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Potential Effects of Agroforestry Practices on Climate Change Mitigation and Adaptation Strategies: A Review

Abrha Brhan Gebre
Tigray Agricultural Research Institute, Ethiopia (TARI)

Abstract
Reviewing on the potential effect of agroforestry practices on climate change mitigation and adaptation through sequestrating carbon and modifying soil profile to have higher organic matter (OM) is critical. The sections of this review covers different agroforestry research findings relating to the effect of agroforestry practice in reducing climate change impacts in different area of the world. Agroforestry practice is a promising practice to sequester carbon while providing enormous environmental, economical, and social benefits. This shows significant carbon accumulation in living biomass carbon, as well as soil carbon, demonstrating the potential to offer the environmental service of carbon sequestration. Agroforestry is an appealing option for sequestering carbon on agricultural lands because it can sequester significant amounts of carbon while leaving the unpackaged of land in agricultural production. Integrating disciplines in order to enhance holistic approach and reduce some of the constraints that may inhibit positive effect of agroforestry practices for carbon sequestration is very important. Agroforestry showed a great potential in sequester carbon and contribute to mitigating CO_2 than treeless systems. Therefore, intensive exertion should be made by different stakeholder in supporting agroforestry to mitigate the climate change impacts.
Keywords: Agroforestry, Carbon sequestration, Climate change, Mitigation

1. Introduction

Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically a decade or longer (**IPCC, 2014**). Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use types. And agroforestry practice is the purposeful growing of trees and crops in interacting combinations, began to attain prominence in the late 1970s, when the international scientific community embraced its potentials in the tropics and recognized it as a practice in search of science (**Kumar and Nair, 2011**). During the 1990s, the relevance of agroforestry for solving problems related to deterioration of family farms, increased soil erosion, surface and ground water pollution, and decreased biodiversity was recognized in the industrialized nations too. Thus, agroforestry is now receiving increasing attention as a sustainable land-management option the world over because of its ecological, economic, and social attributes. Consequently, the knowledge-base of agroforestry is being expanded at a rapid rate as illustrated by the increasing number and quality of scientific publications of various forms on different aspects of agroforestry. So, the severity of climate change impact will be reduced by climate change adaptation and mitigation. In many GHG reports, agroforestry practices are absent in the lists and tables of potential mitigation activities. For example, the report on potential management practices to reduce carbon dioxide (**Clark et al. 2001**). However, from the different alternatives of climate change mitigation, agroforestry is the best and can sustain all over the world if we manage in a proper manner. Agroforestry is a climate-smart production system and considered more resilient than mono-cropping in mitigating climate change (**Charles *et.al*, 2014**).

Agroforestry, an ecologically and environmentally sustainable land use, offers great promise towards mitigating the rising atmospheric CO_2 levels through C sequestration (**Nair, 2011**). Tree crop sequestered carbon at a higher rate than those containing only in annual crops or grasslands (**Brakas and Aune, 2011**). Since annual crops will only accumulate carbon through roots and retention of crops residue, whereas tree crops will accumulate carbon through, roots, litter and aboveground biomass (**Nair, 2009; Singh and Pandey, 2011; Jose, 2009**). Agroforestry is all about using trees on farms and in landscapes for the benefit of rural communities and other land users. At the center of agroforestry innovation and adoption is the agroforestry tree or shrub that provides products and services such as fruit, fodder, firewood, timber, medicine, soil fertility, shade, erosion control and carbon sequestration (**Dawson et.al, 2012**). Agroforestry is recognized as an important component in climate-smart agriculture (defined as agriculture that brings humankind closer to safe operating spaces across spatial and temporal scales for food systems, in the context of climate change (**Neufeldt et al. 2013**). Agroforestry research has mainly focused on food production, soil fertility, and ecological and economic interactions among components (trees, crops and/or animals) (**Nair, 1998**). But recently the importance of agroforestry as a sink for CO_2, climate change mitigation and adaptation has been recognized (**Smith et.al, 2007**). As **Kumar and Nair (2011)** reported that agroforestry involved in special attention as a carbon sequestration strategy following its recognition as a carbon sequestration activity under the afforestation and reforestation activities of Kyoto Protocol. The post-Kyoto Protocol discussions on climate change are heavily oriented towards an agenda on mitigating the rising atmospheric CO_2 levels through C sequestration in terrestrial vegetation systems. Because of this many countries includes agroforestry systems and practices for implementation in their policy. This review stands with the objective of summarizing literatures related to the effect of agroforestry on climate change mitigation and adaptation strategies as well as interpreting and discussing the results on the selected literatures.

