

The Potential Contribution of Carbon Sequestration in Soil and Forest to Enhanced Climate Smart Agriculture in Ethiopia

Girma Asefa Bogale^{1*} and Tufa Feyissa Negewo²

¹School of Natural Resource Management and Environmental Sciences, College of Agriculture and Environmental Sciences, Haramaya University, Ethiopia

²Department of Civil Engineering, Indian Institute of Technology, Guwahati, Assam, India.

Abstract

Climate change and variability are a significant factor in food security challenges where Ethiopia currently and will experience the consequences. Climate smart agriculture increasing the productivity and incomes from smallholder crop, livestock, fishery and forestry production systems will be key to achieve global food security. In the context of national food security and development goals, to tackle three main objectives of climate-smart agriculture are; sustainably increasing food security by increasing agricultural productivity and incomes, building resilience and adapting to climate change and finally, developing opportunities for reducing greenhouse gas emissions compared to expected trends. Climate change has likely hampered and reduced suitability of some areas for agricultural crop production particularly in Ethiopia as a result of flooding and drought events. Climate information and policies are very fundamental to deal with the impacts of climate variability and changes on development and resources management problems. Carbon sequestration in the agriculture sector refers to the capacity of agricultural land and forests to remove and capture carbon dioxide from the atmosphere, so as to calm down the global warming condition. The sequestration of soil organic carbon, is a practical option not only to increase the soil organic carbon stock and quality, but also to decrease soil degradation, increase productivity, and mitigate impacts related to climate change.

Keywords: Carbon Sequestration, Soil, Forest, Climate, Smart, Agriculture

Introduction

Climate change has contributed to reduce agricultural productivity and threatens food security across the world [1]. In sub-Saharan Africa, where high vulnerability to weather shocks has already existed, are expected to be hardest hit, with decreases in agricultural productivity between 15-35% [2-4]. Moreover, increased in temperatures and changes in precipitation will stress agricultural and natural systems, through increased water shortages, shorter growing periods in some areas, an increased magnitude and frequency of flooding and drought, changes in plant/animal diseases and pest distribution patterns, and extensively, reduced suitability of some areas for agriculture. Climate change has likely hampered food production in Horn of African countries, because the agricultural systems are mainly rain fed and characterized by low inputs such as fertilizers, crop protection chemicals (herbicides, insecticides, and fungicides) and improved seeds [5,6]. In addition to climate-related production constraints, soil nutrient depletion is a challenge to food security in the region [7].

In spite of its act as a source of greenhouse gas(GHG) emission [8, 9], soils play a crucial role in climate change mitigation through carbon sequestration [10, 11]. Soils sequester about two-thirds of the terrestrial carbon and contain two to three times more carbon than the atmosphere [10, 12]. Thus, progressive climate-smart soil management interventions are needed to enhance agricultural production and ensure food security in the changing climate. Agriculture is always a back bone of the Ethiopian economy. Agriculture in Ethiopia includes crops, livestock, forestry, fisheries and apiculture. It is the most important sector of the national economy and the main sources of livelihoods for 85 percent of the population. Yet, the agriculture sector in Ethiopia is characterized by low productivity and is unable to meet the food security needs of the people and the country. Smallholder agricultural production remains low, particularly for cereal crops, which is attributed to erratic and unreliable rainfall. The failure of current agricultural techniques to mitigate such conditions are; inefficient use by farmers of agricultural resources such as soil amendments, and

rainwater that contributes to soil degradation.

Climate information and policies are principal to deal with the impacts of climate variability and change on development and resource management problems. A climate-smart agriculture (CSA) production system would consider understanding systems and clients to enhance institutional capacity for the implementation and ups calling of CSA practices and approaches. The substantial difference between the two grassland systems in terms of soil carbon stocks also demonstrate the importance of grassland management to mitigate climate change through carbon sequestration. According to the findings of Sanderman *et al.*, 25 found that a marginal effect of rotational grazing on soil carbon sequestration after 15 years of implementation. Agro forestry practices improved climate change mitigation potential of carbon poor degraded soils through several mechanisms. For instance, intensive management practices, such as litter incorporation and manure application coupled with soil conservation measures, likely contributed to the higher soil carbon sequestration in the agro forestry systems. The agro forestry practices being promoted and tested are intended to address issues of soil fertility, soil erosion and diversification of farm produce as well as agricultural yield, resilience to climate variability (for example through provision of shade during hot spells) and creation of favorable microclimates for certain crops.

