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Contribution of Agroforestry Practices in Adaptation to Climate Change

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ABSTRACT

Purpose: The purpose of this paper was to investigate the contribution of agroforestry practices in adaptation to climate change.

Methodology: This study employed a systematic review of the literature as its research methodology in answering the research questions. Inclusion criteria was used to give relevance to this work. Data collection primarily involved examining existing research and documents to gather information and synthesize findings on the importance of agroforestry in adaptation to climate change. Data analysis involved grouping findings from multiple studies to address a research question, using qualitative method.

Findings: The role of agroforestry in climate change adaptation are: increasing tree-crop diversification that's leads to more carbon storage, generation of multiple livelihood and environmental benefits, key in reducing carbon emissions and achieving the Paris Agreement targets, offers greater economic stability and reduced risk under climate change by creating more diversified enterprises with greater income distribution over time, providing habitat that offers a range of microclimate and resources, increasing landscape connectivity for species to migrate as climate changes, providing other ecosystem services, such as erosion control and water quality protection. protection, that prevent the degradation and loss of surrounding habitat, can reduce air pollution and enhance both warming and cooling of the atmosphere, creating a resilient microclimate for crops and livestock, enhances water security through improved infiltration to soils and groundwater protecting water catchments and watersheds. , and can be a suitable land management system to reduce gender inequalities related to natural resource access, while contributing to increased control of their benefits.

Unique contribution to theory, practice and policy: Through agroforestry innovations/ essential elements {learning from success and failures, availability of germplasm, technology options, farmer centered and research extension approaches, knowledge information sharing, local institutional capacity building, facilitation, policy realignment, availability of reliable markets, and strategic partnerships}, cooperatives, NGOs and community organizations, introduce an agroforestry certification that will allow farmers to get more money for their products, demand driven participatory and inclusive research, and new models for funding. Agroforestry shows a great potential in mitigating C_{O2} than treeless systems, it enhances environmental quality, sustains economic viability and enhance quality of life therefore concerted effort should be made by different stakeholder in supporting it.

Keywords: *Climate Change, Adaptation, Agroforestry, Carbon Sequestration*

INTRODUCTION.

Climate change is a burning issue of the world. Increasing of CO2 by industrialization, fossil fuel burning, etc can cause a subtle change in global climate. Greenhouse gases include CO2, N2O, CH4, and CFC etc are foremost region behind global warming leads to changing climate. Carbon dioxide (CO2) is the main heat trapping gas largely responsible for most of the average warming over the past several decades (Forster P. *et al,* 2007). The atmospheric concentration of CO_2 has increased from a preindustrial era (AD 1000 – 1750) concentration of approximately 280 parts per million (ppm) to around 383 ppm, as measured at Mauna Loa, Hawaii in 2007 (Forster P. *et al,* 2007, Keeling R.F. *et al,* 2008). A graphical representation (figure 1) is shown below for global projection of CO2 emission (1751-2010) that leads to rise in temperature (CDIAC, 2013). Earth biodiversity is greatly affected by unusual climate leads to loss and degradation of natural resources and environment. Change in weather regime such as rainfall pattern causes flood and drought not only effects on agricultural production but also influence emergence of several cause emergence of infectious disease.

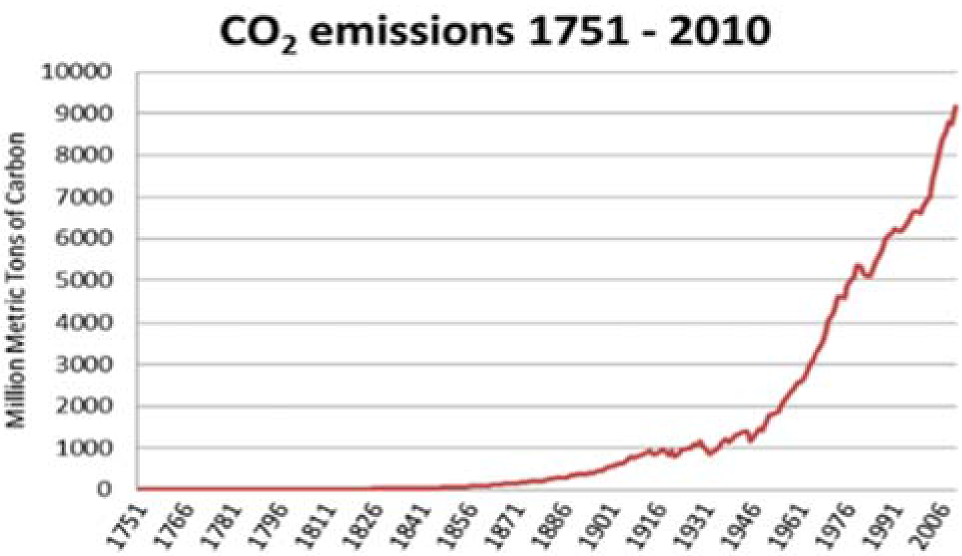

Fig 1: Global projection of CO_2 emission (1751-2010) (CDIAC, 2013)

The rate at which atmospheric CO_2 is increasing has risen from about one ppm per year in 1960s to two ppm for 2000s and it is still continuing to increase every year. At present, atmospheric carbon increases by about 4.5 Pg per year on average. 1 kg Carbon (C) equals to 3.67 kg Carbon Dioxide (CO_2) and one Pg C equals to 3.67 billion tons CO_2 or 3.67 Gt CO_2 [1]. (Figure 2).