2. Methodological Approach for agroforestry practices

Using appropriate designs is a very important aspect of agroforestry experimentation, especially because of the long-term nature of the experiments (**Nair, 1993**). Randomized Complete Block Design (RCBD) and Split-Plot Experiment are the most widely-used patterns because of their simplicity. But incomplete block designs will become more widely used, especially when microcomputer-based Statistical packages for data analysis become increasingly popular. Carbon sequestration in land use systems is a rather loosely defined concept (**Kumar and Nair (eds.), 2011**). Several methodological challenges, arising from difficulties related to sampling, analysis, computations, and interpretation make its measurement a difficult task. These difficulties are of a higher magnitude in the case of agroforestry system (AFS) because often the systems involve complex multispecies combinations and the measurements are made from pre-existing sites rather than randomized and replicated experiments. There is no easy, fast, and pragmatic solution to these issues in the short term.

And the approach we follow for agroforestry tree domestication is that interacting with individuals and communities who will ultimately benefit by sustaining their agricultural crop. As a result, the knowledge, opportunities and constraints of local people are taken into account in the research and development process. And also the contribution of new research finding by research centers as well as higher educational levels (Universities) is very helpful for the demonstration of multipurpose agroforestry tree which can have the ability to mitigate climate change impacts. Therefore, the severity of climate change will be reduced or mitigate to the contrivable stage by the hands of the community. Computer program was used to analyze ecological data and allometric equations were used for estimation aboveground biomass and carbon (**Richard et.al, 2014**).

3. Agroforestry Practices

In Africa, of all agricultural land management activities suggested for GHG mitigation, agroforestry practices has been the most widely applied and studied, with the majority of research (**Oladele and Braimoh, 2014**). Agroforestry has the potential to sequester significant amounts of carbon for two reasons. First, the area currently in crops and pastoral systems is large. Second, although the density of carbon storage is low in comparison with forests, the woody biomass of agroforestry systems could provide a source of local fuel. This fuel would reduce pressure on the remaining forests in the area and, at the same time, provide a substitute for fossil fuel. These effects are important because the most effective way to use land for stabilization of atmospheric carbon is not through reforestation but through the substitution of wood fuel for fossil fuel. Carbon sequestration potential of agroforestry systems varies greatly from under 100Mt to over 2000Mt of carbon dioxide equivalent per year particularly the use of Faidherbia albida, in Malawi and Niger (**Takimoto *et.al*, 2008**).

Agroforestry systems distinguish themselves from other forms of agriculture through their *ability to store higher amounts of carbon (C) in their biomass*, and often also to conserve more biodiversity (**Kumar and Nair, 2011**). However, in both regards they are generally inferior to forests. Therefore, the impact of agroforestry practices on landscape C stocks and biodiversity needs to be analyzed both in terms of the interactions between agroforestry and forest, which may be positive or negative, and in terms of the conservation of C and biodiversity in the farming systems themselves.