Integrating perennial trees or shrubs in agricultural lands used both for crop production and grazing in Ethiopia has been documented to improve soil cover and ensure green cover during the off-season [13].

***Corresponding author:** Girma Asefa Bogale. Department of Civil Engineering, Indian Institute of Technology, Guwahati, Assam, India; E-mail: girmaasefa12@gmail.com

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Carbon losses that normally occur through soil disturbance was controlled by minimum tillage practices in the agroforestry systems [14]. The root system of multipurpose leguminous trees and shrubs are also responsible for carbon climate 2020, 8, 124 8 of 12 input [15] carbon stabilization within soil aggregates [16-18] and reduced erosion [19]. De Stefano and Jacobson, 2017 performed a meta-analysis on soil carbon sequestration potential of agro forestry and found up to a 40% increase in SOC stocks due to the transition from cropland to agro forestry which is in accordance with the present study.

Agriculture accounts for more than 40% of Ethiopia's gross domestic product (GDP) (UNDP, 2015), and contributes significantly to GHG emissions (FDRE, 2015) [20]. In Ethiopia, annual GHG emissions were estimated to be 150 Mton CO₂e in 2010, with 50% of emissions coming from agriculture, and another 37% from forestry sectors mainly agriculture related deforestation (FAO, 2016) [21]. As a set forth in the second GTP, reaching this goal will require boosting agricultural productivity by introducing climate-smart technologies and practices that include integrated watershed management, conservation agriculture, as well as nutrient and crop management across agro ecosystems and landscapes with the potential to reduce GHG emissions by 40 Mton CO₂e in 2030 (CRGE, 2011) [22]. Therefore, the overall objective of this study was to review potential contribution of carbon sequestration in soil and forest conservation to enhanced climate smart agriculture in Ethiopia.

Review of Related Literature

Some Definitions and Conceptual Frameworks

Carbon sequestration: Carbon sequestration or carbon dioxide removal is the long-term removal, capture or sequestration of carbon dioxide from the atmosphere to slow or reverse atmospheric CO₂ pollution in order to mitigate global warming [23, 24]. Carbon sequestration describes long-term storage of carbon dioxide or other forms of carbon to either mitigate or defer global warming and avoid terrible climate change. It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels and more so caused by industrial livestock production.

Climate-Smart Agriculture Practices: Climate-smart agriculture (CSA) is defined by FAO (2010) as agriculture that sustainably increases productivity, enhances resilience of livelihoods and ecosystems, reduces and/or removes greenhouse gases (GHGs) and enhances achievement of national food security and development goals. CSA includes proven practical techniques such as mulching, intercropping, conservation agriculture, crop rotation, integrated crop-livestock management, agroforestry, improved grazing and improved water management. CSA also involves innovative practices such as improved weather forecasting, early-warning systems and climate-risk insurance. CSA aims to get existing technologies off the shelf and into the hands of farmers, as well as to develop new technologies such as drought-tolerant or flood-tolerant crops to meet the demands of the changing climate.

Climate change: Climate change refers to a significant and sustained (over decades or longer) change from one climatic condition to another. Climate change is a normal component of the earth's natural variability and occurs in all time and space scales. The rapid alteration of climate change is a results of socioeconomic development, deforestation, population growth, urbanization, and land-use cover changes, which are leading to global

warming/emissions of greenhouse gases [25]. The manifestation of climate change such as rising temperature, increasingly erratic rainfall, frequent and severe floods and droughts have serious consequences on the livelihood security of smallholder farming communities life standard in many African countries [26].

