Study on Review of Literature on Carbon Sequestration in Agroforestry Systems

Manju Kodope,Research Scholar, Department of Botany, SunRise University, Alwar, Rajasthan (India)
Dr. Devendra Kumar, Assistant Professor, Department of Botany, SunRise University, Alwar, Rajasthan (India)

ABSTRACT:

Agroforestry has been defined in various ways. The World Agroforestry Centre (www.icraf.cgiar.org) defines it as ‘‘a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels.’’ The Association for Temperate Agroforestry, AFTA (www.aftaweb.org) defines it as ‘‘an intensive land-management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock.’’ Several other definitions are also available (Nair, 1993). In essence, they all refer to the practice of the purposeful growing of trees and crops, and/or animals, in interacting combinations, for a variety of benefits and services (Nair et al., 2008, 2009a).

Keywords: **REVIEW OF LITERATURE, CARBON SEQUESTRATION, AGROFORESTRY SYSTEMS**

INTRODUCTION:

Globally, an estimated 700, 100, 300, 450, and 50 Mha of land are used for tree intercropping, multistrata systems, protective systems, silvopasture, and tree woodlots, respectively (Nair 2012b). Numerous and diverse agroforestry systems are especially practiced in the tropics because of favorable climatic conditions and various socioeconomic factors. Tropical and temperate agroforestry practices can be grouped under the subgroups (a) tree intercropping, (b) multistrata systems, (c) silvopasture, (d) protective systems, and (e) agroforestry tree woodlots (Nair and Nair 2014).

The awareness of agroforestry’s potential for climate change adaptation and mitigation in boreal and temperate systems is growing (Nair et al. 2008; Schoeneberger et al. 2012). Growing agroforestry biomass for biopower and biofuels and thereby replacing fossil fuel has also the potential to reduce increases in atmospheric CO2 (Jose and Bardhan 2012). Thus, agroforestry has been recognized as having the greatest potential for C sequestration of all the land uses analyzed in the Land-Use, Land-Use Change and Forestry report of the IPCC (2000).

Agroforestry was also included in global programs such as Reducing Emissions from Deforestation and Forest Degradation including the role of conservation, sustainable management of forests, and enhancement of forest C stocks (REDD+) related to climate change adaptation and mitigation (Nair and Garrity 2012). Further, implementation of some agroforestry systems has been recommended to reduce soil erosion and improve water quality (WBCSD 2010). Agroforestry is a key approach in the integration of climate change adaptation and mitigation objectives, often generating significant co-benefits for local ecosystems and biodiversity, and should be promoted in the voluntary and compliance C markets (Matocha et al. 2012; Stavi and Lal 2013). While providing project financing and a source income to resource-poor farmers and smallholders, agroforestry practices can make a significant contribution to climate change mitigation by C sequestration in vegetation and soil (FAO 2009).

However, designing co-benefit smallholder agroforestry projects for climate and development is challenging (Anderson and Zerriffi 2012). In conclusion, land-based C sinks including those in agricultural ecosystems take up about one third of anthropogenic CO2 emissions. Some practices of agroforestry, i.e., the purposeful growing of trees and crops and/or animals in interacting combinations, have received increased attention for their capability to store C in plants and soil.

Review of Literature:

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The potential of agroforestry systems for C sequestration depends on the biologically mediated uptake and conversion of CO_2 into inert, long-lived, C-containing materials, a process which is called biosequestration (U.S. DOE 2008). Biosequestration temporarily removes C from active cycling. More generally, C sequestration can be defined as the uptake of C-containing substances and, in particular, CO_2 into another reservoir with a longer residence time (IPCC 2007). However, it has become customary for the term C sequestration to imply a contribution to climate change mitigation (Powlson et al. 2011). For this reason, C sequestration in an agroforestry system must slow or even reverse the increase in atmospheric concentration of CO_2. Thus, movement of C from one reservoir in the system to another should be appropriately termed accumulation, whereas an additional transfer of C from the atmosphere into a reservoir of the agroforestry system should be termed sequestration as this process is a genuine contribution to climate change mitigation (Powlson et al. 2011). However, there is little consensus in the literature what the term C sequestration means (Krna and Rapson 2013). The reasons why a specific agroforestry practice contributes to C sequestration at a specific site whereas another practice does not are not well known (Jose and Bardhan 2012).