Agroforestry showed a great potential in mitigating CO2 than treeless systems therefore concerted effort should be made by different stakeholder in supporting agroforestry (**Richard et.al, 2014**). **Hemalatha *et.al.* (2013),** also reviewed on the increasing population and scarcity of productive lands that cannot sustain intensive exploitation, one method that has been proposed to enhance the sustainability of agricultural production is the growing of trees in association with crops. Alley cropping is an agroforestry system in which food crops are grown in alleys formed by hedge rows of trees or shrubs and these hedge rows are kept pruned during the rainy season. The hedge rows are usually cut to a height of about 2 m when crops are sown and kept pruned to reduce competition with crops. According to **Neufeldt *et.al* (2009)**, Study from Nepal on the impact of agroforestry on soil fertility and farm income showed that agroforestry intervention nearly doubled farm income per hectare from USD 800-1580.

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Agroforestry system of alley cropping (Source; **Neufeldt *et.al*, 2009** and **Uprety e*t.al*, 2012**)

Richard *et.al* (2014), reason out the importance of agroforestry with the specific study area in Mwanga district, Kilimanjaro, Tanzania which summarize, Agroforestry is a climate-smart production system and considered more resilient than mono cropping in mitigating climate change. The diversity of agro forestry practices such as parklands, home gardens and woodlots stored a substantial aboveground carbon stock (10.7 to 57.1 Mg C ha-1 with an average of 19.4 Mg C ha-[1], species selection, and planting density for various agroforestry practices to optimize carbon sequestration. Even though, there is difficulty in estimation of carbon sequestration in agroforestry these authors have estimated to be around 548.4 Tg from 54 million hectare which is only from the United states. It indicates that if agroforestry demonstrates worldwide the concentration of carbon dioxide will reduce as a result of utilized for the food preparation of trees and agricultural crops. And selection of multipurpose tree species which have higher capacity in mitigating or sinking carbon should be demonstrates in every country to combat climate change. **Hemalatha *et.al,* (2013)** also advocates different research findings on which was done in the benefit of in alley cropping or any other design agroforestry there is higher yield as compare with the mono cropping agricultural crops.

As I have try to write the author **Neufeldt *et.al.* (2009)** in the literature review which says the study from Nepal on the impact of agroforestry on soil fertility and farm income showed that agroforestry intervention nearly *doubled farm income* per hectare from USD 800-1580. This indicates that the land use system is already indorsed by green multipurpose tree. Not only the benefit of agroforestry is that for the enhancement of farm income but also sequesters carbon from increasing concentration in the atmosphere and then the Nepal community will live with high capability for climate change impacts. This author is also recommends for policy ratification to be implementing or adopt the agroforestry practice by pointing out like increased adoption of agroforestry should be supported through finance for agricultural development and adaptation as well as mitigation. And Payments for environmental services including carbon finance should be geared towards increasing the extent of trees on farms. As **Neufeldt *et.al* (2009)**, try to mention more support is needed to increase the contribution of tree-based crops to smallholder incomes, thus diversifying income sources and increasing food security in the face of climate change.

Agroforestry showed a great potential in mitigating CO2 than treeless systems therefore concerted effort should be made by different stakeholder in supporting agroforestry (**Richard *et.al*, 2014**). This study described the great potential of tree component of AFS in increasing C sequestration compare with treeless agricultural systems, and therefore its implementation should be considered as a climate smart land use option in ‘Mwanga’ district. Therefore, comprehensive and interdisciplinary strategies are needed in understanding how to deliberately transform agroforestry system and society in order to avoid the long-term consequences of environmental change.

3.1. Agroforestry System Components and Interaction

Agroforestry system must have trees and at least one of the other components. This is the basis of the classification into trees plus crops (agrosilvicultural), trees plus pastures and/or animals (silvopastural) and trees plus crops and animals (agrosilvopastural). The tree component (E.g. *Faidherbia albida*) provides mulch and nutrients (The World Bank, 2012). This means that the land use with agroforestry is more cost-effective than non-agroforestry land use systems, because the will be a sustainability in agricultural crop and other functioned by the benefit of agroforestry.

