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Agroforestry as a Strategy for Sustainable Soil Management

Raj A[1]*, Mehta CM[2] and Sadawarti RK[3]

[1]Assistant Professor, School of Agriculture, Lovely Professional University, India
[2]Associate Professor, School of Agriculture, Lovely Professional University, India
[3]Dean, School of Agriculture, Lovely Professional University, India

***Corresponding author:** Abhishek Raj, Assistant Professor, School of Agriculture, Lovely Professional University, Phagwara-144411, Punjab, India, Email: ranger0392@gmail.com

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Abstract

Soil is the medium through which plant grows and which is derived from disintegration of parent rock materials under joint effect of plants, human and varying climatic regime. The burgeoning population causes serious pressure on land to fulfill the increasing food demand, animal feed, fibre as well as fuel, which leads to adopting practices such as intensive tillage, monoculture, excessive and improper use of inorganic fertilizer, use of agro-chemicals, deforestation, over-grazing, among others. These modern practices of agriculture are considered to be the major unsustainable practices leading to soil health degradation. Some of these practices lead to climate change, which in turn accelerates the rate of soil health degradations. Perennial woody plant based systems has a prime role towards improvement of soil health to sustain production systems. Thus, agroforestry systems is win-a-win strategy which posses various agroforestry systems that are practiced by farmers over the ages and these systems are devoid of intentional intensification of soil for the production of tree in combination with agricultural or forage crops in the same land. This system is distributed and practices most parts of the tropics in the world with varying different models which depends on bio-physical, socio-economic attribute along varying ecological services specific to a particular continent, region, country or community. Organic residues input and its decompositions, nitrogen fixations, nutrient cycling process, carbon sequestration, erosion control and microclimate amelioration etc improve the soil health under agroforestry systems. This paper gives a comprehensive insight on agroforestry importance, history, scope and potential along with its role towards soil health management in the tropics of the world.

Keywords: Agroforestry System; Agro-Chemicals; Climate Change; Deforestation; Ecological Services; Nutrient Cycling; Soil Health

Introduction

The term agroforestry is the joint venture of agriculture and forestry. In its simplest term, agriculture is the art and practice of food production. On the other hand, forestry in a broad sense is the science of planting and managing trees and forest. Therefore, it can be regarded as crops production with trees in same land unit. Agroforestry is the age old practice whose origin dates long back. It has gained wide traditional importance due to its diversified practices of location specific models in India. Farmers used various models that integrate woody plant and livestock's in varying agro-climatic zones. These models and practices vary as per varying topography, climatic regimes and availability of resources. Integrating wood plants is a smart choice that provides various multiple products such as timber, fuelwood, fruits and several other NTFPs. These products not only fulfill the food and nutritional needs but also provide economic gains [1].

Agro-forestry has several benefits ranging from delivery of multiple products of high economic value that improve the socioeconomic status and livelihood standard of poor farmers, rehabilitation of degraded land, restoring the fertility and productivity of soil, climate change mitigation, protecting and stabilizing the ecosystem, watershed protection, biodiversity conservation, maintenance of soil quality health, among others [2-6]. Soil health is the ability or potential of the soil to act in response to agricultural practices with maintaining productivity and sustainability of ecosystem [7-9]. Soil health indicates the fertility and productivity status of soil, which determines the crops yield and sustainability of crop production. In this context, agroforestry system (TAFs) is win-a-win strategy which improves soil health through continuous additions and decompositions of dead plant, leaf litter, pruned leaves and branches that improve organic matter content into the soils. It leads to soil health and quality sustenance by enhancing the soil organic carbon and organic matter content which helps in improving the population of soil inhabiting microorganism which plays a key role in decaying and decomposition of organic residues that release essential nutrients, uptake by plants and produce quality food and nutritious fruits which raise crop productivity and farmers profitability along with maintaining food-soil-climate security for better ecosystem stability through carbon sequestration [10,11].

This paper discusses about scope, potential and historical progress of agroforestry system in the tropics. A rigorous discussion has been made on soil health management though agroforestry systems in the tropics.