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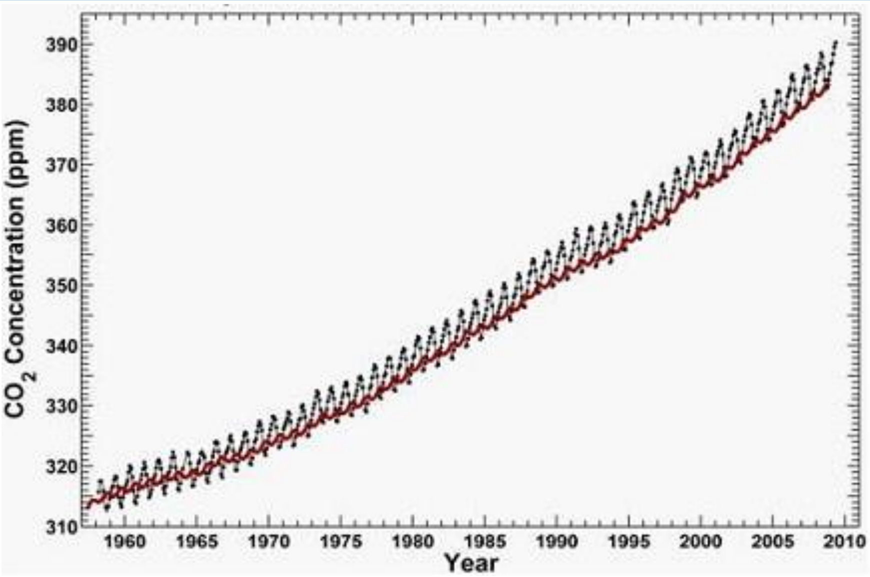

Figure 2: Trends in CO_2 Concentration in Atmosphere.

(Source: Mauna Loa Observatory, Hawaii & South Pole Antarctica

By extracting fossil fuels (oil, gas and coal) from deep in the Earth, we are overloading the atmosphere with carbon, and changing our climate in irreversible ways. (Figure 3).

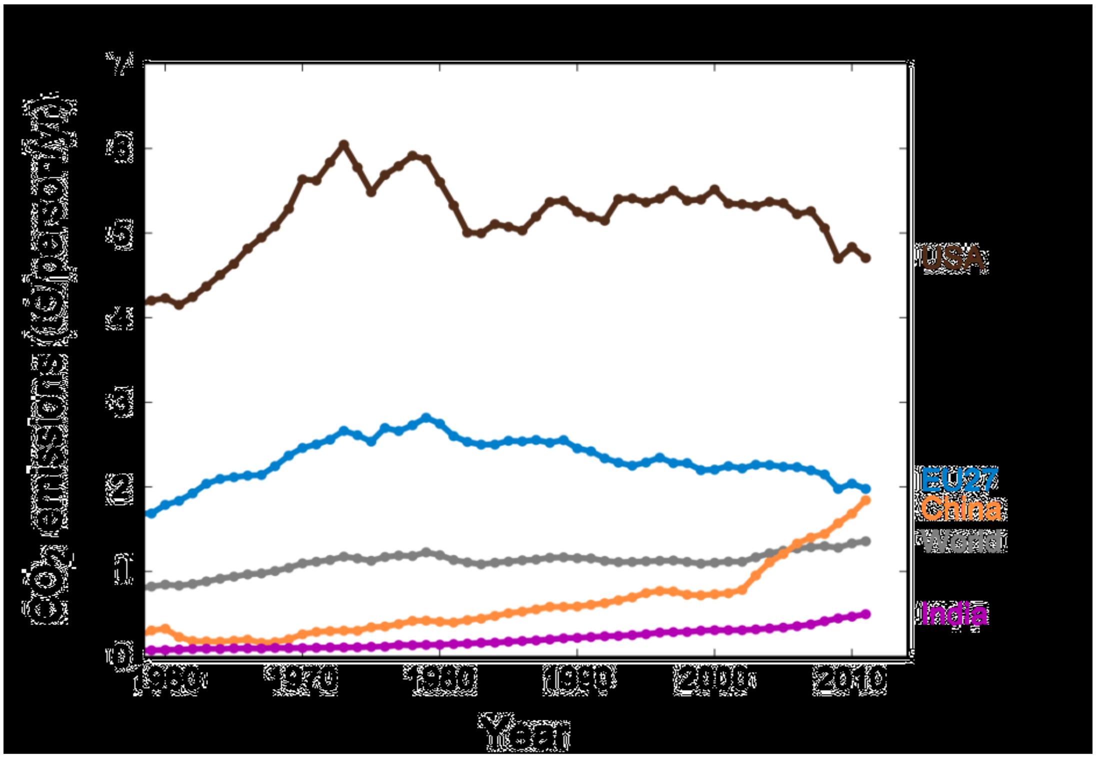

Figure 3: Top Fossil Fuel Emitters - Per Capita (Source: CDIAC, US Oak Ridge National Laboratory).

Adaptation by Agroforestry can add a high level of diversity within agricultural lands and, with it, an increased capacity for supporting numerous ecological and production services that impart resiliency to CC impacts (Verchot *et al*, 2007). From a landowner's perspective, the most valued services would be those that can dampen the negative effects of CC and weather extremes while augmenting the positive benefits provided by tree-based systems. CC risk management is difficult in annual-only systems due to the increasing uncertainty and volatility of interannual variability in rainfall and temperatures. The mixing of woody plants into crop, forage, and livestock operations provides greater resiliency to this interannual variability through crop diversification produced seasonally, as well as through increased resource-use efficiency (Olson *et al*, 2000). Deep-rooted trees allow better access to nutrients and water during droughts and, when appropriately integrated into annual cropping or forage systems, may extract from a different pool of resources and/or from resources that would otherwise be lost from the system (van Noordwijk *et al*, 1996). Agroforestry increases soil porosity, reduces runoff, and increases soil cover, which can improve water infiltration and retention in the soil profile thereby reducing moisture stress in low rainfall years (Jose *et al*, 2009). Agroforestry practices are used to alter microclimates to produce more favorable conditions for crop, forage, and livestock production, and empirical results suggest these agroforestry-induced conditions could be critical in providing extra resiliency to shifting temperature and moisture regimes. Field studies have shown that air and soil temperatures too cold or too warm for forage growth can be favorably modified by trees in silvopasture systems to create an extended production period (Feldhake, 2002; Moreno *et al*, 2007). With warmer temperatures, insect pests and plant diseases are expected to increase due to range expansion, higher winter survival, and increased number of generations per season (USGCRP, 2009). Enhancing opportunities for biological pest control will become increasingly important and could be accomplished through agroforestry (Dix *et al*, 1995). For example, alfalfa intercropped with walnut supported twice as many predators and parasitic hymenoptera and half as many herbivores as did alfalfa alone (Stamps *et al*, 2002).

