

Role of Agroforestry in Conservation of Natural Resources in Rainfed Areas

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Abstract

Agroforestry (AF) systems play a great role in conservation of natural resources, especially soil. The soils are protected from wind and water induced erosion. The adverse effects temperature and wind on soil fertility, soil flora and fauna are effects are ameliorated by AF systems. AF systems increase nutrients inputs through nitrogen fixing trees and nutrient uptake from deep soil horizons. They reduce nutrient leaching losses through tree root and micorrhizal systems. AF systems recycle nutrients through decomposition of litter, prunings and root residues. Most of the studies have shown that tree residues in AF systems have N, K and Ca in sufficient quantity to meet the requirements of associated crop with clear exception of P. However, the return of the prunings/ retention of leaf litter in the site is must. The returns to soil are much higher in fertile humid areas than the poor semi-arid zones.

Introduction

“Agroforestry (AF) is a collective name for land-use systems in which woody perennials (trees, shrubs, palms, bamboos etc.) are deliberately grown in association with herbaceous plants (crops, pastures) or livestock, in a spatial arrangement, a rotation, or both; there are usually both ecological and economic interactions between trees and other components of the system” (Lundgren, 1982). This definition implies that:

- agroforestry normally involves two or more species of plants (or plants and animals), at least one of which is woody perennial;
- an agroforestry system always has two or more outputs;
- the cycle of agroforestry system is always more than one year; and
- even the simplest agroforestry system is more complex, ecologically (structurally and functionally) and economically, than a monocropping system.

The practice of trees and arable crops together on the same piece of land is an age-old practice with the Indian dry land farmers. Agroforestry results in multiple products, increases income, reduces runoff and soil loss, utilizes off-season rainfall and radiation and gives stability to dry land agriculture. Further it makes the future generation farmers to inherit not only the land of their predecessors, but also the wealth of standing biomass of trees. Fifty seven per cent of the geographical area of the country suffers from one or the other kind of soil degradation (Table 1)

Table 1. Extent of soil degradation (human induced) in India.

Type	Area (m ha)	Geographical Area (%)
Water erosion	148.9	45.3
Wind erosion	13.5	13.5
Chemical	13.8	13.8
Physical	11.6	11.6
Total	187.7	57.1

Source: Sehgal and Abrol (1994)

AF has great role in conservation of natural resources especially soil by

1. Protecting it from wind and water erosion;
2. Conservation of soil nutrients, flora and fauna from winds, high temperatures.
3. Build up of soil nutrients and carbon

Classification of agro forestry systems (Nair, 1990).

Predominantly agrosylvicultural (trees with crops)

Rotational

- Shifting cultivation
- Managed tree fallows, including relay intercropping
- Taungya

Spatial Mixed

- Trees on cropland
- Perennial-crop combinations
- Multistrata systems (agroforests), including forest gardens, home gardens

Spatial zoned

- Boundary planting
- Trees on erosion-control structures
- Windbreaks and shelterbelts (also sylvopastoral)
- Hedgerow intercropping (alley cropping), including tree row intercropping
- Contour hedgerows
- Biomass transfer (cut- and- carry-mulching)

Predominantly Sylvopastoral (trees with pastures and livestock)

Spatial mixed

Trees on pastures (parkland systems)
Perennial crops with pastures (including orchards)

Spatial zoned

Hedges and live fences
Fodder banks

Trees predominant (see also taungya)

Farm and village forestry
Reclamation agroforestry

Special components present

Entomoforestry (trees with insects)
Aquaforestry (trees with insects)

How we know that trees improve soils

The soil that develops under natural forest and woodlot is fertile. It is well structured, has good water-holding capacity and has a store of nutrients bound up in the organic matter. Farmers know they will get a good crop by planting on cleared natural forest.

The cycles of carbon and nutrients under natural forest ecosystems are relatively closed, with much recycling and low inputs and outputs
The practice of shifting cultivation demonstrated the power of trees to restore fertility lost during cropping
Experience of reclamation forestry has demonstrated the power of trees to build up soil fertility on degraded lands.

Processes by which Trees Improve Soils

Trees improve soils in two ways, viz., maintenance or increase of soil organic matter and reduce losses from the soil

Processes increase additions to the soil

Maintenance or increase of soil organic matter: Build-up of organic matter in forest fallows through reclamation forestry has been clearly demonstrated.

