Agricultural Economics Research Review
Vol. 20 July-December 2007 pp 179-202

Review Article

Forestry to Support Increased Agricultural Production: Focus on Employment Generation and Rural Development

S.K. Dhyani [1], J.S. Samra [2], Ajit, A.K. Handa and Uma

Abstract

India possesses several advantages due to its varied ecological range and agro-climates to cultivate several important and diverse commercial food commodities ranging from cereals, fruits and spices to medicinal plants. The country has abundance of human resource comprising skilled, educated, technical and scientific manpower on one hand and unskilled manpower on the other. Forests- and agriculture-based industries are a major source of employment in the primary, secondary and tertiary sectors all over the country. This article has presented a brief overview of the potential of forest and agriculture in generating employment, providing livelihood and environmental services, sequestration of green house gases, carbon trading, rehabilitation of degraded lands, production of fuel wood, etc. There are clear linkages and synergies between agricultural production and sustainable forest management. If the sustainability of the agriculture and forests can be assured, food security and employment generation would go in long-term perpetuity.

1. Introduction

Forests and trees are essential for human life. A forest cover of 20.68 per cent of the total geographic area (FSI, 2003) plays a major role in sustaining all forms of life, landscape and environmental services of India. Forests and trees renew the air we breathe, moderate our climate, regulate atmospheric moisture, recycle processes and conserve soil in the fragile, hilly and coastal ecosystem with the canopy cover. Apart from providing multiple outputs, vegetation communities are the source of many commercial

---

National Research Centre for Agroforestry, Jhansi – 284 003 (UP), India
[2] Chief Executive Officer, National Rainfed Area Authority (NRAA), NASC Complex, Pusa Campus, New Delhi – 110 012
Authors are thankful to the anonymous referee for his constructive suggestions.

and traditional medicines and serve as a valuable bank of diversity for genetic enhancements, including wild life.

The major environmental functions of forests and vegetation may be summarized as:

- Conservation of soil, water resources and genetic resources
- Control of soil degradation, desertification and floods
- Moderation of drought
- Reduction in the pollution of groundwater resulting from high inputs of fertilizers
- Increasing biodiversity in the farming system and watershed scale
- Increasing food security and thereby reducing pressure on land resources
- Checking deforestation and its associated impact on environment
- Reducing pressure on agriculture by meeting the requirements of fuel wood, fodder and other products, instead of utilizing agriculture byproducts, which may be used elsewhere
- Reduction in the build-up of atmospheric carbon dioxide and other greenhouse gases, and
- Disaster prevention, rehabilitation and reconstruction.

Forest and agriculture are the two sectors interdependent on each other. However, in order to sustain the benefits of enhanced productivity of the two sectors over long periods, adherence to the scientific principles of soil and plant health management cannot be overemphasized. ‘Green revolution’ today, after almost four decades of its inception, is aptly recognized as ‘forest or land saving agriculture’. If the yield improvement associated with the green revolution in wheat and rice had not taken place, India would have had to convert nearly 80 million hectares of forestland to produce the current yield (about 207 million tonnes) of food grains (Kesavan and Swaminathan, 2006). At the same time, for sustainable agriculture in one ha area, 2.5 ha forest (vegetation) is essential.

India possesses several relative advantages to be internationally competitive in agriculture. It has vast ecological range with a forest cover of more than 67 million hectares, agroclimates to cultivate commercially important and diverse commodities ranging from cereals, pulses, oilseeds, vegetables, almonds, apples to tropical mangoes and pineapples. About 40 per cent of India’s agriculture is irrigated as compared to the world average of 20 per cent and there are still some untapped potentials. The gap between present productivity and proven technological potential is very large for most crops, despite the country having an abundance of social capital of skilled, educated, technical, scientific and unskilled manpower with advantages of lower wages. However, the weakening agricultural performance in recent years is a national concern. Despite shrinking share of the agricultural sector (21%) in the economy, a majority of the labour force (nearly 65%) continues to depend on agriculture. About 75 per cent of India's poor households with low purchasing power live in the rural areas and nearly 72 per cent of the cultivated area is under rainfed farming. Today, it is a big challenge to ensure an economically and ecologically sound access to food for every Indian, while conserving and improving the natural resources (soil, water, vegetation and biodiversity) in a WTO regime of competitiveness.

2. Forests and Tree Cover in the Country

Realization of the multiple economic benefits of forests to human beings, particularly to the agricultural sector and their environmental functions have created a great concern for the protection and preservation of trees, bushes and grasses. Destruction and degradation of forest resources may have detrimental effect on soil, water, human life and animal life. The underlying causes of forest degradation are the ever-increasing population and persistent poverty. Unfortunately, most forest soils are not suitable for profitable agriculture and quickly become unproductive. The felling of trees for commercial and domestic wood products is mostly unregulated and beyond the forest's ability to replenish itself. Similarly, the grazing of livestock is often beyond the carrying capacity of forested areas. Going by the potential for economic exploitation today, it would appear that 90 per cent of the forests are performing the critical functions of protecting fragile watersheds and are not fit for commercial exploitation. Owing to a shift in the National Forest Policy of India, harvesting from forests has practically been banned with social benefits mainly flowing from the protective and environmental functions of the forest apart from meeting the subsistence needs of the communities living close to the forests.

According to the latest report, the forest cover of the country is only 67.83 M ha (20.68% of the geographical area) and other tree cover is estimated as 9.99 M ha (3.04% of the geographic area), thus the total forest and other tree cover is computed as 77.82 M ha, which is 23.68 per cent of its geographical area (FSI, 2003). Apart from this, about 25.72 M ha area is under various types of tree plantations, which include agroforestry, social forestry, farm forestry, etc. (Table 1).

Table 1. Area under various types of tree plantations in India

S. No.	Plantation type	Area (M ha)
1	Agroforestry and social forestry	23.00
2	Externally aided social forestry	
	a) Farm forestry/ agroforestry	1.24
	b) Village woodlots	0.50
	c) Strip plantations	0.07
	d) Rehabilitation of degraded forests	0.24
	Sub-total	2.06
3	By NGOs	0.04
4	Tree growers co-operatives	0.04
5	Conservation forestry	0.19
6	Afforestation (Windbreaks/ Shelterbelt)- under irrigation region development programme of the *Indira Gandhi Nahar Project*	0.40
	Total	25.72

Forest management practices and production methods ranging from conventional to scientifically managed production in time and space have witnessed many changes after the independence of India. Due to the programmes of social forestry and agroforestry initiatives, woods in large quantity are now being produced from non-conventional forestlands. Small and marginal farmers, through short-rotation forestry and agroforestry practices are now providing the bulk of country's domestically produced timber products; theses are competing with annual imports valued at about US $ 1 billion. This has a great significance because the extraction of timber from the state-owned forests has been banned to reduce deforestation, preserve biodiversity and conserve environment.