Climate change is a global phenomenon that imposes economic, social, and ecological challenges to the global community. Research has shown that climate change is attributed to human activities, which bring about CO2 emissions, through the removal of forest cover (Owolabi, 2010). Deforestation, human induced conversion of forests to non-forest land uses, is typically associated with large immediate reductions in forest carbon stock through land clearance. Poor forest management policies and illegal encroachment into forest reserves, urban development, road construction, fossil fuel combustion and excessive harvesting of fuel wood, contribute to the depletion of the ozone layer. Food and Agricultural Organization of the United Nation FAO (2010), observed that deforestation account for approximately 18% of global carbon emissions. It was further reported by that reduced deforestation, forest regeneration, increased plantations development and agroforestry accounts for 12 to 15% of global sequestration of carbon emission from fossil fuels. Agroforestry has high potential to reduce atmospheric concentration of carbon dioxide (CO2) and mitigate climate change. It is an established fact that planting of more trees, to increase the amount of forested land or to increase the density of the existing forest in Nigeria would help mitigate climate change impacts in the country and at global level. Morgan et al (2010) also supported the fact that rising level of atmospheric carbon dioxide and associated global warming can only be addressed by adopting CO2 reduction strategies. Agroforestry, as a system that combines trees and/or shrubs (perennial) with agronomic crops (annual or perennial), offers great promise to sequester Carbon, both above and below-ground. Agroforestry systems even though not primarily designed for carbon sequestration have been reported to present a unique opportunity to increase carbon stock in terrestrial biosphere (Jacob *et al,* 2013). The problem of environmental instability brought about by mounting pressure on the available land resources as a result of persistent rise in population, has probe lot of disturbance on the existing natural ecosystems. These human disturbances and unsustainable use of natural ecosystem which posed a lot threat to local biodiversity; leading to environmental degradation need to be addressed. Therefore there is need to embrace agroforestry a promising land use system that involves the integration of variety of trees species with herbaceous crops and / animal in some form of special arrangement or temporal sequence (Sobola *et al,* 2015).

According to Martini *et al*, (2020) climate change refers to significant changes in average weather parameters such as temperature, wind and rain experienced in a region over a long period of time. Increasing temperatures, erratic rainfall patterns, extended droughts, more frequent typhoons, warmer nights and hotter days are commonly associated with climate change. These impacts differ from place to place depending on the context of the specific ecological region. There are serious impacts of climate change on land, water, trees, crops, animals and people. Some examples are listed in the table below.

Table 1: Impacts of changes in climate according to Martini *et al,* (2020)

Climatic issues	**water**	**Land**	**Crops & Trees**	**Animals**	**Farmers**
Rising temperatures	Decreased water availability	Hardened soils	Stunted, slow growth and loss		
Prolonged dry seasons, droughts	Lack of water for irrigation and human use	-Cracked soils -Increased wind-induced soil erosion	Decreased yields		Declining harvests and income
Intense storms, typhoons, strong winds	-Landslides and Floods -Contaminated water	-Increased run-off and soil erosion -Decreased soil fertility	-Crops Damaged -Growing seasons and Cropping patterns changed	Increased diseases and deaths	-Increased Debts -Food shortages
Extreme and erratic rainfall			Decreased yields		
Sea-level rises	-Saltwater Intrusion -Decreased freshwater availability	-Damaged Shorelines -Inundation stress, Increased salinity	Mangrove ecosystems threatened	Decreased areas for grazing	

Agroforestry is a multiple land-use system in which agricultural crops and woody perennials are grown on the same land management unit (Owunubi & Otegbeye, 2012). Agroforestry is land use that combines trees with crops, trees with livestock, or trees with both crops and livestock. This mix of components creates an agroforestry system in which the components interact in a beneficial manner, improving agriculture in many ways; for example, by improving farm yields, increasing farm incomes, and contributing to soil and water conservation. Agroforestry is not new. Farmers have practised it for thousands of years, and scientists have recognized it since the 1970s as a productive and ecologically sustainable form of agriculture and land use. But now agroforestry is suddenly at centre stage. It is promoted as a land use strategy to support climate change mitigation and climate change adaptation, biodiversity conservation, sustainable agriculture and other goals. Many organizations recommend or use it as a tool for restoring ecosystems, not only agricultural ones, but also forest landscapes (Gassner & Dobie, 2022). Agroforestry can reap substantial benefits both economically and environmentally, producing more output and proving to be more sustainable than agricultural monocultures. The productivity of agroforestry system is often attributed to mixture of species as they make better use of growth resources than the same species grown separately. Components in agroforestry interact one to another that leads an interaction effect. Interaction is defined as the effect of one component of a system on the performance of another component and/or the overall system. Increased productivity, improved soil fertility, nutrient cycling, soil conservation are the major positive effect of interaction and competition is the main negative effect, which substantially reduces the crop yield. It may be space, light, nutrients and moisture. This indicated that tree crop interactions depend upon availability of growth resources, site conditions and the moisture / nutrient status of the site (Muhammed, 2019).

