Selbyana 21(1,2): 105–111. 2000.

Canopy Development Studies in an Ecoregeneration Site in Garhwal Himalaya, India

K.S. Rao*

G.B. Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora 263 643, India. E-mail: gbpgu@nde.vsnl.net.in; srkottapalli@dwp.net

R.K. Maikhuri and R.L. Semwal

Garhwal Unit, G.B.P.I.H.E.D., P Bag 92, Srinagar (Garhwal), India

K.G. Saxena

Presently at School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110 067, India

Abstract. Mixed plantations with 19 native or naturalized tree species valued by local communities were established in 1991 in the central Himalaya on abandoned agricultural land and degraded forestland. Apart from use values, the species varied in ecological attributes, such as nitrogen-fixing capability, phenology, and leaf morphology and dynamics. Density of mixed plantations at the two study sites was 1110 trees/ha. In 1996, tree species selected for the study were classified in three groups based on vertical stratification of the canopy during the 5-year growth period. Fast-growing upper canopy species were *Alnus nepalensis, Dalbergia sissoo,* and *Ficus glomerata*; slow-growing lower canopy species were *Pyrus pashia* and *Quercus glauca*; and the third group contained the remaining 14 species. All species showed better growth at the abandoned agricultural land site, where agricultural crops were grown under irrigated conditions, than at the degraded forestland site, where no crops were grown and no planted trees were irrigated. Fast-growing tree species responded to site conditions at a greater rate than did slow-growing species. The authors recommend further research on mixed plantations coupled with policy support to promote mixed-tree plantations in the Himalaya.

Key words: ecorestoration, Himalaya, native and naturalized trees, tree growth, canopy volume

Introduction

Introduction of pure plantations, mostly of coniferous species, has been a widespread treatment for rehabiliting degraded lands in the Himalaya, but performance of these plantations is, by and large, poor (Rao & Saxena 1992, Saxena et al. 1993). Some isolated examples of successful plantations do exist (Gilmour et al. 1990, Gilmour & Nurse 1991, Fox 1993). Key factors causing failed plantations and depleted natural forest cover can be traced to marginalizing local communities when selecting plantation species, when implementating afforestation programs, and when considering economic interests (Bartlett 1992; Maikhuri et al. 1995; Ramakrishnan et al. 1992, 1995; Rao & Saxena 1996; Dobriyal et al. 1997).

Local communities in the Himalaya value a range of broadleaved tree species for fodder, fuelwood, medicinal products, supplementary food, and minor timber products (Rao & Maikhuri 1996, Maikhuri et al. 1997a). Broadleaved trees also are valued in other forested landscapes inhabited by traditional societies (Guldin & Lorimer 1985, Dubrasich et al. 1997). Mixed plantations of locally valued broadleaved species are more appropriate species for tree plantations than are coniferous species. Broadleaved trees provide multiple benefits to local people and result in higher productivity as well as soil, water, and nutrient conservation. They also reduce risk of biological invasion.

The potential advantages of mixed plantations have been discussed in many studies, but experimental evaluations of tree species in pure and mixed situations are limited (Anonymous 1992; Ball et al. 1995; Keenan et al. 1995; Montagnini et al. 1995; Saxena et al. 1990, 1991, 1993; Rao & Saxena 1992; Menalled et al. 1998). The concept of competitive exclusion suggests that, if two species are identical in their growth characters (i.e., with a complete overlap in ecological niches), one will be more successful in a given habitat and will exclude the other. Thus tree plantation managers need to combine species that differ in characteristics, such as height growth, shade tolerance, crown structure, phenology, and rooting depth. A mixture of species that differ in growth patterns will be more likely

* Corresponding author.

to capture the growing space and use resources effectively. Such mixtures are said to have complementary characteristics or good ecological combining ability (Harper 1977). The objective of the present study was to measure the performance of some native and naturalized tree species in mixed plantations on degraded lands in the Himalaya.

