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# Where the Land is Greener - Some Evidence from the Impact of Sustainable Land Management in the Senegalese Sahel

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## Introduction

About 41% of the earth's surface is covered by drylands and about 10-20% of those suffer from the process of desertification (or land degradation) (Dregne, 2002). The consequences are diverse including reduced productivity, damage to ecosystems and socio-economic problems such as uncertainty in food security, migration or limited development (FAO, 2008). Senegal, located in the semi-arid West African Sahel, is one of the countries highly concerned by these adverse impacts. Land degradation poses a huge threat to agricultural production with 47% of soils already being unfit for farming and 37% having a poor-average production capacity (Lô Planchon, 2003). To mitigate this threat, local land users have been applying a wide range of sustainable land management (SLM) technologies, traditional ones as well as such introduced by external projects (CSE, 2009). Soil vegetation cover is an important feature of sustainable land management as the importance of plant cover in controlling water erosion through reducing water runoff and increasing infiltration is widely accepted. Plants further fix the soil with their roots and reduce the energy of raindrops with their canopy (Duran Zuazo & Rodriguez Pleguezuelo, 2009). Many SLM technologies are therefore based on the improvement of vegetation cover. The aim of the present study was to assess the impact of SLM technologies on the extent of vegetation cover and vegetation composition compared to areas under conventional land use.

## Methods

This research includes two case studies of sustainable land management in northern Senegal: the first one from the silvopastoral region of the Ferlo and the second one from the agropastoral region of the Niayes. In each of these regions, five respectively four SLM technologies aiming at the improvement of vegetation cover, as well as the respective conventional land management (CLM) systems were selected for an assessment of vegetation cover (see *Table 1*).

*Table 1*. Overview of selected land management types in two case study regions in northern Senegal

| | | Silvopastoral | | Agropastoral | |
|---|---|---|---|---|---|
| | **No.** | **Land use** | **No. of plots** | **Land use** | **No. of plots** |
| **CLM** | 1 | Extensive pasture | 20 | Extensive pasture | 3 |
| | 2 | Cropland | 3 | | |
| | **total** | | **23** | | **3** |
| **SLM** | 3 | Agroforestry *Acacia senegal* with fallow | 5 | Dune fixation with *Casuarina equisetifolia* | 8 |
| | 4 | Homegarden | 2 | *Eucalyptus* plantation | 5 |

| | Silvopastoral | | | Agropastoral | |
|---|---|---|---|---|---|
| No. | Land use | No. of plots | | Land use | No. of plots |
| 5 | Parkland | 2 | | Agroforestry (mainly with *Neocarya macrophylla* and *Faidherbia albida)* | 5 |
| 6 | Natural grove | 3 | | Fruit orchard | 3 |
| 7 | Pasture reserve | 5 | | | |
| **total** | | **17** | | | **23** |

In all selected SLM and CLM sites between 2 and 20 sampling plots were established and in each plot all trees (defined as woody perennial species) with a diameter at breast height (DBH) ≥ 2 cm were determined and measured. Crown diameter was measured in two directions to allow for estimation of the canopy surface area. For regeneration with a DBH < 2 cm the number of individuals per species was recorded separately.

The BiodiversityR statistical software (Kindt & Coe, 2005) was used to analyze coupled datasets containing information on tree communities and environmental descriptors. *Species richness* was calculated by counting the number of species in a given sampling unit (plot). *Tree density* was the total number of individuals recorded in a certain area presented per hectare. The *Shannon diversity index* (*H'*) was used as a diversity indicator of trees in sites under different land management and calculated as (Magurran, 1988):

$$H' = -\sum Pi \times \ln Pi$$

*Rényi diversity profiles* are a diversity ordering technique. In such profiles, a site with higher diversity than a second site will have a diversity profile that is above the profile of the second site at all points (Tothmeresz, 1995). They were calculated following Kindt & Coe (2005) as:

$$H\alpha = \frac{\ln(\sum Pi\alpha)}{1-\alpha}$$

where Hα = Rényi diversity profile; Pi = proportional abundance of a species; α = scale parameter with values 0, 0.25, 0.5, 1, 2, 4, 8, and ∞. Non-parametric Mann-Whitney U tests were applied to test for differences between SLM and CLM in general. If significant differences were found, pairwise Mann-Whitney U tests were carried out to discriminate between different land use types. A level of $p < 0.05$ was chosen as the minimum for significance. All statistical tests were carried out using the Statistical Package for Social Sciences SPSS 17.0.0. (SPSS, 2009).

**Results and Discussion**

Silvopastoral land use system of the Ferlo

In the silvopastoral land use system, tree density, species richness and diversity as well as canopy cover were significantly higher at sites under SLM than under CLM (see *Table 2*). The much lower values of vegetation parameters of conventional land use systems than of land under sustainable management illustrates a consequence of land degradation. Because people in northern Senegal depend on tree species to cover a variety of needs, especially in times of famine (Gonzalez, 2001), further degradation of vegetation cover would seriously diminish the human carrying capacity of this semi-arid land.

