

# Conservation agriculture with trees in the West African Sahel – a review

Jules Bayala, Antoine Kalinganire, Zac Tchoundjeu,  
Fergus Sinclair, Dennis Garrity





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## Executive summary

In the Sahel, the traditional parkland systems, which are the main providers of food, incomes, and environmental services, are rapidly degrading. In spite of the desperate situation, there is a growing number of cases which document success in crop, livestock and forest production, in environmental management, in empowerment and capacity building of farmers, and in a mix of all these. Thus, there is a need to better understand the drivers of such successes as well as the circumstances in which they work, to serve as a basis for future actions. This paper looks at how we can draw lessons from success stories of conserving vegetation cover in the Sahel and enhance the role of parkland systems through conservation agriculture with trees (CAWT). Conservation Agriculture (CA) refers to farming practices that contribute to three key principles, namely, reducing soil disturbance, maintaining soil cover and crop rotation/association. These practices are more specifically CAWT, where a woody perennial is used as a technological element within the practice. The geographical scope of the review covers four Sahelian countries, which are Burkina Faso, Mali, Niger and Senegal.

A systematic collation of CA and CAWT practices in the Sahel was carried out for the four Sahelian countries. These were grouped into six main categories: (1) parkland trees associated with crops, (2) coppicing trees, (3) green manure, (4) mulching, (5) crop rotation and intercropping, and (6) traditional soil/water conservation. In general, yield improvement

occurs where the productivity potential of the soil was low for the key staple food crops which are maize, millet and sorghum. Coppicing trees and rotations appeared to be better adapted for zones with an annual rainfall of over 800 mm. Mulching seemed to improve crop yields when the rainfall is below 600 mm. Trees can play a key role in stabilizing the soil and water conservation structures provided the most suitable species are identified. For all practices involving the tree component, application of appropriate tree management to reduce crop yield losses while still providing products and services for long-term sustainability of the production systems in the drylands of West Africa is needed.

From the livelihood standpoint, low-cost techniques like FMNR can be upscaled regardless of the wealth status of the farmer. However, there is need for collective commitment to avoid the destruction of young seedlings by free roaming livestock. There is also need for clear ownership of preserved trees through forest laws or local by-laws authorizing such practices even on borrowed lands as in Bankass district, Mali. For the labour-intensive or resource-demanding techniques such as zaï, there are some prerequisites for their larger adoption and/or adaptation. They need to be developed and applied in conditions where people have no alternative but to reclaim their degraded lands due to high human and animal pressure, such as the Central Plateau of Burkina Faso, the Maradi region in Niger and the Dogon Plateau in Mali.

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## Abbreviations & acronyms

AAFBA	Association Africaine de la Fixation Biologique de l'Azote
AFRENA	Agroforestry Research Networks for Africa
BNF	Biological N <sub>2</sub> Fixation
CA	Conservation Agriculture
CAWT	Conservation Agriculture With Trees
CES/AGF	Conservation des Eaux et des Sols/Agroforesterie
CFA F	Franc de la Communauté Financière Africaine
CIEH	Comité Inter Africain d'Etudes Hydrauliques
CIEPCA	Centre d'Information et d'Echanges sur les Plantes de Couverture en Afrique
CILSS	Comité Permanent Inter-Etats de Lutte contre la Sècheresse dans le Sahel
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CIRDES	Centre International de Recherche/Développement sur l'Elevage en zone subhumide
CNRA	Centre National de la Recherche Agronomique
CNRF	Centre National de Recherche Forestière
CNRST	Centre National de la Recherche Scientifique et Technologique
CRESA	Centre Régional d'Enseignement Spécialisé en Agriculture
CTFT	Centre Technique Forestier Tropical
DAP	Days After Planting
DEF	Dryland Eco-Farm
DM	Dry matter
DPF	Département Productions Forestières
FAO	Food and Agriculture Organization
FMNR	Farmer-Managed Natural Regeneration
FMAFS	Farmer-Managed Agroforestry System
GRN/SP	Gestion des Ressources Naturelles et Systèmes de Production
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (Coopération Technique Allemande)
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDESSA	Institut des Savanes
IDR	Institut du Développement Rural
IER	Institut de l'Economie Rurale
IFPRI	International Food Policy Research Institute

IITA	International Institute for Tropical Agronomy
INERA	Institut de l'Environnement et de Recherches Agricoles
IPNM	Integrated Plant Nutrition Management
IPR	Internal Profitability Rate
IPR-IFRA	Institut Polytechnique Rural de Formation et de Recherche Appliquée
IRAT	Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières
IRBET	Institut de Recherche en Biologie et Ecologie Tropicale
ISRA	Institut Sénégalais de Recherche Agricole
IWMI	International Water Management Institute
MDG	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
Ndfa	Nitrogen derived from atmosphere
NGO	Non-governmental Organization
NPK	Nitrogen, Phosphorus, Potassium
NPT	Natural rock Phosphate of Tilemsi
ORSTOM	Office de Recherche Scientifique et Technique d'Outre Mer (current IRD -- Institut de Recherche pour le Développement)
PDRAA	Projet de Développement Rural de l'Arrondissement d'Aguié
PRODS/PAIA	Intergrated Production Systems -- Priority Area for Multi-disciplinary Action
RCS	Renforcement des Capacités Scientifiques du Sahel
RPT	Rock Phosphate
SAD	Djenné Agricultural systems project
SALWA	Semi-Arid Lowlands of West Africa
SEF	Sahelian Eco-farm
SIM	Serving In Mission
SWC	Soil and Water Conservation
TLU	Tropical Livestock Unit
TSBF	Tropical Soil Biology and Fertility Institute
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPB	Université Polytechnique de Bobo-Dioulasso
USA	United States of America
WCA	West and Central Africa

## Acknowledgements

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## Key words

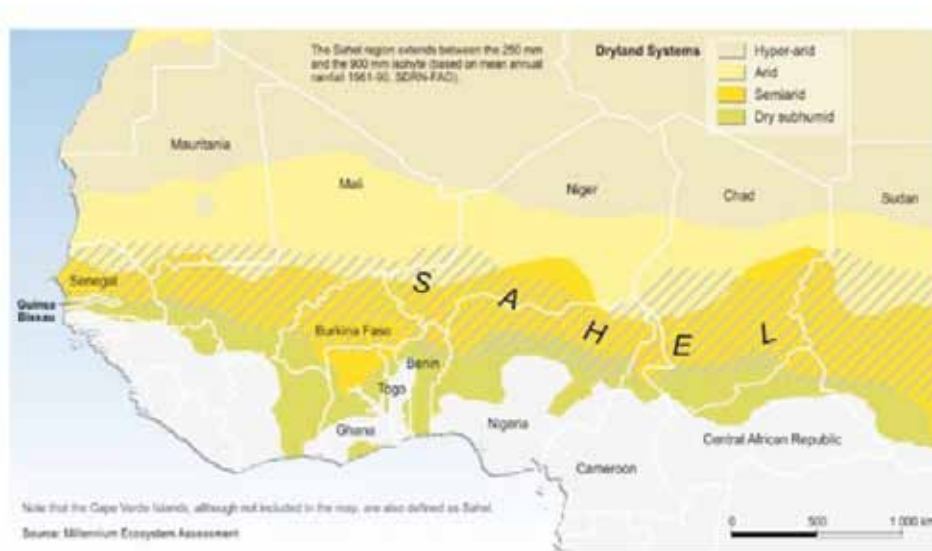
Conservation agriculture, ecological niche, livelihood system, parkland system, soil and water conservation, vegetation cover

## Background information and problem definition

The Sahel (Arabic *Sahil*), refers to the semi-arid region of Africa between the Sahara to the north and the savannas to the south. This belt stretches across the southern edge of the Sahara desert, over 6000 km from the Atlantic coast of Senegal and Mauritania in the west to the Red Sea coast of Sudan in the east with a north-south width of 400 to 600 km (Figure 1). From the late 1960s the Sahel was afflicted by a prolonged and devastating drought that further reduced the region's normally meagre water supplies, shattered its agricultural economy, contributed to the starvation of an estimated 100,000 people, and forced the mass migration southward of many people. Although rainfall and international relief efforts helped, drought and famine affected the Sahel again in the mid-1980s and early 1990s.

The Sahel cuts across 10 nations, which are among the poorest of the world, and is home to about 50 million people, the majority (85%) of whom practise subsistence agriculture (Hiernaux and Turner 2002). Therefore, developing sustainable agriculture will play a crucial role in addressing food and income

security and eradicating poverty. In order to achieve the Millennium Development Goals, agricultural productivity in many sub-Saharan countries will need to dramatically increase, at a rate of about 6% per year, without harming the environment. However, agriculture-poverty-environment linkages are particularly important in the Sahel, due to the semi-arid environment and extreme poverty levels. The Sahel is characterized by a 9-month dry season and frequent droughts during the short rainy season. Abject poverty is prevalent and the population growth rate at 3% per annum exceeds the food production growth rate of only 2% per annum. The traditional parkland systems (integrated crop-tree-livestock systems), which are the main providers of food, nutrition, income and environmental services, are rapidly deteriorating—woody biodiversity and cover is being lost, and soil fertility is declining from already low levels through exhaustive cropping practices and soil erosion (Bationo et al 2003). The restoration and protection of these Sahelian parklands is vital for the future welfare of over 43 million people living in the semi-arid drylands of West Africa (Bonkougou et al 1998).



**Figure 1:** Map of the Sahel (From Millennium Ecosystem Assessment report on Ecosystems and Human Well-Being Desertification Synthesis)

Despite the desperate situation in the Sahel, there is a growing number of cases which document success in crop, livestock and forest production, in environmental management, in empowerment and capacity building, and in a mix of all these (Reij and Smaling 2008). Such positive developments do not receive the level of global attention as some of the “big” studies do. Niger offers a striking example of how positive trends have remained unrecognized (Reij and Smaling 2008). In the Maradi and Zinder regions of this country, many farmers have been protecting and managing natural regeneration on their cultivated fields since the 1980s. This has resulted in a substantial re-greening, in particular in the most densely populated parts of the country (Reij and Smaling 2008). A similar situation can be observed on the Central Plateau of Burkina Faso (Belemviré et al 2008). Thus, there is need to better understand the drivers of such successes as well as the circumstances in which they work to serve as a basis for future actions.

The present synthesis aims at looking at how we can draw lessons from success stories of conserving vegetation cover in the Sahel and enhance the role of parkland systems through evergreen agriculture or conservation agriculture with trees (CAWT). This review has been validated by partners from the Sahel region and also from eastern and southern Africa during a workshop held in Bamako, Mali, in March 2010.

## Scope of the review

The main objective of this review is to identify researchable constraints and evidence for where and when trees do contribute to maintaining productivity by reducing soil disturbance, maintaining permanent soil cover and using crop rotations. This is deliberately focused and analytical because:

- A necessarily descriptive review would be repetitive of existing descriptions of farming systems in the region and beyond the scope of the resources available
- A view of ‘production systems’ is outdated (Sinclair 1999) – farming practices that integrate crops, trees and livestock are nested within more complex livelihood systems, rather than having system properties themselves (Figure 2), and some of these practices are conservation agriculture (CA)
- While targeting CAWT, we need to focus on rigorous evaluation of available knowledge and the potential for its expansion in a Sahelian context,

rather than reviewing the whole farming system context of the region

- Analytical, as opposed to descriptive, outputs can be readily commented on by other key scientists, and will be directly useful in a) developing customized recommendations from existing knowledge, and b) identifying knowledge constraints and research needs.

The geographical scope of the review covers the following countries: Burkina Faso, Mali, Niger and Senegal.

## Definition of concepts

### CA and CAWT

Conservation agriculture (CA) is a combination of tested technologies and/or principles in agricultural production. CA is a toolkit of agricultural practices that combines, in a locally adapted sequence, the simultaneous principles of reduced tillage or no-till; soil surface cover and crop rotations and/or associations, where farmers choose what is best for them. CA as a concept for natural resource-saving, strives to achieve acceptable profits with high and sustained production levels while concurrently conserving the environment (FAO 2009). We are adopting a broad view of CA as farming practices that contribute to three key principles: reducing soil disturbance, maintaining soil cover and crop rotation/association. These practices are more specifically CAWT, where a woody perennial is used as a technological element within the practice. We are particularly interested in defining how and where trees will enhance CA within the Sahel by providing key functions.

### Techniques, systems, practices and technological elements

A technique is an ordered set of operations with a production purpose which can be described independently of the farmer or the herder who implements it. In turn, practices are related to the operators and in particular to the conditions in which they carry out their business: natural environment, production system, family status, etc. (Elis 1993; Sinclair 1999). Peasant practices are the result of accumulated knowledge and know-how and are related to the environment, the perception of the farmer or herder, and the use of the practice; while the

techniques can be external to the area, that is, technical innovation and technical theme introduced in the framework of development operations (Elis 1993).

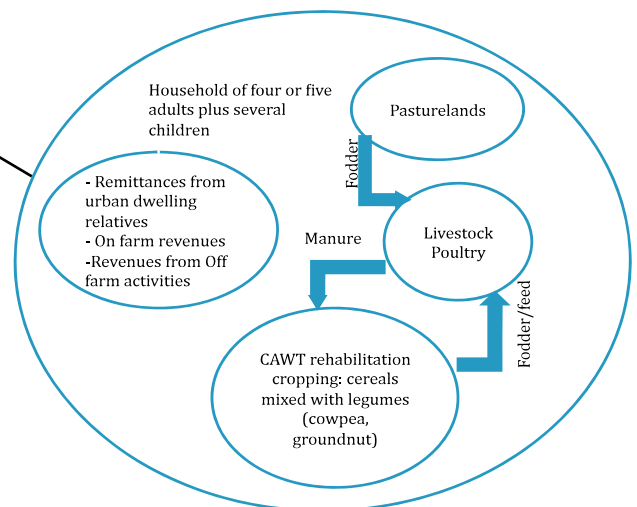
The nesting of farming practices within livelihood systems has been established below whereas practices represent combinations of technological elements that work under given circumstances. Technological elements are particular components (e.g. food crops, cover crops, trees) and/or methods (e.g. planting basins, ripping, mulching). A technological element is an indivisible component of a farming practice but several technological elements are combined in any CA practice – which has to be defined by the rotation length. We can talk generically or more specifically about technological elements (e.g. cover crop, herbaceous cover crop, *Crotolaria juncea*, *C. juncea* established through relay cropping with staple food crop at the end of the rainy season) depending on what is appropriate. Information is usefully held at different levels of specificity, for example, some information could be relevant to all herbaceous cover crops, while other information only to *C. juncea*. Therefore, taking an example from northern Burkina Faso, there is widespread CA practice on small portions of the degraded lands (referred to here as rehabilitation cropping) (Figure 2):

- Mulching (biomass transfer from tree and shrub species mixed in the field and from neighbouring fields)
- Dry pit planting (consists of digging a pit about 3-5 cm deep with a hand hoe or a direct-seeder

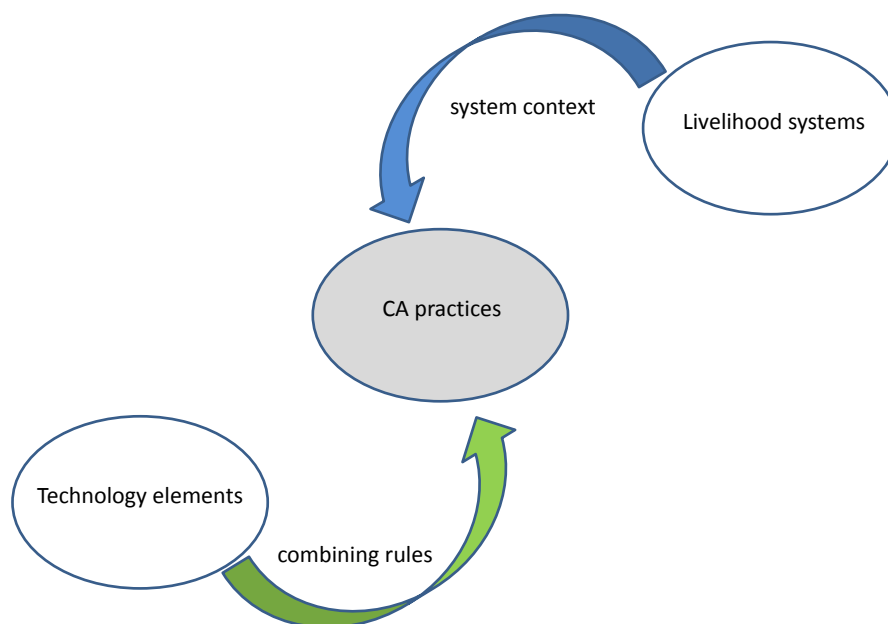
and adding the grains before the first rains when the soil is still dry) of sorghum and cowpea before it rains or after the first major rain

- Conventional harvest of sorghum at the beginning of the dry season (may also harvest fruits from some trees, e.g. *Piliostigma reticulatum* for cattle fodder during the dry season)
- Dry pit planting of the next crop before it rains or after the first major rain
- Rotation is not fixed – but sorghum and pearl millet are interchanged depending on farmer forecast for the rainy season (millet if less rain is anticipated). Legumes (cowpea) are intercropped rather than rotated.

The system context could be better understood by disaggregating the other farming practices, indicating what land types are used for what practices and associating actors (men, women, children) that are involved in different practices. In this way, practices can be seen as a central integrating management entity that combine technological elements within a livelihood system context (Figure 3). The review needs to include an inventory of technological elements, and what we know about how to combine them in specific system contexts. Clearly improvement of the system can occur through improvements of the CA practices, though we must recognize that other improvements to the livelihood systems could be equally or more effective. There are likely to be tradeoffs between improving CA practices and other interventions.



**Figure 2:** Example of a CAWT practice within its system context in Burkina Faso



**Figure 3:** CA practices as the central management entity that integrates technological elements within a livelihood systems context

## Hypotheses and aims

The hypotheses are:

- Promotion of CA in the Sahel will bring development benefits (principally enhanced food security and resilience of environmental productivity)
- The integration of woody perennials within CA practices, at least in some cases, will enhance development benefits (products and environmental services).

