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Potential of Agroforestry for Climate Change Mitigation through Carbon Sequestration: Review Paper

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Abstract

Climate change is widely accepted that human activities are now increasingly influencing changes in global climate. Carbon emission is higher from deforestation and forest degradation. However, this can be managed through the sustainable management of land and forest. Thus, the purpose of this review paper is to present the compiled studies which have been done on the potential of agroforestry in climate change mitigation through carbon sequestration. The enhancement of forest C stocks through agroforestry can be considered as one of the main options for reducing greenhouse gases in the atmosphere Agroforestry is a unique extensive action involving the integration of woody plants with crop and livestock components. Therefore, in the recent decades, the role of agroforestry in climate change mitigation received strong attention. Thus, the greatest role of agroforestry in relation to climate change is in mitigating the emissions of CO2 by sequestering carbon from the atmosphere. Because the adoption of agroforestry practice has greater potential to increase C sequestration of predominantly agriculture dominated landscapes than the monocrop agriculture.

Keywords: Agroforestry; Carbon sequestration; Climate change; Mitigation; Atmosphere; Landscapes; Woody plants; Crop; Greenhouse gases

Introduction

Climate change is evident to all of us. It is a global problem affecting all over the countries. Now more than anything else, climate change is going to be alarming and emergency for all worldwide. Particularly, developing countries are going to bear the brunt of climate change and suffer most from its negative impacts. Mitigation efforts will only provide a partial softening of the effects of climate change. Climate change is widely accepted that human activities are now increasingly influencing changes in global climate [1]. Local climates and terrestrial ecosystems will change, threatening biota and human livelihoods. Potential adverse impacts of climate change include sea-level rise; increased frequency and intensity of wildfires, floods, droughts, and tropical storms; changes in the amount, timing, and distribution of rain, snow, and runoff; and disturbance of coastal marine and other ecosystems [2].

Agricultural systems affected by unsustainable management, and land and resource degradation are the most vulnerable to climate change. Agricultural practices lead to the reduction in carbon stocks mainly due to removal of aboveground biomass as harvest with subsequent burning and decomposition, loss of soil carbon as CO_2, and loss of soil C by erosion. Tropical deforestation contributes as much as 25% of the net annual CO_2 emissions worldwide [3]. Atmospheric CO_2 concentration currently is about 388ppm & predicted to increase to approximately 470 – 570 ppm until year 2050 [4]. Trees have important roles in reducing vulnerability, increasing resilience of farming systems and buffering households against climate related risks [5]. Globally, forestry has taken a central stage as one of the options to mitigate CO_2 climate change. Conversely, agriculture & plantation could also be a solution for climate change by adoption of mitigation and adaptation action [5]. This happens with the help of well managed agroforestry practices [6]. Agroforestry is an interface between agriculture and forestry as a promising and sustainable land use practice in developing countries where trees on farmland form an integral part of the farming system [7]. It is an integrated

approach to solving land-use problems by allowing farmers to produce food, fiber, fodder, and fuel simultaneously from the same unit of land. In agroforestry system there are both ecological and economical interactions between the different components [8,9]. Some agroforestry practices received increased attention regarding their net carbon sequestration effect by their ability to capture atmospheric CO_2 and store carbon in plants biomass and soil [10]. Thus, the purpose of this review paper is to present the compiled studies which have been done on the role of agroforestry in climate change mitigation through carbon sequestration (Table 1).

Table 1: Carbon sequestration potential of different agroforestry system.

Agroforestry System	Carbon Accumulation
Taungya agroforestry system	174MgC ha^{-1}
Mixed multistory/multistery system	162MgC ha^{-1}
Falcata-coffee multistorey system	92MgC ha^{-1}

Methodology

This is exclusively a review paper. All of the information has been collected from the secondary sources. All the data herein were compiled from documents (such as, published articles, books, reports, dissertations and conference proceedings) including Google Scholars. Some studies were also identified through a manual Google search. Additional articles were also searched from the reference lists of retrieved articles. No restriction was applied on the year of publication, methodology, or study subjects. Primary search terms were "climate change", "agroforestry", "mitigation", "adaptation" and "Carbon Sequestration".