Agroforestry systems may be classified on the basis of the following four criteria (FAO, 2022):

a. *Structural Basis*: This criterion refers to the composition and the spatial and temporal arrangements of the system. Addition of woody plants can greatly affect the horizontal and vertical arrangement of plants in a system which often increases the diversity of the system and typically increases the length of time that the system is in use.

b. *Functional Basis*: This refers to the function of the woody component. Specifically, the addition of woody plant species increases the number of products generated by the system.

c. *Socio-Economic Basis*: This refers to the purpose of the system which often splits into subsistence, commercial, or intermediate. In addition, agroforestry may be managed to meet specific social objectives such as reduction of poverty (social forestry) or to increase accessibility of community to resources on communal lands (community forestry).

d. *Ecological Basis*: This refers to the suitability of the agroforestry system for a given environment. Hence, there are various types of agroforestry for tropical, temperate arid environments which consider the biological, environmental, and ecological conditions of each place.

The importance of agroforestry cannot be overemphasized, as it has several advantages in the provision of food and other basic needs (i.e. fuel wood, staking materials, fibers, timber, medicinal concentrates, oils, fruits, and fodder for animals) for a large proportion of the rural population as well as its role in soil fertility restoration and the control of weeds in addition to amelioration of environmental degradation. Agro-forestry practices are being increasingly advocated as possible remedies and had been claimed, to have the potential of improving agricultural land use systems, providing lasting benefits and alleviating adverse environmental effects at local and global level. Adedire (2004); Adekunle (2005) and Oke (2008); agreed that agroforestry can provide new and useful solutions to many of the adverse consequences of human land use, including increased diversification of agricultural production system, increased yield of crops and livestock, reduction of non-point source pollution and increased rural development by contributing to an ecosystem-based management system, that guarantees sustainability and environmental quality. Agroforestry should therefore be seen as a system that addresses the declining quality of the environment, including the soil, while also increasing the variety of produce by the farmer. This will not only increase the farmers' income but also help ensure food security and balance.

The retention of trees in farming systems has been recognized to increase crop output in the semi-arid region of Adamawa state (Amadi *et al*, 2003). Ajake (2012) also recognized the function of forest trees in term of income generation, good medicare, employment generation, raw materials, and provision of food among others. Agro forestry is increasingly promoted for restoring forest, degraded environment, reducing greenhouse gases, and gaining other co-benefits that agro-forestry puts into sustainable development programs, these include: Biodiversity conservation, environmental (watershed) Protection, and Climate change mitigation and adaptation. It was therefore viewed as being useful in promoting afforestation /reforestation and in the unfurling mechanism for forestry development: "Reduction of Emissions from Deforestation and forest Degradation (REDD)" has also been recognized, as well as, meeting (inter)national climate change objectives. Agroforestry is also being known for, its role in traditional employment generation, thus it has the capability to deliver several benefits (e.g. income generation for poor farmers, environmental and ecosystem stabilization including control of desertification and deforestation), (Richard et al; 2009). According to (Dwivedi, 1992; Nair, 1993).

Agroforestry, the growing of trees or shrubs in association with crops, pastures and livestock, has been invariably identified as an ideal, ecologically and economically suitable land-use system which aims to increase the total production per unit area while maintaining or enhancing soil fertility. Agroforestry practices are used to alter microclimates to produce more favorable conditions for crop, forage, and livestock production, and empirical results suggest these agroforestry-induced conditions could be critical in providing extra resiliency to shifting temperature and moisture regimes. Field studies have shown that air and soil temperatures too cold or too warm for forage growth can be favorably modified by trees in silvopasture systems to create an extended production period (Feldhake, 2002; Moreno *et al*, 2007). Using a process-based model, Easterling *et al*, (1997) showed that windbreaks would increase dryland maize yields in Nebraska above corresponding unsheltered yields for most levels of predicted climate change. Increased heat, disease, and weather extremes are likely to reduce livestock productivity, and studies show that the negative effects of hotter summers will outweigh the positive effects of warmer winters (USGCRP, 2009). By providing shade, silvopasture can reduce the energy expended for thermoregulation, leading to higher feed conversion and weight gain. Mitlöhner *et al*, (2001) found that cattle provided with shade reached their target body weight 20 days earlier than those without shade.

According to Kalu *et al*, (2022)**,** agroforestry dates as far back as the origin of human civilization when man started integrating food crops with tree crops on the same piece of land. Therefore, agroforestry can be summarized with these three agroforestry applications:

(i). Agrisilviculture: This involves a combination of arable crops with tree crops on the same site which can be expressed arithmetically as: arable crops + tree crops.

(ii). Silvopasture: This involves an integration of forage crops and livestock with tree crop production. This can also be expressed arithmetically as: arable crops + livestock + tree crops.

(iii). Agrosilvopasture: This type is a combination of arable and forage crops with tree crop production which can be modelled arithmetically as: arable crops + forage crops + tree crops. So, agroforestry is a comprehensive system of farming which encompasses all the spheres of food production such as food crops, tree crops, livestock and api-silviculture. And for defining agroforestry practices include:

- *Intentional:* trees, crops and/or livestock are intentionally designed, established and managed to work together and yield multiple products and benefits

• *Intensive:* agroforestry practices are created and intensively managed to maintain their productive and protective functions

• *Integrated:* the trees, crops and/or animal components are structurally and functionally combined into a single, integrated management unit

• *Interactive:* agroforestry seeks to actively manipulate the biophysical and physical interactions among the components to yield multiple harvestable products while providing numerous conservation and ecological benefits

According to Martini *et al*, (2020), factors to be considered in the selection of tree species for climate resilience are: knowledge about management of tree species, commercial value or local use of the trees, growth rate, availability of quality, certified germplasm, resistance to pests and diseases, less competitive for associated crops, small and open canopy, good root distribution

Agroforestry- the incorporation of trees into farming systems has enormous potential to mitigate the effects of drought, prevent desertification and restore degraded soils. It can also help to boost food production (for humans as well as animals) and provide alternative sources of nutrition or income when crop yields are low. With climate change expected to lead to unpredictable seasons in the future, placing even greater pressure on agricultural systems, food production and food prices, agroforestry is a viable option to help buffer farmers against the impacts" (WAC, 2012)

There are several criteria for defining agroforestry practices.