Agriculture and Climate Change

Temperature and rainfall vary across the main regions of Ethiopia. There is a trend of decreasing temperatures and increasing rain fall from the lowlands in the south and north-east to the central and upper highlands; with rainfall reaching over 2000 mm annually in the southwestern highlands compared to as low as 300 mm in the lowlands. The regions also experience very different seasonal regimes: while the June–September wet season (also known as the *kiremt* season, with rainfall reaching as high as 350 mm/month) is common throughout most of the country, farmers and pastoralists in the North and the Centre rely yearly on an additional short wet season from February–May known as the *belg* season. The South is exposed to rains between February–May and October–December (the *bega* season), while rains are very scarce in the far eastern parts of the country (DSU, 2016) [27].

Agriculture and Carbon Sequestration

The U.S. agricultural production sector contributes more greenhouse gas emissions from methane (CH₄) and nitrous oxide (N₂O) than from carbon dioxide (CO₂). Carbon sequestration in the agriculture sector refers to the capacity of agriculture lands and forests to remove carbon dioxide from the atmosphere. Agriculture sinks of greenhouse gases are reservoirs of carbon that have been removed from the atmosphere through the process of biological carbon sequestration. As organic carbon decomposes, it is converted back to carbon dioxide through the process of respiration

Soil carbon stock across different land uses

Agroforestry had the highest mean soil carbon stock of 312.1 ton/ha that was statistically significant compared to other land uses (Figure 1). Agroforestry is mostly practiced around homesteads, instead of on crop fields, where farmers typically incorporate animal manure to improve soil fertility. This is due to the longer distances between the household and the farmlands. Cropland with CSA had the second highest soil carbon stock of 229.4 ton/ha, attributed to crop residues. While cropland had statistically higher carbon levels compared to the community forest, it did not differ significantly from grasslands (208.9 ton/ha). Grassland soil carbon stock is mainly a result of belowground carbon in roots and soil organic matter [4]. Soil carbon stock in the community forest was much lower at 145.4 ton/ha, compared to other land uses. The area is characterized by steep slopes without soil and water conservation structures (exposed to higher erosion) and lack of biodiversity as it is mainly dominated by the black wattle (*Acacia decurrens*) tree species.

Sources of GHG emissions from agriculture

Ethiopia is one of the world's lowest emitters of GHG emissions, ranking 182 of 188 countries on per capita emissions and contributing only 0.27% of global emissions (MOFAN, 2018). Today's per capita emissions of less than 2 ton CO₂e are modest compared with the more than 10 ton per capita on average in the European Union (EU) and more than 20 ton per capita in USA and Australia [28]. According to Engdaw (2020) [29] revealed that, except land use and land cover changes in forestry, Ethiopia has shown increasing trends of emission in most sectors. However, land use change and forestry is the first

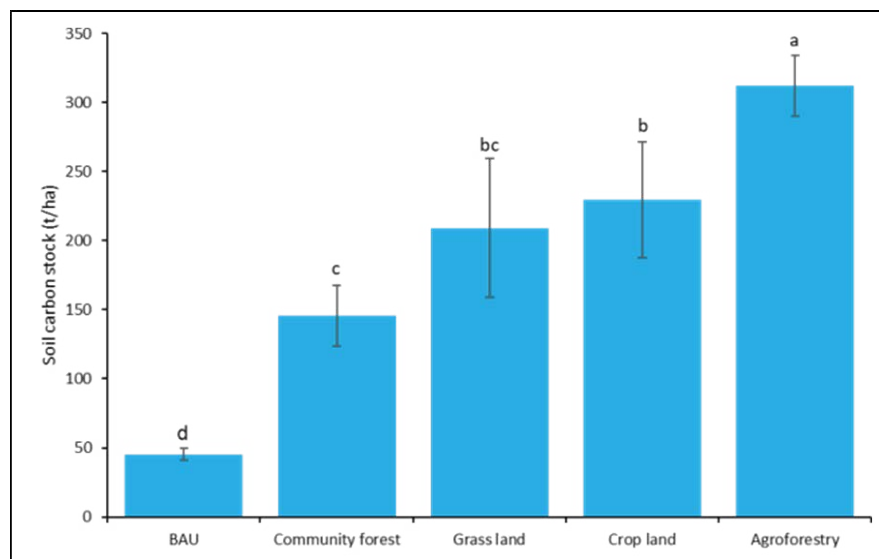


Figure 1: Soil carbon stock variations at a depth of 100 cm in the different land management systems in Tula- Jana landscape.

leading sector that has contributed to the largest greenhouse gases emission in the country (Figure 2).

