Forest Ecology and Management 310 (2013) 450–459

Contents lists available at ScienceDirect

Forest Ecology and Management

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

# Growth and carbon stocks of multipurpose tree species plantations in degraded lands in Central Himalaya, India

R.L. Semwal [a,1], S. Nautiyal [b], R.K. Maikhuri [c], K.S. Rao [d,*], K.G. Saxena [a]

[a] School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India
[b] Center for Ecological Economics and Natural Resources, Institute for Social and Economic Change, Bangalore 560072, India
[c] G.B. Pant Institute of Himalayan Environment and Development, Garhwal Unit, Srinagar 246174, Uttarakhand, India
[d] Department of Botany, University of Delhi, Delhi 110007, India

ARTICLE INFO

*Article history:*
Received 26 March 2013
Received in revised form 13 August 2013
Accepted 13 August 2013
Available online 20 September 2013

*Keywords:*
Afforestation
Carbon sequestration
Peoples' participation
Soil
Himalaya

ABSTRACT

Deficiency of long-term data on performance of multipurpose tree plantations in degraded lands delimits the scope of realization of economic benefits from the United Nations-REDD+(Reducing Emissions from Deforestation and Forest Degradation) initiative of climate change mitigation by making payments for reducing emissions in developing countries. This study reports survival, growth and carbon stocks over a period of 20 years of mixed-species (*Albizia lebbeck*, *Alnus nepalensis*, *Boehmaria rugulosa*, *Celtis australis*, *Dalbergia sissoo*, *Ficus glomerata*, *Grewia optiva*, *Prunus cerasoides*, *Pyrus pashia* and *Sapium sebiferum*) plantations (planting density of 110 trees ha$^{-1}$ of each species and random mixing such that neighboring individuals did not belong to the same species) established with people's participation in abandoned agricultural land (AAL) and highly degraded forest land (HDFL), in Central Himalaya, India. Trees were lopped and crops were grown at the AAL site, while grasses were cut after planting at the HDFL site. Mortality occurred during the initial 3-year-period at both sites but after 7 years only at the AAL site. After 20 years, average survival at the AAL site was 87% compared to 51% at the HDFL site, with *B. rugulosa*, *G. optiva* and *F. glomerata* showing higher mortality than other species at the latter site. Annual height, girth and aboveground biomass increment rates across species and sites over 20-year period varied in the range of 23–84 cm year$^{-1}$, 1.3–3.9 cm year$^{-1}$ and 1.0–8.0 kg tree$^{-1}$ year$^{-1}$, respectively. The site as well as species effects tended to diminish with age. At the age of 20 years, *B. rugulosa* accumulated aboveground biomass 5.7-fold, *G. optiva* 3.2-fold, *C. australis* 2.3-fold, *F. glomerata* and *P. cerasoides* 1.5–1.6-fold and, *A. nepalensis* and *D. sissoo* 1.2-fold greater at the AAL site compared to the HDFL site. *S. sebiferum* and *A. lebbeck* had marginally lower biomass at the AAL site than the HDFL site, while the site effect was not significant in *P. pashia*. Over the 20-year period, tree-crop mixed system at the AAL site, apart from supporting better tree growth, provided larger quantities of utilizable biomass (206 Mg of food, fodder and fuelwood ha$^{-1}$) compared to the HDFL site (14.4 Mg of palatable grasses ha$^{-1}$). The two sites had similar total (vegetation + litter + soil) C accumulation rates (2.3–2.5 Mg C ha$^{-1}$ year$^{-1}$). With ban on income from timber in the current policies, payments for carbon sequestration from exclusive tree planting (US $ 37 family$^{-1}$ year$^{-1}$) would be negligible compared to the income from crops (US $ 400–900 family$^{-1}$ year$^{-1}$) in tree-crop mixed system. There is an urgent need of policies (i) safeguarding economic interests of local people from tree planting in degraded lands and (ii) enhancing silvicultural and ecological knowledge of multipurpose tree species to optimize multiple benefits from them.