Thus, what this review needs to provide is:

- Systematic collation of the evidence on CA and CAWT practices in the Sahel along a continuum from experiments, via practical trials to farmer practices
- Systematic collation of the evidence of the costs and benefits associated with use of CA and CAWT practices within their system context, and an assessment of opportunities for their improvement
- Identification of key cropping practices and livelihood system contexts where CA and CAWT are not currently practised but their promotion has potential to make development gains (together with potential for improvement, this is the priority domain)
- Systematic collation of information available on CA and CAWT technological elements and how they are combined in specific practices that can be used to recommend promotion of specific practices in the priority domain
- Key knowledge gaps and constraints, and hence prioritized research needs required for promotion of CAWT in the region.



## Conservation agriculture practices in the Sahel

The review of practices is organized by country since research and development approaches have distinct national characteristics. Within each country information has been organized by agroecological zone, determined primarily by rainfall. There are other factors which are likely to be drivers and determinants of the role of different practices, notably population density and access to markets (Wood et al 1999). However, information on these is not always available in the documents reviewed, and so cannot be used to organize the results.

### Conservation agriculture practices in Burkina Faso

#### On-station experiments in Burkina Faso

On-station experiments were more focused on mulching using a range of vegetation materials (wild grass, cereal residues and tree biomass, both leguminous and non-leguminous) in the semi-arid area and very often in association with soil and water conservation techniques. In turn, the scientists in the more humid zone which is located in the southern part of the country were more interested in the cover crops and rotation cropping systems (Traoré and Zougmore 2008).

#### *Northern and central zones*

In the northern and central parts of the country (300–800 mm rainfall per year), material screening work was done by Zougmore (1999). Eight herbaceous leguminous cover plant species were compared with natural fallow. The experiment was carried out in Saria agricultural research centre and the screened materials were *Mucuna pruriens* var. *utilis*, *M. cochinchinensis*, *Mucuna* spp. Rajada, *Mucuna* spp. Ghana, *Mucuna* spp. Nagaland, *Dolichos lablab*, *Canavalia ensiformis*, *Cajanus cajan* and natural fallow. The land cover rate was faster for *Mucuna* spp. followed by *Canavalia ensiformis* and *Dolichos lablab*. Among the tested *Mucuna* species, *Mucuna* spp. Nagaland, *Mucuna* spp. Rajada and *Mucuna* spp. Ghana were the most suitable for this semi-arid area. These species have good germination rates and grow faster (at 95 DAP (days after planting), average total dry biomass ranged from 6 to 9 t ha<sup>-1</sup>) and

as a result can protect the land against soil erosion only four weeks after sowing. *C. ensiformis* was also well adapted to the local conditions but its land cover rate and the quantity of biomass produced were lower than the *Mucuna* species. All tested species were able to complete their growth cycles and produce seeds, which is important for availability of the seeds locally to allow for up-scaling of this practice. However, roaming livestock and termites constitute real constraints. If the first constraint can be handled through new forms of social organizations, the problem of the termites may not be easy to solve as they also play an important ecological role in soil physical properties (Mando 1997) and large scale spraying with insecticide is out of reach of local people in that region.

In addition to cover plants, tree/shrub leaf and twig biomass can also be used as mulch materials to reduce soil erosion, improve soil fertility and crop performance. Thus, another experiment, conducted in Saria, compared the effect of different mulch materials (control, *Azadirachta indica* leaves, *A. indica* leaves plus aerobic compost of sorghum straw, aerobic compost, *Acacia holocericia* phyllodes, and wild grass) on soil variables and crop performance (Tilander and Bonzi 1997). The mulching rate was 5 t dry matter ha<sup>-1</sup>, and base mineral fertilizers were applied to all plots. The results showed that *A. indica* leaves, *A. indica* leaves plus compost, wild grass and *A. holocericia* phyllodes treatments all significantly influenced the soil by conserving water and reducing temperatures compared with the control or the treatment with compost alone. Plots treated with *A. indica* leaves, *A. indica* leaves plus compost or compost alone gave higher yields than the three other treatments, which were generally poorer in nutrients. *A. indica* leaves gave the highest grain yield (1.54 times greater than the control), corresponding to a grain yield increase of 554 kg ha<sup>-1</sup> when averaged over the three years of the study. The highest yields were achieved with mulch that combines high nutrient delivery with water conservation and temperature reduction, namely the mulch of *A. indica* leaves (Tilander and Bonzi 1997). The use of *A. indica* leaves as mulch is widespread in an area of 3 km radius around the homestead in many villages of Bulkiemdé Province on the Central Plateau of Burkina Faso (Bationo et al 2004). However, no information was given by Tilander and Bonzi (1997) on the land area needed to produce the 5 t of mulch they have tested. Similarly, Bationo et al (2004) failed to provide some information on the quantities of leave produced and used or their effect on soils.

An alternative to working with the products of tree individuals of unknown age and density is to actively produce the biomass through plantations of known spacing allowing a much easier estimation of the land area required for the needed rate of biomass to be applied per unit of land. That is what Dibloni et al (1999) have tried by evaluating the effects of *Faidherbia albida*, *Albizia lebeck* and *Prosopis africana* planted at different spacings on soil fertility and sorghum yield at Saria research station. Seven years after the establishment of the experiment, the survival rates were 86% for *F. albida*, 75% for *P. africana*, and 36% for *A. lebeck*. However, lack of funding hindered the initiators from reaching the stage of the management of the biomass produced by the planted trees (Dibloni et al 1999). A visit in 2009 of this experiment (18 year after it was started) showed that only *P. africana* had survived in that semi-arid environment while the two other species had almost disappeared from the site, probably due to water stress during the dry seasons (Pers. observation). All the above mentioned difficulties did not allow the generation of data on the way to manage the trees and the biomass they could have produced.

CA practice can also be a combination of techniques like stone bunds and grass strips combined with fertilizers (compost and mineral fertilizers) and evaluated on station. Water runoff was reduced by 53% using stone bunds and 45% using grass strips. These erosion control structures, when associated with the compost, improved sorghum grain yield by 106% and 160%, respectively (Zougmore et al 2003). While trees have been used to stabilize such structures there appears to have been no systematic evaluation of their effect.

Finally, cereal-cowpea intercropping, which is a common practice, was tested for its ability to control soil erosion in the Central Plateau where runoff on bare soil amounts to 40% of annual rainfall and soil losses reach 4 to 8 Mg ha<sup>-1</sup>, despite slopes under 3%. Several studies have shown that mulching the soil surface can reduce runoff by over 60%. However, the scarcity of straw and the incompatibility of mulching with mechanical soil preparation have hindered large-scale adoption of the technique. Cereal-legume intercroppings were tested as alternatives to mulching using wild grass or crop residues. Results after three years showed that sorghum-cowpea intercropping reduced runoff by 20-30% compared with a sorghum monoculture, and by 45-55% compared with a cowpea monoculture. Soil loss was also reduced by at least 50% using intercropping compared with sorghum and cowpea monoculture. Moreover, it appeared that

sorghum-cowpea intercropping is also beneficial in agricultural production terms, since the grain yield of the intercropped plots was double that obtained with sorghum or cowpea monocultures. The better crop production can be an asset for the widespread use of this technique in the country (Zougmore et al 2000; 2004). The high potential for adoption is also related to the fact that the technique is well known by local people, but their practice of mixing cereal and cowpea seeds in the same pits (Photo 8) increases the competition for growth resources. The tested approach separated the lines of cereal from those of the legume crop, e.g. one line of cereal for one line of cowpea (Zougmore et al 2000; 2004). Despite separating crop lines, the above reported experiments failed to show how the intercropping helps to reduce the interspecific competition. Nor, is it clear how intercropping reduces the problem of insufficient or competing uses for crop residues, one of the key constraints of using them as mulch and ground cover.

### *Southern zone*

Similar to the northern and central parts of the country, screening work was carried out from 1994 to 1998 in the southern zone (rainfall 1000-1200 mm). Forty-five (45) cover crop species were introduced and evaluated at Farako-bâ research station (Segda et al 1997; Segda and Toé 1998). *C. cajan*, *Mucuna cochinchinensis* and *M. pruriens* var. *utilis* produced the most dry matter with 18 t ha<sup>-1</sup>, 9 t ha<sup>-1</sup> and 8.5 t ha<sup>-1</sup> respectively. The N content of these cover crops varied from 1.65% to 3.95%, which makes 61 to 650 kg ha<sup>-1</sup> of N accumulated in the biomass. In the same research station the effect of P application on *M. cochinchinensis* biomass production was studied in a 1-year experiment (Musabimana 1998). As expected, P application significantly improved *Mucuna* biomass production. However, the highest P dose (120 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>) applied as TSP negatively affected *Mucuna* biomass production whereas the acidulated rock phosphate of Burkina applied at 60 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> generated the highest *Mucuna* biomass production, and can therefore be considered the best P fertilization technique for cover crop biomass production in the region (Musabimana 1998).

As the results of the screening showed good potential of these legume crops to replace the natural fallow, the five most promising species (*Calopogonium mucunoides*, *M. cochinchinensis*, *M. pruriens*, *Lablab purpureus* and *C. cajan*) were used in a one-year improved fallow (Segda et al 1997; Segda and Toé 1998). All the biomass produced after that year was completely incorporated in the soil by ploughing and the natural fallow was considered as control. The effect of these cover plants on cereal (maize and sorghum) productivity showed a grain yield benefit from 300

to 950 kg ha<sup>-1</sup> depending on the legume species (Segda and Toé 1998). In a rice farming system, *Calopogonium mucunoides* Desv. and *Macroptilium atropurpureum* (cd.) Urb. were used as short duration fallows and the results also showed significantly higher rice yield as well as a reduction in weed infestation in the improved fallows compared with the control treatment (INERA 1996). Cover plants were also tested within cropping systems on acidic soil after the following treatments: natural fallow, improved fallow (*Mucuna*), cotton, maize, maize/*Mucuna* intercropped, sorghum, and sorghum/*Mucuna* intercropped (Segda et al 1998b). The following year, two N treatments were applied (0 and 60 kg N ha<sup>-1</sup>) and all plots were planted with upland rice to evaluate the residual effects of various cover crops and management systems. The results showed that the biomass of *Mucuna* was reduced by 52% when mixed with maize and by 71% when mixed with sorghum. Cereals grain yields were reduced by 9% for sorghum and 5% for maize when they were mixed with *Mucuna*. The weed pressure was decreased in the *M. cochinchinensis* plots whether in monoculture or intercropped. Upland rice yield was significantly higher in improved fallows than in the natural fallows (Segda et al 1998b).

Similarly, the effects of *Mucuna* on maize and cotton productivity on degraded soil in Farako-Bâ research centre were evaluated by Traoré et al (1998) based on four farming systems: maize-cotton, cotton-maize, (maize+*Mucuna*)-cotton, and (cotton+*Mucuna*)-maize. The maize and cotton were fertilized according to the recommended doses and the biomass produced by both the *Mucuna* and the crops was kept on the plots. In the second and third years, cotton and maize were directly planted under the mulch. The production of biomass in mixed plots was 11 t ha<sup>-1</sup> on average for the *Mucuna*/maize and 13 t ha<sup>-1</sup> for *Mucuna*/cotton (Traore et al 1998). During the first year, crop grain yields were higher in mono-cropping than in intercropping. Crop grain yield reduction was about 15% for maize and 50% for cotton. However, during the second year, the use of the mulch of *Mucuna* generated a yield benefit from 200 to 1000 kg ha<sup>-1</sup> for succeeding maize and sorghum (Traore et al 1998; Segda et al 1999). The results showed that when mixing *Mucuna* with crops, the cover crop

should be planted at least 40 days after the main crop is sown to avoid competition between the two plants. It is also preferable to mix the cover crop with maize than with cotton. The large quantity of biomass produced by the intercropping can be considered the most important output of the system. The biomass can be used either for land protection or as livestock feed during the dry season and the manure brought back in the field.

In a cereal-legume rotation experiment, the effects of two legumes on soil N availability and succeeding sorghum (*Sorghum bicolor*) yield was assessed by Bado et al (2006). Groundnut fixed 8 to 23 kg N ha<sup>-1</sup> and the percentage of N derived from the atmosphere varied from 27% to 34%. Cowpea fixed 50 to 115 kg N ha<sup>-1</sup> and the percentage of N derived from the atmosphere varied from 52% to 56%. Cowpea-sorghum and groundnut-sorghum rotations doubled N uptake and increased succeeding sorghum yields by 290% and 310%, respectively. The results suggested that, despite their ability to fix atmospheric nitrogen, N-containing fertilizers (NPK) are recommended for the two legumes. The applications of NPK associated with dolomite or cattle manure, or NK fertilizer associated with rock phosphate were the best practices that improved biological N<sub>2</sub> fixation (BNF) of legumes and succeeding sorghum yields (Bado et al 2006). Relative increases in sorghum yield (from 12% to 37%) due to rotation with groundnut were also observed at Kouaré in the eastern part of Burkina Faso (Bagayoko et al 2000). All the above results showed the potential of crop rotation to improve productivity sustainably.

### On-farm trials in Burkina Faso

Most of the on-farm tested CA practices were geared to reclaiming degraded soils in the Sahelian zone and producing cereals, notably sorghum and millet. In the Sudanian zone the alternatives tested were introduced by research institutes and extension offices (Traoré and Zougmore 2008). The main aim of the introduced alternatives was to boost the widespread adoption of CA.



**Photo 1:** Zai as a water conservation and reduced tillage technique in the Sahel (R. Zougmore and J. Bayala)

### *Northern and central zones (300-800 mm)*

In the Sahelian zone, the climatic conditions do not allow for development of a significant amount of biomass for covering the soil surface. Thus, the strategy in this zone is not to fully respect the three principles of CA, but to use and improve existing minimum tillage practices that would be able to substantially increase crop biomass production. One of the best known practices in this domain is the zai technique. Zai is a technique for recovering encrusted soils that consists of digging holes of 20 to 40 cm in diameter and 10 to 15 cm deep to collect surface water and increase infiltration (Photo 1).

Depending on the farmers, variable amounts of organic matter (600 g hole<sup>-1</sup> approximately), such as manure or compost, are put in the hole to attract macrofauna and make the nutrients available to the plants after decomposition. Various on-farm trials revealed that the advantages of zai include reduction of erosion by slowing down the water stream, and the concentration of water and organic matter that increase agricultural production. Zougmore (1995) observed a 34% to 47% increase in soil moisture content at 0-10 cm depth in holes of zai in Passoré. The technique also improves soil structure and chemical content (Mando 1997). Finally, zai increases crop production from 0 kg ha<sup>-1</sup> when the land is not managed to 300-400 kg ha<sup>-1</sup> for zai-managed land in a year of low rainfall and 1500 kg ha<sup>-1</sup> during a good rainy season (Reij et al 2009). The practice is efficient in areas of 300 to 800 mm rainfall on very degraded land. However, its profitability decreases when the rainfall is higher than 800 mm. On bare soils, the zai technique also helps the local vegetation to regenerate: for instance, the appearance of 20 herbaceous and 15 woody species after two years of zai application was reported by Kaboré (1994). This is due to the dispersal of seeds, either by the wind or runoff water, which are then trapped in zai pits. The main constraint of the zai technique is lack of manure or compost, and the labour needed to dig the pits. To tackle these problems, INERA scientists recommended a 'mechanical zai' that consists of making appropriate holes mechanically with animal-drawn tools (Dent IR12 for sandy soils, or Dent RS8 for other types of soils). This reduces by more than 90% the amount of time required to make the pits as it takes only 11 to 22 h ha<sup>-1</sup> to dig these pits with oxen that are well-fed with crop residues. In addition, manually dug pits cost more (166 700 CFA F ha<sup>-1</sup> or US\$ 333) compared to the animal-drawn tools (93 660 CFA F ha<sup>-1</sup> or US\$ 187). Thus, the economic benefit was 165 000 CFA F ha<sup>-1</sup> (US\$ 330) for the mechanized method compared with only 17 000 CFA F ha<sup>-1</sup> (US\$ 34) for the manually dug zai (Barro et al 2005). Kaboré (2001) noted that

the relative profitability of the zai is associated with the price of the crop in the market and the high costs of the zai practice are mainly attributed to labour. Several studies in the Sahel region reported that compost or animal manure application to soil allows significant increases in sorghum grain yield, i.e. about 10-39 times (700-1500 kg ha<sup>-1</sup>) the yield obtained in the zai or half-moon basin without any amendment (< 100 kg ha<sup>-1</sup>). This remains a simple solution to reclaiming degraded lands, and to rehabilitate the agroforestry cover in the Sudano-Sahelian semi-arid area (Reij et al 1996; Roose et al 1999) since it allows, thanks to the plant seeds in the manure, the regeneration of shrubs and trees in the zai pits. The regenerated trees are protected by farmers and left to grow. These trees will later contribute to increase soil cover and organic matter, improve soil structure and fertility thus leading to better annual crop yields. The manual zai method is labour-intensive, about 60 working days for 1 ha. Despite that, Kaboré and Reij (2004) estimated the gross margins of zai per ha of about US\$ 184 and returns to labour of US\$ 0.19 per hour and US\$ 1.14 per six-hour work day.

Like the zai technique, half-moon is another method of minimum tillage used for rehabilitating sealed and crusted bare soils. Half-moon is a basin of half-circle shape with the excavated soil laid out in a semicircular pad flattened on the top (Photo 2). The half-moons are laid out in staggered lines on the contour lines to collect the runoff. A trial conducted to study the effects of this technique in association with different nutrient sources on sorghum production revealed that applying compost or animal manure at a rate of 35 kg per half-moon (equivalent to about 10 t ha<sup>-1</sup> which may not be accessible to many farmers) produced grain yields of sorghum from 900 to 1600 kg ha<sup>-1</sup>, which is 20-39 times the yield obtained in the half-moon treatment without amendment (Zougmore et al 2003). Combining local rock phosphate with compost in the half-moon basins increased sorghum yields by 10% in the first year and 26% in the second year. This study showed that restoring favourable soil moisture conditions by breaking up the surface crust to improve infiltration was not enough to improve sorghum production on the degraded land. Organic matter applied as compost or manure is needed to make the half-moon technique an efficient tool for the rehabilitation of degraded soils (Zougmore et al 2003). The effectiveness of the technique decreases with increasing soil clay content (Collinet et al 1980). Note that we refer to the technique as used for rehabilitation of degraded land rather than something that is used as an ongoing management practice. The distinction is important when considering the level of investment by farmers.



