Agroforestry as a Sustainable Land Use System

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Introduction

Agroforestry though practiced for long, has become a new subject of scientific activity in recent years. In tropical countries like India, agroforestry has special significance because of ever growing pressure of fast expanding human and livestock population. This has resulted in excessive deforestation, land degradation, soil erosion, runoff, drought, waterlogging, shortage of fuel, fodder, timber and other tree products, environmental deterioration and numerous associated problems. Agroforestry as a part of land management strategy is recognized as a sustainable land use system which not only enhances production and improves environmental stability but also helps meet the varied demands.

Several field experiments have been conducted, the results of which show the benefits of agroforestry in reducing soil loss, upgrading soil fertility, increasing crop productivity, avoiding risks arising from crop failure during drought and other calamities, and raising economic returns. Since for a sound system of agroforestry a positive compatibility between the woody perennials and companion annual crops suited to the specific site conditions is essential, synergistic or antagonistic interactions occurring between different components have been evaluated. Research work has also brought out the prospects of utilizing the degraded lands affected by soil salinity/alkalinity, erosion and other hazards for growing trees and grasses successfully. Certain major areas of further investigation have been indicated.

Indiscriminate continued deforestation, excessive grazing, unscientific cultivation, intensification of agriculture, unplanned developmental activities, defective use of irrigation water, and increased heavy pressure on the finite natural resources are some of the important factors responsible for causing accelerated soil erosion, runoff, waterlogging, soil salinization and alkalization, floods, droughts, depletion of soil fertility, decline in crop productivity and deterioration of environmental ecology. This has resulted in degradation of extensive areas in many countries. Moreover, owing to weather aberrations especially in rainfed regions, agricultural production is highly unstable and prone to great risks. A wide gap has been created between the demand and availability of food, fodder, fuel, fibre, fertilizer and timber for the fast expanding human and livestock population, particularly in the developing countries like India. Thus, adequate production of various materials and environmental protection are the two most serious challenges these days the world over.

The best alternative to combat the prevalent as well as the likely dismal situation is to adopt agroforestry production system which integrates agriculture with forestry. This land use system will not only help maintain environmental ecology but will also enable agriculture a sustainable enterprise. Agroforestry, which is a new technical terminology for the old practice, has been in vogue in most tropical countries of Africa, Asia and Latin America. In India, the agroforestry system has been as old as the very culture wherein socio-religious traditions of the people have developed an intimate attachment with raising and worshipping trees.

Agroforestry, an Old Practice

Several kinds of agroforestry systems are adopted in different agroclimatic conditions and are given names depending upon the nature and arrangement of the components. The more common ones are: agri-silviculture, silvi-pasture, agri-horticulture, horti-silviculture, agri-horti-silviculture, agri-silvi-pasture and home gardens.

In India, shifting cultivation and taungya system can be considered as the oldest form of agroforestry. The combination of *Alnus nepalensis* and *Amomam sabulatum* in humid temperate condition of Sikkim, scattered trees of *Prosopis cineraria* within the cultivated fields and live fences of *Acacia* and *Prosopis* genera in the arid areas of western India, growing of trees of *Acacia nilotica, Azadirachta indica, Dalbergia sissoo* etc. along the boundary or within the field in the alluvial plains, and shade trees in tea and coffee gardens are excellent examples of agroforestry. Home gardens having multi-tier crop combinations are very common in the humid low lands of Kerala state.

Eucalyptus trees are grown extensively either in rows within the field or along the boundary. An example of successful agroforestry is the growing of poplar with agricultural crops in the states of Uttar Pradesh, Haryana and Punjab in northern India. *Leucaena leucocephala* which is a nitrogen fixing multipurpose tree species (MPTS) has been tried at several locations. *Zizyphus mauritiana* is identified as a promising MPTS for the arid areas of Rajasthan and poor degraded lands of Bundelkhand region. *Hardwickia binata* has shown a good promise for the infertile soils of semi-arid tracts.