## 1. Introduction

Himalaya, a vast mountain system extending across eight Asian countries (viz., Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan), is a biodiversity hotspot (Myers et al., 2000). Deforestation and forest degradation are widespread, with immense variation in their rates and driving factors (Rao and Pant, 2001; Wangda and Ohsawa, 2006; Panta et al., 2008). Scarcity of fodder, manure (the mixture of forest leaf litter and livestock excreta), fuelwood and a range of other non-timber forest products crucial for local livelihoods coupled with increasing aspiration for off-farm economy resulted in outmigration and abandonment of agricultural land use after 1980 (Maikhuri et al., 1995). Degraded forests and abandoned agricultural lands cover 37% area of the total geographical area of Indian Himalaya (59 million ha) (Maikhuri et al., 1997).

* Corresponding author. Tel.: +91 09313294607.
*E-mail address:* rao.srkottapalli@gmail.com (K.S. Rao).
[1] Presently at Mountain Division, Ministry of Environment and Forests, CGO Complex, Lodhi Road, New Delhi 110003, India.

0378-1127/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2013.08.023

Farmers of Himalaya have been using and managing several multipurpose tree species (Thapa et al., 1995; Singh et al., 2008) as also by farmers in mountain regions of south-east Asia (Mulyoutami et al., 2009) and Latin America (Diemont and Martin, 2009). However, cover and vigor of these species are quite poor due to: (i) selective protection of natural regeneration rather than systematic tree planting, (ii) excessive lopping (Semwal et al., 2002), (iii) small farm holdings, (iv) restrictions on commercial utilization of tree products (Singh et al., 2008; Sood and Mitchell, 2009), (v) stress on planting timber/industrially valued species by government agencies and (vi) exclusion of people in designing plantation programmes (Maikhuri et al., 1997; Lamb and Gilmour, 2003).

Tree planting in degraded lands, apart from enhancing ecosystem functions of the treated areas, contributes to conservation of the remaining forests (Lamb et al., 2005), climate change mitigation (Antle et al., 2007) and to socio-economic upliftment of local communities (Hayes and Persha, 2010; Adnan and Holscher, 2011) in developing countries. Though huge investments have been made to rehabilitate degraded lands by planting trees since the 1970s in the Himalayan region, the impact has, by and large, been poor because of inappropriate technologies and callous or negative attitudes of the local people (Saxena et al., 2001; Lamb and Gilmour, 2003).

As a result of research priorities on industrially valued tree species, quantitative information on growth and ecological impacts of multipurpose trees in Himalaya is quite limited (Gilmour et al., 1990; Maikhuri, 1993; Dhyani and Tripathi, 1999) as is also the case with other developing regions (Deans et al., 2003; van Breugel et al., 2011). Deficiency of long-term data on performance of multipurpose tree plantations in degraded lands delimits the scope of realization of economic benefits from the United Nations-REDD+(Reducing Emissions from Deforestation and Forest Degradation) initiative of climate change mitigation by making payments for reducing emissions in developing countries. Repeated sampling of a plantation over long term is likely to yield more accurate biomass/carbon accumulation trends compared to the chronosequence based ones (Johnson and Miyanishi, 2008; Walker et al., 2010) but has been rarely attempted.

We developed participatory approaches to tree planting as a component of land rehabilitation plans in selected villages in Indian Himalaya spread over an elevation range of 1200–2500 m amsl. (Maikhuri et al., 1995, 1997; Rao et al., 1999). At mid-elevations (1200–1350 m amsl.), mixed plantation of ten multipurpose tree species with cropping developed in abandoned agricultural land sequestered carbon in tree component 2.8 times and in top 15 cm soil 1.5 times higher compared to exclusive tree plantation in degraded forest land, with *Alnus nepalensis*, *Albizzia lebbeck* and *Dalbergia sissoo* showing higher mortality at the latter site but insignificant site effect on aboveground biomass (Maikhuri et al., 2000). Comparison of crop performance under varied lopping regimes in 6-year-old tree-crop mixed system suggested that retention of 25% branches did not reduce crop yields (Semwal et al., 2002). The objective of the present study was to collect additional data on tree survival, growth and carbon stocks to describe the long term effects of growing multipurpose trees in degraded lands in Himalaya. To our knowledge, this is the first attempt of evaluating the performance of plantations in degraded lands based on repeated-measurements of the same sites over a 20-year-period in the Himalaya.

