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IMPROVEMENT OF SOIL FERTILITY IN AGROFORESTRY SYSTEMS OF CALCAREOUS SOILS

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Abstract: A significant increase was observed in exchangeable Ca, CEC, and water infiltration in the alleys of both the species. Chander et al. (1998) demonstrated that adoption of Dalbergia sissoo Roxb. ex DC., a N-fixing tree, under agroforestry significantly increased nutrient pool, organic biomass, and activities of enzymes—hydrogenases and alkaline phosphatases—in the soil. Further, agroforestry trees also help in improving soil physical and biological properties (Rao et al., 1998). Thevathasan and Gordon (2004) reported that tree intercropping under temperate AFS significantly enhanced the diversity of birds, insects, and earthworms; increased soil organic carbon content and N cycling; and improved soil health.

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Introduction:

Agroforestry is a sustainable land use system with a promising potential to sequester atmospheric carbon into soil. This system of land use distinguishes itself from the other systems, such as sole crop cultivation and afforestation on croplands only through its potential to sequester higher amounts of carbon (in the above- and belowground tree biomass) than the aforementioned two systems. According to Kyoto protocol, agroforestry is recognized as an afforestation activity that, in addition to sequestering carbon dioxide (CO_2) to soil, conserves biodiversity, protects cropland, works as a windbreak, and provides food and feed to human and livestock, pollen for honey bees, wood for fuel, and timber for shelters construction. Agroforestry is more attractive as a land use practice for the farming community worldwide instead of cropland and forestland management systems. This practice is a win-win situation for the farming community and for the environmental sustainability. This review presents agroforestry potential to counter the increasing concentration of atmospheric CO_2 by sequestering it in above- and belowground biomass. The role of agroforestry in climate change mitigation worldwide might be recognized to its full potential by overcoming various financial, technical, and institutional barriers. Carbon sequestration in soil by various agricultural systems can be simulated by various models but literature lacks reports on validated models to quantify the agroforestry potential for carbon sequestration.

Potential increases in carbon sequestration may occur in agricultural and forest lands via improved land use management, conversion to land use with higher carbon storage, or increased carbon storage in harvested products (IPCC, 2000). Agroforestry systems provide options to mitigate climate change with the possibility of increasing in crop yields, and providingother positive environmental outcomes such as climate change adaptation (Tubiello et al., 2008, Smith et al., 2013, Mbow et al., 2014; Luedeling et al., 2014; Coulibaly et al., 2017; Waldron et al., 2017).

In these systems, woody perennials (e.g. trees, shrubs, palms, bamboos) are cultivated in the same land-management unit with crops and/or animals, in some form of a spatial arrangement or a temporal sequence (Nair, 1993;Montero et al., 1998;Joffre et al., 1999).The diversification of the farm system into an agroforestry system can increase agricultural productivity, improve soil fertility, control erosion, conserve biodiversity, and diversify income for households and communities (Bishaw et al., 2013). Agroforestry systems are currently more common in temperate, sub-tropical and tropical zones, and include a wide range of land uses and practices (Torquebiau, 2000; Nair, 1985).In the tropics agroforestry systems are especially practised by smallholder farmers (Lorenz and Lal, 2014).

Soils are the largest carbon reservoirs of the terrestrial carbon cycle. Soil, if managed properly, can serve as a sink for atmospheric carbon dioxide. As the atmospheric CO2 concentration continues to increase globally, more attention is being focused on the soil as a possible sink for atmospheric CO2 . There is every possibility that atmospheric carbon dioxide concentration would increase in the near future. Under such circumstances, soil will remain a potent sink for atmospheric carbon-dioxide. The global soil organic carbon storage corresponds to 615 Gt C in the top 0.2 m depth and 2344 Gt C in depths of up to 3 m, which is more than the combined C content of biomass and atmospheric CO2. Soils constitute the largest pool of actively cycling carbon (C) in terrestrial ecosystems and stock about 1500- 2000 Gt C (to a depth of 1 m) in various organic forms ranging from recent plant litter to charcoal, to very old, humified compounds and 800 to 1000 Gt as inorganic carbon or carbonate carbon. The total quantity of CO2 -C exchanged annually between the land and atmosphere as gross primary productivity is estimated at ~120 Gt C yr-1 and about half of it is released by plant respiration. Soils are the largest carbon reservoirs of the terrestrial carbon. Soils contain 3.5% of the earth ís carbon reserves, compared with 1.7% in the atmosphere, 8.9% in fossil fuels, 1.0% in biota and 84.9% in the oceans (Lal, 1995). Mean residence time of soil organic carbon pools have the slowest turnover rates in terrestrial ecosystems and thus C sequestration in soils has the potential to mitigate CO2 emission to the atmosphere. Furthermore, higher carbon stabilization in soil is benefitting the other ecosystem functioning like improvement in soil structure, water holding capacity, nutrient retention, buffering capacity and greater availability of substrates for soil organisms. However, little is known about the actual achievable carbon level in soil under different agro-ecological regions of the country.