Nitrogen Fixation: NTFs can make substantial contributions to nitrogen inputs. The major group consists of leguminous tree species nodulating with *Rhizobium*, *Bradyrhizobium*; these include many of the most widely used MPTs such as *Acacia*,

Erythrina, *Gliricidia*, *Leucaena* and *Sesbania* species. In addition, a limited number of non-leguminous genera, *Alnus*, and *Casuarina* species nodulate with *Frankia*.

Nutrient uptake: Nutrient uptake from weathering rock (soil BC and C horizons) is difficult to demonstrate; it is highly probable, however, that it makes a substantial contribution to nutrient budgets. There is evidence for uptake from deep soil horizons, beyond the reach of crop roots.

Atmospheric inputs: Atmospheric deposition comprises of nutrients dissolved in rainfall (wet deposition) and those carried in dust (dry deposition). Trees do not increase rainfall but they reduce wind speed and thus favor deposition of dust.

Increased water infiltration: Through a combination of higher soil permeability, caused by the effect of organic matter on bulk density and porosity, and infiltration along root channels, trees increase the infiltration capacity of soil. This can substantially reduce runoff and increase water inputs to the soil.

Processes, which reduce losses from the soil

Protection from erosion

Nutrient retrieval and recycling through reducing leaching

Reduction in the rate of organic –matter decomposition

Reduction of water loss from evapotranspiration

Increased water storage capacity

Processes, which affect soil physical conditions

Maintenance or improvement of soil physical properties

Penetration of compact or indurated layers by roots

Modification of extremes of soil temperature

Processes which affect soil chemical condition

Reduction of acidity

Reduction of salinity and sodicity

Reduction of soil toxicities caused by pollution

Soil biological processes and effects

Improvement in the activity of soil fauna

Improvement of nitrogen mineralization through the effects of shade

Root nodulation

Exudation of growth promoting substances by the rhizosphere of trees

Adverse of Effects of Trees on Soils

Allelopathy

Acidification

Removal of organic matter and nutrients in the tree harvest

Competition for Resources at the Tree-Crop Interface

Interactions between trees and non-tree components in AF system can be complementary, neutral or competitive. In complimentary interactions, the total production from a system is greater than that obtained separately. In neutral interactions, there is no difference and in competitive interactions, the AF system less than the two plants grown separately. The complimentary interactions comprise the effects of trees upon soils, including soil water, together with favourable microclimate influences: shelter, protection from frost and for few crops shade. The main competitive interactions are:

- displacement of crops by stems of trees;
- competition for light: shading of crops by the crowns of trees or branches of shrubs;
- competition for water;
- competition for nutrients;
- allelopathy

What Makes a Good Soil –improving Tree?

- A high rate of production of leafy biomass.
- A dense network of fine roots, with a capacity for abundant mycorrhizal association
- The existence of deep roots
- A high rate of nitrogen fixation
- A high and balanced nutrient content in the foliage: litter of high quality (high in nitrogen, low in lignin and polyphenols).
- An appreciable nutrient content in the root system.
- Either rapid litter decay, where nutrient release is desired, or a moderate rate of litter decay, where maintenance of a soil cover is required
- Absence of toxic substances in the litter or root residues.
- For soil reclamation, a capacity to grow on poor soils.
- Absence of severe competitive effects with crops, particularly for water.
- Low invasiveness
- Productive functions, or service functions other than soil improvement.

Agroforestry and Soil Organic matter

Agroforestry systems can maintain soil organic matter and biological activity at levels satisfactory for soil fertility. In AF systems opportunities for soil organic matter management through the following means:

- increasing the supply of inputs as plant residues;
- reducing the proportion of plant material (tree and crop) removed from the system;
- reducing the rate of humus decomposition, through shading and mulching;
- reducing the loss of humus in eroded soils.

The supply of plant residues to the soil in agroforestry systems is determined by the biomass production (per unit area) of each plant component, tree and herbaceous system:

- The area occupied by each plant;
- Which part of each plant;
- Leaf, fruit, wood and root are added to the soil.

Agroforestry system can maintain more favorable soil physical properties than agriculture through organic matter maintenance and the effects of tree roots. Trees in agroforestry system can assist in maintenance of organic matter by

- increasing supply of biomass, as litter, prunings and root residues;
- reducing the rate of decomposition of soil organic matter;
- reducing the loss of organic matter through erosion.

