Forest Ecology and Management 320 (2014) 13–20

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Soil amelioration through afforestation and self-repair in a degraded valley-type savanna

Guoyong Tang *, Kun Li [1]

Research Institute of Resource Insects, Chinese Academy of Forestry, Kunming 650224, China
Yuanmou Desertification Ecosystem Research Station, State Forestry Administration of China, Kunming 650224, China

ARTICLE INFO

Article history:
Received 22 November 2013
Received in revised form 11 February 2014
Accepted 16 February 2014
Available online 15 March 2014

Keywords:
Soil restoration
Vegetation restoration
Afforestation
Tree species
Savanna

ABSTRACT

Land degradation and soil deterioration are key environmental problems in the savanna of southwestern China. Restoration programs require scientific information about tree species that represent the best options for rehabilitating degraded lands and about the responses of key edaphic constraints to these tree species. Five plantations (*Leucaena leucocephala*, *Albizia kalkora*, *Acacia auriculiformis*, *Azadirachta indica* and *Eucalyptus camaldulensis*) and one self-repair treatment were established to restore a degraded savanna, and soil properties associated with these treatments were investigated four times during 22 years of vegetation restoration.

The results showed that treatment and sampling time have significant effects on the soil properties of the degraded savanna following vegetation restoration. Soil physical properties improved slowly relative to its microbial and chemical properties. After 22 years of vegetation restoration, soil amelioration *via* self-repair mechanisms was more successful than *via* the planting of *A. kalkora*, *A. indica* and *E. camaldulensis* but was inferior to or close to the planting of *L. leucocephala* and *A. auriculiformis*.

The tree species control the soil amelioration process in the degraded savanna. The manual restoration of vegetation (i.e., afforestation) could not always accelerate soil amelioration relative to natural restoration (i.e., self-repair) in the savanna. *L. leucocephala* and *A. auriculiformis* are recommended as pioneer trees for soil amelioration of the degraded savanna. The cost-free self-repair of the degraded savanna is also a recommended approach to soil amelioration.

1. Introduction

Savannas occupy nearly one-third of the world's land surface (Walter, 1979). Valley-type savanna is a unique type of savanna that develops in deeply incised river valleys of southwestern China, with a total area of approximately 3.0 Mha (Jin, 2002). As a result of the combined rain shadow and foehn wind, strikingly different from the dense shrubland or evergreen subtropical forests occurring at higher altitudes in these valleys, the vegetation in the river valleys (below 1300–1600 m a.s.l.) is poor, characterized by sparse grasses and shrubs with scattered small trees (Jin, 2002). The dominant grass species are *Heteropogon contortus*, *Bothriochloa pertusa* and *Imperata cylindrical*, and the native woody plants primarily include *Dodonaea viscose*, *Phyllanthus emblica* and *Acacia farnesiana*. Extensive anthropogenic activities, such as overgrazing, woodcutting and burning, have intensified land degradation and soil deterioration in this unique ecosystem (Jin, 2002; Li, 2007). The soil of these savannas is always shallow, rocky, compacted and nutrient-poor and would be washed away rapidly following the deterioration of the vegetation (Jin, 2002; Li, 2007; Zhu et al., 2008). These soils are rich in potassium (K) but poor in nitrogen (N), phosphorus (P) and organic matter and produce low productivity (Jin, 2002; Li, 2007).

During the past two decades, national large-scale ecological projects in China have been implemented to restore the degraded savanna, primarily through afforestation/reforestation with a wide range of tree species. Restoration programs require scientific information about tree species that represent the best options for rehabilitating degraded lands and about the interactions in plant-soil systems. Tree plantations play a major role in soil formation, and tree species differ in their effects on soil features and soil processes in ways that influence the functioning and structure of the ecosystem (Dobson et al., 1997; Lamb et al., 2005; Sardans and Peñuelas, 2013). Once key soil constraints have been ameliorated or restored, it is not difficult to restore a full suite of plant

* Corresponding author. Tel.: +86 871 63860039; fax: +86 871 63860027.
E-mail addresses: tangguoyong1980@gmail.com (G. Tang), caflikun@163.com (K. Li).
[1] Co-first author.

http://dx.doi.org/10.1016/j.foreco.2014.02.018
0378-1127/

species to constitute the required vegetation in a degraded ecosystem (Dobson et al., 1997; Lamb et al., 2005; Steven, 2005). In general, the times required for ameliorating degraded soil tend to vary substantially due to differences interaction mechanisms in plant–soil systems (Dobson et al., 1997; Lamb et al., 2005). To date, however, no studies in the literature have been reported on the soil amelioration of degraded valley-type savanna through the establishment of various tree species or the self-repair mechanism of ecosystem. Tang and Li (2013) have recommended *Leucaena leucocephala* as a suitable tree species for afforestation in valley-type savanna based solely on soil carbon (C) sequestration and C stabilization.

In this study, we attempt to test the role of tree species and restoration approaches (i.e., afforestation and self-repair) in soil amelioration at different stages during 22 years of vegetation restoration in a degraded savanna. Our objective was to determine which species or restoration approaches are better adapted to the restoration of degraded valley-type savanna.