3. Employment Generation in Forestry

Forests and the related industries are a major source of employment in the primary, secondary and tertiary sectors all over the country. It has been estimated that in the primary and secondary sectors, forestry activities generate employment of approximately 240 million person days per day. Forestry activities are labour-intensive, especially in the remote and diffucult areas. At least 10 per cent of the present tribal population of 50 millions derive their livelihood directly from forests. The various forest industries provide another gainful source of employment. Out of 445 million cattle in the country, nearly 270 million cattle graze in the forests at present. Assuming that one man looks after grazing of 10 cattle in the forests, the total number of men looking after the grazing of these cattle comes to 27 million. Overall, it is estimated that at least 10-12 per cent of the population of the country, depends for their livelihood on the forests and forest-based industries. This number will constantly increase if the major forest development programmes including JFM (Joint Forest Management) are initiated.

Forest-based enterprises generate high level of employment to the tune of 30 million people in India. Outstanding among the products that create jobs are oil seeds (36.5 million humandays/year), gums and resins (31.3 million humandays/year), bamboo (17.5 million humandays/year) and kapok floss (3.6 million humandays/year). The highest turnover forest products are the beedi, tendu leaves from tendu tree (*Diospyros melanoxylon*). India produces more than half a million tonnes of bidi leaves a year. Gathering, processing and selling them provide employment for at least one million people.

The Tribal Cooperatives Marketing Federation of India (TRIFED) facilitates procurement, processing and marketing of forest and agricultural commodities produced in the tribal (8% of the total population in India) areas. About 50 commodities are traded, including cashew nuts, lac, pepper, sal oil, sisal, hemp, aloe, tamarind fruit, cardamom, tassar silk, etc. Polmyrah palm (*Borassus flabellifer*) provides major products as neera, leaves, fibre, timber and fuelwood in the southern India. These products are generally sold as palm sugar candy and handicrafts. The total annual income from the sale of polmyrah products was estimated at Rs 120 million (Jambulingam and Fernanades, 1986). Vilayiti babool (*Prosopis juliflora*) in addition to providing fuel wood is also creating a large market of high-value products. For example, from Ramnathpuram district of Tamil Nadu, about 15,000 t of charcoal is transported to Chennai. Trees like kapok (*Ceiba pentendra*), imli (*Tamarindus indica*), etc. have a tremendous potential to be exploited through value addition. These trees provide regular additional income of Rs 500/tree/year

4. Agroforestry Options

The combination of forestry and agriculture is truly represented by agroforestry practices. Agroforestry is a land-use system that involves deliberate retention, introduction of trees or other woody perennial in crop/animal production systems. It is a combination of agriculture, agrostology, forestry, horticulture, animal husbandry and other components. Growing trees and shrubs in the crop field is an age-old practice. Agroforestry can be an appropriate technology under the Indian situation where there is land scarcity, plenty of labour but less productive and scarce capital. Under such a situation, agroforestry has a very important place in the life of human beings, as it is directly related to the livelihood of inhabitants and also provides an important service of climate moderation in many forms in an inhospitable environment. Its role in environment protection, employment generation, etc. is discussed in the following sections.

4.1. Fuel Wood Production and Bioenergy

Fuel wood production and bioenergy is a very critical need, especially in the rural sector. According to a study of Forest Survey of India (FSI), the total requirement of fuel wood in the country was of around 201 Mt in 1996. Out of this, roughly 103 Mt was brought from the forest areas (including plantation), which constituted nearly 51 per cent of the total requirement, and the balance 98 Mt from the agroforestry sector, including plantation on common land. As per latest estimates (FSI, 2003), the annual increment of India's forest in terms of fuel wood is around 26.3 million cu m (21 Mt). Of this, around 17 M t is available on sustained basis. In this way, nearly 86 Mt of fuel wood is being removed from the forests and plantation of India every year in excess of what they are capable of producing on sustained basis. The projected demand of fuel wood for 2006 was of 247 Mt.

The main biomass energy sources that are being used in the households, include wood from forests, croplands and homesteads, cow dung and crop residues. Due to non-availability of such energy sources as kerosene oil, electricity, biogas, liquefied petroleum gas (LPG), etc. to rural households coupled with their low economic status, the easily available wood, cow dung and crop biomass are still their main sources of energy. Rural India uses 180 M t biomass per annum for cooking only. Ravindranathan *et al.* (1997) have reported for a Karnataka village that 79 per cent of all the energy used came mainly from trees and shrubs.

Prosopis juliflora is the major source of fuel for the boilers of the captive power generation plants in Andhra Pradesh (the other materials are rice husk, cotton stalks, wood shavings, etc.). About Rs 700-1300/t is the price offered for *P. juliflora* wood at factory gate, depending on the season and moisture content. Forest Development Corporation, Gujarat, estimated 1,70,972 ha area under *P. juliflora* in 2005 in the three districts of Bhuj, Patan and Surendranagar, with a potential of 1,52,600 t of charcoal production and employment generation of 1.86 million human days per rotation. The fuel wood potential in terms of calorific value of indigenous (*Acacia nilotica, Azadirachta indica, Casuarina equisetifolia, Dalbergia sissoo, Prosopis cineraria, Ziziphus mauritiana,* etc.) trees ranges from 19-21 MJ $kg^{-1}$and for exotic (*Acacia auriculiformis, A. tortilis, Eucalyptus camaldulensis* and *E. tereticornis*), it was 17- 19 MJ kg^{-1}(Puri *et al*., 1994). Pathak *et al*.

(2000) have opined that species such as *C. equisetifolia*, *P. juliflora, Leuceana leucocephala* and *Calliandra calothyrsus* have become prominent due to their potential for providing fuel energy at the highest efficiency, shorter rotation and also their high adaptability to diverse habitats and climates.

Renewable energy generation from tree biomass (dendrothermal energy) is a viable alternative for fossil fuels. Establishment of dendro-power plants requires lower investment and maintenance costs, as compared to other power plants. It also provides geographically diversified options for reclamation of wastelands. There is additional advantage of employment generation for rural people besides prevention of land degradation and desertification, particularly in the dry zone. A person can earn Rs 300 per day by harvesting biomass and selling it to dendro-power plants and enhance their cost effectiveness. Bamboo species such as *Dendrocalamus strictus* can yield up to 150 t/ha/yr of biomass. Accordingly, 0.4 ha is sufficient to produce 1kW of power. There is potential of electrical power generation of 4000-30,000 MW in the rural areas.

4.2 Animal Husbandry and Livelihood Opportunities

Animal husbandry and fisheries have an important role in the national economy and socio-economic development of the country. The contribution of these sectors is estimated at about 29 per cent of the total value of output from the agricultural sector. These sectors play a significant role in supplementing family income and generating gainful employment in the rural areas, particularly for the landless, small and marginal farmers and women besides providing cheap and nutritious food to millions of people. Nearly 27 million people are engaged in the livestock sector. For a rapid growth of the livestock and fisheries sectors, Department of Animal Husbandry and Dairying utilized Rs 1678 crore during the Ninth Plan. The major thrust was on genetic upgradation of livestock to improve the productivity and production of major livestock products.