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Objective One: What is the role of Agroforestry in Adaptation to Climate Change?

Agroforestry, a form of Climate Smart Agriculture, is a promising adaptation option for smallholder farmers throughout the developing world. The diverse adaptive benefits of agroforestry have been captured in case examples and scientific studies in developing countries in Asia, Africa, and Central and South America. Agroforestry systems comprises different models in different region worldwide, which plays an enviable role to combat negative impact of climate change by increasing tree-crop diversification that's leads to more carbon storage (carbon sequestration) capacity than alone cultivation of sole agricultural crops (Colin, 2013). Agroforestry can generate multiple livelihood and environmental benefits, as it can help to mitigate climate change and help farmers to adapt to extreme and variable weather (IPCC, 2019). Climate change is happening now (Ripple et al. 2019) and urgent action is required to limit the temperature increase to 1.5 degrees (IPCC, 2019). Climate change risks (e.g. severe droughts, flooding, diseases) can have extensive impacts on agricultural systems, triggering soil erosion, crop failure, loss of biodiversity, reduced soil moisture, pest damages and economic losses. More extreme events and greater occurrence of drier and wetter conditions are already making it difficult for farmers to plan planting and harvesting (SIWI, 2018), threatening current production systems and food security as a result. Trees, forests and agriculture are key to reducing carbon emissions and achieving the Paris Agreement targets. Replanting the right tree species in the right place can help farmers adapt to climatic impacts. Agroforestry contributes to a number of the Sustainable Development Goals (SDGs) (Agroforestry Network, 2018) as highlighted below:

SDG 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality

SDG 13.2: Integrate climate change measures into national policies, strategies and planning

SDG 15.3: By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world

Agroforestry systems can offer greater economic stability and reduced risk under CC by creating more diversified enterprises with greater income distribution over time. Like alley cropping, a silvopasture system mitigates risks associated with climate variability and fluctuating prices by providing short-term (forage and/or livestock) and long-term (timber) income sources (Cubbage *et al,* 2012). Conserving biological diversity under shifting climates is a global priority (Korn *et al,* 2003). Agroforestry can play three major roles in supporting this priority: (1) providing habitat that offers a range of microclimate and resources (2) increasing landscape connectivity for species to migrate as climate changes; and (3) providing other ecosystem services, such as erosion control and water quality protection. Protection, that prevent the degradation and loss of surrounding habitat. Realizing these beneficial adaption services will require additional work to develop improved combinations and arrangements of species that better maximize facilitative interactions, while minimizing the competitive interactions between crop and trees (Jose *et al*, 2009). Climate change can increase risk for agriculture such as droughts, flooding and pests. The ability of farmers to continue living on their land depends on how well they adapt to climate change risks. Agroforestry for climate adaptation at the farm level and enhanced resilience at the landscape level can take many forms. For instance, agroforestry can reduce air pollution and enhance both warming and cooling of the atmosphere, creating a resilient microclimate for crops and livestock. It also enhances water security through improved infiltration to soils and groundwater protecting water catchments and watersheds. The potential to improve soil properties and water availability to plants also make agroforestry practices suitable for landscape restoration. Moreover, trees provide a number of ecosystem services, such as water regulation, climate buffering, soil fertility, erosion and flood control, as well as food, fodder, medicine and wood – all important for resilience to climate change and reduced vulnerability of local people (Verchot *et al,* 2007; Mbow *et al,* 2014). Equally important, agroforestry can improve livelihoods in smallholder farming systems through diversified income and cash crop systems (e.g. cocoa, coffee, nuts), increased food security and improved access to nutritious food. Trees on farms can also help the farmers reduce the economic recovery time after natural disasters (Simelton *et al,* 2015). Agroforestry can be a suitable land management system to reduce gender inequalities related to natural resource access, while contributing to increased control of their benefits ((Leder *et al,* 2016). Agroforestry practices can reduce or remove significant amounts of GHGs through increased carbon storage in biomass above-ground and below-ground and in soil organic carbon (IPCC, 2019). Integrating agroforestry into cropping and livestock keeping systems can enhance carbon sequestration by significant amounts. Home gardening, boundary planting, fruit orchards, riverine, hedgerows, woodlots and firewood lots are major agroforestry practices that sequester CO2. Agroforestry stores more carbon than pastures and fields with annual crops, but less than forested areas (Verchot *et al*, 2007)).

The Kenya Agricultural Carbon Project promotes agroforestry and has helped almost 30,000 farmers in western Kenya to grow over 3 million indigenous agroforestry trees, alongside learning other sustainable land management practices; such as composting, mulching, and application of livestock manure. The project is a partnership backed by the World Bank, where Vi Agroforestry trains the farmers involved in practices to increase the content organic matter in the soil. Increased organic content in soil improves yields, provides resilience to droughts and heavy rains, limits erosion, and stores carbon, for which the farmers receive payment. The project sequestered about 345,000 tons CO2 between 2010 and 2016, while improving agro biodiversity, food security and adaptation to climate change as co-benefits. Increasing yields was the main economic incentive for the farmers to engage in the project, and since the start of the project savings among farmer families have increased – along with a greater resilience to a wide range of shocks, including climate change impacts. Other results include increased knowledge about climate change and increased access to firewood, fruits and fodder from trees. When the project ends in 2030, the expected sequestrated amount of carbon will be about 2 million tons (Agroforestry Network, 2018).

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 CO_2 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. 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. 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 (Abrha, 2016).

Objective two: How can agroforestry be up scaled?