Agro-Forestry Systems: Definition, Scope and Potential

Several definitions are offered for agroforestry by many researches. As per Dev, et al. [12] the practice of agroforestry integrates forest tree species with important food crops and fodder/pastures (for livestock's) in single piece of land in both temporal and spatial arrangement. Similarly, Handa, et al. [13] have considered agroforestry as sustainbale farming system that includes woody perennial tree species, arable crops and livestock's (pastures/fodder) on single piece of land. Osman [14] believe that agroforestry is a integration of all three elements such a perennial trees, crop and pastures (for livestock's) in single piece of land that is socioeconomically acceptable and ecologically viable. According to Viswanath, et al. [1] agroforestry is an intentional cultivation of woody perennial trees, arable crops and grasses/pastures simulteneously due course of time and space. Thus, tree, crop and livestock's are integral components of agroforestry system that ensure higher biodiversity and improve village landscape through maximizing productivity and profitability along with other ecosystem services.

At present time agroforestry has greatest potential for sustainable agriculture amid the current situation of climate change and soil degradation. Optimum space utilization, soil fertility enhancement, erosion control, and human energy conservation etc are the several significant advantages can be delivered through this system [15]. Resource conservation, soil fertility enhancement, erosion control, efficient nutrient cycling, better nutrient availability and its pumping etc are important ecosystem services through AFs. Thus, agroforestry is gaining wider recognition due to its continuous supply of wood and quality food in sustainable ways along with resource conservations and uncountable ecosystem services.

Agro-Forestry Practices in the Tropics

The practices of agroforestry system are most prevalent and prominent in the tropics. The agroforestry models vary as per varying topography, climate and biophysical attributes. In sub-tropical highland region, the region is characterized with an altitude of greater than 1000 m and a very cold temperature. The major problem of this region is erosion of soil, thus agroforestry system is geared toward conservation of soils. Cultivating bamboo+ rice along with fish productions are important agroforestry practices in this regions. This system minimized food shortage problem, ensures maximum land utilizations and enhance soil fertility through addition and decomposition of plant residues [16]. Indian dry regions experienced arid and semi-arid climates having less rainfall, harsh climate and drought problem. The regions are facing serious challenges in this region along with fodder shortage problems. Adopting agroforestry system play inevitable role by diversifying products and better ecosystem services in this region. Growing Khejri tree (*Prosopis cineraria)* along with some major cereals and pulses are socioeconomically profitable and ecologically viable agroforestry practices in dry belt of Rajasthan [17].

Home gardening is considered to be the predominant agroforestry system practiced in tropical wet land, for example in Kerala. For centuries, home gardening has potential to improve farmer's economy and maintain food security. Homestead gardens comprises fruit and nut trees predominate the upper layer of the canopy, root crops and spice are found in the middle layer while the understory layer are dominated by food crops, cash crops or even medicinal plants on small size of land.

Tree as live hedge is used from ancient time. Using some woody tree species as fence and hedge is work as live hedge which is age old practices in agroforestry systems (AFs). This system delivered many ecosystem services as production of food, timber and fuel wood and as protection from wild animals, human and other foreign source by restriction of entering. Tree as live hedge also work as wind break and improves soil fertility by adding some litter and residues. Species like bamboo, *Acacia*, *Lawsonia inermis* and *Dodonaea viscosa* etc are suited for live fence in agroforestry system [14]. Live fence and its ecosystem services are depicted in figure 1 [18].

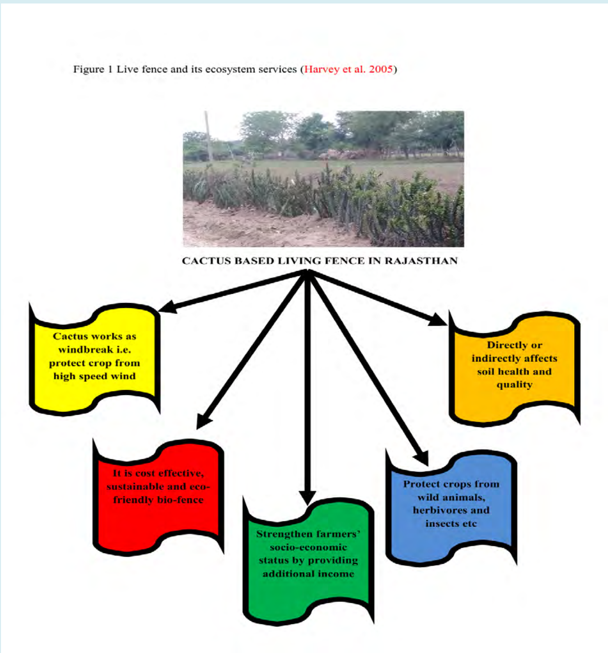

Figure 1: Live fence and its ecosystem services [18].

