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The African Great Green Wall project

What advice can scientists provide?

A summary of published results

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French Scientific Committee on Desertification

CSFD was founded in 1997 to provide support for the French Ministries in charge of the United Nations Convention to Combat Desertification (UNCCD). CSFD is striving to involve the French scientific community, especially on an international level, to guide and advise policymakers and stakeholders associated in this combat.

CSFD includes a score of members and a President, who is the French scientific and technical agent for the Convention. They are appointed by the Ministry for Higher Education and Research and come from various specialities of the main relevant institutions and universities.

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Dossiers thématiques du CSFD and *Topical Issue*

The first issue of the *Dossiers thématiques du CSFD* was published in January 2005. This collection is now continually being expanded and enhanced by Committee members, with the aim of covering all of the main topics relevant to desertification. Many exchanges between one or more volunteer authors responsible for a *Dossier* and the Committee are necessary prior to publication. The time between the decision to focus a *Dossier* on a specific topic and its ultimate publication is therefore often very long, and sometimes even too long when an ongoing ever-evolving issue is being covered.

This is what prompted the decision to launch the present *Dossier d'actualité* focused on scientific issues arising when the **pan-African Great Green Wall** project was initiated. It was prepared by coordinating contributions from the different Committee members in order to draw up a summary of the main available information culled from the current scientific literature.

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TABLE OF CONTENTS

PREAMBLE

The African Great Green Wall initiative has reopened discussions on this concept, its significance with respect to combating desertification (CD), as well as its effectiveness and cost. Based on fragmentary knowledge culled from sometimes very early experience, the scientific community, civil society organization and the media have focused on the situation and issued public criticisms and questions. We could not—as researchers specialized on these regions—overlook this debate. This *Dossier* attempts to answer some of the questions on the basis of available information.

Following the serious droughts in Africa (1958-1963, 1968-1974, 1984-1990), it became clearly evident that inhabitants' food security could no longer be fulfilled due to the fragility of the agricultural systems and ecosystems[1], and the difficulty of maintaining land productivity in these arid and semiarid regions, especially in the Sahel region bordering the Sahara. Everyone has become aware of the fact that land degradation has a serious impact on local communities that depend on renewable natural resources and are undergoing rapid population growth.

In this setting, scientists and civil society were involved in development support projects and programmes (reforestation, stabilization of sandy areas, degraded soil recovery, water storage and use, etc.) in the 1970-80s. Although these initiatives were not always successful, the lessons learnt led to a better understanding of the ecological, technical and social complexity of desertification issues. With this pool of experience, we now have sufficient strong scientific and technical knowledge in agricultural sciences, natural sciences, social sciences and economics to better guide decisions on sustainable land development and management.

Top level decisionmakers—with the strong support of scientists—also committed themselves to providing the human, technical and financial resources necessary to meet the CD challenge. The signing of the United Nations Convention to Combat Desertification (UNCCD) in 1994 at UNESCO (United Nations Educational, Scientific and Cultural Organization) in Paris was an international milestone in this quest.

CD is still relevant, as illustrated by the ambitious African Great Green Wall project that is already under way in Senegal. This 15 km wide, heterogeneous multispecies vegetation belt will pass through 11 countries from Dakar to Djibouti over a total distance of around 7000 km (AU *et al.,* 2008b) (Mauritania-Djibouti). This large-scale project goes much beyond the simple image of 'plantations to stop the desert' and is arousing considerable enthusiasm and questions.

Enthusiasm, because it is an African initiative involving all Sahelian countries to the highest policymaking level, which is aimed at planting vegetation on a broad band of arid and semiarid lands affected by desertification using sustainable land management practices.

Questions, because a project of this magnitude, conducted in several countries with different climatic, ecological, social, land, legal, economic conditions, etc., requires ongoing reflection and planning to guide the field work as effectively as possible on a local scale. This should involve an assessment of the value of available scientific knowledge and past experience in these regions by focusing on both their successes and failures.

This *Dossier* aims to shed light on the underlying issues that should be dealt with in priority so as to ensure its efficient operational implementation based on the **main scientific knowledge pertaining to this initiative**. It is not an exhaustive summary, but rather a factual summary that could be useful for policymakers, authorities and the general public.

[1] The terms listed in the glossary (page 40) are highlighted in green and underlined in the text.

INTRODUCTION: DESERTIFICATION, SUSTAINABLE MANAGEMENT OF LAND AND GREEN WALLS

The image of a green wall marks minds and the imagination, but desertification cannot simply be halted by planting trees to stop the desert at the outskirts of civilization. Those managing the initiative in Africa are fully aware of this. This is just one more of the many ongoing public misconceptions concerning the Sahara and desertification.

The **desertification process** is defined in the UNCCD at local and regional scales as “land degradation in arid, semiarid and dry subhumid areas resulting from various factors, including climatic variations and human activities”.

Desertification consequently describes an irreversible decline or destruction affecting the biological potential of lands and their capacity to sustain or feed the populations. This process highlights the need to improve the standard of living of the must vulnerable societies by ensuring long-term support for their activities, preserving land fertility or finding other activities that could alleviate pressure on lands. Desertification is an integral part of the issue of sustainable development in drylands. As highlighted in the Annexes to the Convention, this notion applies to every continent, and mainly to dry areas where aridity and drought are two common climatic features.

From Requier-Desjardins & Caron, 2005.

The Saharan Desert has a very long history!

The Sahara is the largest desert within tropical regions. Based on the discovery and analysis of paleoclimatic dune formations in Chad (Schuster *et al.*, 2006), this desert formed at least 7 million years ago, while others estimate that it appeared 25 million years ago. It is hard to accurately determine the boundaries of the Sahara (Rognon, 2000), and geological and geomorphological studies have shown that for millennia the edges of the Sahara have fluctuated slightly. Locally, sand and silt layers advance in some areas due to soil erosion.

The Sahara is not advancing, but humans create conditions conducive to desertification in the Sahel!

Although the Sahara is a stable desert ecosystem, the Sahel is affected by desertification—which is not a sand encroachment process. It is a specific form of land degradation that occurs in dryland regions where it rains irregularly and in small quantities (100 to 600 mm/year).

Population concentration and the development of agrosilvopastoral activities are the main triggering factors. Under these conditions, natural renewable resources (water, soil, fauna, flora) are thus overused and not given sufficient time to recover, and drought worsens land degradation (Mainguet, 1994 & 1999; Mainguet and Da Silva, 1998; Jauffret, 2001).

Combating desertification is not easy!

Although some attractive slogans manage to mobilize populations and donors, clichés and misconceptions should be avoided as they may give rise to simplified and therefore counterproductive concepts. The images they convey can ultimately generate an inaccurate picture of the actual situation, thus making it hard to make effective choices of objectives and initiatives to be undertaken.

Three misconceptions to clarify

1. The desert is a Sahelian ecosystem disease.

The Sahara is sometimes considered as a kind of cancer that spreads into surrounding areas whereas it is actually a perfectly healthy ecosystem that existed long before the birth of humankind and that, like other deserts worldwide, contributes to the Earth's diversity and wealth (biological, landscape, cultural). It is not in any way the image of an unhealthy environment. Global warming has modified its extension pattern in the past, and current climatic changes could lead to a gradual shift in the northern and southern boundaries of the desert.

2. The Sahel is being invaded by a sand sea.

The idea that a gradually advancing sea of Saharan sand dunes is relentlessly invading the Sahel is also unfounded. This is not the pattern that scientists have noted. Sand has been shifting in different areas, sometimes covering infrastructures or dwellings when this movement occurs in their vicinity. These are manageable local and regional phenomena. Hence, this is not a continent-wide movement trend that should be stopped like an invader. Desertification is a diffuse local phenomenon that does not always have its most severe impact in areas bordering the desert.

3. A great forest wall could be planted in uninhabited or sparsely inhabited regions.

The Great Green Wall will not be planted in uninhabited or sparsely inhabited desert regions. On the contrary, the proposed trajectory is to pass through inhabited regions where agriculture and livestock farming are already fully developed on lands allocated according to local traditions (*see map page 7*). Local inhabitants should thus be associated with this initiative while striving to enhance the sustainable environmental, social and economic benefits.

Combating desertification and land degradation is part of a comprehensive approach to environmental and sustainable development issues: enhancing and diversifying resources to improve inhabitants' living standards; stabilizing the resource/resource use balance; restoring viable social and political natural resource management frameworks; and promoting agricultural intensification in order to curb land clearing, overgrazing and deforestation, which contribute to desertification (Cornet, 2002).

The following questions immediately come to mind:

☛ **How could trees play a role in sustainable land management?**

Planting trees in the Sahel is certainly a useful quest. In some cases, this could be done in the form of continuous forest plantations. Trees represent just one constituent of sustainable land and resource development and management. As many factors as possible (water, soil, flora, fauna, etc.) should thus be taken into account over the entire area, if possible, in this management process. To be realistic, this should initially only concern as wide as possible a band, while promoting initiatives within this band as well as beyond in order to take specific national features into account.

What is sustainable land management?

At the Earth Summit in Rio (1992), sustainable land management (SLM) was defined as "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions."

SLM therefore concerns all development sectors (agriculture, livestock farming, water, forestry, etc.). It also addresses global environmental concerns by reducing inhabitants' vulnerability to climate variability and change and ensuring their adaptation (Woodfine, 2009), especially by preserving biodiversity and ecosystem services.

☛ **Where and how to act?**

Where are the intervention areas and what are the limits (climatic, land, social, etc.)? How could agricultural, silvicultural, and pastoral activities be carried out to ensure sustainable land management in collaboration with all stakeholders (farmers, foresters, farmers, etc.)? Who is responsible for their implementation? How can the land issue (ownership and uses) and land access rights be taken into account? How could the initiative be hinged on the decentralization process under way or in force in these countries? Who will benefit from the products generated by the project (wood, fodder, fruit, tannin, gum, resin, honey, etc.)?

☛ **What extent of local community involvement?**

How could the project be formulated while identifying, jointly with local inhabitants, major environment and development problems facing these people in their setting? Are they not in the best position to identify the many uses and rights that could be disrupted by the intervention? And to help in determining intervention strategies that could improve the situation for the many different stakeholders?

These are questions for which scientists could provide some answers through their research knowledge and results, and also via project support analyses and monitoring.