Materials and Methods

The study was conducted at Banswara (30°27′N and 79°05′E at 1200 m elevation) in Chamoli District of Garhwal Himalaya. The study sites were 65 km from Srinagar, Garhwal, en route to Kedarnath. Mean annual maximum and minimum temperatures were 26.1°C and 11°C, respectively. Annual precipitation was ca. 1690 mm. The sites had ca. 2 ha of agricultural terraces abandoned ca. 18 years ago and ca. 4 ha of highly degraded forestland. The soil was well to poorly drained with pH ranging 6.2–6.6. A water-harvesting tank was constructed as an irrigation facility, with surface runoff and subsurface flows around the site diverted to the tank.

The study area was an integral part of the Jalai-Sursal village until 1980, when the sites were abandoned during an emigration of inhabitants to other villages and urban centers. Land productivity had become too low to support livelihood. We initiated land restoration with the help of the village council and based the study on the preferences of the local people.

Selections were made for a mixed-tree plantation with 19 tree species valued locally for fodder, fuel, manure, and minor timber. In selecting tree species, we presumed that variable species attributes, such as shade tolerant vs. shade intolerant, evergreen vs. deciduous, rapid vs. slow juvenile height growth, deep vs. shallow rooting, straight trunk vs. heavily bifurcating below 1.5 m height, would allow trees to perform better and provide closed canopies in mixed plantations. A total of 16 species were planted on the degraded forestland site, and 13 species on the abandoned agricultural land site. Ten species were common to the two sites. All of the tree species had markedly different phenologies. Only three species, *Ficus roxburghii, Quercus glauca,* and *Boehmeria rugulosa,* were absolutely evergreen. *Ougeinia dalbergioides, Grewia optiva,* and *Cedrela toona* exhibited a short leafless period (Table 1).

The study sites were cleared for planting in February 1991, with saplings planted between May and July of that year. Based on experience from earlier trials for optimum spacing and land preparation techniques, we prepared pits of 0.45 × 0.45 × 0.45 m at a spacing of 3 × 3 m. The species mixture contained equal numbers of all species planted as random combinations with an initial density of 1110 plants/ha. All dead individuals were replaced with the same species at the end of the first and second year. Survival rate was calculated based on census of all planted individuals. At each site, 20 individuals of each species were selected randomly for measuring height, circumference at collar height (10 cm above ground level), canopy width, and canopy depth (height from lowest branch to treetop). These measurements were taken at yearly intervals.

Results

At the abandoned agricultural land site (AAL), all species except for *Bauhinia variegata* showed 75% or greater survival rate. At the degraded forestland (DFL) site, species survival was lower than that at the AAL site. The highest survival rates were observed for *Ficus glomerata* and *Prunus cerasoides* (100%) at the AAL site and for *Ougeinia dalbergioides* (74.5%) at the DFL site. At the end of 5 years of growth, *Alnus nepalensis* attained the highest level of height growth at both sites. *Ficus glomerata* was the second tallest species at the AAL site, and *Albizia stipulata* at the DFL site. *Ficus glomerata* and *Alnus nepalensis* showed the highest circumference at collar height at the AAL site (40.1 cm and 37.88 cm, respectively). At the DFL site, *A. nepalensis* showed the highest circumference (25.3 cm) and was closely followed by *Albizia stipulata* and *Dalbergia sissoo* (21.3 and 21.2 cm, respectively), as shown in Table 2.

Stem bifurcation below 1.5 m height occurred most often for *Bauhinia variegata, Boehmeria rugulosa, Ficus glomerata, F. roxburghii,* and *Grewia optiva* at the AAL site and for *Albizia stipulata, B. rugulosa, Ougeinia dalbergioides, Prunus cerasoides,* and *Sapium sebiferum* at the DFL site (Table 3). Crown volume was highest in *Alnus nepalensis* and *F. glomerata* at the AAL site and in *A. nepalensis* and *Dalbergia sissoo* at the DFL site. Crown volume was relatively higher at AAL site compared to the DFL site for all species common to both sites. Canopy closure and crown differentiation occurred in the third year at the AAL site and in the fifth year at the DFL site. *Alnus nepalensis* dominated the top canopy but was also prone to dieback, which was severe at the DFL site.