Discussion

In this section the role of agroforestry in mitigating to climate change through carbon sequestration were summarized, based on reports by various studies across the world. Here, this part includes concept of an agroforestry system, carbon sequestration and potential of agroforestry for climate change mitigation.

Definition and basic concepts

Agroforestry is a unique extensive action involving the integration of woody plants with crop and livestock components [3,11]. Therefore, in the recent decades, the role of agroforestry in climate change mitigation and adaptation received particularly strong attention [12]. Noteworthy among such practices in tropical environments include incorporation of fast-growing, nitrogen fixing trees and shrubs in agricultural fields to improve soil fertility and minimize erosion, improved management of fallows, domestication of new and underutilized tree species, and intensification of agriculture on smallholder farms through use of appropriate tree and shrub species [11]. Climate change mitigation consists of actions to limit the magnitude or rate of long-term global warming and its related effects [2]. Climate change mitigation generally involves reductions in human (anthropogenic) emissions of greenhouse gases (GHGs) [3]. Mitigation may also be achieved by increasing the capacity of carbon sinks, e.g., through reforestation [3]. Mitigation policies can substantially reduce the risks associated with human-induced global warming [4].

"Mitigation is a public good; climate change is a case of the 'tragedy of the commons'. Effective climate change mitigation will not be achieved if each agent (individual, institution or country) acts independently in its own selfish interest (see International cooperation and Emissions trading), suggesting the need for collective action [13]. Carbon dioxide is the most commonly produced greenhouse gas. Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change [14].

Agroforestry for climate changes mitigation through carbon sequestrations

Agroforestry for climate changes mitigation: Climate change has strong relationship with agriculture; typically, in developing countries where their livelihood directly associates to farming activities which particularly used rain fed [5]. Different authors such as [5,11,15-16] described their studies how much agricultural systems are the most vulnerable to climate change. A tropical agriculture, particularly subsistence agriculture is vulnerable, as smallholder farmers do not have adequate resources to adapt to climate change [11]. Used improved agricultural practiced incorporating with trees is one of the alternating and promising strategies to combat climate change. In fact, currently agroforestry is going to be a "bright sector" for combating climate change in different parts of the world. Additionally, agroforestry is considered as cost-effective strategy. Agroforestry systems have the potential to provide significant mitigation options, but they require proper management that influences the amount of carbon sequestered [17]. [12] Under his study, in Africa while agroforestry may play a significant role in mitigating the atmospheric accumulation of greenhouse gases (GHG), it also has a role to play in helping smallholder farmers adapt to climate change. With the majority of research, in Africa, of all agricultural land management activities suggested for GHG mitigation, agroforestry practices have been the most widely applied and studied too [18]. [19] Under reviewed paper, clarified agroforestry as a coping mechanism with the adverse impact of climate change and it provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation. As he said, agroforestry has the ability to enhance the resilience of the system for coping with the adverse impacts of climate change. Research done in Kenya described that the potential of agroforestry systems in the adaptation to expected changes in climate by smallholder farmers in the tropical regions in general and in sub-Saharan Africa in particular. Regarding to this result, agriculture is one of the high priority sectors where the impacts of climate change exceed tolerance limits with implications for the livelihoods of millions of smallholder farmers dependent on this sector.

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Then put prospects task for development and to alleviate such problems as used agroforestry interventions, because of their ability to provide economic and environmental benefits, are considered to be the best "no regrets" measures in making communities adapt and become resilient to the impacts of climate change by using potential agroforestry systems in the area [11] Further study in Ethiopia by [5] revealed, trees have important roles in reducing vulnerability, increasing resilience of farming systems and buffering households against climate related risks. The tree component of the agroforestry systems can be a significant sink for carbon in lands devoted to agriculture. A significant amount of carbon emission caused by deforestation could be reduced by establishing agroforestry systems [5]. Agroforestry showed a great potential in mitigating CO_2 than treeless systems. Therefore, this could imply that concerted effort should be made by different stakeholders in supporting agroforestry.

