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Role of agroforestry in soil conservation and soil health management: A review

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Abstract

Agroforestry systems play a great role in conservation of natural resources, especially soil. Agroforestry have promoted soil conservation as one of its primary benefits, empirical estimates of these benefits have been lacking due to temporal and spatial complexity of agroforestry systems and soil resource dynamics. 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 agroforestry systems. The function and relevance of soils in agroecosystems has been recognized in the context of sustainable management, soil quality, soil resilience or soil conservation, and protection of local or regional agroecosystems. Agroforestry practices help in increasing productivity, improving nutrient cycling and also improving the socio-economic status of farmers. Dominance of many traditional agroforestry systems in India offers opportunity worth reconsidering for carbon sequestration, livelihood improvement, biodiversity conservation, soil fertility enhancement and rural employment. The comparative study on nutrient accumulation in the trees, their removal during the tree harvesting, nutrient return through litter fall and improvement in soil nutrient level of different cropping system has been discussed in this article. The agroforestry practices studies reflecting its superiority over pure cultivation from nutrient management point of view.

Keywords: Agroforestry, soil conservation, soil health, soil management, nutrient cycling

Introduction

Agroforestry practices encompass an entire spectrum of land use systems in which woody perennials are deliberately combined with agricultural crops and/or animals in some spatial or temporal arrangement (Lundgren and Raintree, 1982) [31]. India has 175 million ha degraded land. It is suffered from various problems of soil erosion and land degradation. These are major causes of land degradation and soil nutrient losses. It is also estimated that 25 percent of the world's lands are either highly degraded or subject to high rates of degradation.4 In Africa, FAO estimates that 65 percent of arable land, 30 percent of grazing land and 20 percent of forests are degraded.5 Land degradation is still occurring at a rapid pace, with some 12 million hectares of land degraded globally each year. As a result, the productivity of the world's lands continues to decline – even as the human population and demand for food and goods grow. It has been estimated that, worldwide, land degradation costs between USD 6.3 trillion and USD 10.6 trillion annually. The rural poor are among the most affected.6 Advocates have contended that soil conservation is one of its primary benefits (Young, 1989). The presence of woody perennials in agroforestry systems may affect several bio-physical and bio-chemical processes that determine the health of the soil substrate (Nair, 1993) [37]. The less disputed of the effects of trees on soil include: amelioration of erosion, primarily through surface litter cover and under story vegetation; maintenance or increase of organic matter and diversity, through continuous degeneration of roots and decomposition of litter; nitrogen fixation; enhancement of physical properties such as soil structure, porosity, and moisture retention due to the extensive root system and the canopy cover; and enhanced efficiency of nutrient use because the-tree-root system can intercept, absorb and recycle nutrients in the soil that would otherwise be lost through leaching (Sanchez, 1987) [44]. Land degradation can have serious consequences for the livelihoods of rural people by decreasing the supply of good-quality water and reducing food and nutrition security. Over time, land degradation can increase the vulnerability of rural communities to biological and environmental hazards and to the effects of climate change. Trees of low moisture content soils have deep root systems and helps in nutrient and water pumping as compared to high moisture soils (Makumba *et al*., 2009; Schroth and Sinclair, 2003; Schroth, 1999) [46, 47]. Tree root systems are involved in some favorable effects on soils such as carbon enrichment in soil through root turnover, the interception of leached nutrients, or the physical improvement of compact soil layers.

Trees have deep and spreading roots and hence are capable of taking up nutrients and water from deeper soil layers usually where herbaceous crop roots cannot reach. This process of taking up nutrients from deeper soil profile and eventually depositing on the surface layers through litter-fall and other mechanisms is referred to as 'nutrient pumping' by trees. This process is mainly depends on characteristics of tree species and other soil, climatic and topographic factors.