Timeline of large-scale green wall and barrier projects

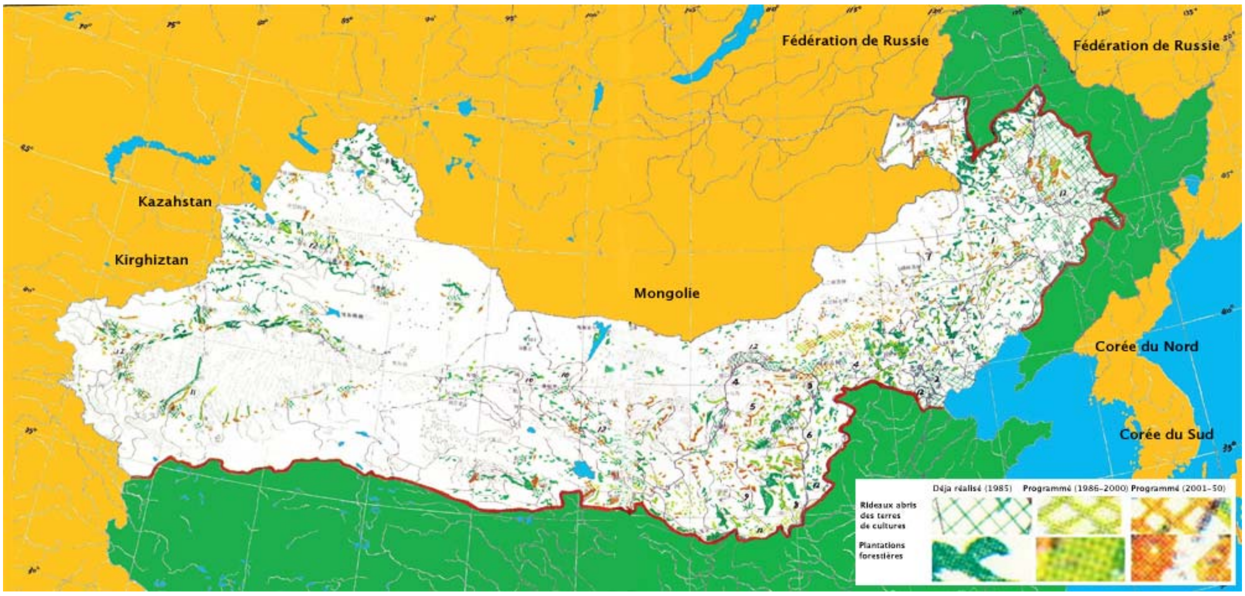
The first green barriers and walls were built in China and Algeria to combat the direct and indirect (socioeconomic, health, etc.) damage caused by the wind: wind erosion, sand and dust storms, silting.

Great Green Wall of China—a first initiative

In 1978, Chinese authorities—mindful of the fact that desertification is linked to vegetation and soil degradation rather than the extension of the Gobi Desert—launched a large-scale integrated management programme in a vast quadrilateral area of over 4 000 km long by almost 1 000 km wide.

In 1989, President Deng Xiaoping called this the 'Great Green Wall' programme in reference to the ancient Great Wall of China, to underline the scope of the work, comparable to the construction of the emblematic wall. It was by no means a bulwark against the desert but rather an integrated agricultural, pastoral and forestry development project. Social development and the creation of infrastructures were also taken into account. The aim was to sidestep the adverse effects of land degradation (Fang *et al.,* 2007) causing dust storms in Chinese cities (Chen *et al*., 2003). The government had planned for annual expenditures of 60 billion yuan (USD 8.77 billion) for the tree planting campaigns. The aim of this large-scale programme was to ensure that 20% of the overall area would be under forest cover by 2010. Due to the economic development, social and environmental conditions in China, 540 million people were involved in reforestation initiatives in 2009, with 2.31 billion trees being planted (AU-EU, 2009).

The project has strong political backing, but many problems have been encountered in the field, e.g. monospecies forest plantations involving barely adapted or non-adapted species, variabilities in climate, soil and relief have not been taken into account, which has led to a high tree mortality rate, as shown by recent studies published by Chinese researchers. These scientists stress the importance of using local species (often steppeland plants) and recommend replenishing natural ecosystems adapted to the conditions that prevail in the region rather than insisting on planting trees that have little chance of survival (Cao *et al.,* 2010; Parungo *et al.,* 1994; Wang *et al.,* 2007; Wang *et al.,* 2010; Yu *et al.,* 2006). In 2000, the programme produced 22 million ha of regenerated forest via planting (70%), grazing prohibition (26%) and aerial sowing (4%). These achievements included 67% protected forests, 33% production forests (14% timber, 16% cash crops, including fruits, and 4% fuelwood). The programme is currently oriented towards environmental protection concepts focused on 'greening' rather than 'forest plantation'. The use of bushy and grassy plants is being promoted alongside a decrease in commercial speculation. Trees with considerable above-ground development are only planted at the most favourable sites.



Global map of the Great Green Wall of China building plan in northwestern, northern and northeastern China.
Legend: Already completed (1985) / Planned (1986-2000) / Planned (2001-2050) / Cropland windbreaks / Forest plantations
According to the map published by the Office responsible for construction of the Three-North Shelterbelt Forest Programme, 1989.

Algerian Green Barrier

Since the 1970s, Algeria has been involved in a national so-called 'Green Barrier' (sometimes called 'Green Dam') programme to combat desertification along the edge of the Sahara (Belaaz, 2003). Initially, it was a civil engineering Aleppo pine reforestation programme carried out by the army on an arid east/west 3 million ha (1 500 km x 20 km) pastoral belt between isohyets 200 and 300 mm. The concept then gradually changed over time. An integrated agrosilvopastoral 'green barrier' approach was fostered by the scientific community in 1976 (MADR, 2004), but this was not taken into account. Clearing activities prior to the monospecies reforestation operations generated ecological and social disruptions and the results were therefore below expectations. As of 1980, the green dam concept had evolved into a set of agrosilvopastoral development initiatives. Thirteen species were used in the reforestation operations. The programme was jointly conducted by the army and forestry services. In 20 years, 120 000 ha were reforested out of the 160 000 ha planned, with a planting success rate of only 42% (Bensaïd, 1995). The green dam concept was abandoned in the early 1990s but then relaunched in 1995, with reforestation activities included in the 'national agricultural and rural development programme'. They were undertaken in areas with suitable conditions (deep soils, an irrigation water supply). The green barrier concept changed in favour of a discontinuous belt combining irrigated high added value crops, managed rangelands and forest plantations. The dune fixation and sustainable rangeland management objectives were maintained and combined with initiatives geared towards infrastructure development and sustainable enhancement of inhabitants' income. Towns and roads were subject to specific arrangements, similar to those described with respect to greenbelts (Mellouhi, 2006).

Green Barrier at Hassi Bahbah, Algeria (35°04' N - 3°01' E).

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(Photograph from the book Algérie vue du ciel, Editions La Martinière*, France)*

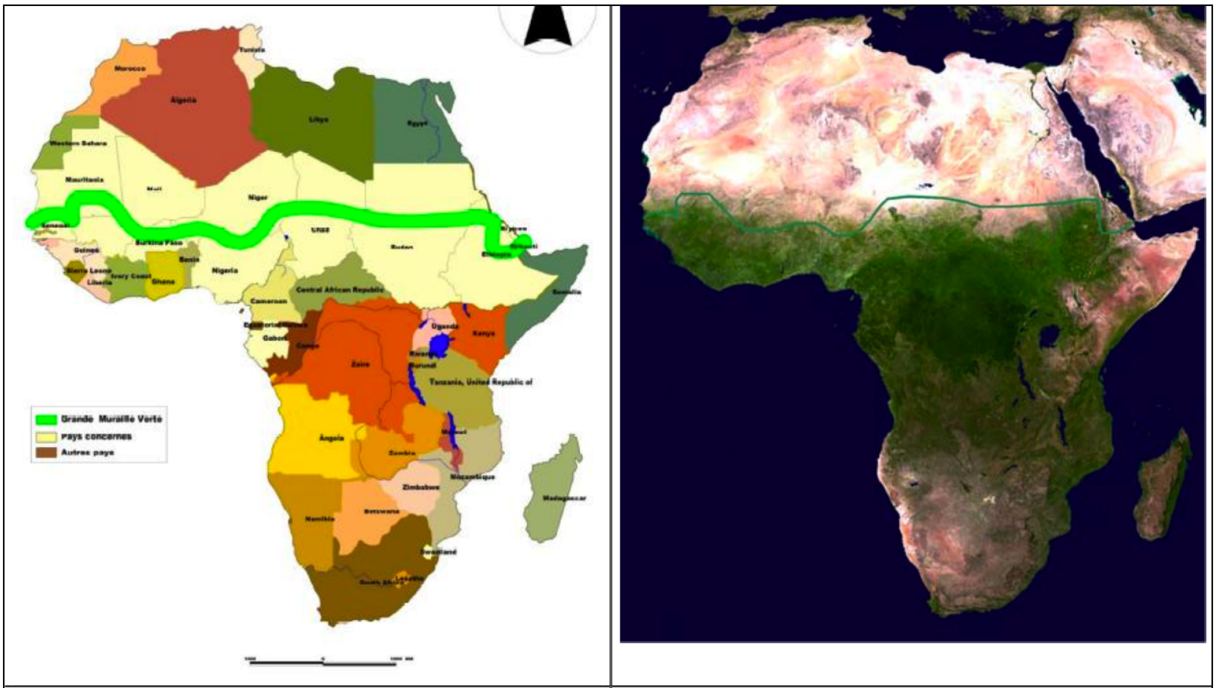
Pan-African Great Green Wall initiative

The pan-African Great Green Wall (GGW) initiative was initially meant to involve the planting of a 15 km wide transcontinental forest belt running from Dakar to Djibouti. This major project is designed to combat desertification. The vegetation belt is to be as continuous as possible, but it may be rerouted if necessary to skirt around obstacles (streams, rocky areas, mountains) or to link inhabited areas (see grandemurailleverte.org). However, prior experience with continuous plantations (see Algerian Green Barrier) set up under unfavourable climatic conditions do not favour such an approach. The map below shows the route initially proposed (left) and a simulated route of a potential 15 km wide continuous transcontinental forest belt plotted on a remote-sensing map (right).

However, the GGW concept note (AU *et al.*, 2008a) specifies that the goal is to ensure the **integrated set up and development of economically valuable plant species adapted to drought conditions, retention ponds, agricultural production systems and other income-generating activities, as well as basic social infrastructures**. It includes several land use and development systems:

- natural formations;
- long-standing artificial plantations;
- agrosilvopastoral production units;
- rangeland sectors;
- protected areas;
- a set of retention ponds located along the GGW;
- basic social infrastructures in the vicinity of the GGW.

The developed units will be managed by local inhabitants (individually or in groups), private producers, local authorities or forestry services.



La tracé de la muraille verte extrait du document de présentation

Le même tracé simulant la largeur annoncée de 15 km (image NASA Modis, traitement Claire Marais-Sicre, CESBIO)

The initially proposed GGW route (from AU *et al.*, 2008b).
GGW route from the presentation document. The same route simulating the planned width of 15 km
(NASA Modis image, processing Claire Marais-Sicre, CESBIO). Legend: Green: GGW / Yellow: concerned countries / Brown: Other countries

"The GGW was not designed as a wall of trees crossing the Sahara, but rather as a set of multisectoral initiatives and interventions to ensure natural resource conservation and protection with the aim of fighting poverty" (OSS, 2008). This is the essence of the information provided in this note.