Improvement of Soil Fertility and Microclimate

Land degradation and declining soil fertility pose a major threat to agricultural productivity. Use of synthetic fertilizers to replenish soil nutrients fails to provide adequate solution. Incorporation of trees in the croplands can help in maintaining the nutrient pool and enhance soil fertility both under sequential and simultaneous agroforestry (Young, 1997; Rao et al., 1998; Giller, 2001; Thevathasan and Gordon, 2004; Jama et al., 2006b). Tejwani (1994) reported that AFS are an excellent strategy for reclamation of salt-affected soils. Tree litter and prunings improve soil fertility not only through the release of nutrients in the soil by mineralization but by also adding soil organic matter. However, it depends on the quality and quantity of tree litter or prunings, soil type, and climatic conditions of the area. Hulugalle and Ndi (1994) demonstrated that hedgerows of Senna (Senna spectabilis [DC] Irwin & Barneby) and Flemingia (Flemingia congesta [Willd.] Merrill) significantly improved soil properties in a newly cleared Ultisol (Typic Kandiudult) in southern Cameroon. In general, the mechanisms by which trees improve soil physicochemical and biological properties are as follows:

1. Release of nutrients from tree litter and prunings
2. Nitrogen input through biological nitrogen fixation (through N-fixing trees)
3. Phosphorus input through mycorrhizal associations
4. Reduced soil erosion and nutrient leaching
5. Nutrient capture from the subsoil through deep-rooted trees
6. Redistribution of nutrients through lateral roots of some trees

Another positive interaction between trees and crops is the improvement of microclimate through modification of temperature to reduce heat stress and evapotranspiration, improvement of crop– water efficiency and energy balance (Brenner, 1996; Jose et al., 2004).

Maintaining Water Quality

Agroforestry can also help in improving water quality by reducing levels of pollution and soil erosion and thus landscape amelioration (Nair and Graetz, 2004; Schultz et al., 2004). For example, riparian buffer zones, if well designed and properly located, can be very helpful in this direction (Dosskey, 2002). These buffers help in reducing the transport of polluted runoffs to the rivers and streams. Agroforestry also improves water-use efficiency and increases environmental sustainability. In addition, trees increase the water-holding capacity of the soil, reduce soil evaporation, increase water infiltration into the soil (Nair, 1993), and efficiently capture rainwater compared with traditional agricultural practices (Lott et al., 2002). Of late, it has been proposed that trees can efficiently increase water productivity, particularly under semiarid regions (Ong and Swallow, 2003; Ong et al., 2007)

Weed and Pest Management

In tropical and temperate agroecosystems, weeds and pests interact and interfere with crop plants and cause enormous harm to crop productivity. Their management is a big challenge and the indiscriminate use of synthetic herbicides and pesticides for controlling them has led to a number of problems like toxicological effects on the nontarget species, environmental degradation, and loss of sustainability of croplands. Presence of trees in agricultural lands may reduce weed populations because of the shading effect of trees, availability of less space for their growth, shifts in species composition, and altered environmental conditions (Liebman and Staver, 2001; Sileshi et al., 2006). Jama et al. (1991) demonstrated that alley cropping with Leucaena leucocephala (Lam.) de Wit reduced weed density by 90% and increased maize yield by 24%–76%. Incorporation of trees into the cropping system, particularly in the east and west Africa, holds a good potential for the control of parasitic weeds. For example, Gworgwor (2007) observed that Faidherbia albida (Del.) A. Chev. trees can fully eliminate Striga hermonthica (Del.) Benth. from pearl millet fields. AFS create a landscape that is important for biological pest control (Pandey, 2007). However, there are conflicting reports regarding the potential beneficial effects of trees in agroforestry for disease and pest management. Studies have indicated that due to modification of microclimate, water regime, moisture, air humidity, and surface temperature, the number of insects, pests, and pathogens increases, particularly near the tree line (Schroth et al., 2000). In contrast, other studies have indicated that trees, particularly as windbreak or hedgerow or shelterbelt, act as barrier to airborne pests and pathogens, repel them, and thus have a protective action (Rao et al., 2000). In addition, trees may provide more habitats for enemies of insect pests and thus more options for pest management (Middleton, 2001).

