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Ecosystem services and agroforestry

a sustainable future ahead

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Agroforestry is an ecologically complex system where various components interact with biotic and abiotic factors providing multiple products or benefits. Ecosystem services are the benefits derived from functioning ecosystem having an estimated worth of $16-54 trillion/year. Agroforestry has been recognized as a facilitator for providing ecosystem services, environmental benefits and economic commodities while being a part of a multifunctional working landscape.

Key words: Agroforestry, Ecosystem, Sustainable future

THE diverse role of agro-ecosystems was highlightened by both the Millennium Ecosystem Assessment (2005) and the International Assessment of Agricultural Science and Technology for Development (2008). Agroforestry applied on a large-scale with appropriate choice of species has immense potential to enhance ecosystem services while enabling agricultural land to withstand extreme weather events, such as floods, droughts and climate change. The ecosystem services are mainly categorized under four main headings: provisional, regulating, supporting and cultural (Fig 1). However, depending on the kind of services rendered by the agroforestry system the scale of ecosystem services provided varies from local to global level.

Some of the important ecosystem services mentioned above are discussed here.

ECOSYSTEM SERVICES	
Provisional services	• Food, Fiber, Fruits, Fodder, Biomass, Water, Oxygen, etc.
Regulating services	• Carbon sequestration
	• Micro-climate amelioration
	• Soil and water conservation
	• Water and air purification
Cultural services	• Aesthetic
	• Recreational
Supporting services	• Primary production (in relation to soil health)
	• Nutrient cycling
	• Biodiversity conservation

Fig 1 Ecosystem services provided by agroforestry

ECOSYSTEM SERVICES

Provisional services

Agroforestry-based products play an important role in contributing towards sustainable livelihoods of rural poor by providing employment opportunities as well as a range of products such as fuel wood, edibles, fodder, pulpwood, building materials and medicines. The rural population depends on agroforestry for part of their subsistence and cash livelihoods, which they earn from fuel wood, fodder and a range of other products such as fruits, flowers and medicinal plants.

At present agroforestry meets almost half of the demand of fuel wood, two-thirds of the small timber, 70 to 80% wood for plywood, 60 % raw material for paper pulp and 9 to 11% of the green fodder requirement of livestock, besides meeting the subsistence needs of households for food, fruit, fibre, medicine etc. However, presently the biomass productivity per unit area and time is less than 2 tonne/ ha/ year which could be safely enhanced to 10 tonne/ ha/ year by selecting appropriate tree-crop combinations.

Regulating services

Carbon sequestration through agroforestry: Agroforestry is going to play an important role in mitigation of atmospheric accumulation of GHGs. Of all the land uses analyzed in the Land-use, Land-use change and forestry report of the IPCC, agroforestry offered the highest potential for carbon sequestration in non-Annex I (developed countries classified in relation to Kyoto Protocol) countries and the reason behind such a high potential is large area under agroforestry which is highly susceptible for the land use change. Improved agroforestry systems reduce the vulnerability of small-land holding farmers and help

Table 1. Total C storage under agroforestry systems in different regions of the country

Agroforestry system and components	Total C storage (tonne C/ ha)	Region
Silvipastoral system (age 5 yrs)*		
Acacia nilotica + natural pasture	9.5-17.0	Semi-arid region
A. nilotica + established pasture	19.7	
Dalbergia sissoo + natural pasture	12.4	
D. sissoo + established pasture	17.2	
Hardwickia binata + natural pasture	16.2	
H. binata + established pasture	17.0	
Silvipastoral system (age 6 yrs)		
Acacia/Dalbergia/Prosopis + Desmostacya	6.8-18.5	North-western India
Acacia/Dalbergia/Prosopis + Sporobolus	1.5-12.3	
Block plantations (age 6 yrs)*Gmelina arborea*	24.1-31.1	Central India, Arid region (Rajasthan)
Agrisilvicultural system (age 8 yrs)		
Emblica officinalis + *Vigna radiata*	12.7-13.0	
Hardwickia binata + *Vigna radiata*	8.6-8.8	
Colophospermum mopane + *Vigna radiata*	4.7-5.3	
Agri-silvicultural system (age 11 yrs)	26.0	Semi-arid region
***Dalbergia sissoo* + crop**		
Agri-silvicultural system (age 5 yrs)		Semi-arid region
Albizia procera + black gram-mustard	34.8	
Albizia procera + green gram-wheat	35.1	
Silvipastoral system	2.2	North-western Himalayas
Agrihortipastoral	1.1	
Hortipastoral	1.1	