**Photo 2:** Half-moon as a water conservation and reduced tillage technique in the Sahel (R. Zougmore)



Besides tillage techniques, mulching using a range of diverse biomass sources was also tested in the semi-arid zone. Mulching consists of covering the ground with a layer of 2 cm of grass, which is equivalent to 3-6 t ha<sup>-1</sup>, or wild grass or crop residues (stems of millet or sorghum; Photo 3) in order to stimulate the activity of the termites (Mando et al 2001). In a mulching trial using composite materials (organic materials of woody plants and straws), Mando (1997) observed an increase in soil porosity (41.1% for mulch treated plot versus 36.1% for the untreated plot). He attributed this increase in soil porosity to the increase of the activity of termites, which resulted in changes in soil structure with the chambers and channels accounting for 60% of the macroporosity in the 0-10 cm layer. The sealed surface was perforated by termites resulting in many visible open voids. In addition, the application of the mulching technique in the semi-arid zones of the Sahel, where wind erosion is common, involves an accumulation of particles in the form of sediments under the mulch (Mando and Stroosnijder 1999). Mulching also facilitates the regeneration of vegetation after the first year of application and can allow the development of vegetation completely covering

bare land in the second year due to soil structure improvement and better soil water and nutrient availability (Mando et al 1999).

Mulching can also be applied using live plant mulch. For instance, most parkland trees in Burkina Faso are fruit trees that need to be managed using silvicultural practices like pruning of old individuals to induce new branches and improve fruit production. When pruning is applied, the leaves and twigs can be recycled as mulch for annual crop production. The results of a field trial on the Central Plateau showed a depressing effect of the mulch of *Parkia biglobosa* by 33% for millet grain yield (yield of control = 471±118 kg ha<sup>-1</sup>) and by 21% for total dry matter (yield of control = 1096±548 kg ha<sup>-1</sup>). However, *Vitellaria paradoxa* mulch increased grain yield by 120% (yield of control = 438±109 kg ha<sup>-1</sup>) and total dry matter by 43% (yield of control = 2624±656 kg ha<sup>-1</sup>). Fast decomposition of *P. biglobosa* leaves may have led to losses of N through leaching. Competition for P and losses of N have certainly contributed to the decline of millet performance with an increase of the amount of *P. biglobosa* mulch (Bayala et al 2003).



**Photo 3:** Mulching using millet residues in the Sahel (J. Bayala)

Synergic effects of the techniques can be sought by combining them as reported by Barro and Zougmore (2005) who tested the combination of zaï and cover crop using *Mucuna* biomass and oxen tools to dig zaï pits in view of improving soil productivity. Sorghum/*Mucuna* intercropping, *Mucuna* monocropping, and sorghum monocropping fertilized with NPK (100 kg ha<sup>-1</sup>) and urea (50 kg ha<sup>-1</sup>) were compared. *Mucuna* was planted two weeks after sorghum: one line of *Mucuna* for two lines of sorghum. The soil was prepared using the traditional zaï pits dug with a mechanical system described by Barro et al (2005). The results showed that soil was completely covered after two months in the sorghum/*Mucuna* intercropping plot. Furthermore total sorghum and *Mucuna* biomass production was comparable for sorghum mixed with *Mucuna* (3700 kg ha<sup>-1</sup>) and sorghum fertilized with NPK and urea (4000 kg ha<sup>-1</sup>). The biomass produced during the rainy season was used to cover the soil during the dry season. The use of *Mucuna* as a cover crop seems to be an effective way to increase soil productivity and farmers' incomes. The technique helps protect the soil against soil erosion and provides fodder for animals. The mechanized zaï technique using cattle traction reduced the labour from 300 h ha<sup>-1</sup> to 22 and 36 h ha<sup>-1</sup> at Pougyanga and Saria, respectively. Mechanized zaï increased soil roughness by 14% while sorghum grain yield increase was 34% compared with that obtained with the manual zaï, which is approximately 1 ton ha<sup>-1</sup> in a normal year in the northern part of Burkina Faso. The mechanization of the zaï generated a significant income that could reach 165,000 CFA F ha<sup>-1</sup> (about US\$ 330 ha<sup>-1</sup>) with sorghum cropping. It may therefore constitute an interesting alternative for increasing the income of the smallholders besides contributing to the preservation of the environment (Barro and Zougmore 2005).

At the end of a cropping phase, the fallow of degraded soil can be entirely protected from any human or animal activities (grazing, bush fire, wood harvesting) to accelerate soil fertility recovery. This practice was studied at Djibo (Rochette 1989) and Oursi (Toutain and Piot 1980). They showed that the integral protection of a piece of degraded land improves primary production and modifies the vegetation structure. Dugué et al (1994) observed a high regeneration of young shrubs and trees such as *Acacia seyal*, *A. nilotica*, *Faidherbia albida*, *Bauhinia rufescens* and *Ziziphus mauritiana* in two years. Of course farmers will later select some of the species as the most preferred and the rest will be eliminated. It should, however, be noted that the integral protection is not suitable for bare and encrusted soils because it requires the presence of a minimum vegetation cover (Mando et al 1999) or soil disturbance by superficial

scraping (Ambouta et al 1999). In cases of bare or encrusted soils, the regeneration can be accelerated by preliminary soil preparation involving a slight scraping of the soil surface to facilitate water infiltration. In addition, the application of integral protection requires negotiation between bordering communities, who share the same space and natural resources.

Grass strips are commonly used to mark the boundaries of land holdings. However, they also play the role of filtering and causing the deposit of sediments coming from the upstream of the band when established along contour lines (Mando et al 1999; Kambiré 2002). According to Lavigne-Delville (1996), the maintenance or the installation of bands along contour lines has an impact on the runoff and erosion similar to the stone rows. However, the efficiency of grass strips is related to their width, the magnitude of the runoff and the species used to build the band (Benoit and Pastor 1997). Damage due to cattle and competition for nutrients, water and light between the grass strips and the crops are limiting factors to this technique. Kambiré (2002) showed that cutting *Andropogon* spp. plants in the strips during crop growing period reduces the competition with sorghum plants. That led to an increase in the yield in the cut plot compared with the uncut control strips.

#### *South zone (rainfall 1000-1200 mm)*

In the south Sudanian zone, INERA and FAO have, since 2002, developed a very promising cropping system through the PRODS/PAIA project dubbed, Developing integrated farming system/priority domain for disciplinary action (Koné 2007; FAO 2009). The main objective of the initiative was to show the possibility of achieving sustainable agriculture through adequate crop management of fragile arable lands. A cover crop (*Mucuna*), double-purpose cowpea (giving both grain and fodder) and crop residue effects on the improvement of soil fertility, soil water conservation and animal nutrition during the dry season were tested in combination with tillage (tillage, no-tillage). The experiment was carried out as pilot sites with six farmers from six villages in western Burkina Faso. In the no-tilled plots, crop residues were left in the field during the entire dry season while in the tilled ones the residues were collected and removed from the fields. Keeping crop residues in one case and removing them in another case introduces a bias in terms of the amount of organic matter and also a risk of N immobilization on mulched plots. The no-tillage plots were treated with a herbicide (ROUNDUP) at the dose of 2-4 litres ha<sup>-1</sup> before sowing. Plots were protected during the first year by an iron fence:

inside the iron fence a vegetative band of *Ziziphus mucronata* and *Acacia nilotica* was planted to replace the iron fence later. In the no-tillage plots, the crops were sown directly under the mulch and the other agricultural operations were similar for the two plots except land preparation. In the maize/*Mucuna* intercropped plots, *Mucuna* (Photo 4) was sown 40-45 days after sowing maize to allow the cereal to avoid the strong competition of the *Mucuna*. In cowpea/maize intercropping, two rows of maize were sown for three rows of cowpea. The impact of the land preparation



**Photo 4:** Cover crop (*Mucuna* sp) in western Burkina Faso (K. Traoré)

### *Both zones*

Parklands not only contribute to increased soil cover through tree crown cover but also through senescent leaves that constitute in some spots a layer of mulch covering the soil depending on the decomposition rate of the leaves. Trees do not necessarily contribute to the two remaining principles of CA that are minimum soil disturbance and rotations, but they do for association.

*Faidherbia* parklands have been evaluated by many authors in Burkina Faso (Sanou 1993; Dembelé 1994; Ouédraogo 1994; Depommier 1996; Roupsard 1997). In a nursery experiment in Ouagadougou, Roupsard (1997) found 9% of fixed nitrogen (%Ndfa) for Dossi provenance (Burkina Faso), 13% for Matameye provenance (Niger) and 45% for Gihanga provenance (Burundi) resulting in large differences in early growth. In the field, a general decreasing trend of C and N contents going from tree trunk to the open area was registered by Depommier et al (1992). Gnankambary et al (2008) also reported higher availability of P and N under *F. albida* than in areas beyond their canopies. A pattern with low yields next to *Faidherbia* trunks and highest yields at the crown edge and gradually diminishing from there onward was observed for sorghum in Bazèga, Dossi and Watinoma (Maiga 1987; Depommier 1996). In an attempt to address the issue

technique differed according to the cropping system. No significant difference was found for biomass yield between tilled and non-tilled plots. The results also showed that mixing maize and cowpea IAR7 (an improved variety) can give better maize grain yield than when maize was mixed with local cowpea or *Mucuna*. The mixed cropping maize-*Mucuna* gave the lowest maize grain yields. This is similar to the findings reported in earlier research (Segda et al 1998a; Traore et al 1998).



of low quality of the litter of some parkland species, Gnankambary et al (2008) evaluated the decomposition of varying proportions of litter of *F. albida* and *V. paradoxa*. The results showed that mixing litter of the two species accelerated the decomposition rate (Gnankambary et al 2008). The potential for mature trees of *F. albida* to fix the nitrogen is still unknown (Roupsard 1997).

For other parklands, many studies on the effects of trees on soil dealt essentially with chemical properties (Kessler 1992; Boffa 1995; Jonsson 1995; Tomlinson et al 1995; Bayala 2002). However, improvement of the physical properties of soil by the trees might be as important as the chemical properties in semi-arid areas because good physical properties enhance water holding capacity and ensure efficient use of applied nutrients (Bayala and Ouédraogo 2008). This review of the literature revealed positive effects of trees on soil bulk density, soil porosity and water infiltration (Mando 1997; Bayala 2002; Hansson 2006; Bayala and Ouédraogo 2008; Sanou et al 2010). Due to different inputs through root decay or leaf litter, nutrient contents were reported to be higher under trees compared with the open area (Jonsson 1995; Tomlinson et al 1998; Boffa 1999; Bayala et al 2002). Furthermore, Jonsson (1995) measured the natural abundance of  $^{13}\text{C}$  in topsoil and found lower

values under *V. paradoxa* and *P. biglobosa* trees than on control plots. Consequently, she found that the fraction of C-derived from  $C_3$  plants, calculated based on  $\delta^{13}C$ , was higher under trees than in the open due to litter from  $C_3$  plants. Similarly, Bayala et al (2006) studied the relative contributions of trees and crops to soil organic carbon in the soils of parklands of *V. paradoxa* and *P. biglobosa*. The results showed that soil carbon contents under *V. paradoxa* ( $6.43 \text{ g kg}^{-1}$ ) and *P. biglobosa* ( $5.65 \text{ g kg}^{-1}$ ) were higher than in the open area ( $4.09 \text{ g kg}^{-1}$ ). The  $C_4$ -derived soil C was approximately constant, and the differences in total soil C were fully explained by the  $C_3$  (tree) contributions to soil carbon of  $4.01$ ,  $3.02$ ,  $1.53 \text{ g kg}^{-1}$  under *V. paradoxa*, *P. biglobosa* and in the open area, respectively (Bayala et al 2006).

Despite the positive contribution of trees to soil fertility, many studies dealing with the subject have shown that yields of the cereals (millet and sorghum) are significantly reduced (by 15–60%) under tree crowns compared with their production in the open area (Maiga 1987; Boffa 1999; Boffa et al 2000; Bayala et al 2002; Zoumboudré et al 2005). Contrary to the above findings, a study on the influence of *P. biglobosa* and *V. paradoxa* on millet yield conducted during a good rainfall season showed no difference between the yields of millet under tree crowns and in the open area (Jonsson et al 1999). The reduction in crop yields was attributed to reduced light and competition for other growth resources (Kater et al 1992; Bayala et al 2002). One approach to solve the problem of light interception by tree crowns is pruning the branches. This option was tested by Bayala (2002) on *V. paradoxa* and *P. biglobosa*. The results showed better crop yield under pruned trees (Bayala et al 2002) and a good recovery of the canopy of *V. paradoxa* together with better fruit production (Bayala et al 2008). An alternative to pruning would be to plant shade-tolerant crops beneath tree crowns and shade-intolerant crops in areas outside the influence of tree crowns. This option was tested by Sanou (2010) who reported that under heavy shade of species like *P. biglobosa*, the yield of *Colocasia esculenta* (a shade-tolerant tuber crop) was higher ( $4.12 \pm 0.47 \text{ t ha}^{-1}$ ) compared with the control plot in the open area ( $2.34 \pm 0.62 \text{ t ha}^{-1}$ ). Apart from heavy shade species, some species were not very competitive even with high light demanding cereals as reported by Sanou (2010) for millet under *Adansonia digitata* and Yaméogo (2008) for maize under *Borassus akeassii*. Van Noordwijk and Ong (1999) presented arguments to explain why old parkland trees may have an overall positive effect on associated crops while younger trees do not. This has obvious consequences for parkland renewal.

## Farmer's practices of conservation agriculture in Burkina Faso

Farmer's practices related to conservation agriculture can be grouped into three main categories: (1) minimum tillage techniques (zai, half-moons); (2) biological techniques (mulching, afforestation, assisted natural regeneration); and (3) agriculture intensification (production of composts, manure). These categories are not mutually exclusive and are often combined (Photo 5).

### Zai

Zai was a traditional technique used in Yatenga (northern Burkina Faso) during drought years between 1982 and 1984. It is now widespread in the Sudano-sahelian zone and is used for recovering encrusted soils. Production increase can go up to 428% in some cases, as reported by Reij et al (2009). The cost of one hectare of zai is about 29 600 CFA F or US\$ 59. The internal profitability rate (IPR) of zai evaluated in four villages of Burkina Faso varied from 37% to 125% if only sorghum grain value was considered. When a lot of manure was used ( $10 \text{ t ha}^{-1}$ ) or millet, the practice was not profitable (Belemviré et al 2008). This approach underestimates the profitability as residues and other services were not included in the calculations.

### Half-moons

Half-moons allow for improvement of ground water reserves as well as increase in soil moisture from 20–40 cm depth. They improve agricultural production through addition of mineral or organic matter. In Burkina Faso, the technique is widespread in the Sahel region. Like the zai technique, the adoption of the half-moons application is hampered by lack of manure or compost, the high labour demand and often by issues of land tenure. Production increase varies from 49% to 112% (Belemviré et al 2008). The cost of one hectare of half-moon varies between 27,200 CFA F and 52,200 CFA F (US\$ 54 to US\$ 104). Half-moon internal profitability rate (IPR) was reported to be 92% on the Central Plateau (Belemviré et al 2008).

### Manure and compost

Manure is either collected from households and applied in the fields or applied through direct corralling of the livestock. There is a Presidential Programme for production of compost, and each year a national target is agreed upon during the Farmers' Day (an annual event during which the President meets with farmers to discuss the problems related to their activities).





**Photo 5:** Combining shrubs with soil and water conservation structures in Burkina Faso (B.A. Bationo)

Therefore, compost production is found all over the country using crop residues and local phosphate rock. However, collecting crop residues leave the soil surface exposed to wind and water erosion during the dry and rainy seasons, respectively.

### *Mulching*

Mulching is a very old and widespread technique in the sub-Saharan zone of Burkina Faso (Photos 3 and 6). It results in an increase in soil porosity which promotes water infiltration (Zombré et al 2001).

### *Natural assisted regeneration*

Natural assisted regeneration is also known as farmer-managed natural regeneration (FMNR) in Niger and comprises selecting and thinning stems which sprout from indigenous tree and shrub stumps. By selecting approximately five stems per stump and pruning side branches, and by culling unwanted stems, very rapid re-growth can be achieved. The resulting parkland is either composed of a mixture of species: *P. reticulatum* (Yélémou et al 2007), *Guiera senegalensis*, and different acacias in the north, or dominated by one species like *F. albida* in specific spots in the whole country, and *V. paradoxa* in the central and southern parts of the country.



**Photo 6:** Management of *Azadiractha indica* to produce mulch biomass and fuelwood on the Central Plateau of Burkina Faso (B.A. Bationo)

### Afforestation

Afforestation is planting of trees in the fields (Photo 7), on field borders, as woodlots in villages and as live fences to protect fields or gardens. The species used are from the village nurseries and the main ones include: *Acacia albida*, *Acacia macrostachya*, *Acacia nilotica*, *Bauhinia rufescens*, *Eucalyptus camaldulensis*, *Leuceana leucocephala*, *Mangifera indica*, *Parkia biglobosa*, *Parkinsonia aculeata*, *Prosopis juliflora* and *Ziziphus mauritiana*. Pure fruit tree plantations are more widespread in the south-western part of the country (*Anacardium occidentale*, *Citrus spp.*, *Mangifera indica*, *Psidium guayava*, etc.). The low rate of plant survival after planting as well as the absence of clear ownership may explain why plantations on communal land are less successful. Farmers do not agree to change their cropping schedule to include tree plantations. Another



problem is that the seedlings produced in the village nurseries are not always of good quality. Despite all this, *A. indica* species has been well adopted by the farmers of Burkiemdé Province on the Central Plateau because of its plasticity as reported by Bationo et al (2004).

### *Faidherbia albida* parklands

*F. albida* is common in parklands throughout the country except for the extreme southwest (Ouedraogo 1995): Markoye, Oursi and Dori in the north, in Kokologo on the Central Plateau, and in Dossi and Boni in the west. The *F. albida* parkland system is dominant in the Bwa and Samo regions extending to Senoufo, Lobi, Dagara and Birifor. It is also found in Bissa and Yatenga as practised by the Mossi, though most of the Mossi Plateau is *Vitellaria*-dominated (Boffa 2000).