Cooper and Denning (2000) identified 10 essential elements for scaling up agroforestry innovations: building local capacity, facilitation, farmer-centered research and extension approaches, germplasm, knowledge and information sharing, learning from successes and failures, market options, policy options, strategic partnerships, and technology options (Figure 4).

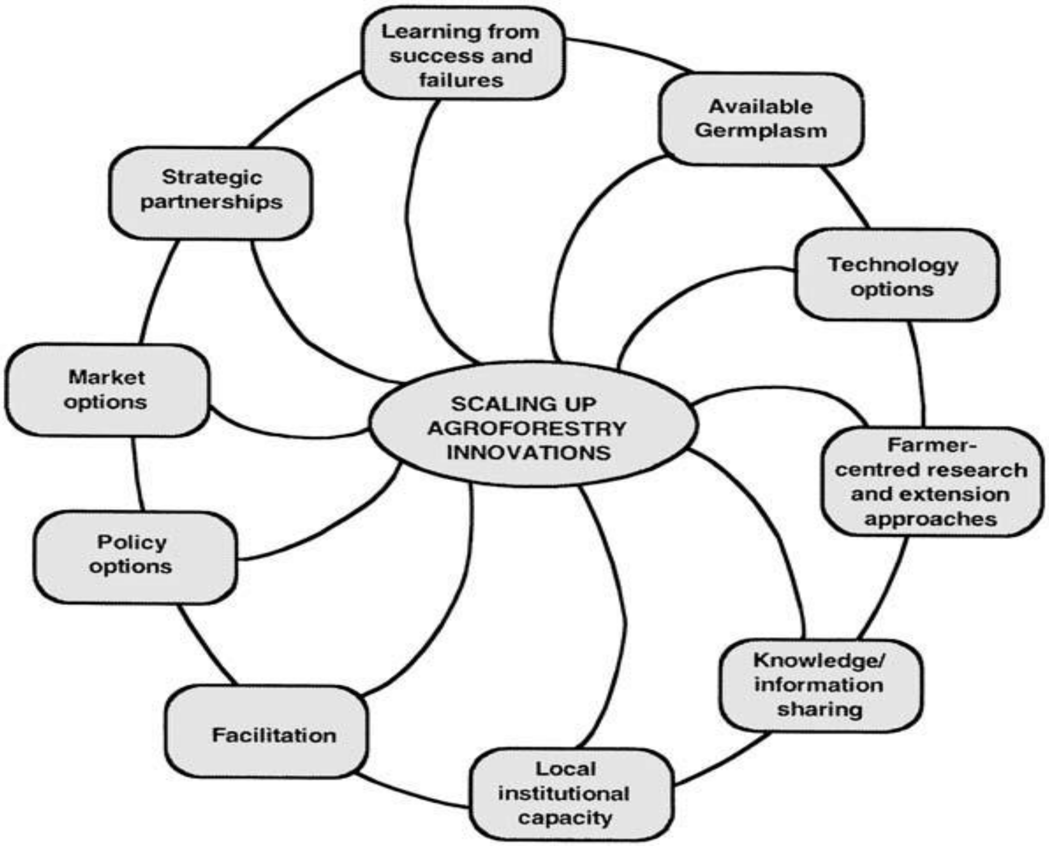

Figure 4. Essential elements for scaling up agroforestry innovations (from Cooper and Denning 2000).

According to (Agroforestry Network, 2018), the following strategies and approaches can be used to upscale agroforestry:

(i) Cooperatives, NGOs and community organizations

Cooperation among rural food producers is essential for scaling up agroforestry. Diversification of production must be met with mechanisms for pooling the produce so that the transactional costs for each product can be reduced. Furthermore, having strong communities that facilitate knowledge dissemination between farmers can provide an environment in which farmers are encouraged to test innovations as they get some stability from being a part of a group Being a part of a community organization also increases the incentives for the individual to do something for the common, i.e. work for a better environment as social contracts are formed.

(ii) Introduce an agroforestry certification that will allow farmers to get more money for their products, as suggested by many experts and scientists and would also give access to public procurement. However, certification systems are in general very complex, expensive and require public awareness.

(iii) Create partnerships between companies with sustainability profiles and agroforestry farmers. Farmers could be given a premium price for their products without certification and the companies promote agroforestry products using a storytelling approach.

(iv) Demand driven, participatory and inclusive research

There is a need for research in agroforestry to move away from studying only biophysical parameters to focus more on socioeconomic aspects and address impacts at larger spatial and longer temporal scales. This could be done through landscape studies with a social ecological systems approach in multidisciplinary research teams, linking biophysical parameters to socioeconomic impacts, exploring synergies and how to manage trade-offs. Furthermore, agroforestry research could focus more on the context of implementation and the scale-up processes to determine why and how practices, initiatives, and extension methods are successful. This goes beyond studies on farmer level and addresses market functionality and value chains as well as policies and the institutional environment.

(v) New models for funding

To be successful in rural land management projects and especially in those involving trees, more time is needed. A scale-up of agroforestry would thus benefit from longer funding cycles from international and national investors and donors, and new funding mechanisms involving other stakeholders such as investors in sustainable development. Furthermore, scale-up processes are based on innovation and thus funders of projects must be able to take on the risk of project failures.

(vi) National policies and coordination between ministries and other institutions.

By including agroforestry in policies and other guiding documents, the status will improve and no longer be seen as a specific technology within either forestry or agriculture. However, including and writing policies for agroforestry is not enough to ensure a change in land management. Appropriate coordination between ministries and other institutions is necessary to avoid rural development programmes, land-use planning and legal frameworks to be dominated by the objectives of one single actor. Of course, it is also necessary to harmonize related policies in forestry, agriculture, environment, etc. to dismantle all those practical barriers preventing agroforestry implementation. A first step to achieve these goals could be to improve policy makers' capacity in agroforestry in tropical countries with large rural populations living in poverty.