(*Source:* Newaz *et al.* 2014).

them to adapt with changing conditions. These systems need to be promoted through Clean Development Mechanism projects create synergies between mitigation and adaptation while producing social as well as environmental benefits.

Carbon sequestered by trees and stored in above ground biomass and soil contributes to reducing greenhouse gas concentrations in the atmosphere. Estimates of the carbon sequestration potential of agroforestry systems vary greatly, from under 100 mt CO_2/year, to over 2,000 mt CO_2 over a 30 years i.e. by 2030 A.D. Regardless of the exact amount, different agroforestry systems tend to sequester greater quantities of carbon than agricultural systems based on type of system, species composition, soil and climate.

In India, evidences are now emerging that agroforestry system are promising land use system to increase and conserve above ground and soil C stock to mitigate climate change which varied with the region and the prevalent system within the region. The above ground carbon stocks are 17 to 36 Mg C / ha in tropical home gardens of Kerala and 21 to 65.6 Mg C/ ha in poplar-based systems of north India.The average potential of agroforestry has been estimated to be 25 tonne C ha^{-1} over 96 m ha. In this way the total potential of agroforestry in India to store C is about 2,400 million tonne. In another estimate, the area under agroforestry in world is 8.2% of total reported geographical area (305.6 m ha) and it contribute 19.3% of total C stock under different land uses (2,755.5 mt C). Scientists proved that agroforestry systems are promising land use system to increase above ground and soil C stock to mitigate greenhouse gas emissions.

Micro-climatic amelioration

Trees on farm bring about favourable changes in the micro-climatic conditions by influencing radiation flux, air temperature, wind speed, saturation deficit of under storey crops all of which will have a significant impact on modifying the rate and duration of photosynthesis and subsequent plant growth, transpiration, and soil water use. A tree acting as wind breaks and shelter belts slow down the wind speed, thus, reduces evaporation and physical damage to crops, adds mulches to reduce soil temperature and various tree crop combinations reduce erosion and maximize resource use efficiency. Similarly, shade trees in agroforestry systems protect heat sensitive crops like coffee, cocoa, ginger and cardamom from high temperatures.

Soil and water conservation

Climatic factors exert a strong influence over various soil processes and the expected climate change may alter these processes and thereby soil conditions. There are several ways by which climate change manifests soil degradation. Higher temperatures and drier conditions are responsible for lower organic matter accumulation in the soil resulting in poor soil structure, reduction in infiltration of rainwater and increase in runoff and erosion while the expected increase in the occurrence of extreme rainfall events will have an adverse impact on the severity and extent of erosion. To arrest degradation and restoration of the productive potential of soil needs for improvement in the physical, chemical and biological conditions of the soil. The advantage with agroforestry systems lies in its ability to bring favourable changes in all the three conditions. Agroforestry systems like improved fallows, contour hedgerows and other systems has the ability to provide permanent cover, improve organic carbon content, soil structure, increase infiltration, enhance fertility and biological activity, thus, plays an important role in arresting and reversing land degradation.