Integration of tree species with pasture/grasses are good source palatable pasture and fodder for animals and maintain better ecosystem in the rangeland of most parts of dry tropical regions in the world. Some important tree species used for this purpose include *Azadirachta indica, Mangifera indica, Acacia nilotica* etc. The system helps in optimum utilization of land, source of fodder in addition to fuel wood.

Integration of woody perennial trees on farms is commonly used in agroforestry systems. This system comprises randomly planted trees species on agricultural land along with crops/pastures. This practice provided uncountable ecosystem services that maintain ecological stability. For example, *Acacia* species found sparsely on farm lands that is a good source of timber, fuelwood and gum. This system is prominent in Central India having Acacia+ paddy based agroforestry system. In this system *Acacia nilotica* provides gum as minor forest products beside timber and fuelwood along with agricultural produces. Thus, this practice improve livelihood of poor farmers and maintains biodiversity and ecological stability [19]. As per Kumar and Dash [20] applying various doses of microbial inoculations in *Acacia nilotica* based agroforestry plantation affects overall biomass production and nitrogen fixation potential. Some other tree species such as *Ziziphus mauritiana* (ber) and *Gmelinia arborea* (Ghamar) etc are used as scattered trees species in agricultural land [21]. Boundary plantation is another important type of agroforestry system in which trees are planted on farm bund. This practice is economically viable and ecologically sound. Tree on boundary works as wind breaks or shelterbelts that protect crops and livestock's from high speed wind. Eucalyptus, Subabul (*Leucaena leucocephala)* and *Acacia* species are commonly used on farm boundary. These species entirely maintains microclimate and improve soil fertility by adding litter inputs. Employing multipurpose N_2 fixing leguminous tree species play a key role in soil fertility enhancement. In this context, Subabul (*Leucaena leucocephala)* and *Acacia* species play important role in soil health and quality maintenance [22,23]. These species not only maintain soil fertility but also improves SOC status by carbon input through carbon sequestration process.

Various multipurpose tree species (MPTs) such as Eucalyptus sp, *Tectona grandis* (Teak), *Dendrocalamus strictus* (bamboo), *Leucaena leucocephala* (Subabul) etc are used as woodlot purposes. Besides, the wood production from agroforestry plantations will reduce pressure from timber extraction in natural forests. Further, eucalyptus based agroforestry system has significant contribution in carbon sequestration potential [24]. These species are leguminous and multipurpose in nature that provides timber, fuelwood, poles, firewood and pulpwood for general and industrial consumptions. Thus, farm woodlot is commonly used agroforestry practices that maintains economical gain and ecological stability for sustainbale world [14].

Role of Agro-Forestry in Soil Health Management

Soil health degradation is a serious problem in present day agriculture because of faulty farming system like monoculture, intensive tilling, excessive and improper use of chemical fertilizer, respectively. These practices influence the soil health parameters which in turn, affect the productivity of the soil, thus, affecting sustainability of crop production. A great synergy exists between agroforestry system and soils which is depicted in figure 2 [10,25]. The integration of woody perennials into agricultural landscape has quite number of potentials to help in the management of soil as a medium in which plant growth and habitat for soil organism.

Thus, agroforestry improves soil health and quality by various means which is comprehensively described below,

Maintenance of Organic Matter

Agroforestry health and performance are depends on soil organic matter (SOM) content because it is crucial to regenerating soil health. Soil organic matter influences many soil properties such as aggregate stability, mineralization, bulk density infiltration rate, cation exchange capacity, nitrogen availability among others [26]. Sharma [27] reported different forms of the nitrogen and phosphorus increment, soil OM in large cardamom plantation (15 years old). After that, a decrement has been observed in overall litter accumulation and productivity plantation stand of 20-40 years.