Annual height increment was highest in *Alnus nepalensis, Celtis australis, Dalbergia sissoo, Ficus glomerata, Grewia optiva,* and *Sapium sebiferum* at both sites. Annual girth increments showed similar trends. *Alnus nepalensis* and *D.*

TABLE 1. Local uses, management practices, and ecological features of tree species used in mixed plantations.

Species	Common name	Local uses	Management practices	Ecological features
Albizia lebbek L.	Siris	Fuelwood, fodder, timber	Lopping	Deciduous, common in upland farms and open forests to 1200 m elevation.
Albizia stipulata Boiv.	Bhandir	Fuelwood, fodder, timber	Lopping, cutting	Deciduous, commonly grows in forests mainly along river banks to 1200–1600 m elevation.
Alnus nepalensis D. Don	Utis	Fuelwood, timber	Lopping, cutting	Deciduous, rare in upland farms, forms nearly monospecific patches on newly exposed moist soils at 1000–2500 m elevation.
Bauhinia variegata L.	Gwiriyal	Fodder, flower buds as vegetable, fuelwood	Lopping, pollarding	Deciduous, common in upland farms to 1200–1800 m elevation.
Boehmeria rugulosa Wedd.	Genthi	Fuelwood, fodder, timber	Lopping, pollarding	Evergreen, common in upland farms to 1200–1400 m elevation, but rare in forests.
Cedrela toona Rottl.	Tun	Timber	Cutting	Mostly deciduous but sometimes considered evergreen, common in forest along river banks.
Celtis australis L.	Kharik	Fuelwood, fodder, timber	Lopping	Deciduous, common in upland farms and occasional occurrence in forests to 2000 m elevation.
Dalbergia sissoo Roxb.	Sishasm	Fuelwood, timber	Lopping, cutting	Deciduous, rare occurrence in upland farms to 1500–1800 m elevation and forests on slopes, dominant species of riverine vegetation.
Ficus glomerata Roxb.	Gular	Fuelwood, fodder	Lopping, pollarding	Deciduous, common in upland farms but rare in forests to 1500–1600 m elevation.
Ficus roxburghii Wall.	Timla	Fodder, leaves used for making plates, fruits edible	Lopping, pollarding	Deciduous, common in upland farms but rare in forest to 1000–1600 m elevation.
Ficus rumphii Blume	Khabar	Fodder	Lopping, pollarding	Deciduous, rare in forests, common in upland farms from 1000–1600 m elevation.
Grewia optiva J. R. Drum ex Burr.	Bhimal	Fuelwood, fodder, fiber	Lopping, pollarding	Deciduous, common in upland farms but rare in forests to 1000–1200 m elevation.
Melia azedarach L.	Dainkan	Fodder, timber	Lopping, cutting	Deciduous, not found in forests, planted along road sides and in upland farms.
Ougeinia dalbergioides Benth.	Sandan	Fodder, timber used for making utensils	Lopping, pollarding, cutting	Deciduous, common in forests, on exposed road sides, upland farms at 800–1500-m elevation.
Prunus cerasoides D. Don	Paiyan	Fuelwood, fodder	Lopping	Deciduous, upland farms and forests at 800–2500 m elevation.
Pyrus pashia Buch.-Ham. ex D. Don	Molu	Fuelwood, fodder	Cutting, lopping, stock for *Pyrus commune*	Deciduous, common in upland farms and degraded open forest at 800–2500 m elevation.

TABLE 1. Continued

Species	Common name	Local uses	Management practices	Ecological features
Quercus glauca C. P. Thunb. ex A. Murray	Phaniyat	Fodder, fuelwood, timber	Lopping, pollarding, cutting	Not found in farms, forms monospecific stands at certain locations at 1200–1600 m elevation.
Sapium sebiferum Roxb.	Charvi	Fuelwood, oil from seeds	Cutting, lopping	Deciduous, native of China but naturalized in northwestern central Himalaya, common in upland farms and open forests around tea plantations.
Sapindus mukorossi Gaertn.	Reetha	Fuelwood, timber, fruit pulp used as soap substitute	Cutting	Deciduous, common in forests at 800–1200 m elevation, not found in upland farms but managed on wastelands near villages.

sissoo showed the highest rates of annual biomass accumulation after 5 years. The biomass accumulation rate at the AAL site was twofold that at the DFL site for most species (TABLE 4).