Agroforestry addresses climate change through; it reduces the need for deforestation because it provides wood products from the farmland; it reduces the need to use fertilizers by improving soil quality & maintaining good nutritional balance and fertility [20]. Also, Agroforestry strengthens agricultural resilience by increasing crop yields and offering better environment for farm animals [21]. It also modifies microclimate in ways that can improve crop yields from 6 to 56 % depending on crop type. Reducing soil erosion from water and wind, and improving soil physical condition and fertility, Climate variability is well buffered by agroforestry because of permanent tree cover & varied ecological niches. Creating habitat, protecting biodiversity, including pollinators and beneficial insects are the most important aspect of agroforestry system in fact [20,22] also indicated agroforestry has the potential to restore degraded lands, provide a broader range of ecosystem goods and services such as carbon (C) sequestration and high biodiversity, and increase soil fertility and ecosystem stability through additional C input from trees, erosion prevention, and microclimate improvement.

Carbon sequestration through agroforestry system: Carbon emission is higher from deforestation and forest degradation [10]. However, this can be managed through the sustainable management of land and forest. The enhancement of forest C stocks through agroforestry can be considered as one of the main options for reducing greenhouse gases in atmosphere. For instance, the U.S. produces about 25% of global CO2 emissions from burning fossil fuels [23]. The greatest role of agroforestry in relation to climate change is perhaps in mitigating the emissions of CO_2 by productively sequestering carbon from the atmosphere. According to [24] from the agroforestry point of view, C sequestration primarily involves the uptake of atmospheric CO_2 during photosynthesis and the transfer of fixed C into vegetation, detritus, and soil pools for "secure" (i.e. long-term) storage [23]. Agroforestry is a mechanism for greenhouse gas mitigation by sequestering carbon (C) in biomass and soils and reducing GHG emissions on agricultural lands, especially through avoided emissions via energy savings and fuel reductions. The adoption of agroforestry practice has greater potential to increase C sequestration of predominantly agriculture dominated landscapes than the monocrop agriculture [25]. Study results showed that there is clear evidence concerning of carbon sequestration difference in various land use system (Figure1).

To estimate carbon storage in different parts of the plants or other pool, researcher used nearly similar method. The method used include measurement of trees at diameter breast height (dbh) and sampling of herbaceous vegetation, litter, and soil for carbon content determination and farmer interview [26,27]. In the tropics, according to the study by agroforestry practices helped to regain 35 percent of the original C stock of the cleared forest, compared to only 12 percent by cropland and pastures. See (Figure 1) how agroforestry system can sequester 600Mt C/year compared to cropland management system, which can sequester only 100Mt c/year by 2040. Carbon stock assessment study conducted in Philippines by [28] showed that as follows: carbon accumulation of agroforestry systems goes along with the following order:

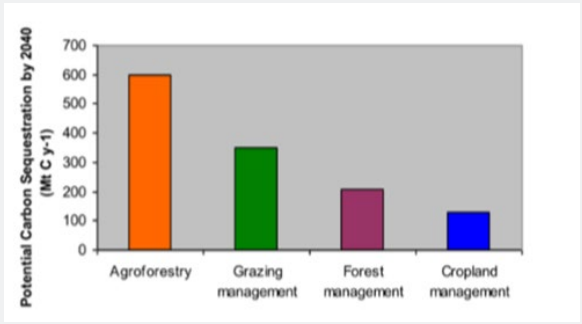

Figure 1: Carbon sequestration potential of different land use system [42].

Moreover, Carbon was stored in the various pools in the following order of magnitude: soil (77-92%) > trees (7-22%) > herbaceous vegetation and litter (1%).