Climate Smart Agricultural Practices in Ethiopia

Climate smart agricultural (CSA) practices are practices that sustainably increase productivity, enhance resilience, remove GHGs, and enhance achievement of national food security and development goals (FAO, 2010) [30]. Ethiopia emitted 141 million metric tons (MtCO₂e) in 2011, with 61 percent of greenhouse gas emissions coming from the agriculture sector and the greenhouse gas emissions in Ethiopia increased by 86 percent from 1993 – 2011 (Figure 3).

There are different climate smart agricultural practices in Ethiopia (FAO, 2016). These practices consist different components and used for specific purposes in GHG emission mitigation and climate change adaptation (Table 1).

Farming Systems and Climate-Smart Agriculture Technologies in Ethiopia

The farming system in Ethiopia can be classified into five major categories the highland mixed farming system, lowland mixed agriculture, the pastoral system, shifting cultivation and commercial agriculture [31]. Such agricultural practices in Ethiopia include integrated watershed management, integrated soil fertility management, sustainable land management, conservation agriculture, agroforestry, crop residue management, composting, promotion of improved livestock feed and rangeland management. The agriculture sector is the backbone of Ethiopia's economy and livelihoods. Yet, heavy reliance on rain-fed systems has made the sector particularly vulnerable to variability in rainfall and temperature.

Climate change may decrease national gross domestic product (GDP) by 8–10% by 2050, but adaptation action in agriculture could cut climate shock-related losses by half. Climate risk management interventions and long-term adaptation actions need to match localized vulnerabilities and impacts. The drought-prone highland areas are likely to experience more intense and irregular rainfall, affecting

yields of slow maturing, long-cycle crops; however, the higher altitude moisture-sufficient parts of the highlands where cereal production dominant is expected to increase in suitability and productivity of some cereals (USAID, 2017) [32] were depicted in (Figure 4).

Climate Smart Agriculture and Biophysical Conditions

The Rural Development Policy and Strategy Document (MOFED, 2003) [33] states that Ethiopia is characterized by the existence of many agro-ecological zones, which differ in terms of rainfall, soil types, altitude and the like. Its further states that all development efforts will be based on detailed development plans for each agro-ecological region so as to bring about the maximum possible growth in each region, thereby accelerating and sustaining the country's overall agricultural development. For drought-prone regions, the policy states that special attention will be given to the regeneration of natural resources as well as soil and water conservation and environmental protection as a matter of great importance (Figure 5). The strategy for regions with reliable rainfall is to increase crop production and productivity while undertaking natural resources development. Agroforestry and animal resources development are areas that can be greatly expanded. The soil affected by inadequate rainfall that is affected by severe land degradation, mostly as a result of erosion and inappropriate land-management.

The Potential of Soil for Carbon Sequestration

Agricultural systems contribute to carbon emissions through the direct use of fossil fuels in food production, the indirect use of embodied energy in inputs that are energy intensive to manufacture, the cultivation of soils and/or soil erosion resulting in the loss of soil organic matter. The direct effects of land use and land use change

(including forest loss and conversion of use) have led to a net emission of 1.7 Gt C yr⁻¹ in the 1980s and 1.6 Gt C yr⁻¹ in the 1990s (IPCC, 2000). On the other hand, agriculture can also be an accumulator of carbon, offsetting losses when organic matter is accumulated in the soil, or when above-ground biomass acts either as a permanent sink or is used as an energy source that substitutes for fossil fuels and so avoids carbon emissions.