The total carbon storage in the aboveground and belowground biomass in an agroforestry system (AFS) is generally much higher than that in land use without trees (i.e. tree-less croplands) under comparable conditions (**Kumar and Nair, 2011**). This is because of the leaves fall from the tree biomass which decomposes to enhance the soil fertility and saves the moisture content. When we say above ground biomass includes branch, stem, leaf, fruit, flower and seeds. And also below ground is also the functioning of the root system. Therefore, we can conclude that agroforestry have a great contribution in sinking carbon dioxide from emitting to the atmosphere.

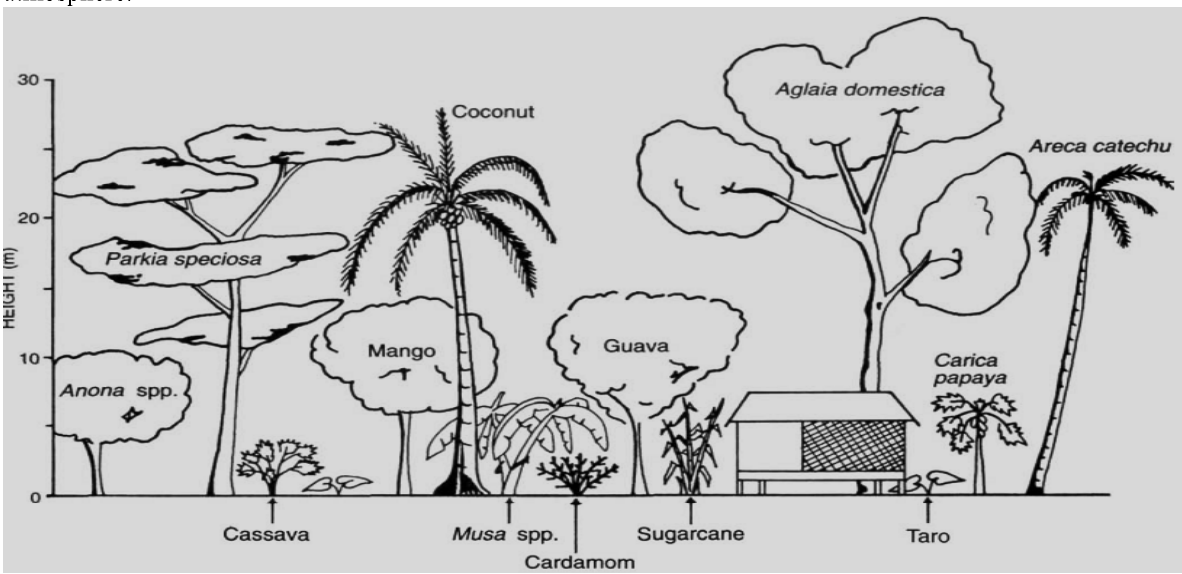

Figure 3; components structures of agroforestry system

3.2. Species Suggested for Agroforestry Practice

Acacia abyssinica, Acacia bussei, Acacia etbaica, Acacia Sieberiana, Acacia tortilis, Acacia seyal, Balanites aegyptiaca, Faidherbia albida, Zizyphus spina-christi, these species can provide fuel wood, charcoal, shade, construction materials and farming implements, and fodder for livestock (**Gebrehiwot, 2004**). Tree species such as Feidherbia albida, Sclerocarya birrea, Tamarindus indica, Balanites aegyptiaca, Ziziphus mauritiana, Lannea microcarpa, and Azadichta indica are the most common in the agroforestry parkland systems (**Khamzina and Vlek, 2014**). Faidherbia albida and Albizia species were all top ranked C-stores; fruits species stored an average of 40.4% of the Carbon stored in agroforestry (**Richard et al, 2014**).

3.3. Agroforestry on Agricultural Crop and Animal Functioning

The shade provided by the trees helps in moderating microclimate and reducing crops and livestock stress and helps to improve crop yields (**World Bank, 2012**). One of the most promising fertilizer tree species is *Faidherbia albida*, an Acacia species native to Africa and the Middle East. *Faidherbia albida* is widespread throughout Africa, thrives on a range of soils, and occurs in different ecosystems ranging from dry lands to wet tropical climates. It fixes nitrogen and has the special feature of reversed leaf phenology, a characteristic that makes it dormant and sheds its leaves during the early rainy season and leafs out at the onset of the dry season. This makes *Faidherbia albida* compatible with food crop production; because, it does not compete for light, nutrients, and water.

