Study on Historical Development of Carbon Sequestration in Agroforestry Systems

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ABSTRACT:

Today, agroforestry is recognized as an integrated applied science that has the potential for addressing many of the land-management and environmental problems found in both developing and industrialized nations. Numerous and diverse AFSs can be found in the tropics, partly because of their favorable climatic conditions, and partly because of the socioeconomic factors such as human population pressure, higher labor availability, smaller land-holding size, complex land tenure, and closer proximity to markets (Nair, 2007; Nair et al., 2008).

Keywords: **HISTORICAL DEVELOPMENT, CARBON SEQUESTRATION, AGROFORESTRY SYSTEMS**

INTRODUCTION:

The IPCC's Second Assessment in 1996, along with additional special materials, provided key input to the negotiations that led to the adoption of the Kyoto Protocol to the UNFCCC in 1997. The Kyoto Protocol, ratified by 190 countries as of December 2009 (UNFCCC, 2010), is an international agreement that establishes binding targets for reducing the heat-trapping emissions of the so-called greenhouse gases (GHGs) from industrialized countries. Among the GHGs, CO_2 is believed to be the most prominent one (other significant gases are methane, CH_4, and nitrous oxide, N2O) causing global warming (Lorenz and Lal, 2010). Atmospheric concentration of CO2 has increased from the preindustrial level of about 280 ppm to the current levels of approximately 380 ppm, and is estimated to be increasing at the rate of 2 ppm annually (Tans, 2009). Thus, reducing global warming entails reducing the atmospheric concentrations of GHGs, particularly CO2. Such reductions are brought about by carbon sequestration (CS), the process of removing carbon (C) from the atmosphere and depositing it in a reservoir, or the transfer of atmospheric CO2 to secure storage in other long-lived pools (UNFCCC, 2007).

Land Use, Land Use Change and Forestry (LULUCF), an approach that became popular in the context of the Kyoto Protocol, allows afforestation and reforestation (A & R) as GHG offset activities. Forest-, crop-, and grazing-land management, and revegetation were added to the detailed list of LULUCF activities in 2001 as an important means to capture and store atmospheric CO2 in vegetation, soils, and biomass products. Consequently, agroforestry became recognized as a CS activity under the A & R activities, and agroforestry systems (AFSs) attracted attention as a CS strategy from both industrialized and developing countries (Albrecht and Kandji, 2003; Haile et al., 2008; Makundi and Sathaye, 2004; Nair and Nair, 2003; Nair et al., 2009a; Sharrow and Ismail, 2004; Takimoto et al., 2008a,b). Since the Clean Development Mechanism (CDM) under the Kyoto Protocol allows industrialized countries with a GHG reduction commitment to invest in mitigation projects in developing countries, there is an attractive opportunity for subsistence farmers in developing countries, who are the major practitioners of agroforestry, to benefit economically from their agroforestry practices. Thus, the role of agroforestry as a CS strategy has raised considerable expectations. Since soils are a major reservoir of C (discussed in Section 3.3), an understanding about C storage in soils under AFSs is particularly important. It is also relevant from the soil fertility point—the traditional role of C in land-use. The objective of this review is to assess the realistic potential of agroforestry as a biological approach to CS in the light of available scientific results, and examine the management approaches to realizing this seemingly underexploited potential of agroforestry. To set the stage, we will first present a brief account of the status of the science and practice of agroforestry.

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).

