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A review of multi-dimensional benefits of innovative agricultural practices with special reference to Agroforestry and agrosilvipastoral system

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ABSTRACT

Agroforestry is a scientific farming practice of ancient times in which farmers maintained trees on agricultural landscape. It is a sustainable land use system in which crops, trees and livestock are maintained together on same land to increase total yield and income. Agroforestry can alter the micro climate of soil under tree canopy. It plays an important role in enhancement of farm productivity, climate change mitigation, carbon sequestration, biodiversity conservation, phytoremediation, water conservation, improvement in quality of soil by addition of plant and animal waste. This land use system combines production with conservation of ecology. This paper examines the major benefits of agroforestry systems on agricultural landscape: (i) conservation of biodiversity (ii) carbon sequestration (iii) soil enrichment. Various studies indicate that agroforestry can be promoted in farming practices due to its environmental benefits and ecosystem services.

Key words: *Agroforestry, Carbon sequestration, Biodiversity conservation, Soil enrichment*

Introduction

According to ICARF (International Council for Research in Agroforestry) Agroforestry is a collective name for land use systems and practices in which woody perennials are deliberately integrated with crops and animals on the same land-management unit.

Agroforestry is a scientific farming practice of ancient times. It is a sustainable land use system in which crops, trees and livestock are maintained together on same land to increase total yield and income. Agroforestry can alter the micro climate of soil under tree canopy. It plays an important role in enhancement of farm productivity, climate change mitigation, carbon sequestration, biodiversity conservation, phytoremediation, water conservation, improvement in quality of soil by addition of plant and animal waste.

Agroforestry systems have both economical and ecological interaction among trees, crops and animals. The total productivity is generally higher in agroforestry systems as compared to monoculture systems because trees acquire resources that crops could not acquire alone. Tree imparted benefits of agroforestry system is related with on farm use of fodder, firewood, live fence, timber, medicinal plants fruits etc. It supports the production of various products like fuel, fodder, timber, fruits, fiber, gums, resin, craft products, gardening material, medicinal products, ecological services, recreation etc.Tress in agroforestry system modify the micro climatic condition like water vapor content of air, temperature, wind speed etc. which is beneficial for animals and crops.

Multidimensional benefits of Agroforestry

Carbon sequestration

Agroforestry systems have high potential of carbon sequestration due to their ability to capture growth resources and their utilization than monoculture systems. Tree based agricultural systems store more carbon as compared to tree less systems in deep layers of soil near the tree as compared to away from the tree. High species richness and density of trees was found to be associated with soil organic carbon content. In agroforestry systems, the amount of sequestered carbon depends on system management and environmental condition (Nair, 2011).

Agroforestry can be adopted for carbon sequestration on agricultural lands because significant amount of carbon can be sequestered by agroforestry systems. Other issues like economic diversification, water quality and biodiversity can also be addressed and it can also help farmers and society too. Activity of carbon sequestration is strong especially in wind breaks and riparian forest buffers. These are established for ecological service they provide like alteration of micro climate to protect crops, livestocks by windbreaks. Riparian forest buffers enhance quality of water by trapping, filtering and bio processing surface run off. These benefits are only possible when plantation is at proper place and reach a level of functional maturity (Schoeneberger, 2008).

Incorporation of trees in pastures and cropland would result into greater net above ground as well as below ground carbon sequestration. Carbon trading is expanding rapidly and least developed nations and developing countries can sell their sequestered carbon to developed countries which was acquired by agroforestry practices (Nair *et al.,* 2009).

One of the option to compensate greenhouse gas (GHG) emission is the removal of atmospheric carbon and its storage in terrestrial biosphere. Agricultural lands are major carbon sinks and large quantities of carbon can be stored if plantation and management of trees is systematic along with crops and animals on them. Agroforestry system as a land use system is important not only for agricultural sustainability but also for climate change related issues also. Homegardens, agroforests and boundary plantations can sequester large quantities of carbon in plant biomass and wood products (Albrecht and Kandji, 2003).

For stabilization of concentration of carbon dioxide in atmosphere, massive reforestation is one of the alternative that can be adopted. Yet due to the current level of tropical deforestation and the ever increasing need for additional agricultural land, this is not feasible. Agroforestry systems can increase the carbon storage on land and can also enhance agricultural production. In agroforestry systems carbon storage per unit area is less as compared to forests but worldwide its area is large. In three ways agroforestry keeps carbon out of atmosphere- (1) Reduced deforestation (2) Carbon accumulation in woody biomass and soil (3) Production of wood for fuel and substitute for fossil fuel (Unruh *et al.,* 1993).