Review by [28] in India, the effectiveness of agroforestry systems in storing carbon depends on both environmental and socio-economic factors. For instances in humid tropics, agroforestry systems have the potential to sequester over 70 Mg/ha in the top 20 cm of the s meta-analysis of 427 soil C stock data pairs grouped into four main AF systems-alley cropping, windbreaks, silvopastures, and home gardens-and evaluated changes in AF and adjacent control cropland or pasture. Mean soil C stocks in AF (1-m depth) were 126 Mg C·ha−1, which is 19% more than that in cropland or pasture. The highest C stocks in soil were in subtropical home gardens, AF with younger trees, and topsoil (0-20cm). Increased soil C stocks in AF were lower than aboveground C stocks in most AF systems, except alley cropping. Home gardens stored the highest C in both aboveground and belowground, especially in the subsoil (20-100cm). AF could store

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5.3 × 109Mg additional C in soil on 944Mha globally, with most in the tropics and subtropics. [30] reported scientific estimation, a 13-year-old alley-cropping system in Ontario, Canada, was found to have 11% to 41% more C, depending on tree species, compared to sole-cropping plots. AF systems could greatly contribute to global soil C sequestration if used in larger areas.

In line with this [31] analyzed the potential for C storage in home gardens and the role of home gardens in reducing CO2 concentration in the atmosphere. This study results revealed that home garden has a higher potential to sequester C compared to monospecific production systems, and the costs are lower than emission reduction or sequestration by other means. Additionally [32] explained that home gardens agroforestry system has high carbon storage (sequestration) potential in their multiple plant species, especially in wood perennial species, and soil; they help in conservation of C stock in existing forests by alleviating the pressure on natural forest. Furthermore, according to [33] home garden agroforestry system can be useful on at least to some extent it reduces in C substitution by reducing fossil-fuel burning through promotion of wood fuel production. Most reports indicated that the addition of a large proportion of the relatively high quantity of plant materials produced in a system will increase C stock in soils. Therefore, it is reasonable to surmise that home gardens will help substantially in C sequestration [31,34].

Carbon is able to sequester in two parts through agroforestry systems: aboveground and belowground. Carbon sequestration in agroforestry systems occurs in aboveground biomass, i.e., stem, branch, and foliage, and in belowground biomass, i.e., roots, and in soil. Especially, the large volume of aboveground biomass and deep root systems of trees in agroforestry systems have received increased attention for climate change adaption and mitigation [35]. The total amount sequestered in each compartment differs greatly depending on a number of factors including the ecoregion, the type of system (and the nature of components and age of perennials such as trees), site quality, and previous land use. On average, the aboveground parts and the soil (including roots and other living biomass) are estimated to hold roughly one-thirds and two-thirds, respectively, of the total C stored in tree-based land use systems [36]. Based on the notion that tree incorporation in croplands and pastures would result in greater net C storage above- and belowground [37,38]. Agroforestry systems are believed to have a higher potential to sequester C than pastures or field crops growing under similar ecological conditions [39,40]. Carbon sequestration rate of soil depends upon the input of dead organic matter provided by plants, soil properties such as soil structures and their aggregations, and climate [21]. Whereas, tree-based agroforestry systems are a preferred method for aboveground biomass C sequestration as compared to treeless pastures, there is evidence that C storage in deep soil horizons is greater [11,15]. For example, the available estimates of C stored in agroforestry range from 0.29 to 15.21Mg C/ha/year above ground, and 30-300Mg C/ha up to 1 m depth in the soil [23].

A study by [41,42] revealed that the average carbon sequestration potential of agroforestry systems is estimated to be 25t.ha-1 over 96 million ha but there is substantial regional variability. His study showed that village communities are dependent on agroforestry systems for income, employment opportunities and livelihood security.

Conclusion

This review paper shows how agroforestry provides a promising and alternative system in reducing and mitigating co2 from the atmosphere through carbon sequestration. A significant amount of carbon emission caused by human activity could be reduced by establishing agroforestry systems, subsequently carbon is able to sequester in two parts through agroforestry systems: aboveground and belowground. Therefore, carbon sequestration in agroforestry systems occurs in aboveground biomass, i.e., stem, branch, and foliage, and in belowground biomass, i.e., roots, and in soil. Agroforestry systems have the potential to provide significant mitigation options, but they require proper management that influences the amount of carbon sequestered.

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