Historical development

The practice of growing trees and crops together has been prevalent for many centuries in different parts of the world, especially under subsistence farming conditions. Homegardening, a major agroforestry practice today and one of the oldest forms of agriculture in Southeast Asia (Kumar and Nair, 2006), is reported to have been associated with fishing communities living in the moist tropical region about 13,000–9000 BC (Wiersum, 2004). Agroforestry in Europe is reported to have started around 4000 BC, when domestic animals were introduced in forests for feeding. The dehesa (animal grazing under trees) system of Spain is reportedly 4500 years old. It has been only during the past three decades, however, that these indigenous forms of growing trees and crops/animals together have been brought under the realm of modern, scientific land-use scenarios (Nair et al., 2008). The motivations for taking a new look at the old practices were several. In the tropics, the Green Revolution of the 1970s (Evenson and Gollin, 2003) largely did not reach the poor farmers and those in less-productive agroecological environments. In addition, defective land-management practices resulted in increased tropical deforestation, fuelwood shortage, soil degradation, and biodiversity decline. The search for strategies to address these problems focused the attention on the age-old practice of combining production of trees, crops, and livestock on the same land unit, and an appreciation of their inherent advantages and led to the establishment of an international center, ICRAF, in 1977 (Steppler and Nair, 1987). The center, now known as the World Agroforestry Centre (www. worldagroforestry.org), one of the CGIAR—Consultative Group of International Agricultural Research—institutions, was initially called the International Council—and subsequently Centre—for Research in Agroforestry (ICRAF). Agroforestry thus began to be recognized and incorporated into national agricultural and forestry research agendas in many developing countries during the 1980s and 1990s (Nair, 1989, 1993).

In temperate regions, ''modern'' agroforestry had a slower evolution than in the tropics. It started with an increased perception on the part of the general public about the environmental consequences of high-input agriculture and forestry. The single-species emphasis of food and wood production in commercial systems has caused considerable decline of biological (including genetic) diversity: compare the diversity of corn (Zea mays L.), soybean (Glycine max (L.) Merr.) or pine (Pinus spp.) production systems with the approximate 100 species found in an oak (Quercus spp.)—hickory (Carya spp.) forest (Gordon et al., 2009). When the entire American food system, from field to table, is considered, 42 kJ of energy input is estimated to be required for each kilojoule consumed (Brown, 2004; www.earthpolicy.org; accessed 16 February 2010). The land-use and land-cover changes associated with the removal and fragmentation of natural vegetation for establishment of agricultural and forestry enterprises and real-estate development are responsible, to a large extent, for the decline in biodiversity, invasion of exotic species, and alterations to nutrient, energy, and water flows, resulting in soil erosion, water-quality deterioration, and environmental pollution (Brown, 2004). Public demand for environmental accountability and application of ecologically compatible management practices increased when the problems associated with row-crop agriculture became clearer. Consequently, the concept of agroforestry gained acceptance as an approach to addressing some of these problems. That led to the development of agroforestry applications in North America and other temperate zones such as Australia and New Zealand, Europe, and China, demonstrating the range of conditions under which