According to the Forest Survey of India, the requirement of green and dry fodder was 593 Mt and 482 Mt, respectively during 1996, which increased to 817 Mt and 615 Mt, respectively, in 2006. It is generally agreed that nearly 30 per cent of the fodder requirement of the country comes from the forest areas. Therefore, there is removal to the extent of 145 Mt of dry fodder and 178 Mt of green fodder annually from the forest areas. To protect the forest vegetation from such removals, silvipasture systems in agricultural lands, degraded lands and other problem areas need to be promoted. Trees and shrubs contribute a substantial amount of leaf fodder not only in the arid and semi-arid regions but also in the hilly areas during the lean period through lopping/pruning, popularly known as top feed. The importance of top feeds increases with the severity of drought and progression of drought season. The top feeds may also play important role as windbreaks or shelterbelts and provide shade for the grazing animals. The species such as *Aegle marmelos*, *Albizia amara, Bauhinia* spp*., Butea monosperma, Cordia dichotoma (syn.C. myxa), Ficus* spp*., Grewia optiva, Hardwickia binata, Holoptelia integrifolia, Pithecellobiam dulce (syn. Inga dulce), Morus alba* and *Moringa oleifera* are very useful as top feeds for livestock. *L. leucocephala* could be fed to goats to increase the rate of productivity per unit of land in terms of products, including milk and meat (Kumar and Sharma, 1998). Further discussion on this aspect has been covered under agroforestry for degraded lands.

India is the fourth largest fish producer in the world. As a result of concerted efforts by the central and state governments, fish production has been increasing in the country, reaching a record level of 6.4 Mt from just 0.75 Mt in 1950-51. Aquaculture is a small (5.8% of the total number of aquafarmers) and marginal (90.6%) farmer's enterprise. It has contributed in a significant way to the upliftment of the underprivileged sections of the society. To meet the requirement of this sector, sufficient good quality water is required, which again depends on the sound management of forest and vegetation. The Watershed Development Programme has contributed significantly in augmenting the supply of water in different parts of the country. Agroforestry interventions based on a judicious combination of forestry, horticulture, livestock and agriculture with erosion control structures, such as half moon terraces, contour bunds, grassed waterways, gully plugging and bench terracing are helpful from water conservation and production point of view. The vegetation cover moderates almost all hydrological events. The post-rainy season flow in the river's network, floods, siltation and droughts can be regulated by improving vegetative cover in the catchments. One of the such studies undertaken by CSWCRTI, Dehradun, was at Nalotanala, a 4-ha landslide area on Dehradun - Mussoorie road which had been successfully stabilized by bio-engineering measures, including agroforestry interventions, such as planting of *Ipomoea carnea*, *Vitex negundo* and Napier with *Erythrina suberosa*, *Dalbergia sissoo* and *Acacia catechu*. The area was completely revegetated and rehabilitated within a period of 10 years. The sediment load which was 320 t/ ha/ year before treatment reduced to 5.5 t/ ha/ year with the improvement of vegetation cover from < 5 per cent to > 95 per cent. Besides, the significant effect of the measures was reflected on the dry weather flow, which used to last for hardly 100 days after the cessation of monsoon before the treatment, increased to 250 days after the treatment (Sastry *et al*., 1981) (Table 2).

Table 2. Effect of bio-engineering measures on land-use stabilization (Nalota Nala, Dehradun, Uttrakhand treated in 1964)

Description	Before treatment	After treatment
Runoff (mm)	55	38
Dry weather flow (days)	100	250
Sediment load, t ha^{-1} yr^{-1}	320	5.5
Vegetation cover (%)	< 5	> 95

Based on 30 years of observations.

A good example of water conservation efforts is the '*Neeru Meeru'* (water and you) programme launched in May 2000 by the Government of Andhra Pradesh. During the past few years, an additional storage space of more than 1800 Mm^3 has been created by constructing various water-harvesting structures such as percolation tanks, dugout ponds, check dams, etc. through people's participation. Tarun Bharat Sangh (Young India Association)(TBS), an NGO, promotes sustainable water management through rainwater harvesting in Rajasthan. Since 1986, TBS has helped in building or restoring nearly 10,000 water harvesting structures in Alwar and neighbouring districts in the Aravalli hills of northeastern Rajasthan. The efforts of villagers are visible in the form of rising water table and regenerated forests on the rocky slopes of Aravalli hills (Kumar *et al*., 2005). The water thus collected has multiple uses, including use for fishery.

4.3. Rehabilitation of Degraded Lands

Soil degradation is a major threat to our food and environmental security. As per the estimates by NBSSLUP (2004), about 45 per cent (146.8 M ha) of the total geographical area of the country is degraded due to different degrading agents. The degraded lands usually suffer from one or more such problems as low nutrient status, eroded top soil, difficult land surfaces (ravines, gullies, torrents), lack of soil moisture, development of soil toxicity or poor physical condition of soil. The problems may be inherent to the site, but in a majority of the cases, these have developed due to persistent biotic disturbances (excessive grazing, biomass extraction, fire and consequent absence of natural regeneration). However, the natural vegetation succession in such habitats is slow. Studies for twenty-four years on the choronosequence of succession of vegetation in the severely degraded ravines at Agra had indicated that in spite of complete protection, no woody perennial was observed to occupy the ravine hump due to extremely harsh conditions (Samra *et al*., 1999a). A number of grasses did occupy the site changing ultimately to *Desmostachys bipinnata-Cenchrus ciliaris* association from fifteen years onwards. Much of this area can be reclaimed with appropriate management and minor investments in the establishment of permanent vegetation that will stabilize the local environment and provide the much-needed fodder and energy resources for rural communities (Raizada *et al*., 2004).

Silvipastoral systems are the most appropriate land-use approaches for rehabilitation of degraded lands, including meeting the varied requirements of the people and ecological considerations. The studies undertaken by the CSWCRTI, Dehradun, have indicated the potential of silvipasture systems, such as *Dalbergia sissoo* + *Chrysopogon fulvus*; *Acacia catechu* + *Eulaliopsis binata*; *Eucalyptus* hybrid + *Chrysopogon fulvus*; and *Leucaena leucocephala* + Napier / *Panicum maximum* in utilizing the degraded lands for productive as well as protective functions. In a study, four multi-purpose tree species, viz. *Albizia lebbek*, *Grewia optiva*, *Bauhinia purpurea* and *Leucaena leucocephala,* were grown in association with two grass species, viz. *Chrysopogon fulvus* and *Eulaliopsis binata*. The findings over a period of 14 years had suggested that gravelly and bouldery lands could be effectively utilized by putting them under perennial vegetation for improving soil fertility and biomass production (Vishwanatham *et al*., 1999; Samra *et al*., 1999b). The annual net returns of Rs 3500/- per ha were obtained in *Grewia optiva* + *Eulaliopsis binata,* followed by Rs 3400/- per ha in *Albizia lebbek* from these bouldery lands. Similarly, *Paulownia fortunei*, an exotic multipurpose tree introduced from China, has shown its potential as a tree suitable for agroforestry systems in different biophysical conditions, including degraded bouldery riverbed lands in the Doon valley (Charan Singh *et al*., 2003).