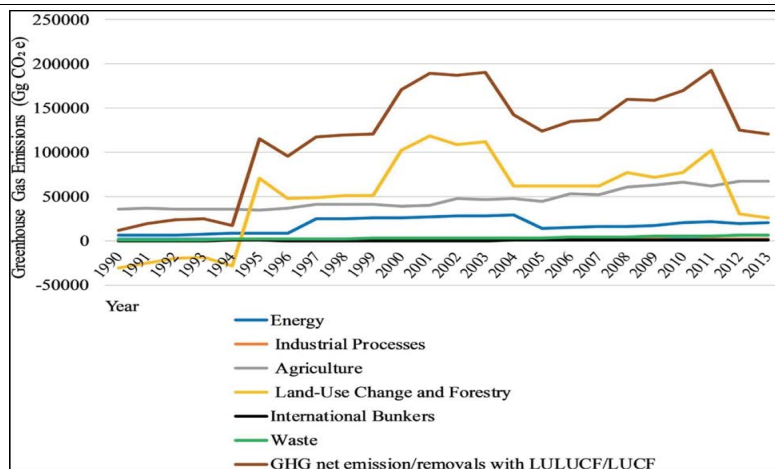


Figure 2: Trends of greenhouse gas emission in terms of sectors (1990-2013) (Engdaw, 2020).

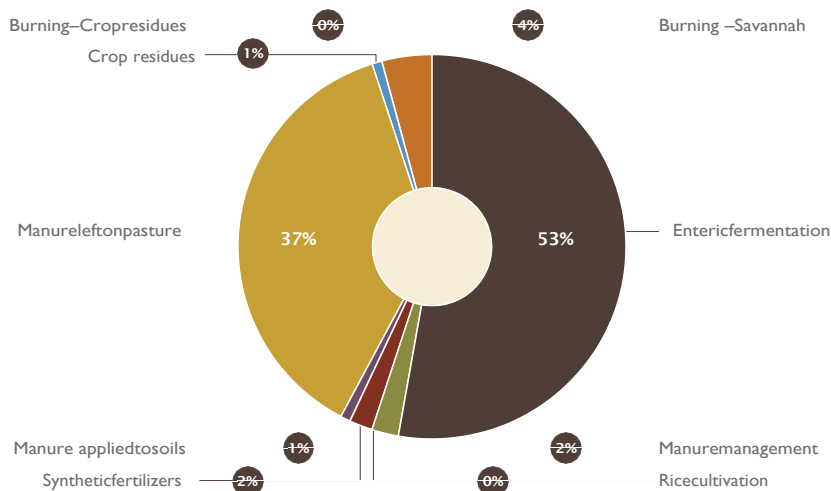


Figure 3: Greenhouse gas emissions in Ethiopian agriculture in 2012 (FAOSTAT, 2015).

CSA practice	Components	Why it is climate smart
Conservation agriculture	Reduced tillage Crop residue management – mulching, intercropping Crop rotation/intercropping with cereals and legumes	Carbon sequestration Reduce existing emissions Resilience to dry and hot spells
Integrated soil fertility management	Compost and manure management, including green manuring Efficient fertilizer application techniques (time, method, amount)	Reduced emission of nitrous oxide and CH4 Improved soil productivity
Small-scale irrigation	Year-round cropping Efficient water utilization	Creating carbon sink Improved yields Improved food security
Agroforestry	Tree-based conservation agriculture Practiced both traditionally and as improved practice Farmer-managed natural regeneration	Trees store large quantities of CO2 Can support resilience and improved productivity of Agriculture
Crop diversification	Popularization of new crops and crop varieties Pest resistance, high yielding, tolerant to drought, short season	Ensuring food security Resilience to weather variability Alternative livelihoods and improved incomes
Improved livestock feed and feeding practices	Reduced open grazing/zero grazing Forage development and rangeland management Feed improvement Livestock breed improvement and diversification	Improved live stock productivity GHG reduction CH4 reduction
Other	<i>In situ</i> water conservation/harvesting Early-warning systems and improved weather information Support to alternative energy fuel efficient stoves, biofuels Crop and livestock insurance Livelihoods diversification (apiculture, aquaculture) Post-harvest technologies (agro- processing, storage)	Resilience of agriculture Improved incomes Reduced emissions Reduced deforestation Reduced climate risk

Table 1: Summary of some common CSA practices in Ethiopia (FAO, 2016).