Agroforestry is capable of increasing carbon content in terrestrial biosphere. It can play an important role in reduction of atmospheric content of CO by growth of biomass for biofuel, storage of carbon in above ground and below ground biomass. It can provide food and fuel wood, protect existing carbon stocks resulting in reduced rate of deforestation (Jose and Bardhan, 2012).

Adoption of agroforestry systems can enhance carbon sequestration as compared to treeless systems. Some factors which are responsible for higher carbon sequestration in agroforestry systems are heterogeneity in the vegetation both above and below ground, production of plant biomass in large amount, litter fall, root exploration of rhizosphere etc. The adoption and implementation of AFS system can result into sustainable land use management by improving soil fertility, carbon enrichment in humus and carbon sequestration in soil and plants.

Carbon stocks can be raised in agricultural systems by agroforestry and it can be sold as carbon credits. Biophysical, technical and economic potential of agroforestry for carbon sequestration was studied for west, east and South Africa. Homegardens, live walls and parks had coal stocks, but only 0.2-0.8 Mg C ha year was collected. Coal was sequestered faster but only during the fallow periods in rotational woodlots and strengthened fallows in South Africa (Luedeling *et al.,* 2011).

The major inputs for carbon content in the soil of the Cacao agroforestry project in Bahia, Brazil, are continuous deposition of root hairs, litter and fine roots. Soil microbial biomass is a significant source of carbon and it affects soil carbon complex processes. These Cacao agroforestry system have accumulation of high amount of soil organic carbon.

Carbon in Cacao system was fine carbon occluded within aggregates.

Carbon sequestration potential was studied in three predominant ecosystems on volcanic soils in Patagonia, Chile. Three systems selected were silvopastoral, plantation and prairie. Soil respiration, litter fall, decomposition and soil carbon was measured. In silvipasture and plantation respectively, the total tree carbon stock above and below ground accounted for 69% and 64% of the total carbon network. The maximum carbon pool above and below ground was 224, 199 and 177 Mg C ha{¹, above ground: below groundcarbon pool ratio 1:10, 1:5 and 1:177 respectively. Leaching of carbon beyond the root zone decreased in sequence: plantation > prairie >silvipasture and soil respiration decreased in the order prairie >silvopasture> plantation (Dube *et al.,* 2011).

Kimaro *et al.,* (2011) in his study observed that agroforestry systems in which fast growing tree species are grown can rapidly sequester atmospheric CO at level equal to natural forests of semiarid lands and reduce forest degradation.

The Brazilian savanna known as Cerradois now threatened due to its conversion to intensive agriculture. Due to the role of trees in greenhouse gas mitigation and carbon sequestration, development of silvipastoral system on pastureland is relevant to this region.Silvipastoral system based on Eucalyptus trees has been established in this Cerrado region with agricultural crops of rice and soyabean. Various studies indicate that agroforestry systems store higher amount of carbon both above and below ground as compared to single species cropping and grazing system (Nair *et al.,* 2011).

Short rotation crops (SRC) system is a better land use option for both carbon sequestration and bio energy production. Carbon storage in soil and biomass in SRC system of *Robiniapseudoacacia*was studied by Quinkenstein *et al.,* (2011). The carbon sequestration rate of SRC system depends on biomass productivity of plantation. *R. pseudoacacia* is a better species for dry marginal sites due to its water stress tolerance capacity and its ability to fix N especially on sandy soils. *R. pseudoacacia* has high potential to increase soil C stock and sequester carbon in marginal sites.

Agroforestry is an important strategy for carbon sequestration due to its potential of carbon storage in multiple plant species and soil. Average carbon storage in agroforestry system was measured at 9, 21, 50 and 63 Mg C ha{¹ respectively in semiarid, sub-humid, tropical and temperate regions. Potential carbon sequestration varies from 1.5 to 3.5 Mg C ha{¹ year{¹ in tropics in the small owner AFS systems. Agroforestry helps decrease pressure on natural forests in terms of carbon sequestration. Another indirect benefit of carbon sequestration is soil conservation by using agroforestry techniques which would enhance carbon storage in soils and trees (Montagini and Nair, 2004).