2. Materials and methods

2.1. Site description

The experiment was conducted at the Yuanmou Desertification Ecosystem Research Station, State Forestry Administration of China (25°40′N and 101°51′E, 1100–1120 m a.s.l.). The study area is a representative example of a valley-type savanna. The average annual mean temperature of the study area is 21.6 °C with a mean maximum of 27.1 °C in May and a mean minimum of 14.5 °C in Dec. The average annual precipitation is 634.3 mm, with approximately 92% falling from May through October The annual potential evaporation is 3911.2 mm, approximately 6.2 times the precipitation. The relative average annual humidity is 53%. The typical soils are classified as Ferralic Arenosols according to the FAO Taxonomy (FAO-UNESCO, 1988).

In 1991, a 15-ha area of wasteland on a barren hill of this station was selected for the study. The wasteland was located at a low-slope landscape position with a slope gradient of approximately 3–5° and had experienced soil erosion due to frequent rainstorms. The native vegetation of the wasteland was *H. contortus* with sparse *D. viscose* and was disturbed by human activities, such as woodcutting, free grazing and mowing for livestock. Before the beginning of the experiment, the wasteland had not been cultivated or planted as for planting industrial purposes for at least 15 years and the vegetation coverage was approximately 30%.

2.2. Experimental details

Five tree species (*L. leucocephala* cv. Salvador, *Acacia auriculiformis* A. Cunn., *Albizia kalkora* Prain, *Azadirachta indica* A. Juss. and *Eucalyptus camaldulensis* Dehuh) were planted in the selected wasteland with a tree spacing of 2 m × 3 m in May 1991. These tree plantations have been widely established in these savannas during the past several decades. A self-repair treatment without tree establishment has also been maintained since the beginning of the afforestation. The experiment was arranged in a randomized block design with six treatments (five plantations and one self-repair treatment) replicated four times. Each plot, representing one replicate, covered an area of 0.49 ha (70 m × 70 m). All of these plantations were protected from human-caused disturbances by barbed-wire fences. Four undisturbed savanna plots (reference treatment) were established near (approximately 2.3 km from) the restored plots in 2012. In 2013, the vegetation coverage of the self-repair and undisturbed savanna plots averaged 79% and 84%, respectively.

One permanent plot with an area of 400 m^2 (20 m × 20 m) was established in each replicated plot without buffer trees in May 1996 for long-term observation and sampling. It was forbidden to cut down trees in these permanent plots. However, trees outside of these permanent plots could be cut down when scientific research needs. Each permanent plot contained 70 stems. In total, 24 permanent plots (four for each treatment) were established for the six treatments.

2.3. Investigation and sampling

The tree crown, tree height, diameter at 1.3 m height (DBH) and tree survival were recorded for all planted trees in each permanent plot in 1997, 2005 and 2013. The total biomass of trees in each permanent plot was calculated based on biomass equations in the relevant literature (Li, 2007).

In the five tree plantations, litter samples were collected semi-monthly from five randomly located baskets (1 m × 1 m in size) over a period of 12 months every 3 years in each individual permanent plot beginning in May 1996. The litter fall in the self-repair plots was annually estimated by the above-ground biomass of *H. contortus* since in 1996 as the approach recommended by Tang and Li (2013). For comparison with the five plantations, the litter fall in the self-repair plots was graphed every 3 years rather than yearly.

The litter horizon was removed prior to soil sampling. Soil samples from each permanent plot in the six treatments were collected randomly at depths of 0–15 cm with a stainless steel cylinder. One composite soil sample representing each replicate was prepared by mixing 12–15 undisturbed soil cores within each permanent plot. In total, four composite samples (one from each permanent plot) were collected for each treatment. The soils were sampled in April 1991, May 1997, May 2005 and May 2013. After the removal of visible plant residues by hand, the soil samples were air-dried, sieved through 2-mm mesh and stored at 4 °C.

2.4. Laboratory analysis

C and N concentrations in litter sample were measured using a dry combustion method with a VarioEL elemental analyser (VarioMAX C/N, Elemental Co., Germany).

Total organic C and N in the $CaCO_3$-free soil sample were measured using a dry combustion method with a VarioEL elemental analyser. Total P were measured by the molibdate colorimetry method after ascorbic acid reduction (Murphy and Riley, 1962) using a spectrophotometer (V-530, JASCO, Japan). Soil inorganic P was measured according to Ames (1966). Soil organic P was calculated by the total P and soil inorganic P. Available P was determined according to Olsen and Sommers (1982) after acid extraction with 1 M NH_4F. Soil available K, calcium (Ca) and magnesium (Mg) were determined (by ammonium acetate extraction, Bower et al., 1952) with an atomic absorption spectrophotometer (Hitachi Z-8100, Tokyo, Japan). Soil pH was measured with a combination electrode (soil-to-water ratio 1:2). Cation exchange capacity (CEC) was determined according to Gillman (1979). Soil bulk density and soil compaction were determined using core method (Blake and Hartge, 1986) and a soil sclerometer (PIK-5552, PKC instrument Inc., Japan), respectively. Soil particle size distributions were determined by pipette method (Gee and Bauder, 1986). Water-stable macroaggregates (>250 μm) was determined by wet-sieving method (Elliott, 1986). Soil total porosity was calculated from the difference between soil bulk and soil particle density (siliceous soil with a certain content of Fe oxides, 2.65 g cm^{-3}). Microbial biomass (C, N and P) was determined by the fumigation extraction method (Vance et al., 1987). Basal respiration was determined by measuring CO_2 evolution. Briefly, approximately 50 g soil