DISCUSSION

The fast-growing upper canopy species, *Alnus nepalensis* and *Dalbergia sissoo,* because of their deciduous habit and less dense foliage were not likely to create as much shade stress as the evergreen and dense foliage tree *Ficus glomerata.* The latter, however, being a fodder tree, was more prone to frequent lopping compared to the former two non-fodder trees. One way of increasing biomass availability from the degraded lands would be to raise high density plantations of fast-growing *A. nepalensis* and *D. sissoo* in the initial stages with subsequent thinning followed by planting of shade-tolerant, slow-growing species. Nitrogen fixation and the quantity of fast decomposing leaf lifter produced by *A. nepalensis* and *D. sissoo* would improve soil carbon and nutrient status and could improve performance of species sensitive to soil stresses. Compatibility in the mixed plantations could be

TABLE 2. Survival and growth after 5 years in ecoregeneration plots in Garhwal Himalaya, 1996.

	Survival %		Height (m)		Circumference (cm) measured 10 cm above ground level	
Species	AAL	DFL	AAL	DFL	AAL	DFL
Albizia lebbek	75	54	6.6	6.5	24.1	19.0
Albizia stipulata	—	56	—	6.6	—	21.3
Alnus nepalensis	86	46	10.5	7.2	37.8	25.3
Bauhinia variegata	24	—	4.3	—	15.3	—
Boehmeria rugulosa	95	36	5.3	2.9	28.1	13.1
Celtis australis	88	57	7.5	3.2	18.8	10.1
Cedrela toona	—	52	—	3.7	—	13.0
Dalbergia sissoo	88	58	7.6	6.2	29.7	21.2
Ficus glomerata	100	43	8.8	4.4	40.1	19.0
Ficus roxburghii	97	—	5.0	—	25.5	—
Ficus rumphii	100	—	5.2	—	21.0	—
Grewia optiva	97	39	6.7	2.9	17.6	7.4
Melia azedarach	—	67	—	3.8	—	9.5
Ougeinia dalbergioides	—	75	—	3.9	—	14.2
Prunus cerasoides	100	65	6.1	4.0	22.6	8.2
Pyrus pashia	91	61	3.0	2.6	14.0	7.8
Quercus glauca	—	50	—	1.4	—	5.0
Sapindus mukorossi	—	59	—	3.6	—	10.9
Sapium sebiferum	85	49	7.7	3.1	29.9	10.9

Note: AAL = abandoned agricultural land site; DFL = degraded forest land site, — = not planted.

TABLE 3. Crown volume (m^3/tree) and trees (%) exhibiting bifurcation below 1.5 m after 5 years of growth in ecoregeneration plots in Garhwal Himalaya, 1996.

Species	Bifurcation		Crown volume (m^3)	
	AAL	DFL	AAL	DFL
Albizia lebbek	10	15	4.9	4.2
Albizia stipulata	—	65.2	—	5.5
Alnus nepalensis	15.0	25.0	28.7	15.7
Bauhinia variegata	70.0	—	5.7	—
Boehmeria rugulosa	70.0	55.0	10.5	1.0
Celtis australis	16.7	15.0	7.7	1.0
Cedrela toona	—	10.0	—	2.8
Dalbergia sissoo	16.0	18.0	13.4	7.9
Ficus glomerata	55.6	30.5	27.4	3.5
Ficus roxburghii	50.5	—	6.9	—
Ficus rumphii	40.4	—	4.3	—
Grewia optiva	63.6	27.3	12.4	1.4
Melia azedarach	—	25.5	—	1.0
Ougeinia dalbergioides	—	56.5	—	2.5
Prunus cerasoides	44.4	50.0	9.7	2.4
Pyrus pashia	30.0	25.0	1.7	0.5
Quercus glauca	—	26.2	—	0.2
Sapindus mukorossi	—	20.2	—	1.3
Sapium sebiferum	35.7	40.0	14.5	1.3

Note: AAL = abandoned agricultural land site; DFL = degraded forest land site, — = not planted.

achieved through appropriate combinations of ecological attributes, such as foliage density, deciduous/evergreenness, nitrogen fixing, and litter production capacities together with management practices, such as lopping and pollarding (Menalled et al. 1998).