Source: World Agroforestry Centre.

Figure 4; Maize Growing under *Faidherbia Albida* Trees in Tanzania

According to **Dawson *et al.* (2014)** report, agroforestry practices can have the potential to mitigate climate change impacts on animal production and productivity. Agroforestry can have the budding as tree fodder, reduces carbon dioxide emission through reducing carbon footprint and carbon sequestration in roots and stems. Furthermore, agroforestry uses for animal mitigation and adaptation as a basal supplementary fodder by increasing protein intake, milk production and reduces various greenhouse gas emissions.

3.4. Agroforestry on Soil Improvement and Carbon Sequestration

The N (nitrogen), OC (organic carbon) and K (potassium) levels were 42, 31 and 25% respectively higher under the canopies of faidherbia albida than outside which is found in Zambia (Umar, 2013). Planting of agroforestry trees is thus an option for the households that will have secure tenure to their land use type.

Abatement rates of agroforestry systems, integrated land-use systems combining trees and shrubs with crops and livestock, are fairly high. This is due to the relatively large time-averaged biomass of trees compared to crops. The average abatement rates in tone CO_2e per ha per year are 7.6 for alley farming (the growing of crops simultaneously in alleys of perennial, preferably leguminous trees or shrubs), 7.5 for tree-crop farming, 8.7 for improved fallow (involving the use of fast-growing trees to accelerate soil rehabilitation), 4.6 to 6.3 for intercropping (the growing of crops near existing trees), and 4.3 to 6.7 for croplands where trees are introduce (World Bank, 2012).

The integration of *Faidherbia* trees into the farming systems is highly efficient and the trees have multiple functions (**Hadgu *et.al*, 2011**). For instance, farmers in eastern Ethiopia maintain naturally regenerated *Faidherbia albida* in their farms for one or more benefits: soil fertility improvement (84%), feed for livestock (59%) and income from sale of products (3%). In northern Ethiopia, benefits farmers derive from *Faidherbia* include soil fertility improvement (95%), soil moisture retention (90%), rain water infiltration (88%), bee forage (80%) and livestock feed (88%). In central Ethiopia, soil fertility improvement (92%), livestock feed (84%), fuelwood (100%) and income from sale of products (81%) were the most important reasons why farmers maintain *Faidherbia* on their farmlands

4. Conclusions and Recommendations

The outcome of agroforestry practices in sequestering carbon for climate change mitigation is promising while providing enormous environmental, economical, and social benefits worldwide. This review revealed that there is high potential to sequester carbon through agroforestry practices. Focusing on multipurpose agroforestry tree which is compatible with the agricultural crop like *faidherbia albida* is not only used for climate change mitigation but also as a win-win fertilizer agroforestry combination strategy and this should be demonstrate and promote throughout the world. So that planting of multipurpose agroforestry tree in a farm land can help for crop yield increment, increase the sustainable land-use practices and modification in micro climate conditions and mitigation strategies. Agroforestry have a pronounced assistance for sinking carbon concentrated in the atmosphere. Therefore, decision makers should have to be encourage climate smart agroforestry practices to mitigate the globally facing climate change challenges that affect the amount and quality of living thing.

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Abrha Brhan Gebre was born in Wukro, Tigray, Ethiopia at 05 may 1986. My educational background is Bachelor degree in Agroforestry (Farm forestry) in Wondo Genet College of Forestry and Natural Resource Management at Hawassa University, Ethiopia, in year 2010 and Master of degree in climate and society specialized in climate affairs at Mekelle University, Ethiopia in year 2016. I am working in institute of Tigray Agricultural Research, Ethiopia (TARI).