**Photo 7:** Plantation of tree species on farmed fields in the Central Plateau, Burkina Faso (J. Bayala)

### Other parklands

The specific composition of other parklands varies depending on the climatic zone (Ouédraogo 1995):

- Sahelian zone: *Acacia raddiana*, *Balanites aegyptiaca*, *Combretum glutinosum*, *Hyphaene thebaica*, *Piliostigma reticulatum*
- Northern Sudanian zone: *Adansonia digitata*, *Azadirachta indica*, *Lannea microcarpa*, *Slerocarya birrea*, *Vitellaria paradoxa*
- Southern Sudanian zone: *Anacardium occidentale*, *Azadirachta indica*, *Blighia sapida*, *Borassus aethiopicum*, *Citrus spp.*, *Cordia myxa*, *Mangifera indica*, *Parkia biglobosa*, *Tectona grandis*, *Vitellaria paradoxa*

In addition to soil cover by tree canopy, leaf litter also contributes to soil protection through “natural” mulch. It is however unfortunate that farmers gather this leaf biomass and burn it each year when preparing the land for sowing at the beginning of the rainy season (Bayala et al 2003).

### Grass strips

These are strips of herbaceous species established along the contour lines of a field, sometimes combined with other anti-erosive constructions. According to Vlaar (1992), covering anti-erosive structures directly with herbaceous species is an effective and durable method to ensure stabilization. For this practice, perennial grasses are preferred because their root systems remain in the soil throughout the year. *Andropogon gayanus* is the most widely used species because its straw can be

used to produce handicrafts and as fodder for cattle. Other species that can be used include *Bracharia ruziziensis*, *Pennisetum pedicellatum*, *Pennisetum purpureus* and *Stylosanthes hamata*. Kessler and Boni (1991) noted that strips of *Andropogon gayanus* are often used to fence fields in the central part of Burkina Faso. These strips, as anti-erosive structures, slow down surface runoff and improve its infiltration (Zougmore et al 2000).

### Association

Traditional intercropping systems are found everywhere in the country except on some fields in the cotton belt. The main reasons for intercropping are flexibility, profit, resource maximization, risk minimization, soil conservation and maintenance, weed control and nutritional advantages. In the Sahelian zone, millet is intercropped with cowpea while sorghum-cowpea association is more common in the Sudanian area (Photo 8).



**Photo 8:** Traditional and modern ways of associating crops in Burkina Faso (J. Bayala and K. Traoré)

### Crop rotation

Crop rotation is a common practice in all climatic zones of the country. Cereal-groundnut is widespread in the Central Plateau and northern part while cotton-maize-sorghum is found in the southern, western and eastern parts of the country. Sesame is also becoming an important commodity as the price of cotton continues to decline.

## Conservation agriculture practices in Mali

### On-station experiments in Mali

Planted fallows using perennial or annual species was the main type of experiment conducted in Mali. The aim was to find an alternative to shortening fallow duration in the southern part of the country.

#### Northern Sudanian zone

At the Institut Polytechnique Rural de Formation et de Recherche Appliquée (IPR-IFRA) research station of Katibougou, the influence of *Mucuna cochincinensis* fallow and the incorporation of biomass with or without natural rock phosphate of Tilemsi (NPT) was evaluated (Yossi et al 2002). The incorporation

of biomass resulted in a decrease in phosphorus irrespective of the management option of the fallow (0.31% in the plots which incorporated biomass, and 0.47% in the plots without biomass). Despite the decrease in total phosphorus content, there was an increase in the content of plant available phosphorus in plots where biomass was incorporated probably as a result of increase fauna activity. The nitrogen content and pH increased regardless of the fallow management option. The average production of sorghum total dry biomass was 9.10 t ha<sup>-1</sup>. Simple effects of fallow type and biomass management factors had a significant impact on the performance of millet. The highest yields were obtained after a fallow of *Mucuna* (2.81 t ha<sup>-1</sup>) and the incorporation of the biomass (2.85 t ha<sup>-1</sup>). The superiority of the performance after incorporation of biomass could be explained by the stimulation of telluric microflora due to the buried fresh organic matter. Another experiment tested the following treatments: sorghum plus NPT, sorghum associated with *Stylosanthes hamata* incorporated plus NPT, sorghum associated with *S. hamata* without biomass incorporation plus NPT and sorghum without NPT (Yossi et al 2002). These treatments produced a biomass of 9.35 t ha<sup>-1</sup>, 11.18 t ha<sup>-1</sup>, 8.37 t ha<sup>-1</sup> and 7.48 t ha<sup>-1</sup>, respectively. The highest yields were obtained with sorghum associated with *S. hamata* and incorporated biomass (1.91 t ha<sup>-1</sup>) and the lowest yields in pure sorghum plot without NPT. In a third experiment, management factors (incorporation and

non-incorporation), nitrogen (supply and no-supply), phosphorus (supply and no-supply) were combined in eight treatments. The results showed that soil acidity increased from 1997 to 1999 regardless of the treatment. However, the acidity was lower on plots with incorporated biomass ( $\text{pH} < 5$ ). Incorporation of the prunings of *Cajanus cajan* revealed an improvement of the soil plant available phosphorus content (37.2 % versus 26.8 % for plots without incorporation). Average yield was  $0.85 \text{ t ha}^{-1}$  (Yossi et al 2002). Green manure of *Cassia tora* at various rates with or without urea and rock phosphate RPT were compared with the farmers' practice in the Katibougou research station (Mbaikoubou, 2005). After three cropping seasons, regardless of the quantity of biomass applied, *C. tora* associated with urea and RPT increased both the grain and dry matter yields of sorghum compared with farmers' practices. The best treatment was green manure associated with 41 N of urea and  $46 \text{ P}_2\text{O}_5$  units (Mbaikoubou 2005).

Pearl millet [*Penisetum glaucum* (L.) R.Br.] and cowpea [*Vigna unguiculata* (L.) Walp] are important crops in traditional bush-fallow production systems in Mali. Human population growth is forcing farmers to consider alternative cropping systems and fertilizer application to meet food needs. To contribute to finding a solution to nutrient depletion due to continuous cropping, a long-term cropping system study with nitrogen applications of zero, 20 and  $40 \text{ kg ha}^{-1}$  was initiated in 1990 at the Cinzana Research Station near Ségou in Mali (Bagayoko et al 1996; Goita and Sidibé 2009). The field had a leached tropical ferruginous soil in the French soil classification. Nitrogen fertilizer application increased pearl millet grain and stover yields linearly per year, but had no effect on cowpea. Rotation with cowpea increased pearl millet grain yield by 17% to 31% each year between 1991 and 1995, but had little effect on cowpea yield. Intercropping reduced yields of both crops every year, but the Land Equivalent Ratio indicated a 14% average increase in land use efficiency. After four years, the soil of plots with the different cropping systems had similar levels of nutrients except for phosphorous which was higher in continuous cowpea plots. Soils of plots with all cropping systems had lower levels of pH, K, Ca, Mg and cation exchange capacity than fallow plots, indicating that all cropping systems were mining soil nutrients. This research indicates that nitrogen fertilizer application up to  $40 \text{ kg N ha}^{-1}$  and crop rotation with cowpea increase pearl millet grain and stover yield (Bagayoko et al 1996; Goita and Sidibé 2009).

Based on a survey conducted at Katibougou, Samaya and Samanko, *Combretum lecardii* and *Guiera*

*senegalensis* were identified as species of high potential for their use as green manure. The effects of applying their biomass on sorghum yield were subsequently evaluated at ICRISAT/Samanko research station in the Sudano-sahelian zone (Tangara 1996). The tested rates of N from the biomass of the two species ( $13 \text{ kg N ha}^{-1}$  and  $26 \text{ kg N ha}^{-1}$ ) were equivalent to the dose and twice the dose that farmers applied and were compared with the farmers' practice. Sorghum was sown one month after incorporating leaf biomass of the two species. The results revealed a significant difference between treatments for only the dry matter, with *C. lecardii* at  $2.5 \text{ t ha}^{-1} \text{ year}^{-1}$  and *G. senegalensis* at  $5 \text{ t ha}^{-1} \text{ year}^{-1}$  giving the highest yields. Soil analysis four years later revealed that the applied biomass was not yet mineralized enough to have any impact on soil properties (Tangara 1996). The association of *Sorghum bicolor* var MIKSOR 86-30-41 and *Stylosanthes hamata* sown before or after with or without incorporated leaves was also tested both for soil properties and crop yield improvement at ICRISAT/Samanko research station. These systems were either fertilized or not with N ( $0, 23 \text{ kg N ha}^{-1}$ ) and P ( $0, 42, 84 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ ). Organic matter increased from 0.38% to about 1.46% in the upper 0-30 cm soil layer in the system with *S. hamata* sown after *S. bicolor* and the leaves incorporated in the soil with or without N and P fertilizers. Other soil properties were also improved significantly except soil N. As a result, this system gave the best grain yield with  $2.03 \text{ t ha}^{-1}$  (Dembélé 1998).

A total of 21 species and provenances of legume plants were compared in two experiments (Coulibaly 2002). Thirteen (13) of these species were able to resprout after pruning and were included in the first experiment of a 2-year improved fallow, while those that could not be pruned formed the second experiment of a 1-year improved fallow. These two experiments were conducted in the ICRISAT/Samanko research station using sorghum as the crop, and green manure of the leaves of the tested species applied in combination with phosphate. For the 2-year improved fallow, all provenances of *Sesbania* gave the highest sorghum grain yield with  $2.1 \text{ t ha}^{-1}$  against  $1.2 \text{ t ha}^{-1}$  for the natural fallow and  $0.6 \text{ t ha}^{-1}$  for the continuous cultivation. For the 1-year fallow, *Crotalaria sp.*, *Tephrosia vogelii* and *Indigofera astragalima* outperformed with an average yield of  $2.3 \text{ t ha}^{-1}$  versus  $1.9 \text{ t ha}^{-1}$  for the natural fallow and  $1.3 \text{ t ha}^{-1}$  for the continuous cultivation (Coulibaly 2002).

The Institut de l'Economie Rurale (IER) has conducted a series of experiments of improved fallows using nitrogen fixing trees in general but not exclusively (Photo 9) (Yossi et al 2002). In

these experiments, the highest survival rates of trees planted in fallows were obtained with *Acacia senegal*, *Sclerocarya birrea* and *Acacia raddiana* whereas the highest growth was with *Acacia seyal*, *A. raddiana* and *A. senegal*. Improved fallows of *Acacia auriculiformis*, *Acacia mangium*, *A. senegal*, *Albizia lebbbeck*, *Gliricidia sepium*, *Pterocarpus erinaceus* and natural fallow have also been evaluated for the number of mycorrhizal fungi spores at the Sotuba research station. Except for the fallow of *A. lebbbeck*, soils of other improved fallows contained more spores than the natural fallow. *A. auriculiformis* appeared to have more soil mycorrhizal activity. Thus, five woody species (*A. auriculiformis*, *A. mangium*, *A. lebbbeck*, *P. africana* and *G. sepium*) improved soil porosity, which is an important physical characteristic of the soil: the improvement was due to their root systems, their litter incorporation into the soil and their mycorrhizal and symbiotic associations. Out of the eight woody species planted, six helped mitigate soil acidity. These are *A. senegal*, *A. auriculiformis*, *A. mangium*, *P. erinaceus*, *G. sepium* and *A. lebbbeck*. Soil organic matter was higher in *A. mangium* fallow (1.4%) and *G. sepium* fallow (1.1%) while planting woody species in fallows did not improve soil phosphorus status. However, *A. mangium*, *A. auriculiformis* and *G. sepium* fallow soils displayed the highest contents of plant available phosphorus. The risk of acidification is still present and a calcium amendment will raise the pH level and prevent acidification. Therefore planting woody species in fallow lands helped improve certain physico-chemical and biological properties of the soil compared with natural fallows, namely mycorrhizal activity through the number of endomycorrhizal fungal spores, soil porosity, soil organic matter, available phosphorus, pH, potassium and calcium. For all enriched fallows, combined soil organic matter content was 8.3 mg g<sup>-1</sup> against 7.6 mg g<sup>-1</sup> for the natural fallow. *G. sepium* and *A. mangium* fallow lands displayed the highest soil organic carbon content in the upper 0-25 cm layer (10-11 mg g<sup>-1</sup>), whereas the fallows of *A. mangium*, *G. sepium*, *P. africana* and *A. auriculiformis* showed the highest levels of plant available phosphorus (Yossi et al 2002). At Sotuba, improved fallows (*Acacia senegal*, *Albizia lebbbeck*, *Gliricidia sepium*, *Prosopis africana*, *Parkia biglobosa*, *Pterocarpus erinaceus*) and natural fallows were combined with fertilizer (without fertilizers, recommended dose, half and quarter of the recommended dose). The factors and their interaction did not have significant effects on the performance of sorghum. The average grain yield was 1.19 t ha<sup>-1</sup> while the best performance was obtained in *A. senegal* fallow (1.34 t ha<sup>-1</sup>) and *P. erinaceus* fallow (1.30 t ha<sup>-1</sup>). The recommended dose gave the highest yield of sorghum (1.4 t ha<sup>-1</sup>). The total

biomass followed the same trend as that of the grain yield (Yossi et al 2002). This contradicts what was observed at Koporokeniepen, where planting fallows with woody species did not improve millet production while the fertilizer did. This is due to many factors such as tree species, crop type and management. The first year of cropping after five years of fallow in the northern Sudanian zone of Mali with sandy soil did not significantly improve the performance of millet. The supply of fertilizer, particularly the recommended dose, and the supply of phosphorus led to improved performance of the succeeding millet crop. Nitrogen alone without phosphorus had no positive impact on millet performance in this site. This is due to inherent phosphorus deficiency in this type of soil.

Despite its low potential, a trial of alley cropping was installed in 1991 at Cinzana agricultural research station to assess the effect of incorporation of the leaves of *Leucaena leucocephala* and *Gliricidia sepium*, with or without fertilizer, on soil fertility and crop yields. The studied factors were the fertilizer (100 kg of a complex NPK at sowing and 50 kg of urea at growth stage) and leaf mulches of the two species. The results showed that combining the mulch of *G. sepium* with half of the recommended fertilizer dose increased the yield by at least 100%. The incorporation of the mulch showed a favourable effect on soil fertility. The mulch of *G. sepium* effectively regulated the soil pH and reduced the mineralization of the organic matter. In spite of the efficiency of the technology, its transfer to the farms poses many problems (Sidibé et al 1997; Sidibé and Goïta 2009).

### *Southern Sudanian zone*

Improved fallow research revealed that in the southern Sudanian zone, the most productive species in terms of total biomass and leaf biomass five years after planting at 2x2 m spacing were *Pterocarpus erinaceus* (13 t ha<sup>-1</sup> and 5 t ha<sup>-1</sup>, respectively), *Parkia biglobosa* (11 t ha<sup>-1</sup> and 4 t ha<sup>-1</sup>), *Albizia lebbbeck* (9 t ha<sup>-1</sup> and 3.4 t ha<sup>-1</sup>), *Prosopis africana* (6.5 t ha<sup>-1</sup> and 2.6 t ha<sup>-1</sup>) and *Gliricidia sepium* (11 t ha<sup>-1</sup> and 1.6 t ha<sup>-1</sup>) (Yossi et al 2002). It wasn't possible to ascertain the amount of biomass a yearly coppicing of the same plantations will produce in the years following this first pruning. The highest contents of nitrogen were obtained in the leaves of *Albizia lebbbeck* (2.84%), *Gliricidia sepium* (2.69%), *Acacia senegal* (2.60%), *Pterocarpus erinaceus* (2.14%), and *Prosopis africana* (2.01%) whereas the lowest content was in the leaves of *Parkia biglobosa* (1.85%). All well adapted species in the southern Sudanian zone are also good fodder trees. This leads to multiple demands for biomass for feeding livestock

or maintaining soil productivity, and hence tradeoffs that farmers have to make. The trees can provide other products such as fuelwood. In addition, *Acacia senegal* provides gum. This is an advantage for their use in the enrichment of fallow land as improving soil fertility alone is not enough to motivate farmers' investment in it.

In the same zone, an on-station experiment was conducted on two types of soils in two sites (sandy poor soil at Farako and finer and richer loamy soil at Finkolo) to test sowing under cover of crop residues involving cotton/cereal (maize and sorghum)



**Photo 9:** Planted fallow of *Prosopis africana* and *Gliricidia sepium* (J. Bayala and B. Kaya)

### *Northern Sudanian zone*

Zaï is suitable for this climatic zone. It performed very well and average yield for eight farmers was 969 kg ha<sup>-1</sup> in the control (farmers' treatment) against 1740 kg ha<sup>-1</sup> in the zaï treatment. This represents a production increase of 80%. This farming method also performed well in the Macina area. It was tested on severely degraded soil in the villages of Bangou-Marka and Fiah, and in Saye where the soil was less degraded. The results were excellent in all these locations (Doumbia et al 2001).

The impacts of anti-erosive structures such as stone bunds+*Jatropha curcas*, stone bunds+*Agave sisalana*, stone bunds+*Lantana camara* were compared with an unmanaged control plot in the forest of Diarrakoungo. The number of species increased on all plots from 1997 to 2001 but the highest increase was registered on managed plots (plus 22-23%). Management options also induced an increase in vegetation cover from 1997 to 2001, whereas the unmanaged plot cover was reduced to zero. This also corresponded to higher

rotations. There was no clear trend as there was better performance of some crops on some soil types for mulched plots and in other areas the mulched plots performed poorly (Autfray and Sissoko 2008).

### **On-farm trials in Mali**

Apart from zaï technique, most of the trials were oriented towards high biomass production using woody and non-woody species as a way of reducing the duration of fallowing for soil fertility replenishment after the cultivation phase.



herbaceous biomass production on plots with stone bunds associated with *A. sisalana* and *L. camara* (2.9 t ha<sup>-1</sup> and 4.1 t ha<sup>-1</sup>, respectively).

Among the tested technologies for biomass production, the impact of mycorrhizal inoculation and fallow duration on growth performance and improvement of fallow was studied on farmers' fields at Oualodjèdo. Species and age factors showed significant effects. *Ziziphus mauritiana* displayed the best growth among the tested species and inoculation did not show any significant effect regardless of the species (Yossi et al 2002).