BENEFITS OF TREES IN SEMIARID ENVIRONMENTS

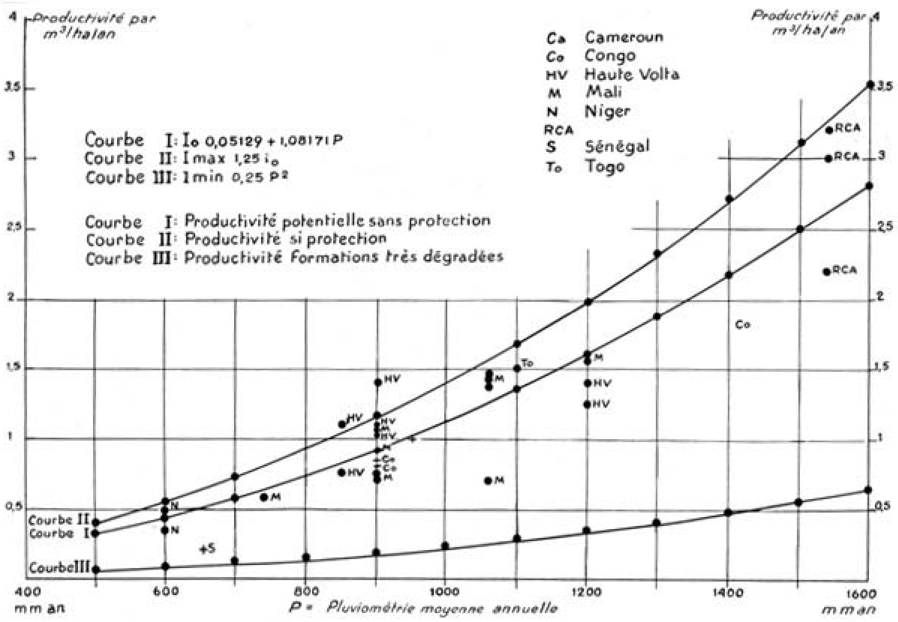
The benefits of trees in semiarid environments are based on:

- biomass production and use;
- the role of trees in ecosystem functioning;
- the status of trees in wind and water erosion control.

Forest biomass production and use

Biomass is defined by biologists as the mass of all living organisms in a given location. It is an important indicator of ecosystem dynamics. Plant biomass produced by a tree is usually the main incentive for planting. Trees and their different products also have an important role for people. Few data are available on forest ecosystem productivity in dry tropical areas. Apart from a few studies (Poupon, 1976; Bellefontaine *et al.,* 2000; Peltier *et al.,* 2009), previous assessments have focused mainly on large woody biomass (trunks and large branches of over 10 cm diameter) and seldom on wood of less than 5 cm diameter.

Clement (1982) compiled the results of studies conducted in eight Sudanian-Sahelian West African countries and established reference values on the potential productivity of stands in three different situations (unprotected, protected from bushfires or developed, degraded). These are still reference curves (*see figure below*), although subsequent studies revealed that the potential productivity for a given rainfall level had been underestimated. In addition, forest production in dry tropical areas is not just limited to timber production. Productivity with respect to fodder, fruit, gum and other non-timber products remains to be assessed. Although some economists and technicians consider that natural forests are not cost-effective, all of these products are clearly beneficial for local inhabitants.



Potential productivity of forest stands in three different situations (unprotected, protected from bushfires or developed, degraded) based on the average annual rainfall (Clément, 1982)

Legend: x-axis: P. Average annual rainfall (mm/year) / y-axis: Productivity (m3/ha/year)

Curve I: Potential productivity without protection / Curve II: productivity with protection / Curve III: Productivity of very degraded stands

Ca Cameroon / Co Congo / HV Upper Volta / M Mali / N Niger / RAC: Central African Republic / S Senegal / To Togo

Woody biomass has two main uses:

- **Fuelwood**: in rural areas, wood is the main domestic energy source (cooking and heating). Due to the quantities required, villagers are gradually obliged to seek fuelwood further and further away as the trees around settlements are cut. Charcoal is easier to carry and regularly sold to city dwellers. This high-demand product is a quick but nonsustainable source of income since trees are cut without concern about their renewal. In both cases, the biomass conversion efficiency is low and a source of pollution. Higher yields can be achieved with simple techniques (e.g. improved stoves, Doat, 1982) while decreasing wood consumption by two- to threefold. This reduces pollution and tree harvesting pressure to meet domestic fuelwood needs, which is the main type of biomass consumption (Minvielle, 1999; Girard, 2002).
- **Timber**: this wood is used locally to make fences, walls, roofs, boxes and utensils.

Non-woody biomass can, in turn, serve as a source of fodder for livestock, foodstuffs and medicines for local inhabitants, e.g. leaves (protein), fruit, honey, gum and resin and raw materials such as fibres and tannins, etc., for craftwork.

Non-timber forest products and traditional medicine

A large number of plant species in the Sudanian-Sahelian region have used medicinal uses (Kerharo and Adam, 1974). For instance:

- Gum arabic, an exudate essentially from *Acacia senegal,* has been known since Ancient Times (Egypt) and extracted from trees along the West African coastal region since the 15th century. This substance is a constituent in many drug formulations, in addition to its widespread use as a food additive. Recent studies indicate that gum arabic has a role in preventing kidney disease in Sahelian people who traditionally consume it.
- Kinkeliba, *Combretum micranthum*, is used in traditional medicine and in modern drug formulations.

Trees and livestock farming—silvopastoralism

Herders and their herds are often portrayed as enemies of trees. Trees are actually essential and herders are generally careful, except in emergency situations. In rangelands *normally* grazed by herds, **trees are considered as a community resource, like grass, and a wide variety of plant species are generally preserved**. Livestock farmers utilize the grassy layer in the rainy season, the shrub layer in the middle of the dry season, and the tree layer in the late dry season. Nomadic herders take advantage of the vegetation complementarity, as well as their own experience and observations concerning the local environment, when choosing rangelands to graze their herds in ecosystems where diverse fodder species grow. In more humid areas, some agro-pastoralists have created a landscape of groves consisting of carefully tended hedges with various functions (Fouta Djallon, Guinea).

Planting forage trees is still not common practice, but should be encouraged. However, in semiarid regions, *repeated overgrazing* may cause regression of the woody vegetation when too many cattle are grazed in a small area. In crisis periods, excessive tree cutting may lead to degradation of the tree layer. The natural resilience of Sahelian ecosystems sometimes promotes regeneration of some broadleaved species by seed dispersal or asexual propagation.

See also Lhoste, 1995; Basset & Boutrais, 2000; D'Aquino, 2000.

Ecosystemfunction

The following are some of the many benefits provided by trees:

☛ **Enhancement of the physical features of the environment**

- The developed root systems of trees, especially in dryland areas, improve the soil structure, making it looser, deeper, providing better support for crops.
- By improving soil porosity, trees promote rainwater infiltration. Their foliage and litter protect the soil surface from the direct impact of rain, thus reducing soil erosivity.
- Above-ground parts of trees reduce the effects of wind, forming a natural windbreak that helps limit soil abrasion, thus reducing wind erosion.
- Under their canopy, some trees create more favourable microclimatic conditions that have an impact on the immediate environment (including the vegetation density).

☛ **Biological effects**

- Soil organic matter enrichment and microclimate regulation by trees can create favourable conditions for the enhancement of above- and below-ground faunal diversity.
- Trees promote herbaceous vegetation growth and diversity while increasing biomass production and improving regeneration (e.g. Ferlo in Senegal, Grouzis and Akpo, 2003). Trees provide shade for crops, thus boosting yields.
- Through symbiotic relationships (with symbiotic bacteria or ectomycorrhizal fungi), some tree species improve their mineral nutrition and soil fertility, especially through airborne nitrogen fixation. This is an interesting criterion to consider when selecting tree species to be planted in depleted soils in the Sahel (Dia *et al.,* 2010).
- Trees take up large amounts of CO_2 and store it in their biomass and in the soil for long periods. They play a carbon sink role. The carbon sequestration potential in traditional and improved agroforestry systems has been documented (Polglase *et al.,* 2000; Farage *et al.,* 2007; Takimoto *et al.,* 2008; Nair *et al.,* 2009; Skutsch and Ba, 2010).

The negative impacts of some plantations should nevertheless not be overlooked:

- Some litter contains relatively toxic products, e.g. plant diversity is reduced under eucalyptus trees.
- Some other species are invasive (e.g. *Prosopis* in Sahelian regions) resulting in ecosystem degradation.
- In addition, some trees, by their above-ground development or shallow roots, can increase water loss and compete with crops.

The choice of species to plant is therefore essential, while favouring well adapted native species (Weber *et al.,* 2008).

Restoring soil fertility

Forests and trees have a well known role in soil fertility restoration. Some species fix atmospheric nitrogen, but all trees help restore soil fertility by recycling nutrients leached by rainfall to deep soil layers, beyond the reach of crop roots, then captured by the tree roots and returned to the soil surface horizons when the leaves fall. In addition, tree roots loosen the soil and facilitate biological activity in the soil throughout the year. The contribution of elements captured by the tree foliage when filtering airborne dust and the droppings of animals (cattle and wildlife, including mammals, birds and insects) attracted by the shelter and shade provided by trees should also not be overlooked. Hence, even trees that do not fix nitrogen may be used in agroforestry and soil fertility restoration programs.

Farmers traditionally make use of this feature through bush fallows (leaving cultivated land fallow for several years) and the creation of wooded parklands, quickset hedges and windbreaks. Agroforestry and agrosilvopastoral systems involve associations of trees, crops and rangelands, simultaneously in adjacent areas, or successively over time in the same area.

Trees help maintain the conditions necessary for farming and herding activities, while providing additional sources of income for local inhabitants. Moreover, responsible tree and forest management initiatives in dryland areas must take all production and their potential services into account. Forests and trees—by providing goods and services to poor people in rural dryland regions and contributing to the diversification of their income sources—contribute to poverty alleviation while reducing food insecurity.

Trees offer shelter and a food source for wildlife and a refuge for biodiversity. They are also appreciated by people for providing shade and decoration around their homes.

Promoting mycorrhizal symbiosis in arid and semiarid environments

The desertification process mainly involves disturbances in the vegetation structure, resulting in a decrease in plant cover in the habitat and in plant diversity within the ecosystem, thus fragilising the soil and increasing the impact of wind and water erosion of the topsoil. The soil becomes fragile and less fertile, thus having low levels of organic matter, macro- and micronutrients necessary for plant growth. The key biogeochemical cycling mechanisms (C, N and P) that ensure soil fertility are also thrown out of kilter. Among the biological components involved in the biological functioning in soil, mycorrhizal fungi are considered to be key microbial factors in the spatiotemporal evolution of terrestrial plant ecosystems, playing a major role in mechanisms that ensure the productivity and stability of the epigeal layer. They improve the growth of plants with which they are associated by optimizing mineral nutrition of plants while also protecting them from the impact of different biotic (e.g. plant parasitic nematodes, phytopathogenic fungi) and abiotic (drought or salt) stresses. Being strict symbionts unable to multiply without the presence of plants, the impact of desertification and disturbances in the epigeal layer is mainly reflected by a decrease in abundance and genetic and functional diversity of soilborne symbiotic fungus communities (Duponnois *et al.,* 2001).

To recover the mycorrhizal symbiosis function in the cover, the development of fungal symbionts can be promoted via two ecological engineering strategies, namely: (i) using plants native to the environment (or 'nurse plants') to serve as vectors for the multiplication of mycorrhizal symbionts in the soil (Duponnois *et al.,* 2011), or (ii) introducing massive numbers of a fungal symbiont previously selected for a given biological parameter (e.g. affecting the mineral nutrition of the plant and its growth)—this is the so-called 'controlled mycorrhization' approach (Duponnois *et al.,* 2005, 2007). Experiments conducted in arid and semiarid environments on native or exotic plants have highlighted the real potential of these farming techniques to offset the effects of desertification. However, it is clear that mycorrhizal fungi have yet to be substantially used in soil remediation operations and in combating desertification. Considerable extension and knowledge transfer initiatives are necessary to boost awareness on technical approaches in line with the ecological and socioeconomic conditions that prevail at the site to be rehabilitated. The Great Green Wall project offers a prime opportunity to achieve these goals and make effective use of mycorrhizal symbionts, which have long been considered topics of laboratory studies but not as powerful tools that could contribute to the sustainable rehabilitation of Sahelian environments.