Nutrient cycling and nutrient efficiency:

Nitrogen fixation:

Nitrogen fixing trees can substantially increase nitrogen inputs to agroforestry systems. It is well established that *Leucaena* can fix 100-500 kg N per ha per year or more in pure stands and 75-100 kg when grown in hedgerow intercropping systems. *Sesbania rostrata* grown in association with Swamp rice systems can also attain 500 kg. N per ha. per year. *F. albida* and *Acacia senegal* are estimated to fix 20-60 kg. N per year. Other fast growing species including *S. sesban*, *G. sepium*, *A. lebbek*, *A. mangium* and non-legume *casuarina* fix amounts of the order of 50-100kg.N per ha per year.

- Nitrogen fixing trees comprising of many legumes and few non-legumes can increase nitrogen inputs to agroforestry systems by amounts similar to those by herbaceous legumes.
- Selection of plant genotypes, and in some cases rhizobial inoculation, can substantially improve the rates of nitrogen fixation.
- Nitrogen transfer from nitrogen fixing trees takes place both above and below ground, within one season through decomposition of litter, prunings and root residues, and over longer periods via soil organic matter.
- Nitrogen fixing trees are neither better nor worse than herbaceous legumes at augmenting nitrogen inputs to plant – soil systems.
- Mulches of non-nitrogen fixing trees can also be suppliers of nitrogen.

Increasing nutrient uptake:

Trees can increase nutrient inputs to agroforestry systems by retrieval from lower soil horizons and weathering rock.

Increasing nutrient use efficiency:

Increasing the nutrient use efficiency through agroforestry can be achieved by;

- Increasing the cycling of nutrients from tree litter and prunings via the soil into the crops;
- Reducing losses by leeching;
- Reducing the losses by erosion.

The nutrient transfer from tree residues to crops is through litter and prunings. Perennial-crop combinations can provide 6-20t per ha per year of leaves and small branches and hedgerows typically provide 5-12 t. The annual hedgerow biomass can be as low as 2 t in SAT and rise to 20t in humid areas. Planted fallows can produce 12-30 t per ha per year during the tree fallow period. The nutrient content from NFTs is typically N 2.5-4%, P 0.1-0.3%, K 1.0-2.5% and Ca 1.5-2.0%. Prunings have the advantage over natural litter in that the leafy matter is transferred before loss of nutrients by senescence. The magnitude of addition through 5t tree residues would be N 120-200, P 5-15, K 50-100 and Ca 70-100 kg per ha per yr. To these should be added substantial quantities in the decay of fine roots (which contain 50% or more of leaf N). The nutrients in a maize crop with a grain yield of 3 t per ha are N 120-150, P 20-25, K 80-100 and Ca 20-30 kg per yr. So, except for P the tree residues can meet the nutrient requirements of associated crop. In SAT, N supply through leucaena prunings was 35-74 kg per ha per yr (Korwar, 1992). The available N at sowing was higher by 49 and 19 kg respectively in plots where prunings returned and not returned than sole sorghum (Korwar and Radder, 1997). A saving of 9.5, 9.4 and 4.3 kg N to groundnut crop was observed when prunings were returned of Dalbergia, Leucaena and Albizia were returned (SrinivasaRao and Bhemaiah, 2001). The organic carbon, P and K were higher (1.02%, 32 kg and 180 kg per ha) in plots with F albida trees (@ 625 trees per ha) than no tree control (0.69%, 16 kg and 162 kg per ha) in SAT (Korwar and Pratibha, 1999).

A study on tracing flows of nitrogen from hedgerow intercropping after 12 weeks of decomposition showed that:

Applied prunings	370
After 12 weeks	
Retained in the prunings	117
Released by decomposition	253
Subsequently	
Recovered in maize	24
Retained in soil OM	85
Recovered in trees or lost by	
Leaching and volatilization	144

The major problem in nutrient cycling in studies in tropical agroforestry systems is lack of appropriate research methodologies. Rigorous methodologies do not exist for determining the dynamics of N fixation, production and decomposition of tree biomass, and nutrient uptake from deep soil horizon. Until this deficiency is corrected, the rate of success in exploiting the seemingly attractive nutrient-recycling potential in tropical agroforestry systems will remain uncertain (Buck *et al*, 1999)

Agroforestry Systems as carbon Sinks and for soil fertility

In India, average sequestration potential in agroforestry has been estimated to be 25 t C per ha over 96 million ha, but there is a considerable variation in different regions depending upon the biomass production (Table 2). However, compared to degraded systems, agroforestry may hold more carbon. For example, the aboveground biomass accumulation in a Central Himalayan agroforestry system has been found to be 3.9 t ha⁻¹ yr⁻¹ compared to 1.1 t ha⁻¹ yr⁻¹ at the degraded forestland. A major uncertainty, and therefore an issue for future research, is that these estimates are mostly derived through biomass productivity and often do not take into account carbon sequestration in the soil. In order to exploit the mostly unrealized potential of carbon sequestration through agroforestry, in both subsistence and commercial enterprises innovative policies, based on rigorous research results, are required.