For degraded lands in the semi-arid region at Kattupakkam (Tamil Nadu), a silvi-pasture system containing subabul*, Gliricidia sepium,* neem and Sissoo + *Stylosanthes hamata* yielded 79 per cent and 34 per cent higher dry fodder and crude protein biomass, respectively compared to that in the natural grazing land. A three tier silvipastoral system developed at NRCAF, Jhansi, with woody component of *Dichrostachys cinerea+Albizzia amara+Leuceana leucocephala* showed top feed production (t/ha) of 0.04, 0.26, 0.48, 1.15, 0.53, 0.55, and 0.54 during first, second, third, fourth, fifth, sixth and seventh years, respectively when pruned up to 50 per cent height of the trees from the ground level (Rai, 1999a). Harvesting of 10 multipurpose tree species at the age of 10 years yielded the maximum dry leaf fodder of 10.6 kg /tree with *A. lebbeck,* followed by *L. leucocephala* (5.4 kg /tree) (Rai, 1999b).

Similarly, CRIDA, Hyderabad, has developed a silvipastoral system with *L. leucocephala* (K-8), *Cenchrus ciliaris* and *Stylosanthes hamata* for shallow red chalka soils of Andhra Pradesh. The system developed very well and has shown the way to rehabilitate degraded or marginal lands. On an average, 6 t/ha/yr dry matter yield was obtained from *S. hamata* and 3 t/ha/yr from *C. ciliaris*, besides, 6 t/ha/yr (biomass) from *L. leucocephala*.

Ravinous areas of the Yamuna, the Chambal and the Mahi rivers were rehabilitated for generating economic biomass and protection against further degradation through suitable agroforestry systems. In the Yamuna ravines of Agra, planting of *Acacia nilotica* in the gully bottom and *Acacia tortilis* in top location along with *Cenchrus ciliaris* was economically most promising. For saline riverbank, grasses, viz. *Brachiaria mutica* and trees such as *Prosopis juliflora*, *Eucalyptus tereticornis* and *Tamarix dioca* were suitable. In the Mahi ravines, *Cenchrus ciliaris* interplanted with *Dendrocalamus strictus* stabilized gully plugs and provided economic returns. For the Chambal ravines ber, aonla and lemon were identified as the promising fruit trees. At Kota, *Leucaena* - based alley cropping systems resulted in the highest yield advantage, land equivalent ratio and organic carbon content in the soil. Application of 50 per cent N each through urea and lopped *Leucaena* leaves gave the highest productivity of sorghum + pigeonpea intercropping system and enriched the soil fertility. The reduction in crop yield due to *Leucaena* hedgerows was minimized by proper pruning and compensated by the biomass of standing trees. Further, boundary plantations of *Acacia nilotica* had the least adverse effect on the associated crops of castor and pigeonpea, followed by *Azadirachta indica* and *Albizia lebbek*.

Desertification is a process by which the productive potential of soil and the vegetation which it supports gets reduced. These areas need to be stabilized with vegetation for soil conservation and also meeting the fuel and fodder needs of the human beings and animals. A study by CAZRI, Jodhpur, from sandy range lands of the western Rajasthan has shown that the plantation of jojoba species in *Cenchrus ciliaris* pasture gave forage yield up to 0.8 t/ha which indicated that even 280 bushes/ha can be safely planted without adversely affecting the forage production (Sharma and Vashistha, 1995). For forage production and livestock maintenance, silvipastoral system was better compared to pasture/ trees alone (Harsh *et al*., 1992). Studies on the sand movement have shown that stabilization of sand dunes with grasses and trees help in checking the movement of sand. Most suitable trees, shrubs and grasses for the arid zone of Rajasthan are: *Prosopis juliflora, P. cineraria, Acacia tortilis, A. radiana, Zizyphus mauritiana, Colligonum polygonides, Crotolaria burhia, Aerua javanica, Z. nummularia, Lasiurus indicus, Panicum turgidum* and *P. antidotale*.

Shelterbelts on field boundaries effectively control injuries to the tender tree seedlings from sand blasting and hot wind. Similarly, development of windbreak across the wind direction has shown to reduce wind velocity by 20-46 per cent and soil loss by 76 per cent. On leeward side of the windbreaks, the soil retained 14 per cent more moisture and pearlmillet crop recorded 70 per cent higher grain yield (Gupta *et al*., 1997). Shelterbelts reduce evaporation and the moisture status of sheltered field is generally higher by 2-4 per cent than of unsheltered field (Gupta and Ramakrishna, 1988). The shelterbelts should be continuous without any gap to avoid the tunnel effect. Usually 3-row windbreaks with central row of tall trees like *Albizia lebbek*, with a single row of branched trees like *Acacia tortilis, Cassia siamea* or *Prosopis juliflora* on other sides of *Albizia lebbek* are very effective. In the western Rajasthan, 3-row shelterbelt of *C. siamea – A lebbek – C. siamea* is highly effective in reducing wind speed and loss of nutrients. About 825 million trees of Eucalyptus, Shisham, etc. were planted as windbreak/shelterbelt in 0.4 M ha area under Irrigation Region Development Programme of the Indira Gandhi Nahar Project (IGNP). The income from the surviving 600 million plants has been estimated to be 140- times of the total project cost.

Saline and Alkaline Lands

A large portion of degraded lands is also affected by salinity, alkalinity and waterlogging problems. Waterlogging is encountered under both semi-arid and arid conditions due to excessive irrigation, low-lying lands under high rainfall areas and high groundwater table conditions. Repetitive waterlogging during the monsoon seasons, followed by high evaporation from the land surface during the subsequent dry seasons result in salt build-up and leads to the formation of salt-affected soils. Reclaiming the waterlogged soils through installation of surface or subsurface drainage system is a costly proposition. An alternative approach is through bio-drainage by growing high transpiring tree species tolerant to such soil and waterlogged conditions, since evapo-transpiration losses from forest plantations are usually 2 to 2.5 times higher than cropped land. A technology consisting of planting *Eucalyptus* hybrid seedlings at a specified interval on a ridge covered with polythene sheet with holes (at the locations where the seedlings are to be planted) has successfully been demonstrated in the Faridkot district of Punjab (Hira *et al*., 1999). This technique is simple and inexpensive, and is based on *in-situ* rain water harvesting along with the addition of chemical amendments such as gypsum and ferric sulphate (industrial waste) and subsequent leaching of harmful soluble salts from the root zone profile to make the land suitable for tree plantation. For alkali soil rehabilitation, silvipastoral system with *P. juliflora, Acacia nilotica* and *Tamarix articulata* trees and *Leptochloa fusca, Chloris gayana* and *Brachiaria mutica* are most suitable. *L. fusca* in association with *P. juliflora* produced 46.5 t/ ha green fodder over a period of four years without applying any amendments and fertilizer (Dagar *et al*., 2001). The agroforestry technology developed by CSSRI, Karnal, has been utilized by the state forest departments, NGOs, NWDB and other developmental agencies for rehabilitation of salt-affected soils. More than 1 million hectare such areas, particularly the village level community lands, areas along roadside, canal and railway tracts, have been rehabilitated (Singh, 1999).