agroforestry can be successfully applied (Garrett, 2009; Nair et al., 2008).
Agroforestry is a dynamic, ecologically base land-use system in which woody perennials are grown along with crops for maintaining soil productivity and biological diversity (Young 1997, Nair 2007). Agroforestry is a useful strategy for soil carbon sequestration for mitigating the impact of climate change under Clean Development Mechanism of Kyoto Protocol (IPCC 2000, Nair 2007). Agroforestry has productive functions as well as provide various ecological services (Young 1997, ICAR 2006, Gupta et al. 2006). A range of products including fuel wood, fodder, fruit, gum, resin and medicinal products can be provided by combining trees and herbaceous plants in agroforestry systems. The service function of agroforestry are in control of soil erosion, wind breaker, maintenance and improvement of soil fertility, control of weeds and fencing, and carbon sequestration in soil (ICAR 2006, Gupta et al. 2009, Nair et al. 2009, Jose 2009) and biodiversity conservation (Pandey 2007). The traditional agroforestry systems in different regions of world support the livelihood people through simultaneous production of timber, food, fodder and firewood (Lundgren 1982, Young 1997). Agroforestry has potential to store carbon in plant biomass and wood products (Schoeneberger 2008). Sustainability of agroforestry is increased with plant diversity (Bernholt et al. 2009).
The oldest form of agroforestry, Toungya system was established in Burma with plantation of teak and wheat as early as 1808. Traditional agroforestry was introduced in South Africa as early as 1887 and in Bengal in 1896. The traditional practice of agroforestry has been prevalent in Kerala, in Uttar Pradesh and Madhya Pradesh in early 20th century. Research work on managed agroforestry was initiating during late 1960s and 1970s (Chundawat and Gautam 1996, Young 1997) in India through a National Co-coordinated project on agroforestry by Indian Council of Agricultural Research and establishment of National Research Centre for Agroforestry in Jhansi in 1988 (ICAR 2006). In India, there are about 39 centers of agroforestry research in different agro-climatic regions. Most of agroforestry is being practiced by resource poor farmers in different regions of world to increase biological productivity from the land and conserving biodiversity (ICAR 2006).
An agroforestry system generally has at least two plant species interacting biologically, one of the plant species is woody perennial and plant species are managed for producing forage, food crops and plantation crops (ICAR 2006). In a good agroforestry system, the trees are characterized by root systems that are below the crop zone, make use of the water from deeper layer of soil, lower competition with crop and positive biological interaction with crops and micro-organisms (Gupta et al. 2009). Normally tree roots act as safety nets and capture the nutrients that are prone to loss because of leaching (Jose 2009). So tree in agroforestry can help in maintaining the nutrient pool and enhancing soil productivity (Kumar 2006, Gupta et al. 2009).
To obtain the maximum benefits from the agroforestry the negative link such as alleopathic effects of trees on crop, entry of invasive species in agricultural land and trees serving as habitat for harmful pests and diseases are minimized through various management practices (Gupta et al. 2009).
On the basis of component present, agroforestry systems have been classified as agrisilvicultural (woody plants with crops), silvipastoral (trees with pastures and or animals) and agrisilvopastoral having crops, pasture and or animals and woody plants (Nair et al. 2009, ICAR 2006, Gholz 1987). Agroforestry has great potential for a sustainable alternative land use on marginal lands (Miller and Nair 2006, Jose 2009) and has great potential for biological carbon sequestration (Nair et al. 2008). At present, the area cover under agroforestry is 1023 Mha world wide and in India it is 96 Mha (ICAR 2006, Nair et al. 2009, Pandey 2007, Jose 2009). According to the estimates of IPCC, 630 Mha of unproductive croplands and grasslands could be used for agroforestry world wide with a potential to sequester 391,000 Mg C yr^{-1} by 2010 and 586000 Mg C yr^{-1} by 2040 (IPCC 2001, Nair et al. 2009).
Recent geospatial analysis of remote-sensing derived global database by the World

ISSN -2393-8048, July-December 2020, Submitted in December 2020, iajesm2014@gmail.com
Agroforestry Centre and other collaborators, the geospatial analysis at 1km resolution has confirmed that agroforestry is practiced on about one billion of agricultural land world wide (Saha et al. 2009). About 1.5 billion farmers practice agroforestry in different regions of India, primarily small land holders, in developing countries. Agroforestry is also an important land-use activity in the industrialized countries of North America and Europe (Nair et al. 2008).
Tree plantations and agroforestry systems are useful in rehabilitation of degraded lands and checking soil erosion (Gupta et al. 2006). The role of small holder agroforestry in carbon sequestration and carbon dynamic was emphasized by Roshetko et al. (2005). Small holder agroforestry system should be beneficial for carbon sequestration or carbon trading in CDM of Kyoto protocol. Carbon sequestration potential of smallholder agroforestry systems has been found to depend upon species diversity, tree density and management practices (Roshetko et al. 2005, Jose 2009). Agroforestry provides other multiple benefits such as biodiversity conservation, water quality improvement and improvement of micro-climate (Gupta et al. 2006, Pandey 2007, Moco et al. 2008, Schoeneberger 2005, ICAR 2006).

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