In Africa, *Acacia albida* has been found to increase the yield of millets in the semi-arid tropics of Sudan. Cultivation of *Leucaena leucocephala* and *Gliricidia sepium* is reported to enrich the soil through addition of organic matter in south-west Nigeria. In China, *Paulownia* intercropped with agricultural crops has been adopted successfully on an extensive scale.

Choice of Trees for Agroforestry

Many bio-physical and socio-economic factors govern the choice of agroforestry systems, but the selected combination should be economically viable, ecologically sustainable and socially acceptable, and should aim at higher productivity, stability and equitability. the selected tree species should have:

- adaptability to adverse soil and climatic conditions;
- rapid growth rate and deep root system;
- desirable phenological characteristics;
- tolerance to lopping, pruning and other operations;
- ability to improve soil fertility and environment;
- compatibility with companion crops;
- multipurpose uses.

In general, the use of nitrogen fixing trees in agroforestry has been more common because of their multipurpose uses, soil fertility improvement and good fodder source. *Gliricidia sepium, Leucaena leucocephala, Acacia albida, Acacia senegal, Prosopis cineraria* and *Sesbania glandiflora* are some examples.

Research on Agroforestry

Scientific activity on agroforestry was promoted mainly after the establishment of the International Council for Research in Agroforestry (ICRAF) at Amsterdam, Netherlands in 1977 and shifted to Nairobi, Kenya in 1978. Thereafter, US AID supported F/FRED (Forestry and Fuelwood Research and Development) Project has created a research network in several countries of Asia to address to the needs of small farmers, wherein programmes are directed to incorporate multipurpose tree species, particularly fast growing nitrogen fixing tree species along with the agricultural crops to evolve a sustainable farming system.

Realizing the need of scientific agroforestry in India, a Coordinated Research Project (AICRP) on Agroforestry under the Indian Council of Agricultural Research was started at 20 locations in 1983 and was extended in the Seventh Five Year Plan to 31 locations representing different agroclimatic regions. In addition, one National Research Centre (NRC) was set up at Jhansi to serve as a central leading unit. The current research programmes are focussed chiefly on:

a) Diagnostic survey and design;
b) Evaluation of promising species of tree species, and
c) Management practices for different agroforestry systems.

Some of the important research results are highlighted below:

Compatibility

The competitive interactions between the trees and annual crops largely determine compatibility of the integrated tree-crop production system. In a field experiment on alley cropping for three years with *Leucaena leucocephala* at Hyderabad, SINGH et al. (1987) observed higher reduction in the yields of pigeonpea and castor than in sorghum and pearlmillet (Table 1). Alley cropping

Table 1
Reduction in yield of annual crops in alley cropping with *Leucaena* at Hyderabad, India

Crop	1984	1985	1986
Sorghum	49	68	11
Pearlmillet	53	51	+ 14
Pigeonpea	61	65	-
Castor	56	77	47

trials at the Forest Research Station, Methupalayam (Tamil Nadu) revealed least detrimental effect of 20-month old *Casuarina equisetifolia* on the associated crops (VINAYA RAI & SURESH, 1980). The highest compatibility was noticed between *Casuarina* and BN - 2 grass (Table 2).

Compatibility between *Prosopis cineraria* and pearlmillet was reported from the arid areas of Rajasthan (MANN & SAXENA, 1980).

Table 2
Yield (t/ha) of fodder crops alley cropped into 20-month old woody perennials

Alley crop	*Eucalyptus tereticornis*	*Leucaena leucocephala*	*Casuarina equisetifolia*	Mono crop
BN-2 grass	14.0	17.4	22.0	18.8
NB-21 grass	9.8	9.1	20.1	20.5
Maize	2.0	1.3	2.5	10.5
Sorghum	2.7	1.0	2.9	9.0
Cowpea	4.8	1.6	6.4	20.8

Soil improvement

The growth of certain trees brings about improvement in soil properties through their root activity, addition of organic matter, nutrient cycling and nitrogen fixation. SHANKARNARAYAN (1984) reported greater increase in the amount of organic matter, nitrogen and phosphorus under *Prosopis cineraria* than under *Prosopis juliflora* of the same age (Table 3).