Alternatives to Shifting Cultivation

Degradation by shifting cultivation of moist tropical and evergreen forests in the north-eastern India has led to serious ecosystem disturbances and biodiversity loss as the fallow cycle has reduced from 20-30 years to hardly 3-5 years. Toky and Ramakrishnan (1983a, b) had investigated forest fallows of different ages in the region. Initially weeds occupied the sites, after five years bamboos (*Dendrocalamus hamiltonii*) appeared and dominated the sites for 10-20 years. By the 20th year, a number of shade-tolerant trees (e.g. *Terminallia bellerica, Schima wallichii,* etc.) appeared along with bamboo. Species diversity increased over time with the number of weed perennials showing a significant increase in terms of biomass and productivity.

The ICAR Research Complex for North-Eastern Hill Region, Umiam (Meghalaya) has developed alternatives to shifting cultivation agroforestry systems using local resources and conservation-based measures in the region. The alternative land-use systems involving agriculture, horticulture, forestry and agroforestry have been designed with the support of local natural resources for almost identical hydrological behaviour as under the natural system. Agriculture with suitable conservation measures resulted in negligible runoff (3.5-5.8%) and soil loss (2.3-3.0 t/ha), which was far less than 40.9 t/ha of soil loss recorded from the traditional shifting cultivation areas (Table 3). The model land-use suggests utilizing slopes below 50 per cent towards lower foothills and valley lands for agricultural crops and pisciculture, middle slopes between 50-100 per cent for horticulture and top slopes over 100 per cent for forestry/silvipastoral establishments. Combining fine-root system of grasses and legumes, such as *Stylosanthes guyanensis*, *Panicum maximum*, *Setaria,* etc. and deep-root system of fodder trees (such as alder- *Alnus nepalensis*) in a silvipastoral system stabilizes the terrace risers and provides multiple outputs. Silvipastoral system comprising *Alnus nepalensis*, pineapple and forage crops like *Panicum maximum* or *Setaria*

Table 3. Erosion losses from different farming systems in the North-Eastern Hill region

Erosion losses	Shifting cultivation	Agri-horticulture	Agriculture with bench terracing
Runoff (mm)	114	57	95
Runoff (%)	7.0	3.5	5.8
Soil loss, t/ha	40.9	3.0	2.3
Organic carbon, kg /ha	698	40	34
Available P_2O_5, kg /ha	0.15	0.02	0.01
Available K_2O, kg /ha	7.1	0.50	0.05

sphacelata coupled with *Stylosanthes guyanensis* in 1:1 ratio has been found to be a sustainable agroforestry practice in soils having 30-60 per cent slope. Forage yield of 13.5 t/ha was obtained from the combination of Stylo and Setaria. In addition, 2.3 t/ha litter from *Alnus nepalensis* and 4000 fruits/ha from pineapple were obtained. This system also restored the fertility of these soils.

Sea Erosion and Mangrove Forest

Serious coastal erosion problems are being experienced in the western parts of the country due to intense monsoon activity. In the state of Karnataka, nearly 0.2 Mt of sand material is lost per year due to monsoons and the resultant sand drift. In the coastal areas, nearly 90 per cent of the coastline is facing the problem of erosion. The tsunami caused extensive damage in Andaman & Nicobar Islands, the states of Tamil Nadu, Andhra Pradesh, Kerala and the UT of Pondicherry on 26th December 2004. It had affected nearly 2260 km of the coastline besides the entire areas of Nicobar Islands. Around 14,8300 ha of cropped areas were damaged, besides causing a financial loss of more than Rs 53.22 billion (US$ 1.8 billion). However, there was no damage to six hamlets (with a population of about 6191) that were physically protected by the mangroves, while other hamlets located on or near to the beach were totally devastated. The mangrove forest reduced the impact of the tsunami by two ways: (i) velocity of the tsunami water greatly reduced after it entered into the mangroves due to the friction created by thick mangrove forest, and (ii) volume of water reaching a point was greatly reduced since tsunami water, after entering into the mangroves, was distributed to all the canals and creeks that were present all over the mangroves. This calls for renewed efforts for conservation of the existing mangroves as well as new plantations with suitable species. Shelterbelts with trees such as *Casuarina equisetifoia*, *Pandanus, Pongamia, Syzygium*, etc. can be employed to combat coastal erosion problems. A shelterbelt creates a mechanical obstacle to the free sweep of wind and reduces its velocity, which ultimately helps in checking the inflow of cyclones, storms, typhoons, etc.

Swamps cover considerable areas in the plains, particularly in the lowlands along the rivers and canals, seacoasts, etc. These areas can be brought under profitable cultivation by adopting suitable technology and tree species. Trees with high transpiration rate can be planted on mounds/ridges above stagnant water. Suitable species for swampy land afforestation include *Salix, Alnus, Populus, Eucalyptus, Lagerstroemia, Bambusa, Syzygium, Terminalia* etc. in different regions.

4.4. Employment Generation in Agroforestry

Dhyani *et al*. (2003) have highlighted the role of agroforestry products and environmental services to meet the subsistence needs of low income households and providing a platform for greater and sustained livelihood of the society. However, creation of employment in the industrial sector demands heavy financial and energy inputs. Agroforestry provides employment with relatively lower investment and that too for the unskilled rural sector. Products like pole/ bamboo and small timber for rural housing, timber for manufacturing, sawn wood and wood composites, e.g. plywood/ particle boards/block boards, bamboos for housing, construction, and transport sectors, bamboos for all types of paper and pulp products, medicinal plant extracts, etc. can absorb millions of unemployed people.

Bamboo has a tremendous potential to create jobs at the village as well as industrial level. It has the capacity to provide employment and income to a fairly large number of people, especially to women to allow flexible working hours nearby their houses. The involvement of women in the bamboo sector is often overlooked, despite the fact that their participation can be absorbed in the nursery raising, plantation, processing, and utilization marketing. Sales of 6 Mt of Indian bamboo sector generates employment for 48-60 million humandays for harvesting and 60-72 million humandays for loading, unloading, handling, etc. annually (INBAR, 2001). Tewari (1992) had estimated that one hectare of bamboo plantation with 500 clumps generates employment for 47.3 persons of unskilled labour and 3.9 persons of supervisors annually over a period of 30 years. INBAR (2001) has estimated 10-25 workdays for unskilled labour per hectare for soil working and maintenance of health and hygiene of clumps, including processing of thinning. It requires 8-10 workdays to harvest one tonne of bamboo, weaving of baskets and tray making provide work for 40 humandays per tonne amounting to 20 million humandays employment in the country as a whole. Craft sector can generate employment for 150 humandays per tonne (Rao, 1996). In this sector, two tonnes of bamboo are enough to employ one person throughout the year.