Other strategies include:

(vii) New value chains for agroforestry products

Developing new value chains for agroforestry products, especially those that are connected to indigenous trees, is an important action to scale-up agroforestry. This will benefit women further if local processing is promoted, as women in general are benefiting from products with a short shelf life (Kiptot & Franzel, 2011).

(viii) Expand schemes for payments of ecosystem services, i.e. provide farmers with direct financial benefits if they implement certain practices. This has to some extent been successful for carbon credits and for watershed management, where hydropower producers or companies selling bottled water are paying upstream farmers (Namirembe *et al*, 2017).

According to Franze *et al. (*2004), there are 12 key elements of scaling up. These are:

(a) taking a farmer-centered research (b) extension approach; (c) providing a range of technical options; (d) building local institutional capacity; (e) sharing knowledge and information; (f) learning from successes and failures; (g) strategic partnerships and (h) facilitation.(i) marketing, (j) germplasm production (k) distribution systems, and (l) policy options

Barriers to up scaling of agroforestry

Agroforestry requires an upfront investment in terms of money and time but the return on the investment is longer than for annual crops (Sharma *et al*, 2016). Many farmers living in poverty, who could benefit from adopting agroforestry practices, lack buffers and capital to do long-term investments and their access to credit is in general low. This is particularly apparent for women, who receive less than 10% of the credit in developing countries because they often lack ownership of land used a collateral (World Bank, 2007). When loans are granted to farmers, they usually have a short payback time and high interest rates making long-term investments less profitable. Many credit institutes do not have credit lines for agroforestry, just for forestry and/or agriculture.

The long return on investment for agroforestry practices discourages farmers from investing when land and tenure rights are unclear. This is the case in many lower income countries and especially for farmers living in poverty (Celander *et al*, 2003), and women in particular. Furthermore, when farmers have informal rights to their land these usually allow them to claim the ownership of the crops but not of the trees. This phenomenon is especially apparent for women, as their rights to the land they manage are in general much weaker than for men. In many countries, farmers do not even have the right to trees on their land or their products. Such tree protective policy measures date back to the colonial era and are of course barriers for agroforestry implementation (FAO, 2013).

Except for a few products, e.g. coffee, cocoa, rubber, acai and shea, value chains for nontimber agroforestry products are poorly developed (Millard, 2011; Belcher & Schreckenberg, 2007). This is especially true for products from indigenous trees, even if there are exceptions locally. The same goes for inputs used in agroforestry systems such as certified seeds and high-quality seedlings. In many countries, high quality germplasm for tree species suitable for agroforestry is difficult to get hold of, especially for indigenous tree species, and infrastructure such as nurseries, for large-scale implementation is poorly developed (Dawson *et al*, 2013).

Female food producers face additional market-related challenges. In many regions they have less access to markets. One part of this problem can be that the mode of transportation to the physical market might not be culturally accepted for women, or that women are considered responsible for the household, giving them less time to travel to markets. Furthermore, female farmers tend to get less paid for the same products as men. This is because women's educational level is in general lower than men's, which reduces their access to market information systems that are developed to primarily serve highly educated traders (Kiptot & Franzel, 2011).

Agroforestry is a practice that requires small amounts of commercial inputs (e.g. inorganic fertilizers), at least after establishment, and the success is instead dependent on labor and correct management techniques and knowledge. Such services are more difficult to commercialize by large companies and these could thus be a barrier for agroforestry as they can potentially advocate against policy changes and drive the value chains of products and inputs to favor monocultures (Sharma *et al,* 2016). In most countries, policies, land-use planning and rural development programmes emphasize high input (e.g. machinery, inorganic fertilizers and irrigation) monocultures as the primary tool for development and a lack of agroforestry knowledge pervades the land management sector. Products supporting monocultures such as fertilizers, certified seeds for staple crops and fuel are often subsidized while products supporting diverse agroforestry systems such as seeds and seedlings of a variety of species are absent from the market. Farmers who plant trees can also be limited by heavy regulations regarding management, harvest and selling, preventing a good integration with the crops (FAO, 2013).

Addressing barriers and moving forward

Domestication of indigenous trees should be prioritized

Many of the ecosystem services, products and benefits that come with agroforestry are dependent on a high biodiversity on the farm and in the landscape. To achieve such a development, the use of indigenous tree species is essential. There is thus a need to domesticate indigenous tree species and to support value chains for these. Historically, such interventions have been few, as fast growing exotic species mostly have been used in forest plantations and also on smallholder farms (Nyaga *et al*, 2015).

Improving access to credit

Access to capital could also be improved by providing better systems for credit, either through informal village savings and loans groups or by more formal set-ups. It is though important that such credit systems are constructed to benefit also women (Kiptot & Franzel, 2011).

Innovation in extension services

Increasing the agroforestry capacity of different institutions working with extension services should be prioritized to enable further implementation of agroforestry. There is also a large potential for innovation in relation to extension services by using social marketing to change behaviours and to introduce new practices and products, i.e. create demands. New technology could as well partially replace physical extension service delivery. However, it is important that extension services keep working with extension officers, good examples and ambassadors showing the inherent possibilities of agroforestry. This enables horizontal knowledge dissemination between farmers and from farmers to extension programmes ((Agroforestry Network, 2018).

Securing tenure rights of trees and land

Unclear land-rights prevent farmers to invest time and money in practices with a longer return on investment. Securing land tenure rights could thus be a major driver for scaling up agroforestry. When advocating for, or working with, land rights it is important to also address women as they in general have very weak legal rights to land. Legal rights to land also improve access to credit, as land is the most common collateral in rural areas. Secure tenure rights do not necessarily imply a complete privatisation and formalisation of land ownership. Such processes involve high costs and other more informal processes might benefit farmers living in poverty more. The right to trees should also be linked with the right to land. One way forward that would promote agroforestry could be to implement conditional leases or tenure agreements, where the farmers are obliged to plant or keep trees ((Agroforestry Network, 2018).