Soil enrichment

Soil productivity and sustainability can be enhanced and maintained for long period of time by agroforestry systems. The physical, chemical and biological properties of soilcan be enhanced by addition of organic matter both below and above ground. Release and recycling of nutrients takes place in agroforestry systems (Shibu Jose, 2009).

Study on five agroforestry tree species namely *Bombaxceiba, Azadirachta indica, Bauhinia variegata, Wandlendia exserta* and *Acacia auriculiformis* was conducted at Rajendra Agricultural University, Pusa, Bihar, India by Das and Chaturvedi (2008). In their study it was observed that species like *Wandlendia exserta* and *Acacia auriculiformis* can be grown together along with crops in agroforestry systems. These are suitable for dry areas. These deep rooted species can be used in agrisilviculture and they can uptake nutrients from deep layers of soil. The soil binding factor is high in *W. exserta*, *A. auriculiformis* and *Bauhinia variegata* and they are also helpful in soil conservation. They can also improve soil moisture level and soil fertility. Among all of them *A. auriculiformis* was most effective in improving soil fertility

Depending on tree species, location, plant component, soil type, tree pruning regime and tree size, the nutrients given by tree pruning are determined by nutrient concentration and production rate. A large number of alley crop tests and sampling in different environment suggest that the pruning of different tree species provideenough nutrients to satisfy crop demandexcept for phosphorous (Palm, 1995).

The integration of woody perennials on farm land along with crops will provide several benefits. Studies showed that trees are required for maintenance and improvement of soil health. They can influence availability of nutrients and their supply in the soil. By addition of organic matter trees can in-

fluence physical, chemical and biological properties of soil. Problems of food, wood, fodder and climate change can be solved by integration of trees on farm land. For climate smart agriculture trees are the best sustainable option (Uthappa *et al.,* 2015).

Agroforestry systems such as inter cropping and agrosilvipastoral system lead to sustainable agriculture, reduce on-site and off-site consequences and increase the sustainability of agricultural production. Agroforestry can be effective in the regions where green revolution could not make any effect due to lack of fertility. Land use system such as agro-silvipasture, agro-horticultural, agro-pastoral are more effective for restoration of soil organic matter. Crop yields of coarse grains can be directly enhanced by trees in agroecosystems through mulching and water conservation. In a study of arid regions of Haryana, effect of *Tecomella undulata, Prosopis cineraria, Acacia albida* and *Azadirachta indica* was found positive on productivity of *Hordeum vulgare* (Barley). Grain yield was enhanced by 86.0%, 48.8 %, 57.9% and 16.8% by *P. cineraria, T. undulata, A. albida* and *A. indica* respectively. Biological yield was also higher under trees as compared to open areas. Soils were rich in moisture availability, organic carbon content and nutrient status under tree canopies (Pandey 2007).

In low input tropical agroforestry system, transfer of nitrogen from N - fixing trees to perennial crops is a good source of nutrient replacement. In tropical agroforestry system, indirect transfer through mineralization and uptake of N from root tissues, litter and branches is the major pathway especially the region where tree legume aboveground biomass is recycled to soil. A smaller and important mechanism is the release of N-rich molecules from N2 fixing trees and their uptake by root system (Munroe and Isaac, 2013).

N-fixation, litter fall, root turnover etc. are the major ways of addition of organic matter and nutrients to the soil in natural ecosystems. In managed agricultural systems, such pathways are not enough for compensation of losses in harvested products. Green manure from trees and shrubs is also required as additional input along with inorganic fertilizer in various mixtures. Trees and shrubs on farmland in indigenous agroforestry systems can be used as green manure for enhancement of soil productivity and fertility (Teklay, 2005).

The rate of improvement in soil in agroforestry systems is determined by three processes: (1) availability of nutrients due to decomposition of tree biomass (2) nitrogen input by N- fixing trees (3) uptake and utilization of nutrients by deep rooted trees from deeper layers of soils. Deep rooted trees can improve physical conditions of soil and microbial activities in soil under agroforestry systems.(Nair, 2007).