In addition, *Gliricidia sepium* was tested on farm conditions at Katibougou and Cho. Prior to the field experiment, a survey was conducted to collect information about the characteristics of the farming practices. Thereafter, *G. sepium* in combination with nitrogen (0, half-dose and the dose) was evaluated on five farms, each considered a replicate. During two cropping seasons, no significant difference was found between treatments (Thienou 2005; Dembélé 2006).

Such results may be explained by high variability of the data as a consequence of large differences in the soil fertility as well as the limited number of replicates.

Another trial studied the influence of pruning and incorporation of the leaves of *Prosopis africana* with or without natural phosphate of Tilemsi on the performance of millet in the village of Lagassagou in the plain of Seno in the northern Sudanian zone of Mali. The pruning and incorporation of *P. africana* leaves had a significant effect on millet grain yield giving the best yield (1.86 t ha<sup>-1</sup>). This option was followed by plots under pruned *P. africana* without incorporated leaves (1.23 t ha<sup>-1</sup>). The lowest yields were recorded on treeless plots with or without incorporated leaves as well as on plots under unpruned trees without incorporated leaves (0.51 t ha<sup>-1</sup> to 0.81 t ha<sup>-1</sup>, respectively). However, applying natural phosphate of Tilemsi did not have any significant effect on millet yield. Crop yield reduction under unpruned trees was about 60% (Togo 1996; Yossi et al 2002).

The effect of green manuring with *Tithonia diversifolia* on *Amaranthus viridis* and *Zea mays* in the gardens of Lafiabougou and Samaya was evaluated by the World Agroforestry Centre. In general, green manure of *T. diversifolia* at 2.5 or 5 t ha<sup>-1</sup> in combination with phosphate (100 kg ha<sup>-1</sup>) improved the growth and doubled the yield of *A. viridis* and tripled the grain yield of *Z. mays* compared with the farmers' practice of 10 t ha<sup>-1</sup> of household garbage (Zerome 2000). A survey revealed that species such as *Cassia sieberiana*, *Combretum lecardi*, *Guiera senegalensis*, *Piliostigma reticulatum* and *Crotalaria retusa* are used by farmers as indicators of soil fertility (Doumbia 2000). The effect of applying the biomass of these species with and without phosphate was evaluated using maize, cowpea and tomato in Sotuba and Samaya, two peri-urban villages of Bamako in the Sudano-sahelian zone of Mali. *C. lecardi* at a rate of 5 t ha<sup>-1</sup> of leaf biomass induced the highest maize yield (4.8 t ha<sup>-1</sup>) followed by *P. reticulata* and *C. retusa* (4.2 t ha<sup>-1</sup>), *G. senegalensis* (4.1 t ha<sup>-1</sup>), *C. sieberiana* (3.4 t ha<sup>-1</sup>) and farmers' practice (3.3 t ha<sup>-1</sup>). A reverse effect was observed for cowpea whereas for tomato applying 2.5 t ha<sup>-1</sup> of biomass of *C. sieberiana* and 75 kg N ha<sup>-1</sup> induced the highest number of branches and the best fruit yield compared with farmers' practice which performed poorly (Doumbia 2000).

As a way of integrating agriculture and livestock, the effect of fire and grazing practices on wood production in fallows and on the following cereal yield were also assessed in Missira village. The absence of burning and early fire practice (applying fire to an area immediately

after the rainy season before the grasses are well dried in order to minimize fire intensity and damage to the vegetation) induced the highest crop yields regardless of the protection conditions and soil type. The same applies to the plots protected from grazing. Therefore, protection against fire or early burning of fallows improve crop yield when the land returns to cultivation, and produces more wood (Yossi et al 2002).

### Sub-humid zone

A trial conducted in the villages of N'Goukan in the sub-humid zone (900-1100 mm of annual rainfall) showed that *Gliricidia sepium*, *Acacia senegal* and *Pterocarpus erinaceus* had the best survival rates in pure plantations or associated with *Stylosanthes hamata*. The best crop yields of maize were obtained on land planted with *Gliricidia sepium* alone or associated with *S. hamata* reaching 2.53 t ha<sup>-1</sup> and 2 t ha<sup>-1</sup>, respectively. The results also proved the importance of applying the recommended dose of nitrogen when cropping maize in the first year after fallowing (Sanogo 1997; Yossi et al 2002). In four villages of Nafanga commune, two tree species (*Gliricidia sepium* and *Leucaena leucocephala*) associated with either *Stylosanthes hamata* or *Mucuna sp.* were compared with sole sorghum. The introduction of leguminous nitrogen fixing tree species resulted in a grain yield of 2.7 t ha<sup>-1</sup> over a period of three years (Kone 2008).

Finally, direct sowing under cover crop mulch was tested in farmed fields in different sites. Yield results were highly variable and globally there were slight differences: this was due to late planting because the rainy season started late, followed by an excess of water and an early end to the rainy season. At a 1000 mm rainfall site, results were slightly better when sowing under cover crop for the major crops (cotton and maize) and moderate for secondary cereals (millet and sorghum). On a site of 900 mm rainfall, yields of the two main crops (cotton and sorghum) were higher by 10% to 20% on the plots with the mulch whereas the opposite was observed on the site of 800 mm rainfall (Autfray and Sissoko 2008).

### Both zones

Takimoto et al (2008) reported that the percentage of soil C (0-100 cm soil depth) with respect to the total C stock (above ground biomass + soil C of 0-100 cm depth) was 38% in a parkland of *Faidherbia albida* in Segou region. The total carbon stock of the same

parkland was 87.3 Mg C ha<sup>-1</sup>. For soil C, the tree's relative contribution was found to be higher near the tree than outside the crown and decreased with soil depth (Takimoto et al 2009).

In other parklands nutrient concentrations were reported to increase with proximity to the trunk of *Vitellaria paradoxa* and *Parkia biglobosa* (Kessler 1992; Kater et al 1992; Diakité 1995). However, there was a reduction of crop yields under these trees. Compared with the open area, millet yield reduction under *V. paradoxa* trees was 50% and 44% according to Kapp (1987) and Kater et al (1992), respectively. A reduction of millet yield of 60% under *P. biglobosa* trees was reported by Kater et al (1992). Kessler (1992) found that sorghum yield was also reduced by 50% and 70% under the crowns of *V. paradoxa* and *P. biglobosa* trees, respectively, whereas Kater et al (1992) reported 60% and 66%, respectively. In addition, cotton yield was reduced under *V. paradoxa* and *P. biglobosa* trees by 2% and 65%, respectively (Kater et al 1992). All these reductions are economically compensated for by the value of the fruit produced by the trees (Kater et al 1992). However, the fact that this general pattern doesn't always prevail raises questions (Boffa 1999). For example, in Mounzou, Diakité (1995) reported higher grain production (+26%) under *V. paradoxa* than at a distance three times the canopy radius. Such findings may be related to smaller crown sizes which allow enough light to reach the crops below the trees.

## Farmers' practices of conservation agriculture in Mali

Farmers in Mali are employing traditional systems for degraded land reclamation and water harvesting. These practices are very effective in mitigating the effects of desertification and they meet the criteria for three types of conservation practices – soil conservation, water conservation and erosion protection (UN-DESA 2005). The practices are related to the farmers' typology developed in the country: Type A is composed of well-equipped holdings that have a complete set of agricultural equipment; type B is composed of holdings with an incomplete set of agricultural equipment; type C is composed of holdings with animals but no agricultural equipment; and type D is composed of holdings with no equipment and no animals. Such classification ignores the fact that even the poorest farmers always have poultry and two or three goats/sheep. The widespread use of CA practices in Mali does not mean that further research and development efforts

are not needed. It is always necessary to understand problems and solutions for contexts in which current practices are not adequate and to keep up with the changing social and economic pressures.

### Zai

Zai technique is widespread on Dogon plateau and is well adapted to the Sudano-sahelian zone (Bengaly 2008). This is due to the fact that no special equipment or knowledge is needed to adopt the technology and the cost of implementation is mainly calculated based on the farmer's opportunity cost of time. The maintenance of the pits does require the farmer to invest additional time in watching over, deepening and refilling the pits. However, the economic return to the farmers' investment is 100%, because the land brought under production is abandoned or unused land. In 1989-1990, a project implemented by the Djenné Agricultural Systems (SAD) project showed that agricultural yields increased by over 1000 kg ha<sup>-1</sup> as compared to traditionally ploughed control plots. Approximately 1600 farmers from 17 villages participated in this project. The zai system is often practised in combination with contour stone bunds and planting of trees (UN-DESA 2005).

### Half-moons

Half-moons are half-circle shape water harvesting structures dug perpendicular to the slope and surrounded by downstream of so-called earth glasses prolonged by wings in stone or earth. Half-moons are used to collect surface water, stabilize soils on steep slopes and recover degraded soils. However, the constraints of half-moons are many: the difficulty of mechanizing farm work, the significant maintenance needed, the ability to plant only 20% of the plot area and economic profitability (cost equals three times that of stone bunds and twice that of the zai).

### Grass strips

Grass strips reduce run-off and promote infiltration. Farmers usually establish grass strips of 3 m width with a spacing of 50 m between strips. Species used include *Vigna unguiculata* (cowpea), *Digitaria exilis* (fonio), *Brachiaria ruziziensis*, *Stylosanthes hamata*, *Andropogon gayanus* or association of for instance *Brachiaria ruziziensis* and *Stylosanthes hamata*. *A. gayanus*, although difficult to establish, has a longer time residence and can withstand fire and grazing, and is therefore the preferred species.



### *Improved fallows*

The introduction into the rotation of a forage sole or an improved fallow using legume helps shorten the duration of the fallow and ensures better agriculture-livestock integration. Free-roaming livestock, bush fires and the difficulty of acquiring seeds, however, remain serious constraints. In addition to the herbaceous species like *Stylosanthes hamata*, some shrub species such as *Acacia auriculiformis* and *Gliricidia sepium* are used in the improved fallows.

### *Mulching*

Protecting soil surface using crop residues reduces water erosion, runoff, soil temperature and soil evaporation. However, for many farmers, the recommended amount of biomass (8 t ha<sup>-1</sup>) is too high. The amount of garbage produced by households increases from farms of type D to type A because the latter have animals that produce manure or a mixture of manure and residues of crop straws fed to the animals (Bengaly 2008).

### *Applying manure*

Directly corralling animals on the fields for the night during the dry season significantly improves soil organic matter, especially on sandy soils. This practice tends to be one of type B holdings. The quantities of manure produced are not sufficient and therefore the applied rate is only 3 t ha<sup>-1</sup> on cotton which is low compared with the recommended rate of 5 t ha<sup>-1</sup>. The general trend is to apply a lot of manure in small areas (20 to 100 t ha<sup>-1</sup>). This prolongs the effects on parts of the field where soil fertility is low. Fertilized crops are cotton, maize and very rarely sorghum and millet. This practice is more common in types A, B and to a lesser extent in type C of households because of its direct link with the number of cattle (Bengaly 2008).

### *Regeneration of vegetation*

Farmer-managed natural regeneration (FMNR) by members of the Barahogon association in the Bankass district of Mali has resulted in significant regrowth of trees on millet fields and short term fallows, with densities of 250 trees ha<sup>-1</sup> recorded on fields where the techniques have been in use since 1999 (Photo 10). Regrowth is dominated by *Combretum glutinosum* (82% of trees inventoried) but overall, 35 of the 49 most useful types of trees, grasses and wildlife identified were perceived to be increasing,

suggesting a broadly improved natural resource base. Key motivations are protection of soils and soil fertility (according to 62% and 50% of interviewed heads of households, respectively). Other benefits are secondary: timber and fuel wood to meet their own needs, foliage and herbaceous grasses as animal fodder for their own and visiting herds, income from cut grass that is sold in nearby towns; and protection of the young millet crops from wind and water at the start of the rainy season (Allen et al 2009).

Adoption rates were found to be very similar for households irrespective of wealth category, when averaged across four villages. However in three out of the four villages, the least well-off households were found to be equally or more likely to have adopted FMNR than the better-off households. This suggests that a shortage of agricultural equipment or labour is not a significant constraint to adoption of FMNR. Indeed it seems reasonable to hypothesize that poorer farmers may be more highly motivated than richer ones to invest in managing their agroforests given that it is a low-cost solution and that exploitation of wood and non-wood tree products may contribute proportionately more to securing their livelihoods (Allen et al 2009; Faye et al 2010).

### *Faidherbia albida parklands*

In Mali, *F. albida* parklands (Photo 11) extend over an estimated area of 8780 km<sup>2</sup>, or 17% of the country's total estimated parkland area (Boffa 2000). They are located in the rainfall range between 500 mm and 1200 mm in the areas of Gondo-Mondoro, the Bandiagara-Hombori, Koutiala and Mandingue Plateaux, the Central Niger Delta and Hod. In terms of density and size, particularly outstanding *F. albida* parklands are found in the Dembéré-Douentza Valley and extending into the Seno plain. There are well developed *F. albida* parklands in the Niger Valley between Bamako and Mopti, and particularly around Segou (Boffa 2000).

### *Other parklands*

Other parklands are composed of *Acacia raddiana*, *Hyphaene thebaica*, *Lannea microcarpa*, *Sclerocarya birrea* in the northern part of the country and in the southern part by *Anogeissus leiocarpus*, *Borassus aethiopum*, *Mitragyna inermis*, *Parkia biglobosa*, *Vitellaria paradoxa* (Photo 11), and *Terminalia laxiflora* (Cissé 1995).

### *Rotations*

Rotations depend not only on the toposequence and soil type (sandy, loamy, clay) but also on the field's distance from the homestead. For example, maize will dominate in the rotation practice on fields close to the houses due to the fact that these types of fields are frequently fertilized using organic matter from households (compost, garbage and manure). Sorghum, cotton and maize are cultivated on clay-loamy and sandy-loamy soils, groundnut on sandy soils and rice on clay soils. Millet will never be found in the lowlands because it cannot withstand flooding. However, it is found on clay-sandy and clay-stony soils. Rotations also depend on ethnic groups because soil classification varies from one group to another (Bengaly 2008).



**Photo 10:** Farmers selecting and thinning stems of indigenous tree and shrub stumps in FMNR technology in Mali (Sahel Eco)

### *Cereal-legume associations*

In order to improve soil fertility and animal nutrition, several cereal-legume associations are found in farmer's fields. Thus, depending on zones, sorghum-cowpea associations, millet-cowpea, corn-cowpea, sorghum-groundnuts, corn-*Mucuna* may be found in farmers' fields. Sorghum-pigeon pea, millet-pigeon pea associations also exist. The production of seeds and sowing mechanization are the main constraints to corn-*Mucuna* and cereal-pigeon pea associations. Associations of crops tend to be a practice of type B holdings.



**Photo 11:** *Faidherbia albida* and *Vitellaria paradoxa* parklands (J. Bayala)

## Conservation agriculture practices in Niger

### On-station experiments in Niger

The activities conducted in Niger were of two main categories of land rehabilitation that aimed at evaluating the combinations of techniques for land reclamation and cropping systems to maintain and even improve soil fertility and productivity. For degraded land reclamation, the Dryland Eco-Farm (DEF), also called Sahelian Eco-farm (SEF), was developed at the ICRISAT Sahelian Centre in Niger in collaboration with the National Agricultural Research and Extension Services partners (Photo 12). The DEF combines the use of live hedges of *Acacia colei*, earth bunds that turn into micro-catchments or 'half-moons', high value trees such as the domesticated *Ziziphus mauritania* planted inside the 'half-moons', annual crops (millet, cowpea and roselle), each planted in half or a third of the field in rotation each year (Fatondji et al 2011). Erosion by wind is prevented by the wind breaking effect of *A. colei* trees and by the mulch produced from the *Acacia* branches and phyllodes. Trees are pruned once a year and their branches spread over the field adding organic matter to the soil. *A. colei* improves soil fertility because it is a nitrogen fixing tree species and also through its root decay. Soil fertility is also enhanced by crop rotation. *A. colei* seeds are used to feed poultry. *Z. mauritiana* produces fruits and the annual crops provide human food. The combined profit per hectare from all the DEF components is ten times higher than the profit derived from the control, which is a millet field without trees. In addition, the system reduces soil erosion, improves water use efficiency, mitigates the negative effects of drought and provides animal fodder (Fatondji et al 2011).



Besides land reclamation, different cropping systems of annual crops have also been investigated in the same research station. For instance, Bagayoko et al (2000) studied the effects of cropping systems on legume yields for three years and observed negligible effects. In turn, relative increases in cereal total dry matter due to rotation varied from 37% in 1996 to 23% in 1998. Enhanced cereal yields following legumes have been attributed to not only chemical and biological factors such as higher levels of mineral nitrogen and arbuscular mycorrhizae, but also to lower amounts of plant parasitic nematodes. In addition, Alvey et al (2001) provided strong evidence that cereal/legume rotations can enhance P nutrition of cereals through improved soil chemical P availability and microbiologically increased P uptake.

### On-farm trials in Niger

Field trials were more about biological techniques to increase vegetation cover and improve soil fertility. Australian *Acacias* were introduced and tested in the early 1980s in the Maradi area. The primary focus was to improve food security (Rinaudo et al 2002; Adewusi et al 2006). A wide range of Australian *Acacia* species with potential for human food were evaluated (*A. colei*, *A. ampliceps*, *A. corlacea*, *A. elachantha*, *A. torulosa*, *A. tumida*, *A. victoriae*, *A. plectocarpa*, *A. eriopoda*). *A. colei* and *A. torulosa* appeared to be the most suitable since they can produce good seed yields and provide other products and services such as soil fertility improvement through nitrogen fixation and the mulch of leaves. Field investigations showed that these species should be planted at wide spacing (10 m x 10 m; 10 m x 30 m) because their root systems are shallow and compete with annual crops (Abasse 2006). However, widespacing will also reduce any positive contributions the trees are making. Depending on farmers' objectives,



**Photo 12:** Dryland Eco-Farm (DEF) developed at the ICRISAT Sahelian Centre in Niger (A. Nikiéma)

trees with rooting characteristics such as this may not be appropriate at all. The trees should be pruned in the third year after planting and thereafter pruned every two years to reduce competition with annual crops and to produce biomass for mulching (Pasternak 2005). In general, these species grow very well on degraded and poor soils while their foliage is unattractive to livestock (Harwood et al 1999; Abasse 2002). A harvest of 50 kg air-dried wood per tree is expected which is equivalent to 1000 F CFA (US\$ 2) around Maradi (Harwood et al 1999). Even though promising, there are still a lot of unresolved issues such as invasiveness of the good seeders, water use and competitiveness in comparison with local species and their acceptability by local people.