Importance of trees in erosion control

Wind erosion

The action of wind is certainly a major feature of dryland environments. This wind is usually hot and dry and promotes water evaporation and plant transpiration. When the wind picks up and becomes loaded with sand and dust particles, it is a real threat to these habitats—this is wind erosion.

Trees to control wind erosion

Wind erosion has impacts on two levels:

1. Local effects: sand invasion and dune formation

The development of new sand deposits in the form of dunes generally occurs as the result of the movement of 'neighbouring' sandy soils that have been disturbed by ploughing and/or grazing and trampling by livestock. Knowledge on the wind regime that carries particles from these source areas, the transit area, topography and obstacles causing sand deposition is essential to curb the spread of these problematic deposits (vicinity of towns and infrastructures, irrigated areas, gardens, oases, etc.) (Mainguet and Dumay, 2006). In this setting, direct planting of trees on active dunes in deposition areas, where the sand is mobile and constantly replenished, is bound to fail. When it is impossible to reduce sand production in source areas, then efforts must be made to create obstacles in the transit area so that sand will accumulate in places where it is less of a hindrance, thus reducing sand build-up in areas where deposition is problematic. When it is absolutely necessary to consolidate threatening active dunes, the first step is to set up mechanical obstacles to stall surface sand movement (e.g. grids of palm fronds) so that grasses can be planted to stabilize the ground surface. This promotes biological activity and an algal crust may form on the surface and stabilize the surface sand. Concomitant tree planting is possible and often successful. The wind erosion control problem is complex. Forest bands are sometimes set up to provide protection against shifting sands.

2. Remote effects on a continental scale: the production of dust that becomes airborne and is carried long distances via fine particle saturated winds and storms

Sandstorms affect much larger areas (with a far larger population) than mobile dunes. Chinese Great Green Wall planting initiatives have thus been carried out with the aim of protecting Chinese cities (including the capital Beijing) against blowing sand and dust. These winds seriously disrupt air transport while also causing serious health problems (respiratory disorders). Recent transcontinental assessments have thus shown that the Amazon, where the soil is very depleted, benefits from substantial amounts of nutrients transported in dust winds from Africa (Bristow *et al.,* 2010), so the impacts of dust depositions are not solely negative. Stabilization and consolidation initiatives in certain source areas could therefore have a negative effect on fertility in 'sink' areas. The balance between positive and negative effects is variable depending on the scale and the concern, e.g. health, air transport or fertility in wet areas.

See also: Brenner *et al.,* 1995; Tengberg, 1995; Mohammed *et al.,* 1996; Bielders *et al.,* 2004; Lamers *et al.,* 1994; Cornelis and Gabriels, 2005; Laurent *et al.,* 2008; Goudie, 2009.

Concerning wind dynamics…

In wind erosion control, a distinction must be made between wind currents (moving air) and sandstreams (air currents bearing particles in saltation or suspension). Saharan wind currents sweep across the entire desert and Sahel from NE to SW before taking an ENE–WSW direction at the Tropic of Cancer. Along the wind current routes, wind loads and discharges sand through a physical load substitution mechanism. Wind currents are often triggered faraway on a regional scale, whereas sandstreams are local phenomena and seldom regional (Mainguet *et al*., 2000).

Replanted protection stands located in areas with high wind activity should be designed as a CD instrument and to hamper major desertification mechanisms, i.e. wind erosion, especially in sandy areas.

A replanted protection stand established in dryland areas with sandy soils, i.e. 20% of the Sahara and 50-60% of the Sahel south of the desert, could serve as a tool to control sand-bearing windstreams, active sand surfaces and sand invasion of human infrastructures.

The first replanted protection stands were set up specifically to control wind erosion, siltation and dust winds, e.g. the three programs carried out in northern China (Wang *et al.,* 2010). The Chinese have understood the importance of planting these structures in dust wind source areas.

Wind erosion control can be divided into three parts:

- controlling deflation, i.e. silt or sand particles of 2–500 µm diameter carried by the wind, which is unable to lift larger particles;
- controlling active dunes (including barchan and seif dunes);
- controlling siltation.

1. Wind deflation in source areas and saltation transport of sand (successive jumps of sand particles) in transport areas could be controlled by two types of green barrier: either in the form of tree cover/wooded band or repeated wooded barriers. In the Aral Sea basin, along the Karakum Canal, deflation was reduced and then halted when plant cover benefiting from the rising groundwater was grown, thus generating an anthropogenic gallery forest on previously bare land. Repeated barriers are more effective than continuous woodland for trapping sand. The main difficulty is to estimate the best interband width, which could be 10- to 25-fold the tree height in the wooded band.

There are also other difficulties:

- the choice of plant species to withstand recurrent droughts and the arrival of large volumes of moving sands;
- grazing resistance;
- adaptability to soil salinity and water.

2. A replanted protection stand could be designed **to control mobile dunes,** such as barchans, or dunes that gradually become elongated, such as seif dunes (linear dunes). Attempts to control the risks associated with dune dynamics are harder to achieve than those focused on managing mobile sand. There are two types of solution:

- Eliminating or reshaping dunes: which is possible for young barchan dunes with a height of one to a few meters. For 5000 years, China has been thwarting barchan dune development by planting grass cover in interdune areas. This grass cover traps sand in the form of a sand veil or layer, thus hampering the formation of new dunes along a sandstream.
- Immobilizing the surface of dunes by growing plant cover or via chemical treatment—seif dunes respond well to reforestation.

3. Greenbelts to **combat sand invasion** around human infrastructures.
Structures could be established upstream (windward) of areas at risk of sand invasion in order to combat this phenomenon. Siltation is just one form of sand accumulation when an obstacle—oasis and palm trees that grow there, a road, railway, canal, etc.—is in the way of a sandstream. Replanted protection stands set up along a sandstream route upstream of areas at risk of siltation could be effective in preventing sand invasion of human infrastructures.

Replanted protection stands must be maintained. When plants disappear due to natural causes (drought), or the environment is degraded due to human activities (transformation into a garbage dump), the previously accumulated sand becomes unstable and readily mobilized by deflation. Blowouts develop along with dangerous mobile parabolic dunes.

Different programs for controlling sand invasion are geared towards making suitable choices of plant species, with trees being preferred over shrubs, bushes and grasses. We believe that this is a lesser evil solution. The main problem when using a replanted protection stand to combat silting by shifting dunes and the risks that these dunes represent for human activities and infrastructures mainly concerns the location of these stands and their patterns (parallel rows, grid, etc.).

Water erosion

The so-called 'dryland' regions that interest us here are not areas without water or rain (i.e. not absolute deserts) but rather places where rainfall fails to cover more than two-thirds of the evaporativity of the air (rainfall represents 65% or less of the evapotranspiration). There is a clearly marked rainy season in the Sahel (known as the 'African monsoon'), but the rains are quite irregular, which results in drier or wetter years than average, and also rainstorms that vary in their intensity and location (Baudena & Provenzale, 2008; Boulain *et al.,* 2009). The most intense rainstorms have large raindrops with a high soil erosion potential, often stripping the surface layer of these unstable and poorly protected soils—this is water erosion. Unfortunately, the mechanisms underlying this phenomenon usually affect the topsoil layer with its high concentration of organic matter, which is responsible for soil fertility. When the land cannot absorb all of the rainwater, it runs off and concentrates in flow areas, scouring the soil and carrying it down the slopes and forming gullies, and large downstream areas can become submerged (Bull & Kirkby, 2002). Dramatic floods may surprise people in Sahelian towns, as was recently the case in autumn 2009 in Ouagadougou and Agadez. Soil particles scoured upstream accumulate downstream as sediment, which may also be problematic when concentrated in high amounts in a small area, with the most obvious case involving dam clogging.

In this setting, trees have an important role in protecting the landscape against water erosion (Boulain *et al.,* 2009; Michaelides *et al.,* 2009; Puigdefabregas, 2005; Sandercock & Hooke, 2010), including:

- A **direct** effect in protecting soils against the impact of raindrops which are intercepted by their foliage and, to a lesser extent, by serving as a windbreak that slows rain squalls. Trees also have a mechanical action through their roots, creating paths that improve soil permeability, but also by improving their cohesion through their web of rootlets and the beneficial effect of the rhizosphere.
- An **indirect** effect by improving the stability of the soil surface via litter and humus formed through the decomposition of fallen leaves and twigs lying on the ground. Stimulating the biological activity also increases the porosity and thus the water infiltration capacity.

The water erosion protection effects of trees are of course most obvious in forests and other natural or created woodland stands. Trees are often planted in association with water and soil conservation structures, such as stone barriers, bunds, half-moon microcatchments and terraces. Trees thus have a stabilizing effect on erosion control structures, by increasing water retention and slowing runoff (Volhand & Barry, 2009). This feature can be advantageous in increasing the tree cover, as illustrated by the case of forest ***zai***. More generally, it is highly utilized in **agroforestry**, where protection against erosion is one of the beneficial effects of trees on annual crops.

Zai technique to control water erosion

The high rainfall intensity in the Sahel induces intense soil erosion when there is little soil protection. Water erosion control techniques, such as terraces, stone barriers and half-moon microcatchments, may be beneficially combined with trees and shrubs to stabilize the soil. Carefully planted trees represent a water erosion control tool, while also facilitating the growth of other plants that stabilize the soil surface and protect the soil from the impact of rainfall. One of the most telling illustrations is the 'forest *zai*' technique (Koutou *et al.,* 2007). This is a traditional technique whereby plants are sown in holes, thus concentrating water and manure in the microcatchments in which the seeds are sown.

This simple technique is designed:

- to enable the development of barren or abandoned lands;
- to reduce water erosion and promote infiltration in impermeable soils;
- to obtain normal yields in areas with under 300 mm of rainfall;
- to collect water for plants.

This technique can be used to cost-effectively increase the extent of arable land and is preferentially used on degraded lands, glacis and lateritic plateaux. The *zai* technique is amongst the different techniques used to control water erosion, which include: gabions, gully microdams, bank seeding, terraces, etc.

Zai technique used on flatlands in Badaguichiri region, Niger. © B. Bonnet

SOCIAL RELEVANCE OF TREES

Status of trees in Sahelian-Sudanian societies

In the Sahel, each local society manages trees using specific traditional practices, creating a landscape mosaic (crops, rangelands and trees)—this highlights the relationships between these societies and their environment. The correspondence between the composition of the plant community and the tree stand and the signature of an ethnic group (Pélissier, 1980; Raynaut, 1997) sheds light on the nature of the society and its history. Agroforestry parklands with *Faidherbia albida* cover are the best example of this type of landscape shaped by Sahelian people.

The baobab is one of the species most known for its multiple uses. **This tree is therefore essential in the functioning of Sahelian societies** as embodied by differentiated rights concerning land and natural resources: cropping rights on lands, season-specific usage rights, tree product gathering rights, the right to use tree leaves as fodder, the right to cut branches for fuel, felling rights, etc. Hence there is a certain degree of **tree ownership,** and therefore an interest in protecting trees, while not allowing anyone to make use of them as they see fit (as opposed to private ownership).