Table 3

Changes in 0-15 cm soil under *Prosopis cineraria*, *P juliflora* and bare field

Tree species	Organic matter, %	Nitrogen %	P_2O_5 %
P. cineraria	0.57	0.042	0.425
P. juliflora	0.38	0.033	0.287
Bare field	0.37	0.020	0.287

PATHAK et al. (1987) reported that a 2-year old plantation of *Leucaena*, which added 5.6 t/ha of organic matter, caused an increase in water retaining ability and cation exchange capacity, and a decrease in soil pH beside an improvement in the yield of successive grain/forage crops. Much less soil erosion was observed under agroforestry comprising cassava intercropped with grass/trees than in the cultivated fallow plot on the sloping hills in the tropical region of Kerala (GOPINATHAN & SREEDHARAN, 1987). On a marginal land in north-western Himalayan region at Dehradun, growing of trees (Eucalyptus, *Leucaena*) and grass (*Chrysopogon fulvus*) along with cereal crops (wheat, maize) reduced the runoff and soil loss substantially (NARAIN et al., 1988). The reduction was more under Eucalyptus than under *Leucaena* (Table 4).

Table 4

Soil loss and runoff under agroforestry system at Dehradun

Land use	Soil loss (t/ha)	Runoff (% of rainfall)
Cultivated fallow	46.70	26.4
Maize	17.70	18.3
Maize + *Leucaena*	5.00	8.9
Maize + *Eucalyptus*	0.91	3.6
Chrysopogan fulvus	0.33	1.6
C. fulvus + *Leucaena*	0.13	0.6
C. fulvus + *Eucalyptus*	0.02	0.1
Leucaena	0.04	0.4
Eucalyptus	0.01	0.1

Rehabilitation of degraded lands

Land degradation in varying intensities has affected vast areas in the world, especially in the tropical countries. In India alone, an estimated area of 175 million hectares (about half of the total land area) is inflicted by the maladies of soil and water erosion, waterlogging, soil salinity/alkalinity, and other degradation processes. Agroforestry farming system has immense prospects in many of these degraded and marginal lands.

According to YADAV and SINGH (1970) certain forest species show tolerance to soil salinity/sodicity, and can be grown on such problematic soils with proper management and ameliorative measures. YADAV et al. (1975) found that the treatment of the highly deteriorated sodic soil with gypsum and FYM along with little fertilizer application in the planting pit, resulted in satisfactory establishment and growth of *Prosopis juliflora, Acacia nilotica* and Eucalyptus hybrid (Table 5).

SINGH et al. (1989) noticed appreciable decrease in pH and EC values and increase in the amount of organic matter and available nitrogen in a sodic soil under *P. juliflora-Leptochloa fusca* agroforestry system (Table 6). This system

Table 5

Height increment (cm) of tree species on a highly degraded sodic soil five years after planting

Soil treatment in planting pit	*Acacia nilotica*	*Albizzia lebbek*	*Eucalyptus hybrid*	*Prosopis juliflora*	*Terminalia arjuna*
Original soil	40	15	33	46	25
FYM	76	46	62	81	68
Gypsum	88	62	91	92	85
Gypsum + FYM	102	71	120	102	95
Soil replacement	107	87	119	100	98

Table 6

Effect of *Prosopis juliflora - Leptochloa fusca* agroforestry system on properties of a sodic soil (0 - 15 cm depth)

Soil property	Before planting	22 months after planting
pH_2	10.15	9.35
EC_2, dS/m	2.05	0.55
Organic C, %	0.25	0.40
Available N, kg/ha	98.50	131.50

being highly tolerant to alkali conditions, would help alleviate the fuel and fodder shortage on the one hand and facilitate restoration of sodic soils on the other, in areas where cultivation of agricultural crops is not feasible or economical.

Insurance against risk

Cultivation of mono agricultural crops in the arid areas is highly prone to frequent risks posed by droughts. Under such uncertainty of satisfactory crop production, agroforestry confers multiple benefits of providing fodder, fuel, fruits, fibre etc. and ensures considerable security against the risks. In other areas also, the risk due to the incidence of insect pests and diseases associated with monocropping is mitigated in a mixed farming system of agroforestry.