## 2. Materials and methods

### 2.1. Study area

The study was carried out at Bhiri-Banswara village (latitude 30°27′N and 79°5′E) at ~1200 m amsl. in Rudraprayag district in Garhwal region of Indian Himalaya. The climate is typical monsoon, with annual rainfall varying in the range of 1400–1700 mm and monthly minimum and maximum temperatures of 7–24 °C and 19–34 °C, respectively. The soil is derived from feldspathic quartz schists, quartz muscovite schists and quartz chlorite schists and can be classified as Dystric Cambisol according to FAO system. Potential vegetation has been described as subtropical broad-leaved/pine forests (Champion and Seth, 1968). At the time of initiation of the study in 1990, the village community comprised 1400 people in 256 families, with mean land holding size of 0.45 ha. Moderately degraded natural forests (15–25 m high trees on 25–30° slopes; tree density: 350 trees $ha^{-1}$; basal area: 41 $m^2$ $ha^{-1}$), highly degraded natural forests (1–2 m tall herbaceous vegetation on 20–30° slopes with isolated stunted <5 m tall trees with basal area of <2 $m^2$ $ha^{-1}$), pure crop system (5–8° outward sloping, 4–7 m-wide and 1–2 m-high terraces devoid of trees), tree-crop mixed agroforestry system (scattered 5–8 m tall multipurpose tree species maintained in land previously under pure crop system; tree density: 170 trees $ha^{-1}$; basal area: 13 $m^2$ $ha^{-1}$) and abandoned agricultural land (herbaceous vegetation on damaged terraces) covered 46%, 3%, 35%, 10% and 6%, respectively, of the total village area (Bhadauria et al., 2012).

### 2.2. Plantation establishments

The information presented here is based on the previous studies of the same area (Maikhuri et al., 1997, 2000; Semwal et al., 2002). Interviews with the heads of 219 families staying permanently in Bhiri-Banswara in 1990–91 revealed farmers' preferences for planting eight tree species viz. *Boehmaria rugulosa* Wedd., *Grewia optiva* J.R. Drummond ex Burret, *Celtis australis* L. and *Ficus glomerata* Roxb. valued most for fodder, *D. sissoo* Roxb. and *A. lebbeck* (L.) Benth. for timber, *Pyrus pashia* Buch.-Ham. ex D. Don. for fuelwood and *Prunus cerasoides* D. Don for its edible fruits and flowers attracting honeybees. Farmers were initially not willing to plant *A. nepalensis* D. Don and *Sapium sebiferum* (Michaux) Roxb. for their poor quality fodder and fuelwood. They agreed to plant *A. nepalensis* after we informed them of its scientifically proven potential to improve soil fertility and support high crop productivity (Singh et al., 1989) and *S. sebiferum* after we informed them of market value of its tallow and oil (Gaur, 1999). Except for *B. rugulosa*, an evergreen tree, all other species were deciduous between December and March/April, with minor species specific differences in leaf fall/production dynamics.

### 2.3. Site and treatment characteristics

After a series of participatory discussions, it was decided to (i) demarcate one plot (~3 ha) each of abandoned agricultural land (AAL) and highly degraded forest land (HDFL) with similar topographic conditions but separated by a distance of 50–100 m, (ii) protect the plots from fire and grazing, (iii) transplant healthy saplings/plantlets of the ten multipurpose tree species listed above obtained from the village farm/forest land in 45 × 45 × 45 cm size pits providing 2 kg of traditional farmyard manure, the mixture of forest leaf litter and livestock excreta (moisture: 265%; C: 29.2%; N: 1.28%), at 3 m spacing in July 1991, (iv) mix species such that neighboring individuals did not belong to the same species, (v) construct a tank with locally available resources to store water to alleviate stress to crops during dry spells only at the AAL site and (vi) monitor all costs/inputs and benefits/outputs related to the trials in each site (Maikhuri et al., 1997). Soil at the AAL site had lower bulk density, higher organic carbon, total nitrogen and exchangeable potassium, calcium and magnesium compared to the HDFL site, while the two sites resembled in terms of soil texture and water holding capacity (Table 1). A summary of