Promotion of agroforestry in farmer's fields through public-private partnership is one of the best examples of a win-win situation. The companies such as WIMCO, ITC, West Coast Paper Mills Ltd., Hindustan Paper Mills Ltd. and institutions, viz. IFFDC, National Tree Growers Cooperatives Federation (NTGCF- a subsidiary of NDDB) and others have opted to promote agroforestry on marginal lands by providing high quality seedlings, technical extension services and buy back guarantee at remunerative price to the farmers (Dhyani *et al*., 2005). IFFCO through its subsidiary Indian Farm Forestry Development Coopeative (IFFDC) leased wastelands of the revenue department (Govt. of MP); *Panchayats* (Rajasthan) and private lands (U.P.) in the three states. Through the cooperative movement, 26,060 ha wastelands have been planted with MPTS in 17 years and have generated employment for 5.10 million humandays @ 196/ha, of which 41 per cent were the women beneficiaries. In addition, 145 Primary Farm Forestry Cooperative Societies with a membership of 28,287, were formed and 820 self-help groups (SHGs) have been registered. It also circulated Rs18.44 million through revolving fund. This ensured availability of fodder and credit-promoted livestock rearing, conservation and amelioration of soil, water and biodiversity. Five societies from the movement bagged *Indira Priyadarshani Vrikshmitra* award. Considering only the direct benefits (harvested biomass, standing tree stock value from the plantations), the IRR at the end of 17 years was highest (17%) in UP, followed by 11.7 per cent in MP and 11.5 per cent in Rajasthan (Kareemulla, 2006). On including the environmental benefits, the IRR increased considerably by 2-5 per cent. Presently 30 million trees of poplar, producing 1,125-million m^3 industrial wood annually are standing in UP, Uttaranchal, Haryana, Punjab, Himachal Pradesh and Jammu and Kashmir in combination with agricultural crops in various spatial patterns. This is equivalent to 60,000 ha pure plantation of poplar (@ 500 trees/ha). It is estimated that around 25,000 ha equivalent plantation of poplar are now being established every year in association with a number of agricultural and horticultural crops under a rotation of 6-8 years. In order to cover this much of acreage, 10 million ETPs (entire transplants) are being raised, though the demand would be around 13 million per year during the current decade. This shall create much needed employment to 40 million people only in plantations activities (Chandra, 2001).

Dhyani and Sharda (2003) have worked out employment generation of 5.763 million human-days year through agroforestry interventions in the Indian Himalayas, which will have great bearing on the migration of landless and marginalized communities from rural to urban settlements. Silvipasture on an average of 10-year cycle for establishment and management could generate employment of 120 humandays/ha/ yr. Accordingly, if the technology is applied in 50 M ha area, it can provide employment to 20 million persons annually and other ancillary activities could provide jobs to another 5 million people (Pathak *et al*., 1995).

A decade back whenever there was a crop failure due to vagaries of monsoon, the people in the southern districts of Tamil Nadu (Ramanathapuram, Viruthunagar and Sivagangia districts) used to migrate to the paddy belts of Tanjor/Madurai district in search of livelihood. Now, such migrations are rare. The main reason is that *Prosopis juliflora* has started giving employment to the tune of 6.34 million mandays and 7.03 million woman days per annum in the southern Tamil Nadu.

Planning Commission (2001) has observed that planting of oilseed trees, especially *Jatropha curcas*, which can grow in the variable agroclimatic conditions, will provide employment for 0.21, 0.23, 0.25, 0.27 million humandays in the first five years, if planted in 2 million hectare area. The total potential of tree-borne oilseeds in India is estimated to be 5.253 Mt or 25 per cent of the total production of about 23 Mt. It would create employment for 0.44 million humandays @ 40 kg seed collection /day /person.

5. Environmental Services, Sequestration of Green House Gases and Carbon Trading

Forests not only have a significant impact on climate change, they also influence it. Forests act as important environmental sink that cushions the impact of ongoing climate change. Expanding the area of forest cover by establishing tree plantations, agroforestry, or analog forests enlarges the capacity of the terrestrial carbon sink. Trees are composed of approximately 50 per cent carbon, which they extract from the atmosphere during photosynthesis. The rate of carbon sequestration depends on the growth characteristics of the species, edaphic conditions, and the tree's wood density. It is highest during the younger stages of tree growth, between 20 and 50 years. FAO has estimated between 1.5 M ha and 2.0 M ha of tree plantations are established every year globally to meet industrial round wood needs and can be called upon to grow more trees and grow them faster for carbon sequestration objectives.

Some agroforestry systems hold considerable potential for storage in both the soil and the biomass. Long rotation systems that use trees for windbreaks, border plantings, and over story shade can sequester carbon for many decades. Tree planting in the urban areas offers the advantages of reducing greenhouse gas build-up by providing shade that reduces energy consumption for air conditioning during summer, and shelter that reduces heating system emissions during winter seasons.

Expanding the use of wood fuels as substitutes for fossil fuels is another important role that forests and agroforestry can play. Globally, wood fuels (firewood and charcoal) account for over 55 per cent of all wood harvested. Biomass fuels, unlike fossil fuels, are considered to be "carbon-neutral," the assumption being that the resulting emissions will be compensated for by the absorption of an equivalent amount of carbon in the regrowth of the fuel wood on sustainably managed woodlots. For example, if fuel wood plantations are managed sustainably and replanted after harvesting, there will be no net emissions because the carbon will be captured by photosynthesis of the new plantation. If energy consumption shifts from fossil fuels to fuel wood, there is a net gain in emission reductions. The total CO_2 emission reduction potential (as a consequence of not using the coal in thermal plants) of the biomass-based power plants on account of 16000MW potential/yr) is 35.3 M t/yr. Although many plants have been commissioned, they are yet to register with UNFCC. As of today, only 2 plants from AP (18 MW) have been registered with UNFCC for a saving of 39670 t of CO_2 /yr and shall certainly claim carbon credits for trade.

6. Complementarities between Agriculture and Forests

About less than 15 per cent of the land in the Himalayas is under agriculture, and forests occupy more than 60 per cent area. On an average, each hectare of agricultural fields receives about 25-30 kg of nutrients through run-off, litter and animal dung grazing in the forests. Cropland also fulfills their water requirements from run-off and springs during post-rainy season. There is tremendous potential of extending perennialities of flows and harvest water for irrigation through watershed management in the forest area. In turn, high biomass production in agriculture curtails biotic pressure on the forest. A complete symphony or harmony between the two land-uses is called upon for their mutual benefits.

The Govt. of India has promoted watershed development programme on a large scale from the VIIth Five-Year Plan with launching of NWDPRA. The Government accorded highest priority to the holistic and sustainable development of rainfed areas and wastelands (107 M ha) through watershed development programmes. The total area treated or reclaimed up to the year 2002 under various watershed schemes promulgated by the Ministries of Agriculture, Rural Development, and Environment & Forests was 25.21 M ha with a total investment of Rs 9267 crores. Agroforestry with the active involvement of watershed community plays an important role in the watershed development programmes to meet the challenges of deficits in food, fodder, firewood, timber, pulpwood, employment generation and ensures sustainability of production systems.

Irrigation consumes about 82 per cent of the total utilizable waters and the down stream effects of forested upper catchments in any watershed play a vital role in rural development. Forest cover moderates almost all hydrological events impinging upon the rural communities. Perenniality of stream, flows in the rivers, floods, siltation and droughts can be regulated by improving vegetation cover in the catchments. Groundwater recharging is becoming very important environmental service of trees for supporting precision agriculture and is one of the widely acknowledged benefits by the farmers from agroforestry-based watershed management strategies in different resource regions of the country. From the various watershed studies, it has clearly emerged that rise in watertable was spectacular in the low rainfall regions (Samra, 1997) (Table 4).