Direct seeding or transplanted bare-rooted seedlings, which makes establishment of *Acacias* cheaper and less labour-intensive, have not been successfully developed. However, research is still needed to improve seed production and that may involve amongst others, genetic improvement and silviculture (application of fertilizer, inoculation, optimum pruning regimes) (Harwood et al 1999).

In 2005, after working for many years with farmers in Niger to help make communities and crops more resilient to drought, the faith-based organization, Serving in Mission (SIM) developed an integrated farming system known as the “farmer-managed agroforestry system” (FMAFS) which incorporates agroforestry and environmental restoration to maximize biodiversity and regenerate indigenous trees. It is an agro-pastoral forestry system that uses a wide range of annual and perennial, indigenous and exotic plant species, including Australian *Acacia* species (*Acacia colei*, *A. torulosa*, *A. tumida* and *A. elachantha*) which thrive in semi-arid lands (Cunningham and Ridaudo 2009). A typical FMAFS model of one hectare has trees on the boundary at 5 m apart while trees within the farm are 10 m apart in rows that are 25 m apart. Rows of trees are planted perpendicular to the prevailing wind direction. Indigenous trees from natural regeneration are kept and annual crops grown within the *Acacia* rows. The *Acacias* provide firewood, timber, mulch and food for humans and animals, while contributing to environmental restoration and crop protection. Even in the absence of a systematic assessment, field observations showed that by creating spots of higher soil humidity, they also help re-establish indigenous trees that have been negatively affected by environmental conditions and inadequate farming practices. Annual food and cash crops such as millet, sorghum, peanuts, cowpea and sesame can then be planted in rotation/association between tree rows.

Currently, there are 483 FMAFS farms in 25 villages in Niger, which directly benefit over 4000 people. The FMAFS itself is still in its infancy, but it already has provided farmers with many tangible benefits, including an additional food source, firewood, crop protection and resilience, and alternative sources of income. The farmers are guaranteed a minimum harvest of varied products in any given year. Soil fertility is improved and degraded lands restored without relying on expensive and sometimes environmentally harmful chemicals. The system has contributed to natural regeneration of indigenous trees and it is affordable and accessible to the poorest farmers. In a nutshell, the FMAFS has helped improve sustainability and reduce drought disaster risk (Cunningham and Ridaudo 2009). It is still not clear how this approach can realistically be scaled up to poor farmers since it requires a lot of inputs.

Another biological approach tested by ICRISAT to reclaim degraded lands involved scarifying the land to break down the surface crust. Half-moons of 2-3 m wide spaced 5-10 m apart are dug and trees planted (*Ziziphus mauritiana*, *Moringa stenopetala*, *Tamarindus indica*, *Sclerocarya birrea*, *Acacia Senegal*, *Acacia tumida*) in a 40 x 80 cm ridge left in the centre of the open side of the half-moon to avoid waterlogging. The area between the half-moons is occupied by zai pits in which about 250 g of compost or manure is placed and covered with a 5 cm layer of soil. Traditional vegetables (*Senna obtusifolia*, *Hibiscus sabdariffa*, *Albemoschus esculentus*) are planted in the zai pits with 0.5 x 1 m spacings. Deep placement of the compost results in extensive growth of roots and hence in good exploitation of water and nutrients. In addition, trenches are dug every 20 m down the slope to further harvest water run-off (Pasternak et al 2009). Nevertheless, it is questionable how realistic such high-labour systems are, despite being very impressive in demonstration plots.

Over a 4-year period, the rotation of pearl millet with groundnut and cowpea resulted in significantly higher pearl millet grain yields than in the continuous cropping of pearl millet (Bationo and Ntare 2000). With no application of N fertilizer, millet grain yield after cowpea increased by 18% at Bengou and 87% at Tara. The response of legumes to rotation with millet also increased at Tara and Bengou where legume yields were consistently lower in monoculture than when rotated with millet. This suggests that factors other than N alone contributed to the yield increases in the millet-legume rotations. Relative increases in millet due to rotation with cowpea at Goberi (control yields were 868 kg ha<sup>-1</sup> for grain and 3331 kg ha<sup>-1</sup> for straw

biomass) and Gaya (control yields were 606 kg ha<sup>-1</sup> for grain and 2556 kg ha<sup>-1</sup> for straw biomass) varied from 0% to 24% (Bagayoko et al 2000).

In addition to biological measures, there are also physical techniques in the domain of minimum tillage as reported by Ambouta and Amadou (2000), who compared the effect of mulching and zai on millet production in the village of Bogodjotou. Compared with the control untreated plot, mulched plots and zai plots performed significantly better for the number of tillers, dry matter and grain yield. The grain yield was 15 to 17 times higher on treated plots than in the control plot for the mulching and zai techniques, respectively. This is due to higher soil fauna activity under the mulch and a double concentration of both water and nutrients in the case of the zai technique.

Mai Moussa (1996) has conducted a study on the effects of the density of *Faidherbia albida* on soil fertility in two villages in Niger: Guilleny with high density of trees and Tilly with more dispersed trees. The values of pH, available P, exchangeable K, total N and exchangeable bases were higher at Guilleny than in Tilly, but the difference was not statistically significant. Thus, the results were inconclusive with respect to N, P, K, Ca, Na, Mg and soil pH. A decreasing gradient of soil fertility was observed with both distance from the trunk and soil depth. Due to its reverse phenology, trees consumed less water than other species bearing leaves during the cropping season and were able to reduce the air temperature in its vicinity by 5°C (Mai Moussa 1996). The key effect of *F. albida* on crop production may be due to its N inputs through litter and N<sub>2</sub> fixation. This is corroborated by the fact that an application of 180 kg N ha<sup>-1</sup> in the open area at N'douga (Niger) yielded similar millet biomass as the plot under this species (ICRAF 1996). Furthermore, in an attempt to quantify the effects of *Faidherbia* trees on crops, Kho et al (2001) reported an increase in millet production by 36% under *F. albida* canopy compared with the open field. N and P under trees were estimated to be more than 200% and almost 30% higher, respectively than in the open field, and this resulted in a 26% and 13% millet dry biomass increase for the two nutrients, respectively. The net effect via other resources (light and water) was only a 3% reduction in millet dry biomass yield (Kho et al 2001).

The work of Mai Moussa (1996) also revealed that the elements N, P, K, Mg, Ca as well as organic matter were more concentrated, the pH higher under *Hyphaene thebaica* than in the bare land. As a consequence, better yield of associated millet was recorded under the tree in relation to the pattern of

soil fertility. This is in line with the findings of Moussa (1997) who also reported a positive effect (2 to 2.5 times) of this species on grain and straw yields of millet in the villages of Kareygorou and Say, southwestern Niger.

## Farmer's practices of conservation agriculture in Niger

### *Zai*

Zai pit preparation is done during the dry season. A business has emerged in which farmers buy degraded lands (50 000 CFA F ha<sup>-1</sup> or US\$ 100) and manage them using zai then sell them off at a higher price. The adoption rate has reached 68% in the regions of Maradi and Tahoua (Adam et al 2006). The initial investment costs 50 000 CFA F ha<sup>-1</sup> (US\$ 100) with an additional cost of 33 000 CFA F ha<sup>-1</sup> (US\$ 66) for the following years. Zai internal profitability rate (IPR) is 39% when the land was bought and 82% when owned by the farmer. The cost of the initial investment is negatively correlated with IPR and therefore any action aimed at reducing this initial cost will improve the profitability of this practice (Abdoulaye and Ibro 2006).

### *Half-moons*

Half-moon is used in Niger to reclaim degraded encrusted lands for crop production. However, its current adoption of 19% is still low (Adam et al 2006). The initial investment costs 100 000 CFA F ha<sup>-1</sup> (US\$ 200) with an additional cost of 33 000 CFA F ha<sup>-1</sup> (US\$ 66) for the following years. The internal profitability rate (IPR) of half-moons is 37% indicating less profit with this technique compared to the zai technique. This may explain why farmers practise the zai technique more than the half-moon (Abdoulaye and Ibro 2006).

### *Litter and household rubbish*

Litter and household rubbish are mixtures of household garbage (straw, grasses, trees and shrubs leaves), animal feed, peanut shells and sometimes, animal dung. This mixture is formed near the paddocks from June to March. It receives water from rain that promotes its decomposition before being transported to the field in March-April. The main constraints are the low number of animals with an average 2.5 to 3.4 Tropical Livestock Units or TLU (1TLU represents 250 kg live weight, equivalent to 1 camel, 1.43 cattle or 10 small ruminants) per farm and the lack of means

of transport. Yields obtained on amended plots are 730 kg ha<sup>-1</sup> in the first year compared to 300 kg ha<sup>-1</sup> for the control. However covered areas are very small (1% to 12.5 % of the total areas by holding) and this is also why farmers combine this practice with mulching and organic fertilizer. To qualitatively improve the effectiveness of this practice, farmers recommend incorporating the garbage in the soil to accelerate its decomposition (Harouna 2002; Issa 2002; Kanta 2002; Saky 2002; CRESA 2006).

### *Corralling livestock on cropland*

To exploit the additional benefits of urine and to minimize nutrient losses, corralling livestock on fields is preferable to the application of farmyard manure (Schlecht and Buerkert 2004). Nevertheless, trampling by livestock can increase soil bulk density and decrease water infiltration rates and therefore enhance water run-off and soil erosion. Treading some soils, however, may increase soil surface roughness and improve infiltration by breaking soil surface crusts. However, breaking soil surface crusts may facilitate wind erosion, leading to mosaics of deflation and accumulation patches in the landscape (Powell et al 1996). About 13% of fields are reportedly corralled (Schlecht and Buerkert 2004). This is a practice reserved for the wealthy, in particular the Fulani. The average annual rate of manure deposition on field-base corrals is 12.7 t DM ha<sup>-1</sup> for cattle and 6.8 t DM ha<sup>-1</sup> for small ruminants (Hiernaux and Turner 2002). Because of these high rates, the aggregated corral area is about only 0.5-1.2% of the village cropped land. However, the effects of such high rates are expected to last 4-5 years. Constraints are lack of animals, the inadequacy of forage, stealing of animals and animal diseases. Obtained yields vary between 500 and 1521 kg ha<sup>-1</sup> against 418 kg ha<sup>-1</sup> for the control. A proposed improvement is to collect and store forage at harvesting period to increase the duration of the stay of the animals on the plots (Harouna 2002; Hassane 2002; Kanta 2002; Saky Souleymane 2002; CRESA 2006).

### *Organic biomass from millet threshing*

These products from the threshing of millet are collected and placed in heaps for a year to promote their decomposition and pre-germination of the seeds they contain. The main constraint is lack of transport. The yield is 1200-1500 kg ha<sup>-1</sup> on the treated plot compared to 412-750 kg ha<sup>-1</sup> on the control plot. Farmers recommend incorporating the products in the soil to avoid their transport by wind, and sprinkling with water to promote their decomposition (Harouna 2002; Hassane 2002; Kanta 2002; Saky Souleymane 2002; CRESA 2006).

### *Mulching*

Mulching comprises covering the soil surface in the fields with straw after harvest by cutting down and spreading them in heaps, setting them in lines, making one or more heaps, and spreading the straw in dashed lines. Lack of straw and their use for other purposes (feed, building materials, sales) are the main constraints. The yield is 500-1450 kg ha<sup>-1</sup> on treated plots compared to 300-320 kg ha<sup>-1</sup> for the control. Improvement proposals relate to fragmentation of the straw and adoption of other sources of organic material (twigs, husks, household rubbish) in order to increase the treated areas (Harouna 2002; Hassane 2002; Kanta 2002; Saky Souleymane 2002; CRESA 2006).

### *Farmer-managed natural regeneration*

Key species promoted through the protection of natural regeneration are *Annona senegalensis*, *Cassia sanguena*, *Combretum glutinosum*, *Faidherbia albida*, *Guiera senegalensis*, *Piliostigma reticulatum* and *Ziziphus mauritiana*, among others (Photo 13). When exploited for wood, the prunings, which include leaves and twigs, are used as mulch to cover the soil surface in order to reduce soil erosion and improve soil fertility. Farmers proposed to improve this practice by combining it with the application of compost (Harouna 2002; Hassane 2002; Kanta 2002; Saky Souleymane 2002; CRESA 2006). Adoption rate is about 63% in Maradi region and tree density varies from 60 to 374 individuals ha<sup>-1</sup> (Adam et al 2006). The initial investment costs were 24 000 CFA F ha<sup>-1</sup> (US\$ 48) with an additional cost of 1000 CFA F ha<sup>-1</sup> (US\$ 2) for the following years. FMNR internal profitability rate was found to be 31% and reduced labour or investment at the beginning, thereby making this practice more attractive for farmers (Abdoulaye and Ibro 2006).

### *Seeding doumier (Hyphaene thebaica)*

This is a practice recently adopted by farmers who have noticed the effect of the tufts of the doumier on crop development and sand trapping. The leaves of this species are also used in making handicrafts such as ropes and mats. Seeding is done in lines, or in tufts. The doumier is also used to mark the limits of the fields in order to avoid conflicts over land boundaries.

### *Tree plantation*

Planted tree species are *Azadiractha indica*, *Acacia senegal*, *Faidherbia albida*, *Piliostigma reticulatum*, *Bauhinia rufescens*, *Maerua crassifolia*, *Prosopis africana*, and some exotic fruit trees on the lowlands along



**Photo 13:** Farmer-managed natural regeneration in Burkina Faso and Niger (J. Bayala)

the rivers (*Mangifera indica*, *Psidium guayava*, *Citrus spp*) (Harouna 2002; Hassane 2002; Kanta 2002; Saky Souleymane 2002; CRESA 2006). The initial investment costs were 60 000 CFA F ha<sup>-1</sup> (US\$ 120). The internal profitability rate (IPR) varies from 13% if only wood and fodder are considered and 37% if gum arabic is also produced. These low profitability rates are due to the fact that during the first 3-4 years, there is nearly no product except small quantities of fodder (Abdoulaye and Ibro 2006).

#### *Faidherbia albida* parklands

In Niger, *F. albida* parklands (Photo 14) are located in the south including the zone between Damergou and the Nigerian border, and Madaroumfa next to Maradi; and in the southwest extending from Tilly near Sadoré to Guilleny as well as in the Dosso Department between the Dallol Bosso and the Dallol Maouri (Boffa, 2000). Well-known examples are the

highly stocked and permanently cultivated parklands in the '3M' (Matameye, Myrriah and Magaria) region, resulting from the enforced protection of the species during the rule of Tanimoun, Sultan of Zinder and the actions of plantation and protection of natural regeneration of different projects and NGOs in the Maradi region (Larwanou 2006). *F. albida* densities in parklands in the Dosso Department are lower than in Maradi and Zinder areas (Boffa 2000). Densities vary from 20 to 120 individuals ha<sup>-1</sup> (Botoni and Reij 2009).

#### *Other parklands*

Other parklands comprise *Adansonia digitata*, *Lannea microcarpa*, *Parkia biglobosa*, *Prosopis africana*, *Vitellaria paradoxa*, *Sclerocarya birrea* in the sudanian zone, *Balanites aegyptiaca* and *Commiphora africana* in the Sahelian zone. *Hyphaene thebaica* and *Borassus flabellifer* are found in the lowlands (Torquebiau and Mousa, 1991).



**Photo 14:** *Faidherbia albida* parklands in Niger (A. Kalinganire)

### *Intercropping*

Associations of trees and crops is widespread compared with pure sole crops in Niger. Associations can improve and stabilize yields and therefore constitute a risk avoidance practice in a rainfed production system because they allow for better utilization of growth resources, a reduction of the effect of insects and weeds, and increase nitrogen content in the soil. Usually, legume and cereal seeds are mixed and sown in the same pit but this practice increases competition between species. Therefore it is recommended that the two crops be sown on two different lines.

During the 1980s, millet+sorghum+cowpea intercropping was the most adopted crop mixture covering about 50% of the cropped area of all regions. In second position was millet+cowpea intercropping at Tillabéri, sorghum+cowpea at Maradi and millet+sorghum at Tahoua (all covering about 20% of the cropped area). Currently, the same intercropping practices are still adopted but at different adoption rates with 59% for millet+sorghum+cowpea and 25% for the other types of associations. The evaluation report of PDRAA (2001) gave an adoption rate of intercropping of 43% in Aguié area where the main crops are millet, sorghum, cowpea and groundnut that are associated in various combinations and the souchet (*Cyperus esculentus*) which is cropped in pure sole (Harouna 2002; Hassane 2002; Kanta 2002; Saky Souleymane 2002; CRESA 2006).

### *Rotation*

Crop rotation is more common for peanuts and cereals than for cowpea-cereals and other legumes-cereals. However, cowpea-millet rotation can result in an increase of up to 46%, and green manure of Sesbania-millet, 27%. Thus a substantial amount of the recommended dose of N for millet can be saved.

## Conservation agriculture practices in Senegal

### On-station experiments in Senegal

On-station activities focused on biomass management options and some experiments have shown that by combining straw (at a dose of 3.5 t ha<sup>-1</sup>) with mineral fertilizers or compost/manure it is possible to increase

the production of millet (Piéri 1979) and soybean (Ganry 1985). Furthermore, the work of Ganry (1977) showed that the incorporation of straw in sandy soil improved the percentage of fertilizer use by the cultivated plant. The application of these results is constrained by the fact that straw is widely used for purposes other than soil fertilization. Therefore, no practice aimed at improving soil fertility based on the valuation of the organic matter is put in place on a large scale with regard to the two key crops that are groundnut and millet. Therefore adoption of this practice is low. An alternative may be the recycling of leaf litter produced by parkland trees. Samba (1997) tested the effect of different quantities of *Cordyla pinnata* litter (0, 39, 78 and 156 kg of litter t<sup>-1</sup> soil) on millet and groundnut yields and nutrient contents. Total N and exchangeable Ca, Mg and K increased with increasing amounts of litter of *C. pinnata*, whereas available P decreased. Total biomass of groundnut plants was reduced by litter additions: by -11%, -13%, and -29% for the three mulched treatments, respectively, compared with the control. In contrast, millet biomass increased and reached a maximum at the dose of 39 kg t<sup>-1</sup> soil. K content in groundnut leaves also increased with litter additions but N, P and Ca in millet grain varied greatly. Thus, the litter of *C. pinnata* has the potential to modify soil fertility and the quality of crop products (Samba 1997). In order to produce more biomass for recycling, an alley cropping experiment was conducted to assess the survival rate, growth, foliar and woody biomass production as well as the effect of spreading and/or incorporating of the foliar biomass on soil and crops. Eight species were tested: *Leucaena leucocephala* P1 (Nigeria), *Leucaena leucocephala* P2 (Burkina Faso), *Cassia siamea*, *Gliricidia sepium* ILG 55, *Gliricidia sepium* IL50, *Gliricidia sepium* HYB, *Albizia lebbek* and *Moringa oleifera*. After two years, the results showed that incorporated foliar biomass had no significant effect on groundnuts and millet yields. The test was then abandoned following a decision by the SALWA network which considered this technology inadequate for semi-arid zones (Samba et al 2000).