Some SOC in agroforestry systems may persist for millennia indicating that terrestrial sequestration for climate change mitigation occurs particularly by avoided net SOC losses and the slowly ongoing accumulation of the slowest SOC pool (Mbow et al. 2014; Schmidt et al. 2011; Wutzler and Reichstein 2007). However, there is lack of consensus over the period for which C has to be immobilized in soil before it is considered to be sequestered as a useful contribution to climate change mitigation (Krna and Rapson 2013; Mackey et al. 2013). For climate change mitigation, C may remain stored not just for 100 years, but probably for more than 10,000 years. Specifically, a “pulse” or unit of CO_2 emitted to the atmosphere is only fully removed from the atmosphere so that it no longer interacts with the climate system when it has completely dissolved in the deep ocean. This process requires the concurrent dissolution of carbonate from ocean sediments lasting about 5,000 to 10,000 years and enhanced weathering of silicate rocks lasting around 100,000 years (Mackey et al. 2013). Thus, SOC sequestration requires that C must persist for very long periods of time in soil by stabilization processes that reduce the probability and, therefore, rate of SOC decomposition. The aim of using agroforestry systems for climate change mitigation should be reducing SOC losses and enhancing SOC stabilization as the SOC pool contains organic matter (OM) with radiocarbon ages of 1,000 to more than 10,000 years especially in subsoil horizons (Schmidt et al. 2011). This article focuses on the relationship between agroforestry practices and SOC sequestration causing a net additional long-term removal of CO_2 from the atmosphere as this process is a genuine contribution to climate change mitigation (Stockmann et al. 2013). In conclusion, useful C sequestration in agroforestry systems for climate change mitigation must slow or even reverse the increase in atmospheric concentration of CO_2 by storing some SOC for more than 10,000 years.

Previous terrestrial C sequestration efforts have largely focused on adaptive management of existing forests and conservation tillage of croplands (Perry et al. 2008). However, tree-based farm practices such as agroforestry systems are a viable C sequestering option. Agroforestry systems have, in particular, a higher potential to sequester atmospheric CO_2 than the croplands, pastures, or natural grasslands, i.e., treeless land uses they replace, but effects on SOC vary greatly depending on biophysical and socioeconomic characteristics of the system parameters (Nair et al. 2009a; Nair and Nair 2014). The incorporation of trees, in particular, improves soil properties and can result in greater net C sequestration (Young 1997).

Trees have extensive root systems which can grow deep into the mineral soil. The root-derived C inputs are critical sources for the SOC pool in deeper soil horizons (Kell 2012). Specifically, root-derived C is more likely to be stabilized in the soil by physicochemical interactions with soil particles than shoot-derived C (Rasse et al. 2005). For example, the relative root contribution of European beech (*Fagus sylvatica* L.) to SOC was 1.55 times than that of shoots (Scheu and Schauermann 1994). Similarly, in croplands, total root-derived C contributed between 1.5 times to more than 3 times more C to SOC than shoot-derived C (Johnson et al. 2006). Thus, agroforestry systems store more C in deeper soil layers near trees than away from trees (Nair et al. 2010). However, quantitative information about belowground C inputs in agroforestry systems is scanty (Schroth and Zech 1995).