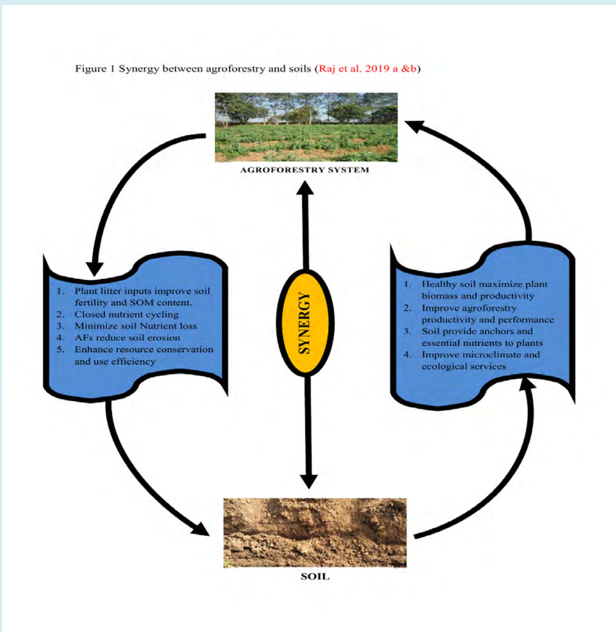

Figure 2: Synergy between agroforestry and soils [10,25].

Biological Nitrogen Fixation

Increase use of Nitrogenous fertilizers in an intensive agriculture is constrained by issues like high costs, micro nutrient deficiency, and environmental pollution, and thus cannot be relied upon for a long-time. Agroforestry systems minimize the higher synthetic inputs as nitrogenous fertilizers due to integration of leguminous and N_2 fixing tree and crops. This system solves the nitrogenous and other nutrient inputs. Nitrogen fixation in TAFs maintains nitrogen status into the soils and makes available nutrients to the tree-crop system for proper growth and development [22]. However, extent and quantity of nitrogen fixation is depends on tree species, their types, nature, soil quality under prevailing climatic conditions. For example, a total 472 and <50 Kg N/ha/yr can potentially fixed by two important leguminous trees as *Leucaena leucocephala* (Subabul) and *Acacia* species [28]. For the poor farmers having limited fertilizers access and for the N and P deficient tropical soils, the optimization of these interactions proved to be significant.

Carbon Transformations and Nutrient Cycling

Agroforestry performs multifarious ecosystem services through organic inputs into the soils that added carbon substrates along with essential nutrients which required for soil inhabiting microorganisms that involved into nutrient cycling and carbon transformation processes. Carbon transformations and release of nutrients occur in two sequential processes; the decomposition of organic inputs into fragments by the collective action of some organisms (e.g. earthworms, millipedes, termites and mites) and fungal and bacterial based enzymatic actions leads to CO_2 emissions and synthesis of soil organic matter [29-31]. A close type of nutrient cycling has been observed under agroforestry system rather than open type of nutrient cycling in sole based cropping system. An extensive root system of woody perennial trees can capture and transfer soil nutrients to minimize nutrient losses through leaching. Nutrient uptake, pumping and movement are essential for better productivity and performance of agroforestry system in the tropical regions. In this context, adopting sustainbale and ecological based agroforestry system proved a better nutrient cycling rather than sole based cropping system where nutrient loss is maximum. Further, carbon storage, flux and transformations is very essential for ensuring carbon balance in agroforestry system. These processes will maintain carbon status in the agroforestry system and regulate carbon cycling and balance in the atmosphere. Furthermore, carbon inputs from addition and decomposition of litter inputs will improve soil fertility and agroforestry performance. A better cycling of nutrient maintains agroforestry ecosystem services for sustainbale world. Similarly, carbon transformation and nutrient cycling also regulated by species types, nature and agroforestry models. A well managed eco-designed model of agroforestry system will improve the carbon status and nutrient availability into the soil. This will further modify by nature and types of decomposers that regulates organic matter inputs and nutrient release into the soil [32]. According to Palm et al. [33], it can be defined as the total nitrogen, soluble polyphenols and lignin concentrations. High quality organic inputs with low lignin and polyphenol/N ratio will decompose faster as compared to low quality organic inputs with high lignin and polyphenol/N ratio. Thus a high quality organic input promotes nutrient availability in the soil as compared to formation of SOM and effects on microclimate.

Nutrient Pumping

Nutrient pumping is an important mechanism that capture nutrient from deep soil through extensive root system and transfer to plant for better growth and development. A better nutrient pumping determines the nutrient availability and its movement that governs overall health and productivity of agroforestry system [34]. Toky and Bisht [35] studied the effect of size of the root system for multipurpose agroforestry species with highest root length of 288 cm. Rooting depth of trees determined their nutrients uptake ability from subsoil and making them available in topsoil which may be available for crops with shallower root systems through nutrient pumping. Thus, woody perennial tree components in agroforestry shed their leaf litter, twigs and other residues that decay and decompose to release essential micro and macro nutrients that again uptake by plant root systems through nutrient pumping techniques that resulted close type of nutrient cycling i.e. lose of nutrient through leaching is less along with higher soil fertility [36].