Biodiversity conservation

Mcneely and Schroth (2005) observed that agroforestry systems plays a significant role in conservation of biodiversity as compared to monoculture system. Traditional agroforestry system helps in biodiversity conservation through *in situ* conservation of tree species on farms, provide suitable habitat for animal and plant species and reduce pressure on natural forests. By applying adaptive management approaches the relationship between forests, agroforests and wild biodiversity can be made productive. Local knowledge and practice, ongoing research and monitoring can be incorporated to feed information into management system.

Major roles played by agroforestry in conservation of biodiversity are: (1) It helps in preservation of germplasm of sensitive species; (2) It provides habitat to wild species of flora and fauna; (3) It creates corridors between habitat remnants and provides connectivity. This can support conservation of area sensitive fauna and flora species and integrity of these remnants; (4) It helps in reduction of rates of conversion of wildlife habitat into agricultural farms by providing sustainable alternative to agricultural systems; (5) It also provides other ecosystem services like water recharge and erosion control and helps to conserve biological diversity and prevents degradation and loss of surrounding habitat (Jose, 2009).

In agroecosystems, variety of ecological services are provided by biodiversity like regulation of microclimate, recycling of nutrients, regulation of hydrological processes, detoxification of poisonous chemicals and suppression of undesirable organisms. Biodiversity mediated ecological services and renewal processes are mainly biological and depend on maintenance of diversity and biological integrity in agroecosystems. Crop rotation, intercropping, agroforestry, livestock/crop mixtures etc. can enhance diversity. Diversification can also be done outside farm like living fences, crop field boundaries with windbreaks, shelter belts which can provide habitat to wildlife and beneficial insects.

(Altieri, 1999).

Silvipastoral agroforestry can increase the diversity of birds and invertebrates in grassland systems. It can also provide opportunities for increasing the diversity of small mammals, arthropods and birds in agriculture systems. The changes in microclimate and increased number of predators can lead to reduction in number of pests (Burgess, 1999).

Plant and animal diversity is added to agricultural farms by agroforestry system which otherwise contain only monocultures of agricultural crops. Under changing climate scenario, field shelterbelts and riparian forest buffers are essential for maintaining animal and plant biodiversity. Introduction of species like fruit trees and medicinal plants in home gardens contributes to species biodiversity. The management of land is directly related to its inhabitants. If poor farmers and rural people are provided with opportunity to earn stable and sustainable livelihood then it will help indirectly in conservation of biodiversity of the planet. A balance between biodiversity conservation and production is the basis of concept of ecoagriculture. Agroforestry is best suited to provide ecoagriculture solutions (Nair, 2007).

Fifanou *et al.,* (2011) on their study of traditional agroforestry parkland systems described its benefits in terms of socio economic factors and woody tree species and supports practice of agroforestry system in farming. It showed that rural people not only depend on trees as source of fodder, food, fruits and medicines but they also helps in conservation of some important species and habitats by proper management of resources. Traditional agroforestry system can be useful method to reduce pressure on natural resources and provide suitable environment to many plant species.

Multipurpose trees and shrubs (MPTS) are integral component of agroforestry system. They have potential and play a vital role in sustainable agriculture development. The importance of MPTS for sustaining soil productivity, meeting human needs for wood and its products is becoming recognized. Various species have been considered to have many uses. Combinations of agricultural crops and MPTS derived through known germplasm can help in increasing food, fruit, fodder, fuel and crop production. Their conservation is essential for sustainable development of natural resources and to meet the demands of future generations (Baig *et al.,* 2008).

Asase and Tetteh (2010) examined and compared variety of trees and forest structure in Cocoa agroforestry process and mixed food crops and natural forest in southeastern Ghana. Significant difference was found in native forest tree species richness between agroforest and natural forest but this species richness was similar in mixed food crop and cocoa agroforest. The density of native forest tree species was higher in natural forest but it was similar in mixed food crop and cocoa agroforest. Basal area of native forest was also higher in natural forest and comparable between food crop and cocoa agroforest. Of the 20 most abundant native forest tree species, 18 are recorded to be used, 100%, 83.3% and 77.8% respectively for fuelwood, medicines and materials. This study shows that agroforestry systems are not alternative for natural forests but they can be handled strategically for plant biodiversity conservation and sustainable agriculture production. It can act as buffer between managed areas and protected areas.

Conclusion

The above stated benefits of agroforestry practices confirm its role as an innovative practice which can be recommended to all stake holders keeping in mind its multi-dimensional benefits.

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