Case studies from Kenya on agroforestry practices.

Fodder shrubs, Kenya:The site, the farming system, and the farmers' problem being addressed

The low quality and quantity of feed resources is a major constraint to dairy farming in central Kenya, where farm size averages one to two hectares and about 80% of households have one or two dairy cows each. The dairy zone ranges in altitude from 1300 m to 2000 m and rainfall occurs in two seasons, varying from 1200 mm to 1500 mm annually. Soils, primarily Nitosols (Alfisols), are deep and of moderate to high fertility. The main crops are coffee (*Coffea* sp.) produced for cash, and maize (*Zea mays*) and beans (*Phaseolus* spp. and *Vigna* spp.), produced for food. Most farmers also grow napier grass (*Pennisetum purpureum)* as fodder (cut and fed to cows). But napier grass is insufficient in protein so milk yields of animals fed on it are low, about 8 kg cow−1 day−1. Commercial dairy meal is available but farmers consider it expensive and most do not use it (Franzel *et al*, 2003).

The innovation and how it was developed

Researchers (of the Kenya Agricultural Research Institute – KARI , the Kenya Forestry Research Institute – KEFRI, and the World Agroforestry Centre) and farmers tested several fodder shrubs around Embu, Kenya, in the early 1990s and *Calliandra calothyrsus* (hereafter referred to as calliandra) emerged as the best performing and most preferred by farmers. Most of the trials were farmer-designed and managed. For example, farmers tested the feasibility of growing calliandra in a range of 'neglected niches' on their farm. They found that the shrub could be successfully planted in hedges along internal and external boundaries, around the homestead, along the contour for controlling soil erosion, or intercropped with napier grass. When pruned at a height of 1 m, the shrubs did not compete with adjacent crops. Farmers were able to 500 shrubs, at a spacing of 50 cm, around their farms, and to begin pruning them within a year after planting. Five hundred shrubs are required to feed a cow throughout the year with 2 kg dry matter per day, adding about 0.6 kg crude protein. On-farm feeding trials confirmed that the farmers could use the shrubs as a substitute for dairy meal or as a supplement to increase milk production. Growing 500 shrubs increased farmers' incomes by between $98 and $124 per year. By the late 1990s, two other shrub species, *Morus alba* (mulberry) and *Leucaena trichandra,* were introduced to farmers following successful on-farm testing (Franzel *et al*, 2003).

The scaling up process

By 1999, eight years after the introduction of fodder shrubs, about 1 000 farmers around the Embu on-farm research sites had planted them. But the scope for reaching the 625 000 dairy farmers in Kenya was limited. Seed was scarce and the farmers, extension staff and NGOs were not aware of fodder shrubs except in areas around the on-farm trials. During 1999–2001, KARI, the World Agroforestry Centre, and the International Livestock Research Institute collaborated in a project to scale up the use of fodder shrubs in central Kenya. An extension facilitator, working with a range of government and NGO partners, assisted 180 farmer-development groups comprising 3200 farmers across seven districts to establish nurseries and plant fodder shrubs. The approach proved to be very effective for facilitating the spread of the practice. By 2002, each farmer had an average of 340 shrubs and each had given information and planting material, seeds or seedlings, to an average of six other farmers. Sixty percent of participating farmers were women. Research projects aimed at understanding the scaling up process examined factors affecting the performance of nursery groups and factors affecting whether adopters disseminated planting material and germplasm to other farmers (Place *et al*, 2002b2).

Beginning in 2002, a project financed by the Forestry Research Programme of DFID (UK Department for International Development) and implemented by the Oxford Forestry Institute and the World Agroforestry Centre is helping a range of partner organizations to increase the adoption of fodder shrubs in Kenya and four other countries. By early 2003, there were about 22 000 farmers planting fodder shrubs in Kenya and several thousand in the other countries. Facilitators are helping to train the extension staff of a range of different organizations, including government, NGOs, churches, community-based organizations, farmer groups and private sector firms. The project is also helping to facilitate the emergence of private seed producers and dealers, and to help linkthem to buyers in areas where seed demand is high (Franzel *et al,* 2003;Wambugu *et al*, 2001).

Conclusion

The goal of this literature review was to find out if agroforestry has relevance in climate change adaptation using a systematic review of the literature using inclusion criteria. The findings are: increasing tree-crop diversification leads to more carbon storage, generation of multiple livelihood and environmental benefits, key in reducing carbon emissions and achieving the Paris Agreement targets, offers greater economic stability and reduced risk under climate change by creating more diversified enterprises with greater income distribution over time, providing habitat that offers a range of microclimate and resources, increasing landscape connectivity for species to migrate as climate changes, providing other ecosystem services, such as erosion control and water quality protection. protection, that prevent the degradation and loss of surrounding habitat, can reduce air pollution and enhance both warming and cooling of the atmosphere, creating a resilient microclimate for crops and livestock, enhances water security through improved infiltration to soils and groundwater protecting water catchments and watersheds. , and can be a suitable land management system to reduce gender inequalities related to natural resource access, while contributing to increased control of their benefits. Yes, agroforestry contributes positively in reducing vulgaries of climate change. Agroforestry shows a great potential in mitigating CO_2 than treeless systems, it enhances environmental quality, sustains economic viability and enhance quality of life therefore concerted effort should be made by different stakeholder in supporting it.

Recommendations:

The study recommends that National and County governments, development partners should support local communities in implementing agroforestry practices to tackle climate change with e.g. financial, capacity building, legislations for creation of multiple socio-environmental benefits, such as improved farm productivity and biodiversity, increased food and water security and soil health, as well as improved gender equality to policy makers and decision makers.

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