Aside from deep soil C inputs, another reason for the promotion of SOC sequestration in agroforestry systems is that tree roots have the potential to recover nutrients from below the crop rooting zone. The resulting enhanced tree and crop plant growth by subsequent increase in nitrogen (N) nutrition may result in an increase in SOC sequestration (van Noordwijk et al. 1996). Similar, mixed plantings with N-fixing trees may cause higher biomass production and, thus, SOC sequestration and pools particularly in deeper soil horizons as N may promote humification rather than decay, but SOC and N interactions are not entirely understood (Gärdenäs et al. 2011; Nair et al. 2009a). Also, changes in microbial decomposer community composition under N-fixing trees may result in greater retention of relatively stable SOC (Resh et al. 2002). N-fixing trees in mixtures with non-N-fixing trees may develop deeper root profiles due to niche partitioning (da Silva et al. 2009). Mixed tree plantings in agroforestry systems may enhance SOC sequestration as increases in tree species diversity may potentially result in increases in fine root productivity (Meinen et al. 2009; Schroth 1999). Further, higher species richness and tree density can result in higher SOC contents in agroforestry systems (Saha et al. 2009). In addition to fixing N, fertilizer trees may recycle the soil's phosphorus, calcium, magnesium, and potassium (Ajayi et al. 2011). However, interspecific root competition may affect SOC sequestration (Schroth 1999). For example, the roots of wheat (*Triticum aestivum* Linn.) intercropped with jujube (*Z iziphus jujuba* Mill.) trees had more shallow distribution in the soil profile and smaller root length densities than mono-cropped wheat (Zhang et al. 2013). In addition, the roots of intercropped jujube trees occupied a comparatively smaller soil space than sole-cropped trees. Decreased soil exploration and apparent root competition led to decreases in yield and biomass (Zhang et al. 2013). This may result in decreased soil C inputs but few experimental studies have quantified patterns of root distribution and their impacts on interspecific interactions in agroforestry systems (Schroth 1999).

Among the reasons for the positive effects of trees on SOC sequestration are that trees modify the quality and quantity of belowground litter C inputs and modify microclimatic conditions such as soil moisture and temperature regimes (Laganière et al. 2010). Root litter usually decomposes more slowly than leaf litter of the same species (Cusack et al. 2009). Further, hydraulic lift of soil water by roots of a single tree may enhance soil water uptake by neighboring trees and other plants in the agroforestry system which may affect SOC sequestration due to an increase in productivity and accelerated decomposition (Kizito et al. 2006; Liste and White 2008). Trees may have a higher potential for SOC sequestration than crop and pasture plant species as trees may be associated with higher proportions of stabilized SOC in deeper mineral soil horizons (Nepstad et al. 1994; Jobbágy and Jackson 2000). Trees contribute to more C in the relatively stable silt- + clay-sized, i.e., lower than 53 μm diameter, fractions in deeper soil profiles than any other agroforestry species (Nair et al. 2009b). Further, in surface soil horizons of intensively managed agricultural landscapes, trees potentially reduce SOC losses by reducing soil erosion (Lal 2005). The changes in soil microbial communities and activities and biodiversity under trees may also enhance SOC sequestration. For example, the addition of a single tree species to moorland resulted in changes in belowground soil microbial communities and in nutrient cycling (Mitchell et al. 2010). However, field studies on the mechanisms and processes associated with C dynamics and storage in tree-based systems such as agroforestry systems are scanty.

The integration of trees into agricultural production systems may create positive interactions such as enhanced productivity, cycling of nutrients, soil fertility, and macroclimate (Nair et al. 2010). However, there are also many possible negative interactions. For example, pests aside from drought, bush fires, or other biotic or abiotic factors may contribute to poor tree performance in agroforestry systems in Africa (Sileshi et al. 2007). Further, understory species may be negatively affected by the tree presence, and trees and crops may compete for water (Burgess et al. 2004). The competitive relationship of tree and understory depends, in particular, on edapho-climatic conditions (Mosquera-Losada et al. 2010; Rigueiro-Rodríguez et al. 2009). Allelopathic and disease vectors are other possible negative interactions in agroforestry systems. Allelochemicals are present in many types of plants and are released into the soil by a variety of mechanisms (Jose et al. 2004). Mulching with plant residues, in particular, may result in the liberation of allelochemicals into the soil (John et al. 2006). Allelochemicals affect germination, growth, development, distribution, and reproduction of a number of plant species (Inderjit and Malik 2002). Most of the tropical agroforestry species compared by Rizvi et al. (1999) have negative allelopathic effects on food and fodder crops. Allelochemicals may also contribute to pest management as trees live long and produce a large amount of leaves and litter. Thus, species mixtures with no or positive allelopathic effects on the companion crops must be created in agroforestry systems (Rizvi et al. 1999). Less well studied are allelopathic effects of temperate agroforestry species (Jose et al. 2004). However, allelopathic investigations in agroforestry systems are often lacking conclusive field verification. For example, separating allelopathic effects of trees from root competition is challenging (John et al. 2006).

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