This 'multiownership' of trees therefore enables more families to benefit from the same resource, which is essential in regions where resources are scarce. These many complex rules concerning access and ownership of tree resources thus do not correspond to the Western notion of property rights. In addition, the same type of rules apply to other resources, not just trees and shrubs.

The actual situation is even more complex. Local people deal with climatic variability by becoming mobile and moving part of their farming activities in order to take advantage of resources wherever they are found (sometimes tens to hundreds of kilometres away). These 'transhumance' farmers and herders have the right to utilize areas where they do not live, and land use and access rights thus apply to social groups temporarily living on this land, but normally living elsewhere. However, with population growth and increasing needs, the rules are often broken (severe topping or pollarding of trees, thus killing them, plots totally cleared for more intensive cropping, overbrowsing of foliage, etc.). In areas colonized for agricultural purposes, newcomers sometimes know little about the local vegetation and are primarily concerned about altering the landscape to ensure that the land will remain under their control, but without concern about preserving the resource. Finally, external interventions in favour of sustainable development (increased agricultural production, reforestation, etc.) can involve initiatives that overlook these rules, out of ignorance or choice (considering that these complex rules are no longer efficient for sustainable production).

Tree cover degradation thus leads to the loss or disturbance of some tree functions (agronomic, economic, medicinal, social or cultural). This gives rise to tensions between social groups, owners, operators and newcomers, especially as the Western perception of ownership is applied to an increasing extent in this setting, through State land reforms or by senior management and operations promoted via development projects. Many different changes take place in response to these disturbances, and depending on the setting and the nature and status of the local society, leading to resilience, adaptation, change or regression.

Faidherbia albida agroforestry parkland, Ségou region, Mali, March 2005.
© A. Cornet

Impacts on reforestation-enhancing intervention modes

The setbacks of development and reforestation operations over the last century (Gautier and Seignobos, 2003) have highlighted the need for caution when interventions are undertaken in complex situations:

- Planting trees is not sufficient to ensure sustainable reforestation.
- New trees should not only be planted to increase the useful tree resources available for local inhabitants.
- Setting aside land for plantations may lead to as many losses (resources, land, passage ways, etc.) as benefits.
- Setting aside land for these plantations can lead to as many land and social conflicts as it resolves, etc.

There are two ways to cope with this complexity:

1. **The people concerned should participate in *drawing up* the project so that it will be specifically tailored to meeting their needs and to the local setting.**
2. **The social, economic, land and cultural impacts should be assessed prior to any external interventions.**

Extensive experience in 'participatory approaches' has been gained in recent decades (Borrini-Feyerabend *et al.,* 2010). Public participation can even be reintroduced when it has been initially overlooked, not with respect to carrying out initiatives but rather, and more fundamentally and meaningfully, to better target the operational objectives so as to be better aligned with the local situation ('participatory monitoring-assessment'). These two conservative responses can be easily combined and yet are still seldom used.

GGW is a real opportunity to include and develop participatory approaches and strengthen the decentralization process underway in Sahelian Africa.

Since the 1980s, many land management experiments have shown that local stakeholders, associations, authorities, communities and individuals are involved in the management of natural resources to the extent that they become truly responsible (Rochette, 1989). Various simple natural resource development and management techniques have been developed and tested, e.g. stone barriers, berms, benches, plantations, direct seeding of trees and natural regeneration (Larwanou *et al.,* 2006; Reij, 2009), as well as simple management plans, local natural resource management codes and conventions (Banzhaf, 2005; Bonnet, 2003; Kirsch-Jung and Sulser, 2000), etc. On the basis of these experiments and their results—resource regeneration and ownership by local people—environmental laws have evolved in several Sahelian countries to encourage genuine transfer of natural resource management to communities and/or to decentralized local governments (Mauritania, Niger, Mali, Chad, etc.).

Most stakeholders in the Sahel are now convinced that State management, e.g. free access to resources, inevitably leads to their degradation. Decentralized management of shared natural resources is therefore considered an effective alternative. Unfortunately, most municipalities that have emerged since the early 2000s in Mali and Niger (to mention the most recent) have no capacity to manage shared natural resources in their territory. Their first instinct is sometimes, however, to boost taxes without investing in supporting local management stakeholders (Boysen, 2008).

GGW must therefore support local stakeholders responsible for natural resource management so as to enable them to develop a shared and coordinated vision of communal, intercommunal or transborder areas, including pastoral mobility and management of common natural resources: grazing areas, transhumance corridors, public pastoral watering places, permanent or temporary ponds, forest regeneration areas, land development strategies, tree development and usage plans, watershed protection by water and soil conservation measures, etc.

Local initiatives for regeneration and sustainable use of silvopastoral resources (**assisted natural regeneration** [ANR], water and soil conservation, rural wood markets, local conventions, etc.) should be financially supported. Indeed, land development schemes, as defined in the Rural Code in Niger, for example, integrating agrosilvopastoral areas, forest areas, grazing areas, transhumance routes, resting areas and pastoral watering places, have required financial resources and tools and methods that are not available to Sahelian stakeholders concerned by GGW (Bodé *et al.,* 2010).

Public policies should be adapted to more actively support decentralized management of natural resources. GGW support in this area would be particularly useful in financing the participatory and collaborative revision of key texts pertaining to sustainable natural resource management in the Sahelian zone: forest code, rural code and pastoral code. In this setting, the mobilization of civil society, farmers' and pastoral organizations, municipalities and land management bodies will ensure the success and adoption of the texts (see also Djerma *et al.,* 2009).

TREE COVER DENSIFICATION

Current scientific knowledge can orient planting and/or management and development of the existing situation, while guiding:

- the choice of sectors, while taking rainfall, the water balance of the species and access to water into account;
- the choice of species and planting techniques to be used;
- the protection of existing bushes, shrubs and trees, and their sexual or asexual propagation;
- consideration of the tenure of the land used;
- participation, support and guidance of local people;
- the role of women, etc.

Regeneration, protection and propagation of local trees

How can the density and protection of tree and shrub cover be enhanced on a village level?

There are various possible ways to densify the woody plant cover. The simplest—with the agreement and support of local people (often women)—is to **protect and manage what already exists**. The effectiveness of assisted natural regeneration (ANR) and the **protection of individual trees outside forests** is low in fields, except in some agroforestry parklands or countries such as Niger and Mali (see box below). However, ANR is a good way to restore conditions favourable for the ecological functioning of agroforestry parklands (more productive, Reij and Botoni, 2009), while contributing to improving the living conditions of local people who implement the sustainable land management (SLM) technique from which they in turn reap the benefits (Zarafi *et al.*, 2002).

Assisted natural regeneration mainly of *Faidherbia albida* and *Acacia* sp., Maradi region, Niger.
© S. Jauffret

Participation of local communities in sustainable natural resource management

In Burkina Faso, since 2003 the Swiss non-governmental organization (NGO) *newTree* has undertaken a program to regenerate natural plant stands to benefit rural people in central and northern parts of the country. *In situ* conservation is aimed at preserving the genetic variability of a maximum of woody species by installing temporary solid fencing to promote natural regeneration of the vegetation cover (natural seedlings, layers and suckers). This avoids costly planting and watering. The involvement of local communities in the identification of problems related to the management of natural resources and proposed solutions is essential. These people are also involved in making decisions on protecting degraded areas, outlining areas to protect and actions to be taken within their area. They provide stones, gravel, sand, water and labour to install fences and develop the site according to their objectives. Monitoring and maintenance of fences are also part of their duties. Partners sign a contract and tenure arrangements (documents that include customary rights and administrative rights drawn up for each site). At the beginning of the next rainy season, a quickset hedge is planted inside the fenced area by the partners to replace the previous fence, which is in turn reused to protect other deforested land. Flying nurseries of species that are endangered and/or useful for the rural population are installed in the fenced-in areas. Management plans are subsequently developed as needed with partners to enable sustainable use of restored areas. Farmers are offered sustainable natural resource management training as well as the opportunity to create additional income generating activities (beekeeping, fodder production), which become possible in the short term as a result of this training.

Assisted natural regeneration in Niger—a textbook case

As of 1985, in southern Niger, in the **densely populated** areas of Maradi and Zinder, **farmers began protecting trees in their fields and ensuring their assisted natural regeneration** by promoting the growth of well adapted local tree species with a high added value *(Faidherbia albida, Acacia* sp., etc.). The area concerned has reached **5 million ha** (15- to 20-fold more trees in 2005 than in 1975).

These trees were not planted but are the result of the protection and management of spontaneous regeneration by farmers. They clearly understand the many different impacts of this greening trend: “for us, trees are like millet”, “trees act as windbreaks”, and “without trees our animals would have nothing to eat”, etc. Trees are part of the production system and have enabled greater integration of agriculture, livestock and forestry (Reij and Botoni, 2009).

See also: Breman and Kessler, 1997; Griffon and Mallet, 1999; Peltier, 1996, Szott *et al.,* 1991.

Location of Maradi and Zinder regions in Niger.

Village in Maradi region, Niger: the green dots are trees or clumps of shrubs (the result of assisted natural regeneration). The grid corresponds to the agricultural plot layout.

Source: Google Earth, 2011.

The preservation of trees in fields, as well as the protection and management of ANR techniques are less expensive and easier to adopt approaches to ensure the sustainable management of forest resources in large areas. It is cheaper and more effective to promote tree regeneration as compared to planting (Bellefontaine, 2005; Reij and Smaling, 2008; Reij and Botoni, 2009).

Local people should be involved in the implementation of these effective sustainable land management practices, through training that experienced farmers provide to other farmers and agro-pastoralists and exchanges of experience. Reij and Botoni (2008) recommended a set of initiatives to encourage large-scale adoption of ANR: (i) in forestry legislation, defining incentive conditions for the usage of unplanted but protected and maintained tree products, and (ii) taking local regulations into account. The authors also recommend that the activities involve:

- the development of individual plantations for wood production (trees outside forests in the form of hedges, groves, etc.) on farms while focusing on native species in suitable areas;
- the reintroduction of extinct or endangered species by creating biodiversity plots in local regions, municipalities or in each agroclimatic area.

Silvopastoral activities should promote:

- maintenance of the soil production potential via water and soil conservation techniques (Sidibe 2005), organic manuring (Lhoste 1995), agroforestry and fertilizer applications;
- intensification of fodder, woody or herbaceous cropping on farms through better agriculture–livestock integration;
- development of income-generating activities in villages (market gardening, handicraft activities, trade, etc.) to support agriculture (to purchase farming equipment, etc.).

Deferred grazing in areas with degraded woody plant stands is another alternative to planting. In Senegal, Niger and Burkina Faso, deferred grazing with the real collaboration of **aware and mobilized local people** has led to regeneration and development of the natural vegetation on marginal land but, so far, seldom on very large tracts of land.

How can planting be done?

Rather than protecting and developing existing tree stands, **hedges** (Yossi *et al.,* 2006), **windbreaks** and **groves** can be **planted** in certain conditions:

- species and their sources are chosen according to the soil;
- appropriate techniques are implemented to manage young plants (Bellefontaine, 2010):
    - deep tillage associated with half-moon microcatchments;
    - use of modern containers and rigid above-ground racks so that plants can be maintained in a nursery for short periods, while promoting the formation of a dense root system (success factor when transplanting in the field);
    - watering during the first two dry seasons.