Soil conservation

Soil erosion is one of the major causes of soil degradation on steeply sloping lands devoid of vegetative cover and often subjected to landslides or landslips during rainy season This process not only affects the land/soil but also cause loss of biodiversity including base resource itself, and human life. The loss of soil under shifting agriculture has been reported in the tune of 5 to 83 t/ha depending upon crops grown and slope of the land (Prasad *et al*., 1986). The loss of soil through runoff on such lands varied from 10.8 t/ha to as high as 62 t/ha depending upon land use for different types of agriculture (Prasad *et al.*, 1986). The loss of topsoil reduces the inherent productivity of land through the loss of nutrients and degradation of the physical structure of the soil.

Restoration of Landscape

Several agroforestry approaches are available for restoring and increasing land productivity while also meeting the needs of low-income farmers, and the presence of trees have a number of advantages. For example, trees can fix nitrogen, stabilize the soil, and be used in terracing, contour cultivation and strip-cropping to combat soil erosion and increase soil fertility.14 Planted in windbreaks and shelterbelts, trees can protect soils against wind erosion. Erosion is now accepted as one of the main causes of soil degradation, including of physical, chemical and biological properties, all of which require attention. Mechanical means of soil erosion control measures are not cost effective and also cannot be well maintained; there is a greater interest in biological means of conservation. There is greater emphasis on the effects of soil cover as a means of controlling erosion, as compared with checking runoff. It is accepted that we cannot stop the cultivation on sloppy lands in this region. The inclusion of trees in soil conservation and erosion control is one of the most widely acclaimed and compelling reasons for including trees on farmlands prone to erosion hazards.Trees can also be planted in improved fallows and alley-cropping systems, with the branches pruned and applied as mulch to increase soil organic matter and nutrient status. In silvopastoral systems, tree canopies provide livestock with shade and wind protection and thus indirectly improve animal welfare, health and productivity.15

Land degradation

The area of land potentially available for landscape restoration has been estimated at 2.2 billion hectares. The aim of agroforestry practices is to maximize the positive consequences, thus enhancing productivity and conserving resources. The capacity of trees to grow under difficult climate and soil conditions, coupled with their potential for soil conservation, gives agroforestry a potential in the main types of marginal and slopping lands with soil productivity constraints.1.5 billion hectares are best suited to mosaic restoration, in which forests and trees are combined with other land uses, such as agroforestry. A further 1 billion hectares of croplands and densely populated rural areas on former forestlands would benefit from the establishment of trees in strategic places to protect and enhance agricultural productivity and other ecosystem functions.

Soil productivity

Soil fertility declines when the quantity of nutrients removed from the soil in harvested products exceeds that being added to the arable soil.17 Declines can also occur due to erosion and inappropriate farming practices such as the use of monocultures and frequent tillage, the removal of plant residues, and a lack of adequate fallow periods. The recovery of soil fertility can be a long process when soil organic matter has been depleted and soil structure damaged. Tree characteristics that help increase soil fertility include high biomass production, nitrogen fixation, mycorrhizal associations, dense, deep networks of fine roots, and a capacity to grow in poor soils. Trees can help rebuild soil organic matter by retrieving nutrients from deeper soil horizons and weathering rock and adding them to the surface layers of the soil through leaf litter.18 Many tree species can also prevent nutrient leaching because of their deep root systems, and trees can be used to combat soil salinization and acidification. The use of nitrogen-fixing trees can increase soil fertility by adding nitrogen to the agro-ecosystem, with the higher soil nitrogen content19 potentially increasing the productivity of agricultural crops.