Table 4. Effect of watershed management strategies on groundwater recharge in different regions

Watershed	Surface storage capacity created, ha-m	Observed rise in groundwater table, m*
Bazar-Ganiyar (Haryana)	79.0	2.0
Behdala (HP)	18.0	1.0
Bunga (Haryana)	60.0	1.8
Chhajawa (Rajasthan)	20.0	2.0
Chinnatekur (AP)	5.6	0.8
GR Halli (Karnataka)	6.8	1.5
Joladarasi (Karnataka)	4.0	0.2
Siha (Haryana)	42.2	2.0

*Difference between pre-project and post-project watertable.

About 40 M ha area in the country is prone to flooding, of which, 7.56 M ha gets flooded annually, including 3.8 M ha of cropped land. Research results from a number of watersheds with inbuilt agroforestry have indicated that integrated development of watersheds reduces runoff or moderates flooding of downstream reaches and improves *in situ* moisture conservation for increased biomass production (Samra, 1997) (Table 5).

Integrated watershed management approach in Sukhna lake catchments in the Shiwalik foothills (Punjab) has demonstrated its effect on flood moderation and amelioration of environment due to reduced runoff from 29 per cent to 7 per cent and sediment yield from 140 t/ha to 18 t/ha within a period of 10 years of treatment (Table 6). The protection of open access forest areas by motivating rural communities could lead to a significant increase in plant cover and stocking rate. Effects of the tree-crop mixture on the water balance are cumulative from year to year, or between seasons in bimodal climates. If trees cause soil water depletion, then it becomes

Table 5. Impact of integrated watershed management practices on runoff (flood moderation) and soil loss

Watershed	Runoff as % of rainfall		Soil loss (t/ha)	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Fakot (Uttaranchal)	42.0	14.2	11.9	2.5
G.R. Halli (Karnataka)	14.0	1.3	3.5	1.0
Behdala (HP)	30.0	15.0	12.0	8.0
Joladarasi (Karnataka)	20.0	7.0	12.0	2.3
Una (HP)	30.0	20.0	12.0	10.0
Aganpur-Bhagwasi (Punjab)	48.5	24.0	12.6	2.8
Salaiyur (Tamil Nadu)	7.2	1.3	8.9	1.6
Kokiraguda (Orissa)	36.8	12.4	38.2	6.6
Bajni (MP)	27.3	12.8	14.1	6.9

Table 6. Effect of watershed measures and social protection in Sukhna Lake catchments on sediment and water yield

Particulars	Pre-treatment (Av. 1970-79)	Post-treatment (Av. 1979-89)
Annual monsoon rainfall (mm)	1003	953
Monsoon water yield (mm)	295	63 (4.7)*
Runoff (% of monsoon rain)	29	7
Monsoon sediment yield (t/ha)	140 (Av. 1958-78)	18 (7.8)

*Values within the brackets indicate times reduction.

successively more severe until an equilibrium is reached. On the other hand, if water is conserved, the water saved can be carried forward through dry periods in the lower soil horizons. This has been documented from a trial in the foothills in northern India with highly variable monsoon rainfall (Grewal *et al*., 1994). In the trial, fuelwood plantation of *Eucalyptus tereticornis* was compared with cropland under sesame and rapeseed. The plantation used 29 per cent more rainfall than the cropland but also retained more by reducing runoff, so that the soil water content at the end of the trial was the same.

Similarly, bioengineering measures carried out for rehabilitation of a mined watershed at Sahastradhara, besides being cost-effective led to reduction in runoff, channel slope, debris load but an increase in lean period flow, improvement in soil health and vegetation cover (Raizada and Samra, 2000). Conservation measures for preventing siltation of reservoirs in the prioritized watersheds for sustaining rural development process of the river valley catchments have indicated that treatment of only 25 per cent critically eroded area of catchments reduced sediment production rate by 50 per cent (Samra, 1997). In general, there was a general increase in productivity of crops as well as livestock production in various watershed studies. The positive effects indicating sustainability of the efforts were increase in cropping intensity (2-25%), productivity (5-20%) and afforestation (5-40%) (DARE Annual Report , 2004-05).

On the success of watershed programmes, the Government of India has set aside substantial budgetary provision for micro-watershed rehabilitation and development. Micro-watershed development is currently attracting over Rs 2100 crore /yr central government funding alone, with a further Rs 700-1400 crore/yr from states and from donor-supported projects. The Planning Commission has projected treatment of 88.5 M ha land under watershed development programme through an investment of Rs 72,750 crores in the next four Five-Year Plans (up to XIIIth Plan, 2017-2022). For peoples' participation and empowerment, recently, *Hariyali* (meaning 'greenary') — a watershed management project was launched by the Central government. The project is being executed by the *Gram Panchayats* (village management bodies) with peoples' participation; the technical supervision is provided by the block (sub-district) administration.

A meta analysis of 311 pilot watersheds by an independent international consortia across India has revealed a B: C ratio of 2.41, I.R.R. of 22 per cent and employment generation of 181 persons/ha/yr. Higher benefits were realized by the low-income group and engagement of the community. The significant finding of the analysis was the role played by forestry and agroforestry interventions for resource conservation and employment generation in the watershed development programmes. Among the various options, crop-based farming/agroforestry system in 700-1100 mm rainfall, livestock-based silvipasture systems in < 700 mm rainfall and fish-based production system in >1100 mm agro-ecologies provided high dividends.

7. Conclusions

The review has clearly indicated that forests have a number of linkages to food security. Firstly, they have direct impact on foods that can be gathered from the forests, forage for animal grazing in the forests or stall fed, forestry-related activities which generate income and employment, and through eco-tourism activities. Secondly, forests provide many environmental services indirectly, such as protection of upland watersheds, protection of agriculture from natural disasters, acting as windbreaks, provision of water for irrigation and drinking, etc. But more so through their effects on environmental issues such as global warming, and the effects this may have on agriculture. Some of the impacts of climate change on food supplies are expected to be direct — with food production influenced by the climate change and aberrant weather conditions. Thus, there are clearly links and synergies between the agricultural production and sustainable forest management. If the sustainability of the agriculture and forests can be assured, food security and employment generation would be improved.

References

Chandra, J.P., (2001) Scope of poplar cultivation. *Indian Forester*, **127**(1): 51-60.

Charan Singh, S.K. Dhyani and A. Raizada, (2003) Integrating *Paulownia* in agroforestry systems – Prospects and potential in India. *Indian Journal of Agroforestry*, **3**(2): 100-106.

D.A.R.E. Report, (2004-05) Department of Agricultural Research and Education, Indian Council of Agricultural Research, New Delhi. 62 p.

Dagar, J.C., H.B. Sharma and Y.K. Shukla. (2001) Raised and sunken bed technique for agroforestry on alkali soils of northwest India. *Land Degradation and Development*, **12**: 107-118.

Dhyani, S.K. and V.N. Sharda, (2003) Agroforestry systems as rural development options for the Indian Himalayas. *IUFRO International Conference on World Perspective on Short Rotation Forestry*, Solan, HP held during 07-13 Sep, 2003. 194 p.