In these conditions, deferred grazing periods could be shortened, while reconciling the expectations of farmers-herders and domesticating the main multiuse species by propagating the best performing clones that have been preserved by rural people (Bellefontaine *et al.,* 2010). These initiatives should preferably be based on strategies that take local economic difficulties into account.

Finally, plantations are expensive and the final outcome could be poor or nil if the **land aspect** is not clearly defined. If the land ownership and agricultural plot usage rights for farmers and herders are not defined, then herders (mainly transhumant) may let their animals wander on agricultural land, which they often consider to be collective land belonging to everyone. In any agrosilvopastoral development project, it is thus essential to define the woody plant resource access and usage rights, especially for women. Wood from plantations could be partially or even completely removed if these rights are not clarified.

A successful example of a windbreak plantation in Maggia valley, Niger

Catchment slopes, which had been deforested since 1930, were gradually dried by persistent severe winds during the dry season. The first windbreaks—mainly in the form of two rows of neems—were planted in 1975 to protect valley lands and the catchment environment. More than 500 km of windbreaks and hedges have now been planted and the valley, which is protected by local people, is densely populated.

From Bellefontaine *et al.,* 2002.

Despite the arid climate and lack of financial resources, satisfactory restoration of the plant cover is possible by using **simple techniques based on sustainable protection of degraded areas, the empowerment and real involvement of local people**.

How can the propagation of tree species be facilitated?

In semiarid regions, natural seedlings barely survive and almost all of them disappear during the first months of a drought (due to heat, aridity, browsing, etc.). The use of nursery seedlings and industrial plantations are too expensive. There is another alternative involving simple techniques (suckers, cuttings, layering, etc., Belem *et al.,* 2008; Bellefontaine and Malagnoux, 2008; Ky-Dembélé *et al.,* 2010). These inexpensive techniques (Meunier *et al.,* 2006) can be implemented by rural inhabitants living far from urban nurseries. These people can manage local species on a small scale.

Other techniques can also be effectively used, such as the production of top quality cloned plants (resistant to drought and diseases, rapid growth, strong root system, high coproduct yields, Bellefontaine, 2010).

How can tree planting be done on dunes?

A recent review by the United Nations Food and Agriculture Organization (FAO Malagnoux, 2011) focused on case studies on dune plantations (Chile, China, Mauritania, Senegal, Niger, Iran) revealed the broad range of different ways of managing these plantations due to the markedly different climatic, economic and social conditions that prevail. The long experience in managing dune protection plantations in some countries (Denmark, United States, France) may be tapped in order to tailor management to changing expectations of society.

New roles of forests, in addition to the traditional consolidation, protection and production functions, are taken into account along with biological diversity conservation and public hosting (recreation and tourism). Multifunctional (or multipurpose) management of these forests is now under way to fulfil the needs of all users concerning fuel and other wood and non-wood products that are sources of income for local people.

The diverse range of situations should encourage dune fixation project developers to carefully study the physical (soil and climate), economic and social conditions of the environment so as not to overestimate the possibilities. Economic objectives should never take precedence over the technical requirements (dune fixation and protection) and must continue to be tools to finance planting operations (by the private sector when plantations are sources of income, or by State services with the participation of people in decisionmaking, labour, management and profit making).

Finally, research activities (support) must be planned in the project design so as to investigate all matters relating to the sustainability of the system and meeting community needs.

Periurban greenbelts

A greenbelt is either a highly degraded forest enriched with exotic species or, more often, a tree plantation around a town. The first greenbelt experiments were carried out in the 20th century, particularly in Africa (OSS, 2008). The objectives were to:

- protect towns and cities from erosion (e.g. coastal cities such as Tangier in Morocco);
- protect cities from desertification (Gao, Timbuktu, Niamey, Essaouira, etc.);
- contribute to the depollution of dusty urban environments and to supplying fuelwood (e.g. Cairo);
- reintroduce extinct animal and plant species (at Edfu, 120 km north of Aswan, Luxor, and Qena, 60 km north of Luxor);
- rehabilitate degraded and fragile ecosystems (Kenya, Sudan, etc.);
- develop urban and suburban areas using a landscape and functional approach (Dakar, Ouagadougou, etc.);
- protect traffic routes (e.g. highways and railways in Central Asia), canals (such as Karakum) and airports.

Various greenbelt models have been tested: 'major urban', 'urban and developed basin', 'urban and cropping area' and 'road' models. These forest plantations were able to provide long-term protection for towns, oases and road infrastructures without maintenance irrigation wherever rainfall was over 150 mm (e.g. Mauritania) or on sites where aquifers were present.

The first facilities were periurban or rural infrastructures usually developed by governments and not geared towards production or usage (OSS, 2008). The concepts then gradually evolved to include local people in planting and maintenance. The many experiments on both sides of the Sahara could thus serve as examples to guide work in rural areas (agrosilvopastoral development projects) or urban areas (landscape improvement) so as to ensure that the projects are in line with the objectives. The long-term success depends mainly on:

- the level of participation of local people;
- the development, in nurseries, of an optimal rooting system accompanied by care and protection during the early years and 'physical respect' for trees by the inhabitants who benefit, especially after proper compensation is provided for landowners.

Some conditions for densification efficiency and sustainability

Accounting for rainfall and water access

In the Sahel, rainfall decreases markedly over a south-to-north gradient and biomass production potentials vary widely. Sahelian trees do not grow in the best climatic conditions, but the different native or imported species have a wide variety of environmental adaptation strategies, as well as a remarkable regeneration capacity after years of rainfall shortages (e.g. *A. senegal*, Poupon, 1980). When rainfall becomes too low (under 150 mm rainfall/year), the amount of water contained in the soil layer tapped by roots is not enough to properly supply a continuous canopy of trees. The vegetation cover then retracts, and the trees benefit from runoff coming from uncovered areas. In natural conditions, this gives rise to vegetation strips, giving a the bush a tiger-striped appearance (D'Herbès *et al.*, 1997). In Sahelian zones further north, near the Sahara where rainfall is less than 100 mm, trees grow only if they receive significant additional water supplies in configurations that concentrate runoff (talwegs, depressions, etc.) or when surface water is available. Supplemental irrigation may be an alternative, but is seldom possible.

When approaching northern Sahel, it gets harder to consider making continuous plantations to form a 'curtain' of trees. **They should be confined to favourable locations where water collects and the soil is able to store it to serve as a reserve that can be tapped by trees during dry periods.**

It is also necessary to make effective use of the experience of local people who may use various water collection systems to irrigate their crops and trees, based on the 'tiger bush' model (Malagnoux, 2008). Agronomists have perfected these traditional techniques and foresters have adapted them to the size and needs of their trees. Moreover, the reclaimed land area has increased considerably through the use of mechanized technologies that have made it possible to work faster at lower cost and to dig deeper bands to better retain water.

In any CD-oriented afforestation program, the current and future water balance of the stand should be systematically estimated for each phase in its evolution.

It would be useful to promote suitable silvicultural practices—selection of species to be planted, woodland planting density, woodland maintenance (thinning, pruning, etc.), conversion of a dense stand into **agroforestry parkland** or grassland—so that annual water consumption will remain less than the annual supply.

Besides rainfall, there are other sources of water, such as reused water and deep aquifers, that must be taken into account. Many drylands and deserts have deep tapable groundwater reserves. For a short period, certain land rehabilitation activities may require tapping of fossil aquifers, while bearing in mind that these water reserves are not replenished. With increasing urbanization in arid regions, there is greater interest in urban forestry and the development of green spaces with plants that consume less water than trees (e.g. shrubs and herbaceous plants). The use of reused water, including wastewater (after treatment or not), is being developed in some countries (Bellefontaine, 1998). This promising practice should gain ground in the future, provided that the associated health risks are efficiently managed.

Concerted initiatives with all stakeholders

Farmers—faced with the problem of repeated droughts and climatic variability, leading to a reduction in production and yields—have developed extensive production systems by clearing existing forest areas. Meanwhile, the disappearance of vegetation cover and watering places during the dry season has also led to problems of livestock migration and mortality, thus prompting farmers to increase their cutting of tree branches to feed their animals. In such scarce resource situations, it is not uncommon for conflicts to arise between farmers and herders forced to temporarily share the same area and resources. It is therefore essential that all stakeholders in an area get involved in **developing agrosilvopastoral resources, while taking the dynamics of plant communities to manage and agricultural and pastoral practices into account** (*see box below*).

In dry areas, the success of crops depends mainly on the **availability of a large labour force that can be quickly mobilized for a very short period of time when the conditions are favourable for sowing and crops.** In the short term, this human labour investment is often the only way to increase agricultural production, especially since there have yet to be any significant improvements in techniques and plant material that would revolutionize agriculture in drylands.

Land rights in favour of women should also be developed, especially in the case of tree plantations outside forests (Bellefontaine *et al.,* 2002).

Finally, forest areas are often viewed as a stock of owner-free products that can be freely harvested by anyone, i.e. trees are cut without considering the long-term impacts. **Forest reclamation** is therefore necessary. It is essential that all of the social, economic and land aspects be taken into account and lead to the drawing up of suitable land, forest, agricultural and land-use policies.

Ecological value of pastoral mobility

The strip of land between isohyets 400 and 100 mm average rainfall, i.e. the route chosen for the GGW, is an area where transhumant pastoralism and rainfed agriculture prevail. The pastoral areas are saturated and overcrowded and threatened with the rise in farming on newly cleared land. The retracted woody vegetation is regenerating following its destruction due to the severe droughts of 1973 and 1984 (Herrmann *et al.*, 2005). This vegetation is dominated by annual grasses and is of high quality for herd grazing (for milk production and reproduction). It occasionally covers huge areas where there are many temporary pools, a phenomenon which is responsible major transhumance movements that enable herders, agro-pastoralists and crop farmers to take advantage of the land for a few months of the year before retreating further south to areas where rainfall is more favourable.

Pastoral and agro-pastoral farming dominates in these areas and these activities make effective use of natural resources that vary from year to year depending on rainfall. The settling of human communities under these constraints is only possible because of the presence of permanent waterholes in the dry season and herd mobility which is necessary to adapt to the irregular availability of grazings.

Mobile transhumant livestock farming has often been considered as a factor of ecosystem degradation in the Sahel because of the massive movements of herds and their concentration around watering places at the end of the dry season. Over the last 10 years, in compliance with the environmental precautionary principle with respect to the building of pastoral wells, studies have been conducted on the specific impacts of grazing on ecosystems in the region within the framework of several programs. It appears that **the effects of grazing are much less marked when the herds are required to move and remain mobile**. Conversely, **herd settling** promotes ecosystem degradation. The concept of **overgrazing applies more to continuous use** of pastoral resources since the animals, even in small numbers, selectively feed on the most palatable species and tend to eliminate them. **The reduction in grazing areas, transhumance corridors and resting areas** (so far utilized by herders in agropastoral and pastoral areas) decreases herd mobility and increases environmental risks.

These areas are also the subject of conflicts concerning the allocation of long-standing traditional grazing rights alongside the increased pressure for cropping due to the rise in agricultural fronts. This high-risk agriculture in areas where rainfall is less than 300 mm a year is in the form of extensive farming systems that are much less productive than livestock farming (Collin de Verdière, 1995) and they leave the soil bare and exposed to wind erosion throughout most of the year (Hiernaux and Bagoudou, 2006).