Soil organic matter

Soil organic matter replenishment is the cornerstone to regenerating soil health and increasing soil organic matter is a goal of most agroforestry systems. Shankarnarayan (1984) [48] reported an increase in organic matter nitrogen and phosphorus of soil under the tree growth as compared to bare site and *Prosopis* species of same age. Under agroforestry system involving *Populus deltoids* and *Eucalyptus* hybrid canopies, enhancement in soil nutrient was 33-83% organic carbon, 38-69% available Nitrogen, 3-33% available Phosphorus and 8-24% arle without canopy (Anonymous 1987) [8]. Further Aggarwal (1980) [4] indicated greater nutrient amount in soil under Prospis based agroforestry system than that of open field). It is apparent from the studies that the agroforestry systems, which promote the use of legumes as fertilizer or shade trees, may increase N_2O emissions compared to unfertilized systems. The significance of different variables on GHG production and soil C sink capacity was investigated by Mondini *et al*., by monitoring CO2 and N2O fluxes from amended soils under laboratory conditions and reported that the C conservation efficiency of organic residues, calculated by the combined loss during composting and after land application was higher for the less transformed organic materials (Lal R. (2005). Samra and Singh (2000) observed in increase in soil organic carbon status of surface soil 0.39% to 0.52% under *Acacia nilotica+ Saccharummunja* and 0.44% to 0.55% under Acacia nilotica+Eulaliopsisbinata after 5 years and suggested that Acacia nilotica + Eulaliopsisbinata are conservativebut more productive and less competitive with trees and suitable for eco- friendly conservation andrehabilitation of degraded lands of Shivalik foot hills of sub-tropical northern India. Ram Newaj *et al.* (2008) observed that in agri- silviculture growing of Albizia procera with different pruning regimes, theorganic carbon of the soil increased by 13-16% from their initial values under different pruning regimeswhich was 5 to 6 times higher than growing of either sole tree or sole crop.Soil fertility can also be regained in shifting cultivation areas with suitable species. For instance,a field experiment to study N_2 fixation efficiency suggests that planting of stem-cuttings and floodingresulted in greater biological N_2 fixation, 307 and 209 kg N ha–1 by Sesbaniarostrata and S. cannabinarespectively. Thus, S. rostrata can be used as a green manure by planting the stem-cuttings under floodedconditions (Patel *et al*., 1996). Within the terrestrial ecosystems, the soil is the main provider of environmental services. The soil is a living system essential to sustain biological productivity, air and water quality, and plant, animal and human health. Unfortunately, soil degradation is a severe problem for food production in rural areas, particularly in developing countries. Therefore, it is necessary to contemplate strategies for land management representing the best possible communion between generations of multiple services while preserving the natural capital (Lavelle 2008).

Soil Structure

Thus most important beneficial effect of the trees on the soil can include improvement of soil structure availability of nutrients (Sanchaz 1983, Nair, 1989) [45]. Soil organic matter influences many soil properties including infiltration rate, bulk density, aggregate stability, cation exchange capacity, nitrogen availability, and a number of key soil quality parameters (Patiram, 2003) [41]. The water stability of soil aggregates is paramount in the restoration of soil structure to destructive forces. Structural stability increases with increasing organic matter content, which in turn is correlated with increased biotic activity. Soil microbial and mega faunal (earthworms) population improve water infiltration by altering soil physical structure. Bacteria produce thread-like polysaccharide adhesive and fungi produce thread-like hyphae that bind soil particles into stable aggregates and reduce potential soil losses by erosion (Gupta and Germida, 1988) [22].

Soil Fertility

Agroforestry trees, particularly leguminous trees, enrich soil through biological nitrogen fixation, addition of organic matter and recycling of nutrients. Some trees such as *Leucaena* species, *Acacia* species and *Alnus* species has been reported to fix as much as 400-500 kg, 270 kg and 100-300 kg nitrogen per hectare per year respectively.

The fixed nitrogen may benefit symbiotically to the crops growing in its association and helps in soil fertility improvement. Biological nitrogen fixation takes place through symbioticand non-symbiotic means. Symbiotic fixation occurs through the association of plant roots with nitrogen-fixing microorganisms. Many legumes form an association with the bacteria Rhizobium while the symbionts of a few non-leguminous species belong to a genusof actinomycetes, Frankia. Non-symbiotic fixation is effected by free-living soil organisms, and can be a significant factor in natural ecosystems, which have relatively modest nitrogen requirements from outside systems (Nair, 1993) [37].

Conclusion

Soil improvement under trees and agroforestry systems is in great part related to increases in organic matter, whether in the form of surface litter or soil carbon. This review gave a description of a few agroforestry systems practiced in relation to soil conservation and soil health.

Agroforestry system play crucial role in soil amelioration and improvement of soil health in many agroecosystem. This paper suggests incorporation and promotion of agroforestry practices considering their multidimensional approaches pertaining to soil health and management for sustainability.

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