Dhyani, S.K., V.N. Sharda and Sharma, A.R. (2003) Agroforestry for water resources conservation: Issues, challenges and strategies. In: *Agroforestry: Potentials and Opportunities*. Eds: P.S. Pathak and Ram Newaj. Agrobios (India) & ISAF, Jhansi. pp.9-30.

Dhyani, S.K., V.N. Sharda and Sharma, A.R, (2005) Agroforestry for sustainable management of soil, water and environmental quality: Looking back to think ahead. *Range Management and Agroforestry*, **26** (1): 71-83.

F.S.I., (2003). *State of Forest Report – 2003*. Forest Survey of India (Ministry of Environment and Forests), Dehradun.

Grewal, S.S., M.L Juneja, K. Singh and S. Singh, (1994) A comparison of two agroforestry systems for soil, water and nutrient conservation on degraded land. *Soil Technolo*gy, **7** (2): 145-153.

Gupta, J.P. and Y.S. Ramakrishna, (1988) Role of shelter belts in checking wind erosion and increasing crop production in sandy wastelands of western Rajasthan. In: *Wastelands Development and Their Utilization*. Scientific Publishers, Jodhpur, India. pp. 271-280.

Gupta, J.P., A. Kar and A.S. Faroda, (1997) Desertification in India: problems and possible solutions. *Yojna,* **41**: 55-59.

Harsh, L.N., J.C. Tiwari, U. Burman and S.K. Sharma, (1992) Agroforestry for arid region. *Indian Farming*, **42**(3): 32-37.

Hira, G.S., P.K. Gupta, S.K. Shakya and H.S. Thind, (1999) *A New Technology for Planting Eucalyptus in Waterlogged Sodic Soils*. Punjab Agricultural University, Ludhiana.

INBAR, (2001) *INBAR News Magazine,* **8** (1): 6-7;10-11.

Jambulingam, R. and E.C.M. Fernandes, (1986) Multipurpose trees and shrubs of farmland in Tamil Nadu India. *Agroforestry Systems*, **4**:17-32.

Kareemulla, K., J.S. Samra, R.H. Rizvi and Munna Ram, (2006) Wasteland afforestation in northern India by cooperatives: A socio-economic evaluation In: *Proceedings of 26th Conference of IAAE*, Gold Coast, Queensland, Australia. 12-16 August. 168 p.

Kesavan, P.C. and M.S. Swaminathan, (2006) From green revolution to evergreen revolution: Pathways and terminologies. *Current Science,* **91**(2): 145-146.

Kumar, G.V.P. and A. Sharma, (1998) Phenotypic alterations in goats fed subabul (*Leucaena leucocephala*). *Indian Journal of Animal Sciences*, **68**(4): 402-404.

Kumar, R., R.D. Singh and K.D. Sharma, (2005) Water resources of India. *Current Science*, **89**(5): 794-811.

NBSSLUP (2004) *Soil Resource Management Reports*. National Bureau of Soil Surveys and Land Use Planning, Nagpur.

Pathak, P.S., S.K. Gupta and P. Singh, (1995) *IGFRI Approaches Rehabilitation of Degraded Land, Jhansi.* IGFRI, pp. 1-23.

Pathak, P.S., H.M. Pateria and K.R. Solanki, (2000) *Agroforestry Systems in India: A Diagnosis and Design Approach*. National Research Centre for Agroforestry. ICAR. 166 p.

Planning Commission, (2001) *Report of the Task Force on Greening India for Livelihood Security and Development*. Planning Commission, Govt. of India, New Delhi. 231 p..

Puri, S., S. Singh, and B. Bhushan, (1994) Evaluation of fuel wood quality of indigenous and exotic tree species of India's semiarid region. *Agroforestry Systems*, **26**: 123-130.

Rai, P., (1999a) Silvipastoral systems-growing green and increasing the production of wastelands. *Wasteland News,* **XIV** (3): 48-50.

Rai, P., (1999b) Comparative growth and biomass production of MPTS at 8 years of establishment under natural grassland in medium black soils in semi-arid conditions at Jhansi, *Range Management and Agroforestry*, **20**: 94-97.

Raizada, A. and J.S. Samra, (2000) Rehabilitation of an abandoned limestone mine in the lowere Western Himalaya: Impact assessment on vegetation development and floristic diversity. *Indian Forester*, **126** (8): 842-855.

Raizada, A., S.K. Dhyani and V.N. Sharda, (2004) Potential and prospects of vegetation recovery in degraded lands in India- A review. *Indian Forester,* **130** (4): 441-455.

Rao, A.G., (1996) Design inputs into craft areas: Implications of 23 rural development and employment generation. *Proceedings of Vth International Bamboo Workshop*, Bali (Eds:Ganpati *et al.*), pp. 285-295.

Ravindranathan, N.H., H.N. Chanakya and J.M. Kerr, (1997) An ecosystem approach for analysis of biomass of energy, pp.561-587. In: *Natural Resource Economics Theory and Application in India*. Eds: J.M. Ker, D.K. Marothia., K. Singh., C. Ramaswamy and W.R. Bentley). Oxford & IBH, New Delhi.

Samra, J.S., (1997) *Status of Research on Watershed Management*. CSWCRTI, Dehradun.

Samra, J.S., A. Raizada, M.C. Prajapati and L.S. Bhushan, (1999a) Floristic diversity and community composition in Yamuna ravines-Impact assessmet of long-term protection. CSWCRTI, Dehradun. *Tech. Bull. No. 41/A-2*.

Samra, J.S., M.K. Vishwantham and A.R. Sharma, (1999b) Biomass production of trees and grasses in a silvipasture systems on marginal lands of Doon Valley of north-west India. 2. Performance of grass species. *Agroforestry Systems*, **46**:197-212.

Sastry, G., H.N. Mathur and K.G. Tejwani, (1981) Landslide control in North-Western outer Himalayas, *Bulletin No. R8/D6,* CSWCRTI, Dehra Dun.

Sharma, S.K. and B.B. Vashistha, (1995) Evaluation of jujuba grass in horti-pastoral systems under arid environment. *Annals of Arid Zone*, **24**: 303-309.

Singh, Gurbachan (1999) Management of alkaline and saline soils through agroforestry. *In: Sustainable Rehabilitation of Degraded Lands through Agroforestry,* Eds: K.R. Solanki, A.K. Bisaria and A.K. Handa. NRC for Agroforestry, Jhansi. pp.52-61.

Tewari, D.N., (1992). *A Monograph on Bamboo*. International Book Distributors, Dehradun.

Toky, O.P. and P.S. Ramakrishnan, (1983a) Secondary succession following slash and burn agriculture in north-eastern India. I- Biomass, litterfall and productivity. *Journal of Ecology*, **71**:735-745.

Toky, O.P. and P.S. Ramakrishnan, (1983b) Secondary succession following slash and burn agriculture in north-eastern India. II- Nutrient cycling. *Journal of Ecology*, **71**:747-757.

Vishwanatham, M.K., J. S. Samra and A. R. Sharma, (1999) Biomass production of trees and grasses in a silvipasture system on marginal lands of Doon Valley of north-west India. 1. Performance of tree species. *Agroforestry Systems*, **46**:181-196.