### On-farm trials in Senegal

In the groundnut basin in Senegal, a number of sites were selected for destructive sampling to develop allometric equations for the estimation of shrub community biomass stocks (Lufafa et al 2009). *G. senegalensis* sites were located in the west of the study area (around the Thies region), whereas *P. reticulatum*



sites were in the southwest (Kaolack region). Total peak-season biomass stock at the *G. senegalensis* sites, as predicted using the allometric equations, ranged from 0.44 to 4.58 t ha<sup>-1</sup> with an overall mean of 2.38 t ha<sup>-1</sup>. Approximately 82% of this biomass was belowground with only 18% in leaves and stems. Similarly, the belowground fraction constituted 86% of the total (3.7 t ha<sup>-1</sup>) biomass stock for *P. reticulatum*, whereas a relatively smaller proportion (0.32 t ha<sup>-1</sup>) was found in the aboveground fractions. These biomass allocations resulted in very high root:shoot ratios (4.5:1 for *G. senegalensis* and 10.2:1 for *P. reticulatum*) for these two shrubs (Lufafa et al 2009). The partitioning of the biomass of these two shrub species commonly found in farmed fields of the Sahel gives some insights into their potential contribution to soil cover and soil carbon increase. This will ultimately improve soil structure and fertility. In addition, these two shrubs have the potential of being planted on soil conservation structures to reinforce their stability and longevity.

In *Faidherbia* parklands, rainfall interception by *Faidherbia* trees induced a reduction in crop density in the area around the trees (Dancette and Poulain 1968). In contrast, different soil analyses have shown higher soil organic matter under the trees with a decreasing gradient away from the trunk (Charreau and Vidal 1965; Jung 1967; Dancette and Poulain 1968; Jung 1969; 1970). As a result, millet yield improved by 62% on more fertile plots and by 113% on less fertile plots (Louppe et al 1996). However, *F. albida* exerted a significant depressive effect on groundnut yield in the first 3 m around the trunk, then an increased yield from 3 up to 8 m before declining again (Louppe et al 1996). In the groundnut basin, *F. albida* parklands helped to mitigate the effect of the lower mineral fertilizer used by farmers after subsidies were removed. The leaf litter during the rainy season contributes to the enrichment of the soil, increasing biological activity and as a result, higher yields of millet are obtained under these trees (Dancette 1968).

For other parklands, foliar biomass production of *Cordyla pinnata* was estimated by Samba (1997) to be 337 kg ha<sup>-1</sup> in a parkland located in the southern part of the groundnut basin of Senegal. Higher nutrient contents were recorded under the canopy compared with the open area. Regardless of the pruning intensity (33%, 66% and 100% of the crown), millet grain yield was reduced by 18%. There was an increasing trend in groundnut yield from tree trunk to the open area for unpruned trees, while the opposite trend

occurred under pruned trees (Samba 1997). The work of Sambou (1989) showed that litter of the male inflorescences of *B. aethiopum* contribute to soil fertility improvement (mainly soil K content).

## Farmers' practices of conservation agriculture in Senegal

### *Mulching*

In general, there are less crop residues left on the fields, and in the north all residues are collected to feed animals or used as construction materials. When left in the field, the straw constitutes feed for roaming livestock, and at the end of the dry season the remains are collected in heaps and burned. Therefore, these residues only reduce wind erosion but not water erosion during the rainy season as they are burned.

### *Corralling livestock on cropland*

Corralling livestock on fields adds organic manure directly to the soil. Animals stay overnight in the fields where they leave their faeces and urine during the time of rest. Animals may be corralled in temporary enclosures that are moved around in order to cover the maximum surface.

### *Regeneration of agroforestry parklands*

The main constraints to the regeneration of agroforestry parklands are the pressure exerted by humans and animals, mechanization, water stress, premature picking of fruit and old age of the trees. The main mode of propagation of tree species is natural regeneration, but germination of seeds is usually hampered by lack of rain. Other propagation techniques include direct sowing and planting, but they have not been successful due to lack of water and maintenance, and free roaming of cattle during the dry season. Planted species include *Azadirachta indica*, *Anacardium occidentale*, *Mangifera indica* and *Prosopis juliflora*. Regeneration techniques and methods are primarily about the protection of resprouts. These techniques aim at preventing the burning or cutting of resprouts during field clearing and protection against animals and are mainly practised in the northern groundnut basin in *F. albida* parklands. The benefits associated with these practices are increasing the number of protected species (plant biodiversity conservation), density and better growth of trees in the parklands.



**Photo 15:** Shrubs on farmed fields covering the soil during the dry season and coppiced at the onset of the rainy season (J. Bayala)

### *Faidherbia albida* parklands

*Faidherbia albida*, as a parkland species, is present in virtually all of Senegal from the Atlantic coast to the Falémé River and from the Senegal River to the Guinea Bissau border. A highly integrated form of the *F. albida* parkland system exists in Serer region. *F. albida* parklands can also be found in the Wolof and Mandingue of Casamance regions. The species grows well on sandy soils within the Thiès-Louga-Kaolack triangle (Boffa 2000).

### *Other parklands*

Their composition varies according to climatic zones as follows (Sall 1996):

- Sahelian zone: *Acacia nilotica*, *Acacia raddiana*, *Acacia senegal*, *Acacia seyal*, *Combretum sp.*, *Sclerocarya birrea*, *Sterculia stiger*

- Sudanian zone: *Daniella oliveri*, *Erythrophleum guineense*, *Khaya senegalensis*, *Parkia biglobosa*, *Pterocarpus erinaceus*, *Vitellaria paradoxa*
- Sub-guinean zone: *Chlorophora regia*, *Elaeis guineensis*, *Parinari excelsa*.

### *Rotation*

The traditional cropping system is based on a biennial rotation of groundnut-millet without fertilizers or application of crop residues. In bush fields, the main rotations are groundnut-millet-fallow, millet-groundnut-millet, groundnut-millet, groundnut-rainfed rice.

### *Association*

Association is widespread compared with pure sole crops in Senegal because it constitutes a risk avoidance practice in rainfed production system. Legumes and cereals seeds are mixed and sown in the same pits.

## Technological elements of CAWT in the four Sahelian countries (Burkina Faso, Mali, Niger and Senegal)

A summary of the technological elements of CA and CAWT and the way they are combined in the four Sahelian countries is presented in Table 1.

**Table 1:** Technological elements of CA and CAWT in the four Sahelian countries (Burkina Faso, Mali, Niger and Senegal)

	Zai	Half-moons	Mulching using a mixture of organic residues, shrub and tree prunings)	Farmer-managed natural regeneration	Afforestation	Faidherbia albida parklands	Other parklands ( <i>Vitellaria paradoxa</i> , <i>Parkia biglobosa</i> , etc.)
<b>Technological elements</b>							
Compost or manure from households	<b>X</b>	<b>X</b>					<b>X</b>
Planted trees					<b>X</b>		<b>X</b>
Regenerated shrubs/trees ( <i>F. albida</i> , <i>V. paradoxa</i> , <i>P. reticulatum</i> , <i>Combretum spp.</i> , etc.)				<b>X</b>		<b>X</b>	<b>X</b>
Crop residues			<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>
Mulching (biomass from tree and shrub species mixed in the field)				<b>X</b>	<b>X</b>		<b>X</b>
Mulching (biomass transfer from tree and shrub species mixed in the field and from neighbouring fields, including exotic species)			<b>X</b>	<b>X</b>			<b>X</b>
Crop seeds (millet, sorghum, cowpea)	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>
Tree seeds	<b>X</b>	<b>X</b>	<b>X</b>		<b>X</b>		

	Zai	Half-moons	Mulching using a mixture of organic materials (crop residues, shrub and tree prunings)	Farmer-managed natural regeneration	Afforestation	Faidherbia albida parklands	Other parklands ( <i>Vitellaria paradoxa</i> , <i>Parkia biglobosa</i> , etc.)
Rotations are cereal (millet-sorghum)-groundnut in the central and northern parts, cotton-maize-sorghum in the southern and western parts (Burkina Faso and Mali)			X	X	X	X	X
Association cereal (millet-sorghum)-cowpea	X	X	X	X	X	X	X
Dry pit planting or pit planting of crops after the first important rain	X	X	X	X	X	X	X
Conventional harvest of sorghum or millet at the beginning of the dry season	X	X	X	X	X	X	X
Pruning/coppicing of trees for poles with production of biomass of twigs and leaves					X		X
Hand hoe or animal implement	X	X	X	X	X	X	X
Burning of the remaining crop residues when preparing the field for the new cropping season			X	X			X
Dry pit planting or pit planting after the first important rain of next crop	X	X	X	X	X	X	X

	Zai	Half-moons	Mulching using a mixture of organic materials (crop residues, shrub and tree prunings)	Farmer-managed natural regeneration	Afforestation	Faidherbia albida parklands	Other parklands ( <i>Vitellaria paradoxa</i> , <i>Parkia biglobosa</i> , etc.)
<b>Combination of technological elements</b>							
Fruit trees planted at variables spacings depending on the species					X		
Rotation is not fixed – but sorghum and pearl millet are interchanged depending on farmer forecast for the rainy season (millet if less rain anticipated)	X	X	X	X		X	X
Compost or manure from households applied before planting	X	X					X
Dry pit planting of sorghum/ millet and cowpea before it rains or just after the first important rain	X	X	X	X	X	X	X
If too many weeds or late season planting then scraping using hand hoe or ploughing using animal drawn implement				X	X	X	X
Annual crops intercropped with trees					X		X
Legumes (cowpea) intercropped rather than rotated	X	X	X	X		X	X
Cereal-groundnut rotation at non fixed frequency	X	X	X	X	X	X	X
Crop straws and shrub/tree fodder supplied to animals	X	X	X	X	X	X	X

	Zai	Half-moons	Mulching using a mixture of organic materials (crop residues, shrub and tree prunings)	Farmer-managed natural regeneration	Afforestation	Faidherbia albida parklands	Other parklands ( <i>Vitellaria paradoxa</i> , <i>Parkia biglobosa</i> , etc.)
Dung and residues of fodder applied to the plots	X	X	X	X	X	X	X
Cowpea and cereal seeds are mixed and sown in the same pit		X	X	X		X	X
Weeding is done using hand hoe or animal drawn implement once or twice during the cropping season	X	X	X	X	X	X	X
Dispersed shrub/tree individuals of various local species (sometime few individuals of exotic species)			X	X		X	X
Conventional harvest of sorghum or millet at the beginning of the dry season	X	X	X	X	X	X	X
Dry pit planting of next crop or planting after the first important rain	X	X	X				X
<b>Livelihood system context</b>							
All over the country				X		X	X
Southern and western parts of the country (Burkina Faso and Mali), along the rivers in all countries					X		
Northern part and Central Plateau, Burkina Faso, Dogon Plateau in Mali	X	X	X				

	Zai	Half-moons	Mulching using a mixture of organic materials (crop residues, shrub and tree prunings)	Farmer-managed natural regeneration	Afforestation	Faidherbia albida parklands	Other parklands ( <i>Vitellaria paradoxa</i> , <i>Parkia biglobosa</i> , etc.)
Degraded crusted lands	X	X	X				
High population density	X	X	X				
Household of four or five adults plus several children	X	X	X	X	X	X	X
Remittances from urban dwelling relatives	X	X	X	X	X	X	X
Cattle, small ruminants, poultry	X	X	X	X	X	X	X
Cattle fattening operations during the dry season for Muslim feasts	X	X	X	X			
Cash crops: cotton, rice, fruits, vegetables				X	X		
Women have small groundnut and vegetable plots	X	X	X	X	X	X	X
On-farm tree ownership (since 1994) in Mali					X		
Gardening where small dams and rivers exist or even using water from wells	X	X	X	X	X	X	X
<b>Costs, benefits and opportunities for improvement or introduction</b>							
No special equipment or knowledge is needed to adopt the technology	X	X					

	Zai	Half-moons	Mulching using a mixture of organic materials (crop residues, shrub and tree prunings)	Farmer-managed natural regeneration	Afforestation	Faidherbia albida parklands	Other parklands ( <i>Vitellaria paradoxa</i> , <i>Parkia biglobosa</i> , etc.)
Cost of implementation is mainly calculated according to the farmer's opportunity cost of time	X	X					
Economic return to the farmers' investment is 100%	X	X					
Inconvenient is the need for additional time to maintain the structure	X	X					
Combination with contour stone bunds and planting of trees		X					
More diverse production					X	X	X
Higher and more stable income					X	X	X
Reduction of erosion by slowing down water stream	X	X					X
Concentration of water and organic matter that contribute to increase agricultural production	X	X					X
Increase in soil moisture content	X	X					X
Improvement of soil structure and chemical content	X	X					X
Increase crop yield by 49 to 112% and even more	X	X					X



	Zai	Half-moons	Mulching using a mixture of organic materials (crop residues, shrub and tree prunings)	Farmer-managed natural regeneration	Afforestation	Faidherbia albida parklands	Other parklands ( <i>Vitellaria paradoxa</i> , <i>Parkia biglobosa</i> , etc.)
Poles and construction wood as well as fire wood available					X		X
Higher vegetation cover and natural regeneration	X	X					
High costs of technique due to its high requirement in labour	X	X					
Mechanical zai reduces by more than 90% the amount of time compared with the manual zai	X						
Healthier draught animals and higher milk production of animals fed with crop residues			X	X		X	X
Higher crop yields due to application of the mulch and manure (dung and straw residues)			X	X		X	X
Increased fodder production, fuel wood availability from pruning and thinning, as well as the potential to sell firewood				X	X	X	X
Possibility of introducing fodder shrubs/trees fixing nitrogen like <i>Faidherbia albida</i> , <i>Pterocarpus sp.</i> , etc. as well as increasing the number of non-nitrogen fixing shrubs (e.g. <i>Piliostigma reticulatum</i> ) to serve as soil cover during the dry season			X	X		X	X

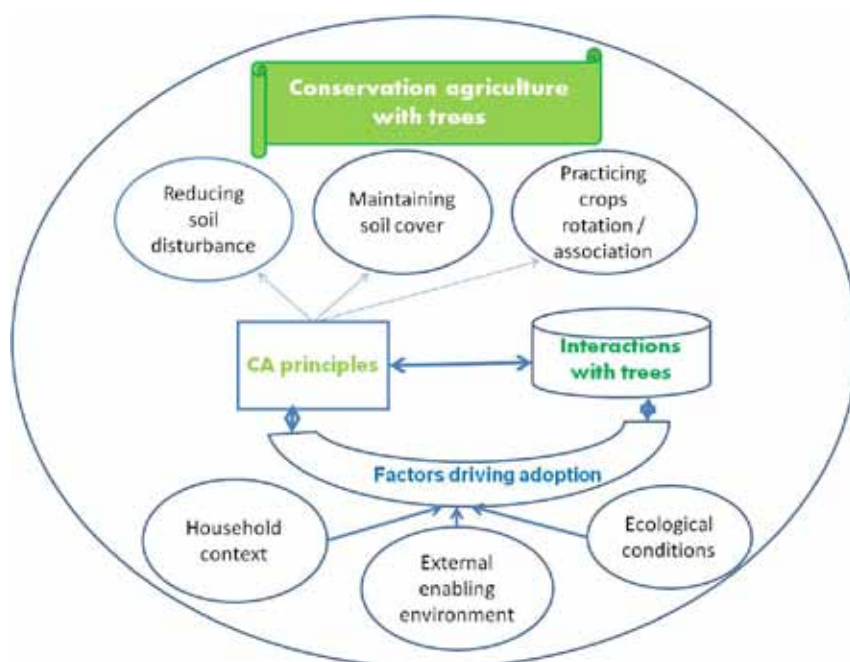
	Zai	Half-moons	Mulching using a mixture of organic materials (crop residues, shrub and tree prunings)	Farmer-managed natural regeneration	Afforestation	Faidherbia albida parklands	Other parklands ( <i>Vitellaria paradoxa</i> , <i>Parkia biglobosa</i> , etc.)
Possibility of associating shrubs to stabilize the soil and increase vegetation cover		X					
Rotations/associations of cereals with legume crops	X	X	X	X			X
Stop burning the biomass when preparing the fields for sowing			X				X
Need for clear ownership of the preserved trees				X			X
<b>Key knowledge constraints and research needs</b>							
Sustainability of the practice and area covered by this technique	X	X					
Dynamics of vegetation cover recovery due to the practice and carbon sequestration	X	X	X	X	X	X	X
Impact on ground water						X	X
Spacings and interactions between different components					X	X	X
Impact of this practice on soil fertility and soil borne diseases							

	Zai	Half-moons	Mulching using a mixture of organic materials (crop residues, shrub and tree prunings)	Farmer-managed natural regeneration	Afforestation	Faidherbia albida parklands	Other parklands ( <i>Vitellaria paradoxa</i> , <i>Parkia biglobosa</i> , etc.)
Selection of better adapted and more productive tree germplasm with the farming/pastoralist communities		X	X	X	X	X	X
Conditions for good survival and performance of <i>Faidherbia albida</i> , <i>Pterocarpus sp.</i> , etc.			X	X		X	X
Most cost-effective techniques (including mechanization of zai and half-moons) on farm and managed by farmers	X	X	X	X	X	X	X

## Key factors affecting adoption of CA technologies

Key factors affecting the adoption and adaptation of CA/CAWT technologies include the household context (wealth status, labour availability, livelihood strategy, social and cultural factors, the appropriateness) and the enabling external environment (access to information, risk, collective action, rural finance, infrastructure and

policy) and the ecological conditions (Figure 4). There is no single technology that works everywhere and under any circumstance leading to a need to define the socio-ecological niche of each technology (Knowler and Bradshaw 2007; Giller et al 2009).