*Table 2.* Total number of species, mean species number per plot, Shannon diversity index H´, tree density per ha for trees DBH ≥ 2 cm and mean percentage of canopy cover averaged over all plots of sustainable and conventional LM in the silvopastoral land use system of the Ferlo, Senegal[1]

| | | | **Species richness (No. spp. / plot)** | | | **Tree density (No. ind. ha$^{-1}$)** | | **Canopy cover (%)** | |
|---|---|---|---|---|---|---|---|---|---|
| | n | total no. spp. | range | mean | mean H´[2] | range | mean | range | mean |
| **SLM sites** | 17 | 39 | 2-13 | 7.0 [0.9] | 1.42 [0.2] | 7-955 | 312.0 [81.9] | 1-47 | 16 [4] |
| **CLM sites** | 23 | 22 | 1-9 | 2.8 [0.5] | 0.57 [0.2] | 8-152 | 49.9 [8.8] | 2-3 | 2 [0] |
| **Sign.** | | | | **p < 0.05** | **p < 0.05** | | **p < 0.05** | | **p < 0.05** |

[1] Standard errors are given in parenthesis. n=no. of samples.
[2] $H' = -\sum p_i \ln p_i$ where $p_i$ is the proportion of individuals of species i in the community (Magurran, 1988)

Those SLM technologies protecting natural vegetation, “natural grove” and “pasture reserve” harbored the highest densities of tree regeneration (see *Figure 1*). For the SLM technologies with a high influence of human selection on the establishment of tree species, “agroforestry”, “parkland” and “homegarden” as well as for the CLM systems, low densities of regeneration were encountered.

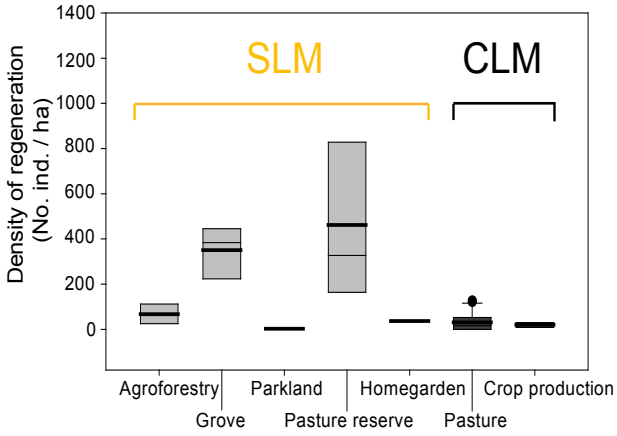


*Figure 1*. Regeneration density in sites of SLM and CLM in the silvopastoral region of the Ferlo, Senegal

Agropastoral land use system of the Niayes

In the agropastoral land use system no overall significant difference in tree density and canopy cover was found between SLM and CLM sites. However, Rényi diversity profiles suggested that sites under SLM had higher tree diversity than sites under CLM, as the curve for SLM did not intersect with the curve for CLM (see *Figure 2*). Single SLM technologies either had higher trees species richness and diversity or higher tree density than the CLM of “extensive pasture”. The highest tree density was found in the SLM systems of “dune fixation with *Casuarina*” and “*Eucalyptus* plantation” as well as in the fruit orchard. The SLM technology of “agroforestry” provided the highest diversity of tree species.