Herd mobility is thus the main coping strategy adopted by local people. It is necessary to take this into account when designing initiatives like the GGW so that pastoralism will be fully integrated and the wall will remain permeable for herds.

“Overall, in pastoral areas, environmental risks associated with pastoral farming are low because of the mobility of livestock whose grazing pressure is adjusted to the available local and seasonal fodder resources. In contrast, introducing cropping in pastoral areas makes arid ecosystems vulnerable to wind erosion, but also to water and biochemical erosion of soils. In addition, the extension of this cropping reduces local and regional livestock mobility, which could ultimately undermine pastoral livestock production and worsen the environmental impact of pastoralism” (Hiernaux, 2006).

INVESTING IN NATURAL RESOURCE MANAGEMENT: COSTS AND BENEFITS

The rate of return of sustainable natural resource management (NRM) investment has still only been partially assessed. However, current scientific findings show the financial benefits that may be reaped by investing in degraded land restoration. As Reij and Botoni (2009) pointed out, the impacts of NRM investment are often underestimated since the assessments generally do not account for indirect investment impacts, e.g. water and soil conservation work that may lead to increased crop yields and locally contribute to recharging the water table and a rise in well water levels, to the benefit of market gardening, etc.

A few examples are presented below on the economic rate of return of Sahelian forests and their products and of investments within the framework of CD projects based on the implementation of a set of sustainable land management practices (benches, trenches, strips of vegetation, windbreaks, dams, dikes, *zai*, etc.).

Assessing the economic viability of dry forests

This is a difficult task because the information required for this type of assessment is seldom available. An inventory on calculations of internal economic rates of return applied to forest-type projects and investments in the Sahel was recently carried out. This inventory was essentially based on the findings of studies conducted by Reij and his teams (Reij and Steeds, 2003; Abdoulaye and Ibro, 2006; Reij and Botoni, 2008 and 2009), also known as the 'Sahel studies'. It presents results on assisted natural regeneration initiatives undertaken by local people on parkland tree plantations and their effects on pastoral and agricultural activities (higher fodder and fertility).

Here the rate of return was calculated following the completion of reforestation projects or initiatives and based on real data compiled from field surveys, investigations and expert opinion (*ex-post* assessments). The benefits of implemented forestry investments (wood production, fodder, enhanced crop yields) are correlated with the forest implementation and maintenance costs (plants, watering, monitoring, land costs, etc.).

In these 'Sahel studies', the rate of return of assisted natural regeneration was evaluated in Niger and Burkina Faso over a 20 year period during which the trees (diversified species) were protected by the inhabitants (labour costs taken into account). These trees produced wood (as of the 6^{th} year), fodder, and enabled an increase in crop yields (5% harvest increase). These field survey based assessments revealed rates of return **of 31% in Niger and 24% in Burkina Faso**.

The rate of return of two types of tree plantation in Niger was calculated over 20 years:

- Non-fruit tree plantations with wood production of 6 m^3/ha (from the 6th year) and fodder production of 15.5 kg/ha: the rate of return was 13%.
- Fruit tree plantations with fodder production of 15.5 kg/ha and gum arabic production of 1.5 kg/tree (from the 6th year): the rate of return was 31%.

In these calculations, however, the tree survival rate was assumed to be 100%, thus greatly overestimated. In fact, studies conducted in Niger have shown that only 20% of trees planted survive to adulthood, thus questioning the economic viability of these initiatives.

In Senegal, coastal dune fixation plantations of casuarina also made it possible to crop vegetables in the surrounding basins, with an actual rate of return of 20%. However, these casuarina plants are now dead or dying in this area.

In different projects and initiatives evaluated in terms of rates of return, the time scope was at least 20 years. This choice enables assessments based on more reliable data and, secondly, it is the duration required to determine long-term returns with respect to investments in the natural environment (as opposed to the short-term economic trends). This is a handicap because very few long-term projects and initiatives have currently been completed.

The current trend is to fund 3–6 year projects and plans adjusted to national plans and international cooperation operator regulations.

This time scale issue raises several considerations:

- On the choice of species (and investment in the improvement of forest species): from the investors' standpoint, for example, projects for planting eucalyptus trees, which produce fuelwood after 3 years, could ultimately boost the rates of return. This partially explains the enthusiasm of donors for this kind of initiative, whereas the issues of sustainability and the distribution of generated income are often not taken into serious consideration.
- On the importance of social and institutional dimensions of long-term projects and the likely consequences (two-way) with respect to management: for instance, the rate of return of a fruit tree plantation must be calculated over a long period in order to get a positive result (time for the trees to reach maturity). However, lengthening the project duration may lead to uncertainty with respect to collective management or maintenance of investments, profit redistribution and land tenure security: Would they be externally imposed, resulting in social costs? Would they be developed or codeveloped by stakeholders, beneficiaries and target groups?

The issue in this debate on the rates of return of forestry projects therefore concerns social and institutional prerequisites, as well as ecological knowledge.

This is also mentioned in the assessment of Reij and Steeds (2003): concerning forest management in Tanzania, they highlighted that it was essential that a reserve forest be managed by the forestry administration in collaboration with local communities. This comanagement substantially reduced illegal harvesting of wood. In this situation, village forest management (rotation of fuelwood cutting), along with the dissemination of more efficient stoves, resulted in a rate of return of 12% (costs estimated on the basis of the forestry administration operational costs)[2].

Modes of collective access and use of plantations (profit redistribution, maintenance organization and tenure clarification) are fundamental data with respect to the rate of return of an investment such as reforestation. Indeed, rate of return calculations cannot directly include the property rights issue, despite the fact that a comparison of results revealed the importance of this criterion. Rate of return assessments are also hampered by:

- The lack of data concerning many costs (Capalbo and Antle, 1989): cost of irrigation, maintenance, associated opportunity costs, social costs for carrying out certain projects, tree recovery rates, climatic events, changes in selling price, etc. Some of these components are connected. This underlines the contextual nature of such assessments (Requier-Desjardins *et al.,* 2010).
- A tendency to overestimate production results and underestimate or overlook certain environmental and socioeconomic benefits: carbon storage, rising water tables and reduction in water fetching, increased biodiversity, reduced resource conflicts, shade and landscape aspects, etc.

Research is underway to introduce some of these data in rate of return calculations (Requier-Desjardins, 2007).

In conclusion, these assessments strengthen the idea that a process involving spontaneous reforestation or collective local maintenance would generate higher profits over time. The ANR situation is one of the best examples in this region.

[2] Here the rate of return was estimated before the project began (*ex ante* assessment).

A bit of jargon: the internal economic rate of return (IERR)

This rate may be considered to assess whether a project or type of investment is profitable. For a given period, this percentage cancels the net present value of economic flows expected as a return on the initial investment (and its maintenance costs).

A discount rate is used to determine the present value of future economic flows with respect to such an investment. This discount rate reflects the present preference, the risk aversion which increases with the project duration (uncertainty) and especially the fact that economic growth (or increased generated wealth) currently reduces the value of a future monetary amount (or return).

For natural resources, however, the trend is more towards increased scarcity over time, particularly since the mid-20th century. Many experts also question the interest of using a negative discount rate to reflect the idea that it is more likely that their current value would increase over time (see especially the discussions on this point in forums dealing with economic and monetary value of biodiversity, TEEB, 2009).

The domestic energy strategy and rural fuelwood markets—a profitable investment

Beginning in the 1970s, Niger and Mali, with the assistance of CIRAD (Agricultural Research for Development), implemented the domestic energy strategy (DES), which has significantly contributed to natural forest management in the Sahelian-Sudanian region. The adopted approach is based on four main pillars:

- commercial exploitation of trees (organization of the wood sector and setting up of rural fuelwood markets);
- empowerment of local people and fulfilling needs (fuelwood and various coproducts) of rural and urban populations;
- the creation of jobs and income;
- sustainable management of wood resources.

This approach was supported by the development, adaptation and implementation of a new tax on wood and the development of silvopastoral management techniques for Sahelian forests, negotiated and tailored to meeting the demands of local residents. In order to reduce pressure on forest resources, these management initiatives should promote local know-how, the extension of tree regeneration techniques that are more effective, easily manageable and less expensive, the training of members of village management structures, the development of an appropriate institutional framework, with more tax and land incentives, and the intensification of agriculture and livestock production (Peltier *et al.*, 2009).

"From 1986 to 1992, cooperatives pumped some FCFA 65.5 million derived from timber sales into the concerned localities. Previously, these funds had remained in the city of Niamey since the loggers were urban employees of transporting firms. Total value added to the national economy thus amounted to FCFA 262 million. These money supplies enabled job creation, a reduction in outmigration of young people, the development of other economic and social activities: hydraulic structure repairs, founding of cereal banks, input purchases, expansion of social buildings, revival of cultural activities, etc." (Bellefontaine *et al.*, 2000).

Successful projects to combat desertification in Tahoua region in Niger

By the early 1980s, many development and CD projects had been conducted by Niger, with the support of international technical and financial partners.

The achievements and results were spectacular in Tahoua region. Among the best known projects, the Ader Doutchi Maggia integrated rural development project ('Keita project') is a textbook case in terms of scale. After 14 years of activity, the results were inconclusive, but the human, technical and financial resource investments were so high that it was not possible to replicate this work. However, this experiment showed that the participation of inhabitants, especially women, is essential to ensure the sustainability of the achievements, along with the training of people to handle land management.

In 1962, Keita region in Niger was covered with dry forests. This vegetation had completely disappeared by 1984. That year, the crop yields were nil due to a new drought. The Keita project (1984–1999) involved an area of 3 500 km² (about 4 860 km² in the district). The aim was to curb erosion, promote water infiltration and livestock watering. The main project achievements concerned water and soil conservation work (benches, trenches, strips of vegetation, windbreaks, dams, dikes). 20 000 ha of land was treated, including 9 300 ha of agricultural land, with the rest being forest and pastoral areas; 17 million trees were planted between 1984 and 1991. Dune fixation was achieved. Many infrastructures were built, including roads, wells and schools.

Cereal yields then dropped from 1.5 t in 1972 to 0 t in 1984 and 0.364 t between 1984 and 1994. Forage production, meanwhile, increased by 50% in the project areas. The population in the region grew from 65 000 in 1962 to 170 000 in 1995 and 231 680 people in 2002.

Cultivated areas increased, i.e. 33 750–44 850 ha in 1979 and 107 000–167 828 ha in 1994. Actually cultivated areas exceeded those devoted to agriculture—it was estimated that the maximum area under cultivation had been reached in 1994 (around 120 000 ha). This barely covered local inhabitants' food needs: 237 kg of cereals are required per person per year, i.e. around 0.7 ha of cropland per person on the basis of yields of 350 kg/ha. It is therefore recommended that diversification activities be enhanced within the framework of development projects (Di Vecchia *et al.,* 2007).

Other rural development projects that have achieved excellent results in Tahoua region should also be mentioned:

- The German development cooperation has been overseeing the Tahoua Rural Development Project for a very long time.
- The Water Conservation and Agroforestry Soil project of the International Fund for Agricultural Development (IFAD) is considered as the reference for the development of *zai* techniques in Niger. An agronomist from Niger is also involved in the manual recovery of degraded land. This initiative has been so successful that the abandoned arid plateau region is now coveted land for growing sorghum.
- The NGO CARE has contributed to the development of windbreaks in Maggia valley and traces of these structures are still visible.