Table 2. Regional Examples of soil- fertility enhancement in multifunctional agroforestry systems in India

Region	Challenge	Changes observed due to agroforestry
Himalayas (Kuruksheetra)	Improvement of sodic soils	Increase in microbial biomass, tree biomass and soil carbon: enhanced nitrogen availability
Himalayas	Restoration of abandoned agricultural sites	Biomass accumulation (3.9t/ha in agroforests compared to 1.1 t/ha in degraded forests): improvement in soil physico-chemical characteristics; carbon sequestration
Western Himalayas	Reducing soil and water loss in agroecosystems in steep slopes	Contour tree- rows (hedge-rows), reduced run off and soil loss by 40 and 48% respectively (in comparison to 347 mm run-off, 39Mg /ha soil loss per year under 1000 mm rainfall conditions)
Sikkim Himalaya	Enhancing litter production and soil nutrient dynamics	Nitrogen-fixing trees increase N and P cycling through increased production of litter and influence greater release of N and P; nitrogen-fixing species help in maintenance of soil organic matter, with higher N mineralisation rates in agroforestry systems
Indo-Gangetic Plains (UP)	Biomass production and nutrient dynamics in nutrient-deficient and toxic soils	Biomass production (49 t/ha/decade)

Himalayas (Meghalaya)	Enhancing tree survival and crop yield	Crop yield did not decrease in proximity to <i>Albizzia</i> trees
Western India (Karnal)	Improvement of soil fertility of moderately alkaline soils	Microbial biomass C which was low in rice-berseem crop (96.14 g/g soil) increased in soil under tree plantation (109.12 g / g soil); soil carbon increased by 11-52% due to integration of trees and crops
Western India (Rajasthan)	Compatibility of trees and crops	Density of 417 trees per ha was found ideal for cropping with pulses
Central India (Raipur)	Biomass production in N and P-stressed soils	<i>Azadirachta indica</i> trees were found to produce biomass in depleted soils
Central India	Soil improvement	Decline in proportion of soil sand particles: increase in soil organic C, N, P and mineral N
Southern India (Hyderabad)	Optimality of fertilizer use	
Southern India (Kerala)	Growing commercial crops and trees	Ginger in interspaces of <i>Ailanthus triphysa</i> (2500 trees/ha) helps in getting better rhizome development of the former compared to solo cropping

References

Buck LE, Lassoie JP and Fernandez ECM (1999) Agroforestry in sustainable agricultural systems. Lewis Publishers UK. PP 416

Korwar GR (1992) Influence of cutting height of *Leucaena* hedgerows on alley cropped sorghum and pearl millet. *Indian J. Dryland Agric. Res. & Dev.* 7: 57-60

Korwar GR and Radder GD (1997) Alley cropping of sorghum with *Leucaena* during the post-rainy season on Vertisols in semi-arid India. *Agroforestry Systems* 37:265-277.

Korwar GR and Pratibha G (1999) Performance of short duration pulses with African winterthorn (*Faidherbia albida*) in semi-arid India. *The Indian Journal of Agricultural Sciences* 69: 560-562

Lundgren B (1982) Introduction (Editorial). *Agroforestry Systems* 1:3-6

Nair PKR (1990) Classification of agroforestry systems. In: Macdicken KG and Vergara NT eds. *Agroforestry: Classification and Management*. Wiley, Chichester, UK. PP 31-57.

Pandey DN (2007) Multifunctional agroforestry systems in India. *Current science* **92**: 455-460

Sehgal JL and Abrol IP. 1994. Soil degradation in India: Status and Impact. New Delhi, India: Oxford & IBH Publishing Co. Pvt. Ltd.

SrinivasaRao MMV and Bheemaih G (2001) Response of groundnut alley cropped with nitrogen fixing tree species to application of organic and inorganic sources of nitrogen. *J. Oilseeds Res.* **18**: 147-149.

Young A (1997) Agroforestry for soil management CAB and ICRAF. PP320.