In the desert regions agroforestry assumes a special significance because of the fact that the livestock rearing constitutes an important subsidiary occupation. In 1985 with 30 per cent of normal rainfall at Rajkot in Gujarat state, 5.6 tonnes per ha of green fodder from *Leucaena leucocephala* hedgerows in addition to 0.2-1.3 t/ha of stover from groundnut, mungbean and urdbean was ob-

Table 7

Risk avoidance in fodder production (t/ha) from alley cropping in a poor rainfall year at Rajkot, Gujarat

Crop	Sole crop (Stover)	Alley cropping	
		Crop (Stover)	Green fodder *(Leucaena)*
Groundnut	1.7	1.3	5.2
Mungbean	0.7	0.3	5.6
Urdbean	0.5	0.2	6.0

Table 8

Economics of *Acacia tortilis* and *Cenchrus ciliaris* agroforestry system after 7 years of establishment

Treatment	Fuel Yield, t/ha	Grass Yield, t/ha	Economic returns, Rs		
			Fuelwood	Grass	Total
A. tortilis 10 x 5 m	6.0	-	3,000	-	3,000
A. tortilis + *C. ciliaris*	5.0	5.6	2,500	1,395	3,895
C. ciliaris	-	4.6	-	1,150	1,150

tained under alley cropping as against only 0.5 to 1.7 t/ha of green fodder from the sole crops of these annuals (Table 7). At the Central Arid Zone Research Institute, Jodhpur (Rajasthan) the combination of *Acacia tortilis* and *Cenchrus ciliaris* grass gave better returns in comparison to the sole crops of trees and grass (Table 8).

Benefits of Agroforestry Land Use System

Trees are not only a source of fuel, fodder, fruits, fertilizer, fibre, timber, industrial wood, medicines, oil and other products, but also provide services of longer value such as protection of land from soil erosion and runoff, moderation of microclimate, environmental stability and maintenance of biosphere. The more important benefits resulting from appropriate agroforestry are summarized as below:

- Prevention of degradation processes and rehabilitation of degraded lands;
- Conservation of soil and water;
- Improvement of soil fertility and total productivity;
- Diversion of cowdung as a source of manure;
- Moderation of microclimate and environmental stability;
- Satisfaction of multiple demands;
- Income generation and employment opportunities;
- Minimization of risks arising from monocropping.

Constraints to Adoption of Agroforestry

Despite numerous direct and indirect benefits accruing from agroforestry, there are certain constraints limiting its large scale adoption. Some of them are:

- Small land holdings and defective land ownership;
- Long gestation period to obtain sustained income;
- Complex management of aggregate farming;
- Lack of time series analysis of economics;
- Limited knowledge about choice of tree species;
- Difficulty in availability of tree seedlings;
- Some reduction in yields of annual crops;
- Deficient processing and marketing facilities.

Conclusions

Agroforestry is a promising sustainable land use system and offers a practical solution to the current and future challenging problems of land degradation and environmental deterioration caused by the unprecedented population pressure and over-exploitation of the natural resources. Systematic concerted efforts are, however, essential to develop compatible systems matching with the specific site situations and socio-economic conditions, and to evolve most appropriate production technologies for such integrated farming systems. This calls for intensive research to evaluate the competitive interactions between the woody perennials and annual crops, to examine recycling of nutrients and effects on soil fertility, to work out comparative cost:benefit relationship, to screen the promising tree species and breed varieties with desirable traits.

Suitable models are required to be developed to predict the productivity of agroforestry systems under a given set of site conditions, input supply and management practices. Since research on agroforestry has been initiated at many places, establishment of an effective database management and information will be highly rewarding. In order to promote agroforestry on a large scale, efficient methodologies of extension education and technology transfer are needed because of the complex management of diverse components, longer period of farming system and numerous direct as well as indirect benefits accruing from it.

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