The overall results currently obtained in this region are impressive. The main secret of the success of all these development initiatives in arid areas is the participation of the Aderawa society (inhabitants of Ader, Tahoua region) and its ability to integrate and maintain the most useful project results.

Nowadays, the Badaguichiri catchment is developed to a remarkable extent on both the plateaux and in the valley despite the fact that the project has not been active there for several years. A set of best practices for sustainable land management is regularly used: *zai,* stone barriers, ANR, etc.

Central valley near Badaguichiri, Tahoua region, Niger. © B. Bonnet

Agricultural development initiatives (stone walls, mulching, etc.) on the Allakay plateaux,
Tahoua region, Niger. © B. Bonnet

Finally, all the experience and lessons learned from development projects carried out in Niger and Burkina Faso were gathered in a book that was published in 1989 by the Permanent Inter-State Committee for Drought Control in the Sahel (CILSS). This collection includes a hundred factsheets and is a useful tool that could serve for the GGW (Rochette, 1989).

CONCLUSION: KEY POINTS

The **'Great Green Wall' initiative** has been rightfully applauded since the political mobilization of African countries around this concept is a clear sign of the approval and success of planned CD, revegetation and particularly tree planting initiatives.

This document provides a brief summary of the literature on the subject. In addition, the many project reports accumulated over several decades and describing the experiments and their findings, and often the resulting recommendations, are generally not available or shared (Briki and Ben Khatra, 2010). CSFD recommends that a maximum of this practical information be made accessible to the highest number of people involved, especially experts and national officials managing current development projects in their countries.

Available studies and research confirm the need to develop the concept through a holistic approach integrating all agrosilvopastoral activities, with the aim of preserving the environment and promoting sustainable land development, and combining different forms of reforestation (protection and management of existing resources, supporting natural regeneration and replanting). It is also important from the outset to determine who will be responsible for implementing these initiatives and using the resources produced, i.e. wood products and nonwood forest products (fodder, fruits, resins, etc.). Land (property) and land access rights are critical issues that must be taken into account from the outset. These initiatives should be focused on all areas affected by vegetation and soil degradation and not limited to strips of land that were previously more or less arbitrarily defined.

Scientists are responsible for disseminating scientific knowledge on the role of plant cover, especially trees, in CD in all sectors (agriculture, livestock production, forestry, economy, society, etc.). The technical success of the initiative partly depends on the proper use of this knowledge and its support through training and research and development measures.

Tree planting, and especially assisted natural regeneration initiatives, have achieved the best results at the village level. However, the results, which are often obtained with the support of NGOs, bilateral cooperation and decentralized cooperation programmes, generally remain local. It would certainly be legitimate and even indispensable to extend and transform these 'microresults' at the national policy and even pan-Sahelian levels in order to combat desertification.

Support measures are necessary to maximize the chances of success and ensure the sustainability of the results of these initiatives to be undertaken, especially training on planting and regeneration techniques (e.g. modern nurseries, above-ground containers, ways to transport plants long distances, *zai*), etc.

Finally, the GGW must also be geared towards providing long-term benefits for local inhabitants. The trees do not represent a separate production activity to be confined to specific areas, unrelated to other production activities. Instead, the planting of well chosen tree species is a significant contribution that can only succeed if integrated with other forms of land use (crops, grazing, gathering, etc.). This requires a land and legal framework to enable people living in these areas to better manage these different constituents with the aim of ensuring their sustainability, which is the objective of SLM.

Ultimately, GGW must allow rural people to live in adequate conditions while ensuring the economic diversification of income sources (basketwork, gum, tannins, etc.) **by being managed within a consistent family production system**.

Proposals for decisionmakers

Research results concerning the development of agrosilvopastoral management projects gave rise to the following recommendations:

1. ***Adopting a flexible approach to promote the best sustainable land management practices***, while taking the results of many already completed greenbelt, plantation and agroforestry projects into account, and placing them in a local know-how setting.

2. ***Identifying and disseminating, where necessary, the most effective tree regeneration techniques,*** that may be readily managed (technically and financially) and are profitable.

3. ***Drawing upon the decentralization process by ensuring the participation of local people*** in planting the GGW, by offering them associated benefits (especially land quality enhancement and yields from income-generating activities and their diversification):

- promoting very light village management structures, such as rural markets;
- enhancing the training of members of village management structures;
- setting up an appropriate institutional framework with more fiscal and land incentives, along the lines of a real decentralization initiative so as to strengthen local resource management, planning and development management capacities.

4. ***Promoting agricultural and livestock production intensification*** so as to reduce their pressure on forest resources.

All of these recommendations foster the integration of tree plantations and regeneration in the overall sustainable land management framework.

LIST OF ABREVIATIONS AND ACRONYMS

ANR	Assisted natural regeneration
CD	Combating desertification
CIRAD	Agricultural Research for Development, France
CSFD	French Scientific Committee on Desertification
DES	Domestic energy strategy
FAO	Food and Agriculture Organization of the United Nations
FCFA	African Financial Community Franc
GGW	Great Green Wall
IERR	Internal economic rate of return
NGO	Non-governmental organization
NRM	Natural resource management
SLM	Sustainable land management
UNCCD	United Nations Convention to Combat Desertification
UNESCO	United Nations Educational, Scientific and Cultural Organization
USD	US dollar

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GLOSSARY

Agroforestry: a system of land-use and practices in which woody species (trees, shrubs) are deliberately integrated with crops in cropfields.

Agroforestry parkland: permanent tree/crop associations that prevail on several tens of millions of hectares of land throughout dryland Africa, from Senegal to Kenya. One or several tree species (*Faidherbia albida*, shea, nere, baobab, etc.) may be associated with one or several food crops (cereal, tubers, etc.) or cash crops (particularly cotton), often in the presence of cattle or goats that wander or graze after the crops have been harvested.

Associated forest species produce fruit, foliage or gums for human consumption on account of their high levels of fats (shea), carbohydrates (nere) or sugars (*Acacia senegal, Sterculia setigera*), or vitamins (tamarind, baobab). They also generate fodder and provide shade for animals, participate in maintaining or restoring soil fertility (*Faidherbia albida*), while serving as a fuelwood and craftwork supply source.

Agroforestry parklands are usually social constructs, even though trees are seldom planted, being derived from selective clearing operations carried out by farmers to create crop fields while retaining part of the initial forest stands. Farmers therefore gradually eliminate a number of unwanted tree or shrub species or favour desired species, thus gradually building an agroforestry parkland often with a low tree density (a few dozen trees per hectare, related to the crops planted and the forest species present) (Mallet, 2004).

Agrosilvopastoral activity: a production system integration practice, combining the preservation of trees (and their uses: wood, fodder, fruits, etc.), plant and livestock production.

Assisted natural regeneration: an agroforestry practice aimed at protecting cropping soils through wind and water erosion control, the improvement of soil fertility, fuelwood or timber production, livestock fodder production, and the reduction of evapotranspiration. During land clearing (in the dry or rainy season), this practice involves allowing the growth of one to three shoots from the stumps of different trees and shrubs (80–150 plants/ha). The different steps in the ANR process are:

- identification and selection of shoots to protect;
- cutting of nonselected shoots;
- yearly maintenance and pruning of selected shoots;
- rational use of branches from regenerated trees according to the species and needs (fodder, wood, organic matter, fruit, etc.).

Biodiversity* (or biological diversity): variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

Casuarina (*Casuarina equisetifolia*): a tree of Australian origin belonging to the Casuarinaceae family. This pioneer tree is able to colonize and enrich highly mineral-depleted soils with nitrogen via nitrogen-fixing nodules growing on its roots (symbiosis with a soilborne bacterium of the *Frankia* genus).

Desertification**: land degradation in arid, semiarid and dry subhumid areas resulting from various factors, including climatic variations and human activities.

Ecosystem*: a dynamic complex of plant, animal and microorganism communities and their nonliving environment interacting as a functional unit.

Ecosystem services: the benefits that people obtain from ecosystems. There are four categories of services (WRI, IUCN, UNEP, 2003):

- **provisioning services**: the goods or products that people obtain from ecosystems, such as food, energy, fibre and freshwater;
- **regulating services**: the benefits that people obtain from an ecosystem's control of natural processes, such as air quality maintenance, climate regulation (flooding, drought), soil erosion control, human disease regulation and water purification;
- **supporting services**: services required to produce all other ecosystem services, such as primary production, oxygen production, nutrient cycling and soil formation;
- **cultural services**: nonmaterial benefits that people obtain from ecosystems such as spiritual enrichment, development of knowledge, reflection, recreation, etc.

Flying nursery: a temporary nursery consisting of small seed holes in which several tree seeds are sown and the seedlings produced are then transplanted in the field.

Half-moon microcatchment: water and soil conservation structures consisting of semicircular earth bunds. These microcatchments are dug with a pick and shovel and the excavated soil is mounded up to form flat-topped, half-moon bunds on the downstream side of the basin. The outer side and two tips of the bunds are edged as much as possible with stones. These half-moon microcatchments are generally installed on lands with a 0–3% slope. They are helpful to:

- rehabilitate land for agrosilvopastoral use;
- boost water supplies for crops;
- reduce rainwater runoff, soil erosion and promote infiltration.

Land degradation**: the reduction or loss, in arid, semiarid and dry subhumid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as:
(i) soil erosion caused by wind and/or water;
(ii) deterioration of the physical, chemical and biological or economic properties of soil;
(iii) long-term loss of natural vegetation.

Mycorrhizal symbiosis: Most terrestrial plants form a close symbiotic relationship with numerous soil organisms. Mycorrhizal symbiosis is an association between a fungus and plant roots. This symbiosis benefits plant growth and protection as well as fungus propagation and survival. The role of mycorrhizal symbiosis has long been reduced to its impact on the mineral nutrition of the host plant and therefore the development of plant species. However, this symbiotic process interacts significantly with other biological components of the ecosystem (microbial microflora, soil microfauna, etc.) to optimize the involvement of these microorganisms in the functioning of major biogeochemical cycles (nitrogen, phosphorus and carbon cycles). Recent results have also highlighted the importance of mycorrhizal symbiosis in structuring terrestrial vegetation: plant diversity, stability and ecosystem productivity.

Neem (*Azadirachta indica*): a tree of Indian origin belonging to the Meliaceae family.

Sustainable land management: the use of land resources, especially soil, water, animals and plants to produce goods and meet ever-growing human needs, while preserving their long-term production potential and environmental functions.

Zai**:** a technique for treating degraded areas and hard soils by inducing a change in the soil structure through a localized supply of runoff water and organic manuring. Small *zai* holes are dug and the excavated soil is arranged in a semicircle downstream of the hole so as to be able to capture rainwater to benefit sown plants. The aims are to:

- enable the development of barren or abandoned lands;
- reduce water erosion and promote infiltration in impermeable soils;
- obtain normal crop harvests when rainfall is under 300 mm;
- collect water and make it available to plants.

* Several definitions prevail, these were adopted on an international scale in the UNCBD (Article 2).
** Several definitions prevail, these were adopted on an international scale in the UNCCD (Article 1).