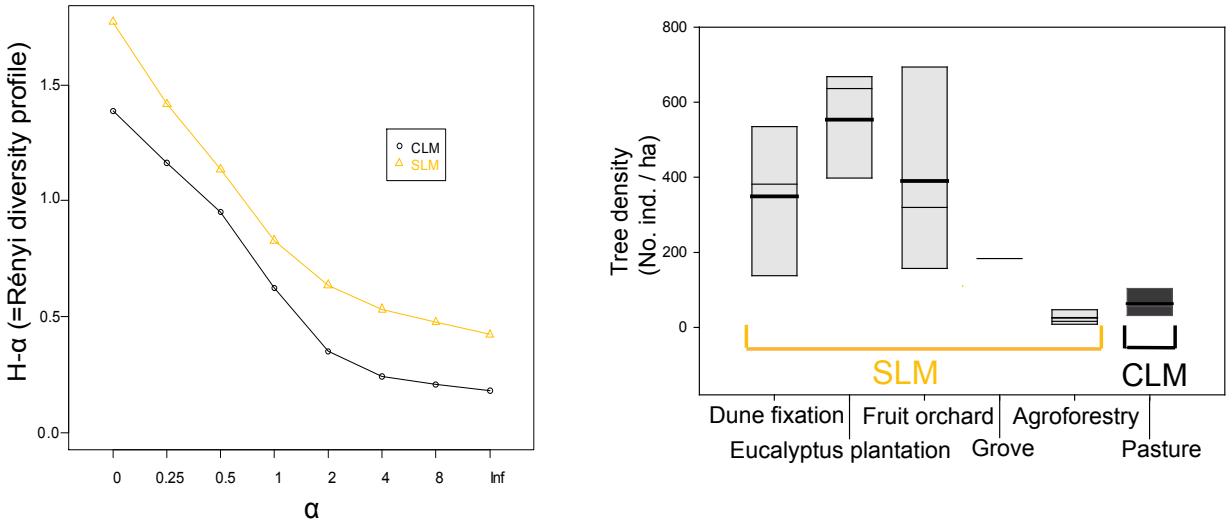


*Figure 2.* Rényi diversity profiles for SLM and CLM (left) and tree density of SLM and CLM types (right; the thick line represents the mean, the thin line the median) in the agropastoral region of the Niayes, Senegal

Regeneration of tree species was entirely absent in the conventional land use type of "pasture" as well as in the SLM sites of "dune fixation with *Casuarina equisetifolia*" and "*Eucalyptus* plantation". The only SLM technology which harbored a significant abundance of regeneration was the fruit orchard (see *Figure 3*). As *C. equisetifolia* is known not to regenerate naturally within its own stand (Mailly et al., 1994), measures in the shape of a management plan have already been taken to assure the maintenance of the system. The same applies to the plantations of *Eucalyptus camaldulensis*. For other systems, such as agroforestry or pastures, no management strategy has yet been developed but will be required in order to guarantee their continuity.

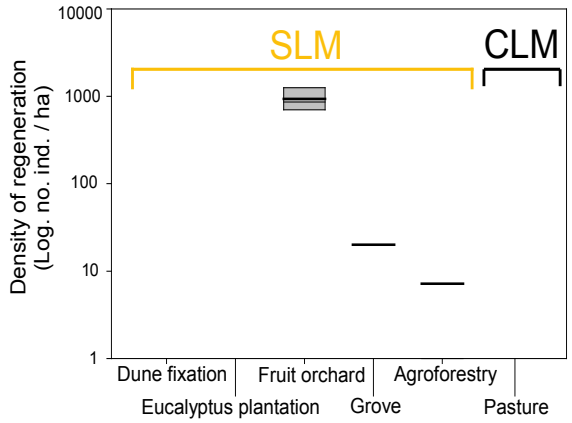


*Figure 3.* Density of tree regeneration (DBH < 2 cm) of SLM and CLM types in the agropastoral region of the Niayes, Senegal; (the thick line represents the mean, the thin line the median)

## Conclusions and Outlook

Land degradation is a big threat to the world's drylands and SLM technologies play an important role in the prevention and mitigation of this threat as well as in the rehabilitation of already degraded land. None of the investigated technologies provides a definite solution to the predominant degradation processes such as wind and water erosion, decline of soil fertility or reduction of vegetation cover. However, they all have a positive impact on at least some of the measured parameters compared to the state of vegetation under CLM. The SLM technologies achieving high tree density as well as high species richness and diversity were those preserving natural vegetation stands. It could therefore be concluded that preserving the natural vegetation was the best way to maintain woody plant biodiversity, density and species richness in the semi-arid ecosystems of northern Senegal. Agroforestry practices on the other hand harbored single individuals of species that were once common in the natural landscape but have widely

disappeared due to land degradation. Poverty is omnipresent in northern Senegal, forcing people to assure their livelihoods by cultivating the land. Agroforestry systems are therefore a compromise to preserve part of the natural vegetation while at the same time allowing for crop production and might reduce the pressure on the few remaining stands of natural vegetation. Special attention needs to be given to the regeneration of tree species in the investigated study sites. The low density of regenerating trees compared to the density of mature trees at the majority of the investigated land use types, sustainable as well as conventional ones, is a striking finding. It agrees with results of several studies that highlighted the decline of woody species in the Sahel (Gonzalez, 2001; Kindt et al., 2008; Sambou et al., 2008; Wezel, 2005). The reason for the infrequence of regeneration at SLM sites that have existed for a long time, such as parklands in the silvopastoral system, is not well understood. Shifts of tree species in response to reduced rainfall and droughts, detrimental impact of ploughing, pressure from heavy livestock browsing and anthropogenic overuse of certain species might all play a role. A study using satellite imagery, however, suggested a strong recent trend of increasing vegetation cover in the Sahel which was partially linked to an increase in rainfall (Olsson et al., 2005). As the present study only allowed for a snap-shot of seedling density at the investigated land management systems on a local scale it cannot be excluded that a general increase in vegetation cover has occurred since the last drought period. The present state of tree regeneration that was observed in the investigated systems does not suggest an increase in tree density in the near future though. While sufficient rainfall will be necessary to facilitate tree regeneration, it strongly depends on the willingness and ability of farmers to protect trees on their fields if a degradation of the vegetation cover in these areas can be avoided. Additionally, better assistance from extension services to get access to appropriate planting material, tree management techniques and intercropping regimes will be indispensable for the maintenance or improvement of vegetation cover in northern Senegal.

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