally changing ecological conditions (Schareika *et al.*, 2000), the sustainable management of most grazing land implemented by mobile or sedentary herders on a regional level is not existent in Sahelian West Africa and it will be very difficult to establish one within the near future.

Conclusions

A broad variety of resource conservation techniques exist in the Sahelian countries of West Africa. Most of them are effective to combat soil degradation as well as to protect soils from wind and water erosion. However, each technique has its limitations. Unfortunately, many of the traditional conservation techniques are only locally or regionally known. The restricted availability of mulch materials, animal manure and fertilizer also inhibits most soil conservation efforts. In addition, the application of fertilizers or manure on all fields is constrained by the precarious economic situation in many rural households. The intensive use and in some areas severe degradation of the natural vegetation will be difficult to be stopped since many people rely on the collection of fire wood or parts of plant species for both human consumption and medicine. Furthermore, farmers traditionally clear areas for new fields or cut down shrubs when annually preparing their fields. Only a few strategies such as natural regeneration and to a smaller extent agricultural parks are promising.

It will be even more difficult to establish management systems for the sustainable use of those communal grazing lands and forest areas, where traditional systems have not yet adjusted their strategy, although the natural resources have become increasingly limited. In some cases land tenure legislation and user rights often counteract the conservation objectives. However, the management of common resources should be given to their immediate users. Some development projects have assisted local communities to develop responsible management for a sustainable and efficient use of their local natural resources (see Reij *et al.*, 1996; Kessler *et al.*, 1998). Local non-governmental organizations can play a significant role. They are usually operating close to the target group, and therefore have a good understanding of local needs and constraints as well as being able to efficiently use local knowledge.

While the high growth rate of the population causes enormous land pressure, local communities should be supported through the wider dissemination of local knowledge as well as a blending of local and modern techniques for the various conservation of the natural resources in the Sahel. Participation of all stakeholders will be the crucial element for the development and adoption of new techniques.

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