Further, allelopathic effects of tree mulch, prunings, and residues can also be useful in weed suppression (Singh et al., 2003). Allelochemicals from trees can be used for sustainably managing the weeds on the pattern of herbicides and pesticides. For example, ailanthone from tree of heaven (Ailanthus altissima [Mill.] Swingle), volatile monoterpenes as well as crude oil from Eucalyptus species, mimosine from L. leucocephala, and caffeine from Coffea arabica L. (Rizvi et al., 1999; Singh et al., 2003). Even plant–plant signals through allelochemicals within the soil can be exploited for weed management in a practical way rather than studying their direct physiological effects on the other plants (Birkett et al., 2001). For this, desirable allelopathic trees could be intercropped with crops to achieve weed management through rhizospheric allelochemicals-based signals.

Conserving Biodiversity

Biodiversity loss, particularly due to deforestation, is one of the major causes of worry to scientists. Agroforestry helps in reducing biodiversity loss by providing a protective tree cover along agricultural fields. The presence of trees further enhances diversity by providing shelter and habitat to a diversity of other flora and fauna. It also helps in conserving genetic diversity of ethnocultivars or landraces and trees that are in danger of loss and require priority conservation (Noble and Dirzo, 1997; Pandey, 2007). Further, it also helps in conserving traditional knowledge about the conservation of wild varieties of trees and other plants. Studies have shown higher biodiversity levels and species richness in AFS than in sole cropping systems (Estrada et al., 1993; Perfecto et al., 1996; Thevathasan and Gordon, 2004). Agroforestry helps in biodiversity conservation through (1) provision of secondary habitats for species, (2) reduction in the rate of conversion of natural habitats, and (3) creation of a benign and permeable matrix between habitat remnants (Schroth et al., 2004; McNeely and Schroth, 2006). AFS enhance diversity both at the site level as well as at the landscape level. At a given site, AFS have more diversity both at above- and belowground levels than the sole cropping system (Vandermeer, 2002; Ruark et al., 2003). AFS also provide refuge to species in the event of some catastrophic fire (Griffith, 2000). Gillison et al. (2004) reported that complex AFS and shade-grown coffee had higher biodiversity levels than simple sun-grown coffee; however, it was lesser than in the primary forests. Although AFS have less species diversity than the tropical forest, they have a variety of species diversity compared with traditional agricultural systems. Their rich diversity makes them ecologically resilient and thus gives them the ability to provide more and better ecological functions (Olson et al., 2000; Vandermeer, 2002). Altieri (1995) opined that since AFS are more diverse and have low-input strategies, these have greater biological interactions and thus are richer in biodiversity. Increased biodiversity further enhances chances of bioprospecting, that is, searching for new chemicals and plant-based products for the welfare of humanity. Guo (2000) viewed AFS as an excellent land-use practice for biodiversity conservation and sustainable development in the tropics. AFS also helps in reducing the dependence of local peasants or farmers on the natural resources of the protected areas—national parks and sanctuaries (Murniati et al., 2001).

Enhancing Food Security and Alleviating Poverty

Trees are the sources of a number of valuable and marketable products. Agroforestry helps in providing an opportunity to marginal and low-income farmers to improve their livelihood by marketing these products as household food, medicine, small timber, domestic wood supply, fiber, or fuel. It thus provides both food and economic security to farmers, particularly in the tropics (Garrity, 2004). Recently, agroforestry has been suggested to play a central role in improving food security, alleviating poverty, and natural resource management, particularly in east and central African regions (Ashley et al., 2006; Jama et al., 2006a; Leakey et al., 2006). Agroforestry adoption has also been viewed as a viable option to provide support in the form of value-added products (i.e., food, medicine, timber), livelihood, and income to HIV- or AIDS-affected communities, particularly in very poor regions of the world like sub-Saharan Africa (Garrity, 2004, 2006; Leakey et al., 2006). Leakey et al. (2006) advocated agroforestry as a new approach for sustainable rural development. However, much needs to be done in this direction to include underutilized and medicinal tree species, which can offer good economic returns to the farmers in addition to providing other benefits of AFS.