All tree species showed poor survival and growth at the degraded forestland site, which was characterized by moisture stress compared to the abandoned agricultural land site, where moisture stress was alleviated by irrigation. Fast-growing upper canopy species were affected the

TABLE 4. Average annual increment in height circumference and above-ground biomass of 19 species of trees in ecoregeneration plots in Garhwal Himalaya, 1991–1996.

Species	Height (cm/year)		Circumference (cm/year) measured 10 cm above ground level		Biomass (kg/tree/year)	
	AAL	DFL	AAL	DFL	AAL	DFL
Albizia lebbek	122	144	7.3	6.0	2.08	1.68
Albizia stipulata	—	146	—	6.7	—	1.95
Alnus nepalensis	212	152	9.2	6.4	9.82	7.54
Bauhinia variegata	88	—	5.5	—	1.60	—
Boehmeria rugulosa	94	48	7.5	3.9	2.43	0.99
Celtis australis	141	50	5.6	3.1	2.00	0.87
Cedrela toona	—	72	—	4.2	—	1.00
Dalbergia sissoo	129	115	7.0	5.7	4.60	3.54
Ficus glomerata	173	66	11.9	5.2	3.68	1.79
Ficus roxburghii	99	—	7.0	—	2.64	—
Ficus rumphii	101	—	7.0	—	2.41	—
Grewia optiva	134	50	5.5	3.5	1.79	0.82
Melia azedarach	—	71	—	4.3	—	0.83
Ougeinia dalbergioides	—	76	—	5.4	—	1.30
Prunus cerasoides	120	76	6.2	4.0	2.32	0.82
Pyrus pashia	54	42	3.7	3.3	1.41	0.79
Quercus glauca	—	27	—	2.9	—	0.44
Sapindus mukorossi	—	72	—	4.8	—	1.02
Sapium sebiferum	158	58	8.0	4.6	3.04	1.20

Note: AAL = abandoned agricultural land site; DFL = degraded forest land site, — = not planted.

most. The intense moisture stress did not allow evergreens, such as *Quercus glauca,* to perform in open environments. *Celtis australis* and *Ougeinia dalbergioides* showed almost complete evergreenness in the absence of moisture stress at the AAL site but deciduousness at the moisture-stressed DFL site. The even-aged-stratified-canopy model of mixed stand development (Smith 1986, Oliver & Larson 1996, Menalled et al. 1998) suggests that stands with a high species diversity tend to develop separate canopy strata under moisture stress conditions. In the present study, vertical stratification of canopy began after 3 years at the site where moisture stress was alleviated compared to 5 years at the stressed site.

Above-ground tree biomass at the AAL site was 11.89 Mg/ha compared to 8.34 Mg/ha at the DFL site (Maikhuri et al. 1997b). This indicates the positive effect of better soil biophysical attributes on tree survival and growth as observed by others (Mehdizaden et al. 1978, Shiekh et al. 1984, Tenbergen et al. 1995).

This study demonstrated that mixed plantations of multipurpose trees valued by local communities could be grown successfully on degraded lands in the Himalaya. Such an approach would recuperate biodiversity and ecosystem function in addition to benefitting local communities. Policy support is needed to promote establishment of mixed plantations in the absence of self-initiatives by local communities. Long-term research is needed to analyze species interactions to optimize composition of mixed plantations.

Acknowledgments

We thank the Director of the G.B. Pant Institute of Himalayan Environment and Development for the research facilities. The TSBF Programme, Nairobi, and the MacArthur Foundation, USA, administered through the UNESCO office in Delhi, provided financial support, and J. Huffman contributed valuable comments on the manuscript. The views expressed here are those of the authors and not necessarily those of the organizations, with which they are affiliated.

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