**Figure 4:** Conceptual framework of the adoption/adaptation of CA and CAWT technologies

The most successful and widespread technologies (zaï, half-moon and FMNR) were developed in areas (Central Plateau of Burkina Faso and Maradi region in Niger) with high population pressure and where land degradation reached such a level that farmers had no other choice but to either reclaim the degraded lands or migrate to new areas. This land-pressure driver is likely to be important in any effort to repeat the process elsewhere. The success of these techniques is linked to the fact that they are based on local practices that are simple and flexible since farmers could adapt them to their own situations and objectives (Reij et al 2009).

In contrast, improved fallows and cover crops introduced and tested by research institutions were not adopted on a large scale despite their potential for preserving soil fertility, improving crop production in the long run and feeding livestock. The main reasons

for their relatively low adoption (compared with zaï, half-moon and FMNR) included (1) improved fallows require more inputs and investments which most farmers could not afford, (2) farmers did not perceive the problem or (3) farmers were not always involved in the research from the beginning and many of the experiments were conducted on-station leaving out the socio-economic conditions in which these techniques are meant to perform. For instance, labour needed for tree coppicing and biomass management for improved fallow was not properly considered. Lack of access to good germoplasm of tree/shrub species was another constraint. Socio-economic and cultural constraints also play a major role in the adoption and rejection of innovations (Fowler and Rockstrom 2001; Perret and Steven 2006). On-farm trials are critical to capture site- and circumstance-specific nature of small-scale farming systems and to better understand the way they

function (Giller et al 2009). They should complement on-station trials which are more about investigating biophysical processes and establishing principles.

Another reason for the low adoption of improved fallows and cover crops is that very often the yields during the first year are reduced (Samba 1997; Traoré et al 1998; Segda et al 1998a; Bayala et al 2003) leading to no immediate tangible benefit for the farmers. Short-term benefits are important because they determine to a large extent the attractiveness of CA/CAWT to farmers (Giller et al 2009). In contrast, farmers applying zaï technique harvest up to 1500 kg ha<sup>-1</sup> in years of good rainfall, making it more attractive to farmers on degraded lands (Kaboré and Reij 2004).

For farmers with the same environmental conditions, wealth status is important as it has an impact on their ability to invest in the required resources to rehabilitate their land. For instance, farmers with livestock (Fulani) are able to apply huge quantities of manure on their lands and thus reclaim it much faster than those without livestock. Similarly, the ability to hire labour for zaï or half-moon constitutes an advantage. In Niger, the well-to-do are able to buy degraded lands, reclaim and re-sell them for profit. In Mali, Bengaly (2008) reported that the adoption rate of anti-erosive control technologies was usually less than 50% and was related in part to the farm equipment in the Ségou region. Thus, 40% of well equipped holdings (Type A) applied anti-erosive techniques against 10% for the least equipped farms (Type D) (Bengaly 2008). According to some studies, CA/CAWT will be more rapidly adopted by smallholder farmers with adequate resources of land, cash and labour, and not by the most resource-constrained groups (Wezel and Rath 2002; Perret and Stevens 2006; Giller et al 2009). In turn, when investment costs for the technique are low, like in FMNR, then all wealth categories can adopt it (Allen et al 2009). Allen et al (2009) hypothesized that poorer farmers may be more highly motivated than richer ones to invest in FMNR, not only because of its low cost, but also because it provides wood and non-wood tree products that may contribute proportionately more to securing their livelihoods.

Land access right should be guaranteed with new forms of social organizations to avoid social conflict, particularly where population density and land pressure are increasing and where market incentives exist. But land ownership *per se* is not a sufficient condition if not embedded in collective action in the adoption of some of the technologies. For instance, investing in FMNR on hired land was a condition to obtaining the land in Bankass district of Mali. This was

collectively agreed to by the community (Allen et al 2009). Another example for which collective action is needed is the mulching technique since crop residues in the field, if not collected, are considered communal assets for free grazing livestock. Thus individual farmers cannot restrict grazing even on their own land without challenging the traditional rights of others in the community (Giller et al 2009). Collective action can also help overcome technical problems, through information dissemination and farmer-to-farmer exchanges (Perret and Stevens 2006).

Market opportunities may also play an important role in the adoption of techniques as revealed by the impact of wood market on FMNR in Maradi region in Niger. In that region, the new market for acacia seeds also greatly boosted farmers' interest in the "farmer-managed agroforestry system" or FMAFS (Cunningham and Rinaudo 2009).

The impact of institutional issues is well explained by the cases of Maradi region in Niger and Bankass district in Mali. In both cases, changes in the political and legislative context created new opportunities for farmers to play an active role in managing the natural resources on which their livelihoods depend. In 2004, the Niger Government moved a step closer by allowing for private ownership of trees, thanks to advocacy efforts by donor community stakeholders, while in Mali decentralization of local government coupled with revision of the Forest Code (1994) created a favourable environment (Allen et al 2009; Reij et al 2009).

In general, CA and CAWT seem to have some real chances of success in the four Sahelian countries. Many farmers are motivated to use the biomass generated by the system to improve soil fertility, to enrich the fallow or to feed livestock. The main difficulties remain the free roaming livestock and bush fires, which have a negative effect on the ability of the biomass to protect the soil during the dry season.

## Synthesis of the key findings

This review was able to collate the evidence of what are CA and CAWT practices in the Sahel along a continuum from experiments, via practical trials to farmer practices for the four Sahelian countries which are Burkina Faso, Mali, Niger and Senegal. The experiences and the information accumulated differed from country to country and therefore the document was structured based on each individual country. Despite the visit to the four countries, a certain number of activities may have been omitted and

therefore, the review cannot be considered exhaustive. Such efforts need to be repeated and sustained in order to update and give a full picture of the work done in that area.

The review also did not allow a systematic collation of the evidence of the costs and benefits associated with the use of these CA and CAWT practices within their system context since this information was missing in most of the collected documents (Table 1). Lack of this information and the fact that we were not able to interact with farmers and farmers' organization did not allow us to assess the opportunities for the improvement of the developed CA and CAWT practices. The practices encountered in the four countries can be grouped in the following categories: parkland trees associated with crops, coppicing trees, green manure, mulching, crop rotation and intercropping, and traditional soil/water conservation. These practices were not all adapted to all climatic zones and to all livelihoods contexts, but in general yield improvement occurs where the productivity potential of the soil was low for the key staple food crops which are maize, millet and sorghum. Coppicing trees and rotations appeared to be better adapted for zones with an annual rainfall higher than 800 mm whereas the opposite happens with parkland and soil-water conservation measures. Mulching seemed to improve crop yield when the rainfall is below 600 mm. The role of trees can be reinforced in parklands which virtually occur in all climatic zones. For this practice,

management options of the tree component need to be developed (Bayala et al 2002) or more compatible associations of tree and crop species looked for (Sanou 2010). Trees can also play a key role in stabilizing the soil and water conservation structures provided the most suitable species are identified. For all practices involving the tree component (Table 2), application of appropriate tree management to reduce crop yield losses while still providing products (fruits, leaves, wood, etc.) and services (soil carbon building up) for long-term sustainability of the production systems in dry lands of West Africa is needed.

From the livelihood and enabling environment standpoint, low-cost techniques like FMNR may be easily adopted/adapted regardless of the wealth status of the farmer. However, there is a need for collective commitment to avoid the destruction of young seedlings by free roaming livestock. There is also a need for clear ownership of preserved trees through forest laws or local by-laws authorizing such practices even on borrowed lands as in Bankass district in Mali. For the high-labour or resource-demanding techniques (like the zaï), there are some prerequisites for their larger adoption and/or adaptation. They need to be developed and applied in conditions where people have no alternative but to reclaim their degraded lands due to high human and animal pressure, such as the Central Plateau of Burkina Faso, the Maradi region in Niger and the Dogon Plateau in Mali.

## Research questions and upscaling issues

### Research questions

CAWT practices in the Sahel can be grouped into four categories as shown in Table 2 which also summarizes what is known or not known about these categories, their technological elements, the climatic zones of application, the related problems and constraints and finally the availability for cost data for these CAWT practices. The review has raised some issues related to various aspects of conservation agriculture with trees:

- About tested species, the densities, the time for the trees to produce the recommended dose to be applied (e.g. 5 to 10 t ha<sup>-1</sup>) on a sustainable basis and the cost associated with were not reported in the literature collated for the present review
- The evidence of trees contributing to the performance of the well known soil and water conservation structures (bunds, half-moon, zai, etc.) was not clear. Some of the techniques like zai seem to favour local species regeneration through their seeds contained in the manure applied. The subsequent impact of these trees on soil carbon and crop production, as well as their management by farmers remain unclear
- Characteristics of a good leaf for feeding animals are very similar to those of a good leaf for replenishing soil fertility in CA. Hence there might be a perennial competition between using biomass for feed and soil improvement, but this aspect has not been well investigated
- In CA with trees, exotic species were introduced, but the literature doesn't report much about their impact on local species regeneration, how they compare with local species, their water use, their tolerance to drought or their invasiveness
- Some of the developed technologies were high-labour and required quite a lot of resources, and as a consequence their practical use by farmers is questionable
- The knowledge about the interactions of trees in parklands with the CA principles seems to be limited to the soil cover and the association dimensions. There is a dearth of information in the literature about their impact on reducing soil disturbance
- There is also a lack of reported information on the the agronomie, silviculture and management of the trees and shrubs used, including the role of inoculation of leguminous woody species
- In intercropping with for instance, cereal-legume, the key issue appeared be to the shortage of mulch as the crop residues are consumed by the livestock. What role can the trees play taking into consideration the variability in rainfall with some dry years and some good rainy seasons? If intercropping is well known but not practised, what is the gap?
- No clear finding was reported about the interactions of CA practices with trees in farmers practices and the role of farmers in the research process on the adoption/adaptation of CAWT technologies
- For the technologies developed by national research institutes, it has not always been possible to clearly show the well known positive interaction between organic matter and mineral fertilizer as promoted by TSBF
- There were some research methodological weaknesses in the designs for on-farm trials reducing the usefulness of the reported data. For instance, comparing one species in different villages, with different densities and probably different soils in parkland studies or limited number of replicates
- Policy and social organization issues and livelihood context still require some investigations.

Table 2: Categories of CAWT practices identified in the Sahel and related constraints

CAWT Practice	Technological elements	Arid	Semi arid	Sub humid	Problems/ constraints	Cost
<b>1. Parklands with positive impact on yields of associated crops</b> ( <i>Adansonia digitata</i> , <i>Borassus aethiopicum</i> , <i>Faidherbia albida</i> ) - mono specific - dominant	Crop, trees and animals contribute to CA	<i>A. digitata</i> , <i>H. thebaica</i> , <i>F. albida</i>	<i>A. digitata</i> , <i>F. albida</i>	<i>A. digitata</i> , <i>B. aethiopicum</i> , <i>F. albida</i>	- Degradation of the parkland - Competition for residues and trees biomass - Bush fire (sub humid)	Yet to be evaluated
<b>2. Other parklands</b> ( <i>Vitellaria paradoxa</i> , <i>Parkia biglobosa</i> , <i>Prosopis africana</i> , <i>Cordyla pinnata</i> , <i>Girardinia sepium</i> , etc.)	Crop, trees and animals contribute to CA	<i>A. digitata</i> , <i>P. africana</i> , <i>H. thebaica</i> , etc.	<i>P. biglobosa</i> , <i>A. digitata</i> , <i>V. paradoxa</i> , <i>P. africana</i> , <i>Borassus spp.</i> , <i>H. thebaica</i> , etc.	<i>P. biglobosa</i> , <i>V. paradoxa</i> , <i>P. africana</i> , <i>Borassus spp.</i> , <i>Cordilia sp.</i> , etc.	<i>V. paradoxa</i> : competition for water, nutrients and light, lack of management options for the trees <i>P. africana</i> : lack of regeneration, over-exploitation for fodder	Some data available within the document for some species
<b>3. Improve fallows/coppicing</b> ( <i>Acacia tumida</i> , <i>A. colei</i> , <i>Albizzia lebbbeck</i> , <i>Azadirachta indica</i> , <i>Combretum lecardii</i> , <i>Girardinia sepium</i> , <i>Guiera senegalensis</i> , <i>Leucaena leucephala</i> , <i>Piliostigma reticulatum</i> , <i>Prosopis africana</i> , etc.)	Crop, trees and animals contribute to CA	<i>A. tumida</i> , <i>A. colei</i> , <i>A. indica</i> , <i>G. senegalensis</i>	<i>A. indica</i> , <i>G. senegalensis</i> , <i>P. reticulatum</i> , <i>P. africana</i>	<i>A. lebbbeck</i> , <i>A. indica</i> , <i>C. lecardii</i> , <i>G. sepium</i> , <i>L. leucephala</i>	Competition for water, nutrients and light, lack of management options for the trees	Some data available within the document for some species
<b>4. Soil and water conservation with trees in marginal land</b> (Zai, half moon, stone bunds, earth dune fixation, trenches)	Trees /shrubs Live fences Contour planting Boundary planting Associate planting (upcoming parklands) Fodder trees Animals Annual crops herbaceous (fodder species)	Zai, half moon, stone bunds, earth bunds, sand dune fixation, trenches	Zai, half moon, stone bunds, earth bunds, sand dune fixation, trenches	Banquettes, stone bunds, earth bunds, sand dune fixation, trenches	- Labour intensive - Tree seed availability and quality - Knowledge and skills Animal pressure - Lack of management options for shrubs	Some data available within the document for some practices



## Upscaling issues

Any effort to upscale some of the CAWT practices to increase vegetation cover by increasing the tree component in the system will require additional information, raising some questions, such as:

- What are the socio-ecological niches in which a given CAWT technology works?
- Which attributes make species more appropriate for CAWT and in which ecological conditions do they perform best?
- What are the appropriate management options for CAWT practices (species composition, spacing, density, pruning frequency, rates of biomass)?
- How can the principles of CAWT best be conveyed to farmers?
- What is the vegetation recovery rate and its impact on carbon sequestration in CAWT practices?
- What are the costs/benefits of the different techniques and management options?
- What are the necessary and sufficient socio-economic and policy conditions for high rates of adoption of the CAWT techniques?

For every one of these the emphasis must be on predicting the appropriate socio-ecological niche as we need to move away from blanket recommendations. The only way to realistically do that is by focusing on processes, not just empirical testing (which can never cover enough of the possible contexts and conditions). As pointed out by Giller et al (2009), a challenge for the CA research community is to assess where particular CA practices may best fit, and which farmers in any given community are likely to benefit the most. To be accepted, the technology must not only fit into the existing farming system, but also fit into the whole livelihood system, which includes the social, economic and institutional context of the household, the strategy developed by the family and the constraints it faces (Kundhlande et al 2004).

In addressing these questions, key stakeholders should be involved at different stages of the process. They

include scientists, extension agents, farmers and policymakers. Scientists should focus their efforts on acquiring better knowledge of cover crops, shrubs-trees, the integration of technological element and the circumstances in which a given CA technique works. From the review, one can see a large scope for identification of better associations/rotations for the annual and perennial species in each agro-ecological zone of the West African Sahel. As much as possible, research activities should be participatory where researchers, farmers and extension agents jointly design and evaluate trials to determine the best combinations, etc.

Skill and understanding of change by agents can play a special role in helping people to understand their actual situation and to be willing to try new ideas. The change agent can greatly help or hinder adoption of new techniques. Empathy, persistence, patience, skill and flexibility are key attributes as indicated by Cunningham and Rinaudo (2009).

Farmers need to recognize that their current farming system is not meeting their needs and to understand the many benefits of CAWT and be willing to change their traditional approaches. Therefore, it appears essential to reinforce the capacities of farmers through their better organizations and information sharing and exchange of experiences with other farmers (Perret and Stevens 2006; Cunningham and Ridaudo 2009).

Farmers' ownership of trees and their natural resources are vital to encourage their investment in a new farming system. Therefore, new forms of farmer's organizations should also emerge to avoid social tensions and conflicts. Government agencies and policies need to support and promote the CAWT through adequate funding of technology development and information exchange program. The government should be assured of the effectiveness of land management and include an evaluation of the environmental impact of all the interventions in rural areas. Great efforts are needed to disseminate the knowledge of the various conservation strategies throughout the different regions of semi-arid West Africa, and to develop new technologies 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 (Wezel and Rath 2002).

## Conclusion

The present review reveals that low-cost techniques like FMNR may be easily adopted/adapted regardless of the wealth status of the farmer. However, there is need for collective commitment to avoid the destruction of young seedlings by free roaming livestock. There is also need for clear ownership of preserved trees through forest laws or local by-laws authorizing such practices even on borrowed lands as in Bankass District in Mali. For the high-labour or resource-demanding techniques (like *zai*), there are some prerequisites for their larger adoption and/or adaptation. They need to be developed with the full participation of farmers and applied in conditions where people have no alternative but to reclaim their degraded lands due to high human and animal pressure, such as the

Central Plateau of Burkina Faso, the Maradi region in Niger and the Dogon Plateau in Mali. When the natural resources are still abundant, as in the south Sudanian zone, soil fertility replenishment issues are not always well perceived and that may explain why improved fallows tested for this zone did not succeed. Participatory research should continue for their better adaptation to the different contexts targeted. Of the reviewed technologies, the most promising for greater soil cover are the *zai*, half-moons associated with shrubs to stabilize them, FMNR associated with mulching using tree/shrub prunings, and *F. albida* parklands with associated shrubs. The suitable socio-ecological conditions for the remaining technologies need further investigation.

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## Our Vision

A rural transformation in the developing world as smallholder households strategically increase their use of trees in agricultural landscapes to improve their food security, nutrition, income, health, shelter, energy resources and environmental sustainability.

## Our Mission

To generate science-based knowledge about the diverse roles that trees play in agricultural landscapes, and use its research to advance policies and practices that benefit the poor and the environment.

## About the Occasional Paper series

The Occasional Paper is produced by the World Agroforestry Centre to disseminate research results, reviews and synthesis on key agroforestry topics. The manuscripts published in this series are peer reviewed.

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