Soil Structure Maintenance

Maintenance of soil structure is utmost important for a better health and quality of soil. Soil structure determines quality of soil that regulates several other parameters. It affects soil microbial populations, rhizosphere biology, nutrient availability and health and productivity of agroforestry system. A well-managed eco-designing agroforestry practices maintains soil structure and related ecological processes. A combine action of higher plant roots and soil inhabiting organisms improves soil structure through better physicochemical parameters of soil that regulates soil pores, aerations, bulk density and infiltration etc [37]. Rillig [38] emphasized the key role of Arbuscular mycorrhizal fungi in hyphal enmeshment of soil aggregates and glomalin decomposition that helps in maintaining of soil structure and its formations. Carbon is lost to atmosphere due to breaking of soil aggregates on wetting. The breaking enhances the rate of erosion and thus soil organic matter is exposed more readily acted upon by microbes [29].

Soil Erosion Control, its Reduction, Evaporation and Transpiration

The ongoing series of forest degradation, deforestation, illicit felling of timber, overgrazing, intensive agroecosystem practices, intensive tillage practices and unsustainable land use system deprive soil health and quality. Intensive use of chemical fertilizers, heavy mechanizations, unbalance use of pesticides etc threatened the soil quality and environmental health. These practices destroy natural resources and break the chain of sustainability. In this context, practicing sustainbale agroforestry system maintains soil health and fertility that ensure soil-food-climate security for environmental sustainability. These practices minimize soil erosion problems and water losses through evaporation and transpiration. Litter inputs from trees covers soil and minimize water losses. Tree shades reduces the chances of water loss through evaporation and transpiration. Applying cover crops and no-tillage practices also ensure highly productive and healthier agroforestry system. Thus, a better management of agroforestry system and good understanding of tree-crop systems ensure healthier and productive agroforestry system with less soil-water losses [34]. The long and extensive root system of higher plant will hold soil and water. For examples, around 20 percent reduction of nitrogen loss and 23 to 10 percent reduction in runoff were observed under agroforestry and contour strip treatments based on calibrations [39]. Mishra [40] reported that traditional agroforestry systems help significantly in soil and water conservation through serving as vegetation barrier to prevent soil erosion as well as helps to retain precipitation under the field for increasing soil moisture retention, reducing evaporation and improving other soil properties.

Policy and Future Roadmap

Soil degradation is ongoing major challenges faces by the all developed and developing countries in the world. Burgeoning population resulted deforestation and intensive agricultural practices that causes land degradation and erosions which directly impacts on soil properties, productivity, food availability and environmental degradation. In this context, agroforestry is a good strategy to solve out these problems but due it low area due less adoptive capacity and awareness among farmers. A good governance and policy are needed for raising effectiveness of agroforestry system in enhancing ecosystem services along with maintenance of soil-food-climate security under changing climate. This can be achieve through people-public partnership in raising quality seeds, high vigor stocks for plantation, and awareness regarding about multifunctional role of agroforestry systems. The future of this farming system is so bright and must be incorporated in the degraded and wasteland development that helps in reclaiming desertification and saline-alkaline soil along with checking soil erosion.

Conclusion

Agroforestry is gaining wide recognition due to its uncountable ecosystem services including delivery of multifarious products and soil health management. Integrating woody perennial trees with herbaceous crops in agricultural farms ameliorate microclimate and strengthen farmer's income. Improving soil health and quality is another potential encompasses by practices of sustainable agroforestry system. Soil enrichment, nutrient additions, efficient and close nutrient cycling, improving soil fertility and higher stock of SOM can be achieve through practicing a better agroforestry systems in the tropics. Healthy soils stores variety of microorganisms that decompose litter inputs and other plant residues that release essential nutrient which is prerequisite for proper growth and development of plants. Thus, healthy soil improves plant productivity which provides variety of healthier food and fruits that sustains billions of peoples by minimizing hunger problems. Thus, the major ways through which soil health is improved through traditional agroforestry systems include; addition and decomposition of organic matter (O.M.), efficient nutrient cycling, nutrient pumping, carbon storage and sequestration, biological nitrogen fixation, micro-climate and control of erosion. All these processes ameliorate the soil properties that regulate overall quality and health of the soil. Thus, a better management of agroforestry systems ensures soil-food-climate security that maintains environmental sustainability and ecological stability.

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