Carbon Sequestration and Greenhouse Gas Mitigation

World over, scientists are facing the challenging problem of loss of carbon (C) stocks in the terrestrial ecosystems and increase in the levels of green house gases in the atmosphere. AFS have a great scope in sequestering aboveground and belowground (soil) C and help in mitigating the greenhouse effect by reducing C emissions (Dixon et al., 1994; Wang and Feng, 1995; Batjes and Sombroek, 1997; Pandey, 2002; Albrecht and Kandji, 2003; Montagnini and Nair, 2004; Lal, 2005). Trees can store C both ex situ (products) as well as in situ (biomass and soil) and are considered as effective C sinks (Montagnini and Nair, 2004). Though the exact potential of agroforestry trees for this purpose is largely unknown, yet some preliminary reports are available. AFS, particularly in the tropics, can even ease the environmental degradation caused by deforestation and reduce the pressure on natural forests (Dixon, 1995). He estimated that AFS on 1 ha of land could compensate the loss caused by 5–20 ha of deforestation. Recently, agroforestry practices in humid tropics have been reported to reduce soil emission of N2O and CO2 and increase the CH4 sink strength when compared to agricultural systems (Mutuo et al., 2005). However, extensive research is required to quantify exactly this underexploited C sequestration potential of AFS, in general, and under specific management patterns. Similar to the impact on global C balance, AFS can also ameliorate the greenhouse gas, particularly nitrous oxide (N2O), emission. Liang and Thevathasan (2003) demonstrated that intercropping of Populus into AFS reduced N2O emissions by 0.69 kg hm2 a 1 . Thevathasan and Gordon (2004) reported that trees intercropped in AFS reduce the N2O emissions due to reduced fertilizer use and efficient N cycling. However, the mitigation of greenhouse gas emission under AFS varies greatly with the tree species used and depends on the C:N ratio, polyphenol content, and protein-binding capacity (Millar and Baggs, 2004).

Phytoremediation and Environmental Clean-Up

Garrett and Buck (1997) suggested that AFS including trees as intercrops, riparian plantations, shelterbelts, and windbreaks have a good potential for cleaning up the contaminated soils. Schultz et al. (1995) reported that multispecies riparian buffer strips are very effective in stopping sediments and flow of runoff nutrients, pesticides, and fertilizers. In this direction, short-rotation woody trees like Populus, Salix, Eucalyptus, Pinus, and Acacia spp. incorporated under AFS hold a great potential for remediation of soil contaminated with heavy metals, pesticides, herbicides, and organic compounds (Rockwood et al., 2004).

Shading Effect

Although the reports available in the literature concerning the effects of shade or competition for light vary greatly, shading by agroforestry trees generally has negative effects on crop productivity. However, it depends on soil type, climate, crop or tree species, and the management practices (Ong and Huxley, 1996; Huxley, 1999). On the other hand, shading may have either no (Gillespie et al., 2000) or even positive effect on associated crops under a given set of environmental conditions. For example, shading by trees increased forage yield (Lin et al., 1999), reduced pest density in intercrops (Stamps and Linit, 1998), and decreased weed density and increased maize yield (Jama et al., 1991). However, it depends on the soil fertility status, especially the N content. The physiological mechanism by which shading affects crop productivity could be the interception of photosynthetically active radiations (PAR) and thus the quantity and quality of light reaching crops (Chirko et al., 1996), and differences in carbon fixation pathways, that is, C3 or C4 plants (Jose et al., 2004). Pillar et al. (2002) demonstrated the shading effect of Eucalyptus spp. on grass communities and indicated that differences occurred in cover abundance of C3 and C4 species. Increased shading by tree canopy reduced the cover abundance of C4 species and increased the number of C3 species (Pillar et al., 2002).

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