Supporting services

Soil fertility maintenance and enrichment: Natural levels of annual soil loss are very small in the region of 0.0045 tonne/ ha for areas of moderate relief and only rising to 0.45 tonne/ ha on steep slopes as compared with rates of 45 to 450 tonne/ ha for agricultural lands. Unsustainable agricultural practices leads to loss of

soil quantity as a result soil quality also suffers as soil fertility is associated with the preferentially eroded smaller soil particles. Fertilizers offer an easy way to replenish the soil fertility but rise of price of fertilizers will hardly help the marginal, and small-farmers. In the climate change context, nitrogen-based fertilizers prompts greenhouse gas emissions by encouraging microbes in the soil to produce more nitrous oxide which is the third most important greenhouse gas, behind carbon dioxide (CO_2) and methane (CH_4), and also destroys stratospheric ozone. Agroforestry systems provide economically feasible and environmentally friendly course to improve soil fertility. Integration of trees in the crop lands can help in maintaining the soil physico-biochemical properties both under sequential and simultaneous agroforestry. Tree litter and pruning biomass release nutrients in the soil by mineralization and thus improves soil fertility status. The trees improve the soil-health through maintenance or increase of soil organic matter through carbon fixation in photosynthesis and its transfer via litter and root decay. Published values for leguminous trees in different agroforestry systems show average annual additions of dry matter biomass of up to 20 tonne/ha/year. Trees act as a nutrient pump, which help in taking up nutrients released by rock weathering in deeper layers of the soil. It also improves the soil by exudation of growth-promoting substances by the rhizosphere. The tree roots act as safety net for trapping and recycling of nutrients which would otherwise be lost by leaching including through the action of mycorrhizal systems associated with tree roots and through root exudation. The scientists reported that leguminous trees in alley cropping systems can contribute as much as 358 kg nitrogen (N)/ ha, 28 kg phosphorus (P)/ ha, 232 kg potassium (K)/ ha, 144 kg calcium (Ca)/ ha, and 60 kg (Mg)/ha.

Soil-based ecosystem services in agroforestry					
Nutrient cycling	Soil structure maintenance	Soil and moisture conservation	Chemical transfor-mations	Symbiotic interactions	Enhancement of soil microclimate

Fig. 2. Soil-based ecosystem services in agroforestry system

Trees and soil biota together interacts in a number of positive ways and one of the major contributions of agroforestry trees to soil-based ecosystem services occurs as a result of above ground and below ground organic inputs that supplies food and nutrients needed for the soil organisms involved in carbon transformations and nutrient cycling (Fig 2).

Increased nutrient availability in agroforestry systems is often linked with higher levels of soil-organic matter under trees than away from trees. Tree biomass also serves as a base material for the synthesis of soil-organic matter (SOM). Regular organic inputs through leaf litter, tree pruning's and root turn over have a long-term influence on soil carbon and nutrient stocks and thus agro-ecosystem sustainability.

Biodiversity conservation

A large body of research on Biodiversity suggests five major roles of agroforestry in conserving biodiversity:

- It provides habitat for species that can withstand a certain level of disturbance in agro-ecosystems;
- It helps in preserving germplasm of socially useful and associated species;
- It helps to reduce the rates of conversion of natural habitat by providing goods and services alternative to traditional agricultural systems that may involve clearing natural habitats;
- It provides connectivity and acts as stepping-stone by creating corridors between habitat remnants and thereby conservation of area-sensitive plant and animal species; and
- It helps in conserving biological diversity by providing other ecosystem services such as erosion control and water recharge, thereby preventing the degradation and loss of surrounding habitat.

Agroforestry also leads to a more diversified and sustainable rural production system than many treeless farming options and provide increased social, economical, and environmental benefits for land users at all extent. Although agroforestry may not entirely reduce deforestation but in many cases, it acts as effective shield to deforestation. These systems also act as shelter to biodiversity after catastrophic events such as fire. Agroforestry systems do support as high as 50 to 80% of biodiversity of as good as natural systems, and also act as buffers to parks and protected areas.

SUMMARY

In this era of environmental consciousness and ecological sustainability, agroforestry has been considered as panacea for all the environmental and socio-economic problems. This climate resilient land use practices offers various tangible and intangible benefits. The quantification and evaluation of ecosystem services such as carbon sequestration, soil enrichment, biodiversity conservation, air and water quality improvement provided by agroforestry systems will boost the acceptability of the system as climate smart practice.

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The National Agricultural Policy recognized the potential role of the private sector in agricultural research, need for human resources development, and recognition of the changing rural landscapes with the repidly growing importance of post-harvest management and value addition.