Figure 4: Farming systems and climate-smart agriculture technologies and practices.



Figure 5: Drought and rainfall that is affected by severe land degradation, mostly as a result of erosion and inappropriate land-management.

Therefore, identify three mechanisms by which positive contributions that can be made by farmers (Table 2). Mechanism A:-Increase carbon sinks in soil organic matter and above-ground biomass. It has been established that SOM and soil carbon can be increased to new higher equilibria with sustainable management practices. A wide range of long-term comparative studies showed that organic and sustainable agricultural systems improve soil health through accumulation of organic matter and soil carbon, with accompanying increases in microbial activity (IPCC, 2000).

Mechanism B:-Reducing direct and indirect energy use to avoid carbon emissions. Nitrogen fertilizers, pumped irrigation and mechanical power account for more than 90% of the total direct and indirect energy inputs to most farming systems [34]. According to the OECD (1993), the absolute energy consumption per hectare increased in OECD countries by 39% between 1970 and 1989. On average, some 1734 MJ are consumed per hectare of agricultural land, rising to 46,400 MJ for the highest consumer, Japan. Sustainable agriculture systems that substitute goods and services derived from nature rather than externally-derived fertilizers, pesticides and fossil- fuels, increase the energy-efficiency of food production [35].

The Role of Reforestation in Carbon Sequestration

Efforts to increase terrestrial carbon sequestration are based on the premise that reforestation adds to the planet's net carbon storage

and helps moderate global warming by slowing the growth of carbon emissions in the atmosphere. In a carbon market, each ton of carbon sequestered is called a carbon credit. The role of forests in mitigating atmospheric CO₂ pollution and climate change provides long-term context, and argues for a closer look at intensified reforestation efforts in the U.S. (Dumroese*et*). In terms of justification, not only is reforestation necessary to promptly re-establish forest cover after catastrophic disturbances such as large wild fires, but deliberate reforestation even after less severe or extensive disturbances may enhance C sequestration rates compared to passive management approaches such as waiting for natural regeneration (MacDonald; Nave; Post and Kwon).

Conclusion and Recommendation

As concluded from the different cumulative view of scholars and researchers, climate change has contributed to reduced agricultural productivity and threatens food security across the world. Furthermore, increased temperatures and changes in precipitation will stress agricultural and natural systems, through increased water shortages, shorter growing periods in some areas, an increased magnitude, frequency of flooding, and drought, changes in plant/animal disease and pest distribution patterns. Generally, climate change has likely hampered and reduced suitability of some areas for agricultural crop production particularly in Ethiopian countries as the result of flooding and drought events.

Mechanism A: Increase carbon sinks in soil organic matter and above ground biomass
Replace inversion ploughing with conservation- and zero-tillage systems
Adopt mixed rotations with cover crops and green manures to increase bio mass additions to soil
Adopt agro forestry in cropping systems to increase above-ground standing biomass
Minimize summer allows and periods with no ground cover to maintain soil organic matter stocks
Use soil conservation measures to avoid soil erosion and loss of soil organic matter
Apply composts and manures to increase soil organic matter stocks
Mechanism B: Reduce direct and indirect energy use to avoid greenhouse gas emission (Carbon dioxide, methane and nitrous oxide)
Conserve fuel and reduce energy use in buildings and stores
Use conservation or zero-tillage to reduce CO ₂ emissions from soils
Use composting to reduce manure methane emissions
Substitute biofuel for fossil fuel consumption
Reduce machinery use to avoid fossil fuel consumption
Reduce the use of inorganic nitrogen fertilizers and adopt targeted- and slow- release fertilizers, as fertilizer manufacture is highly energy intensive
Reduce use of pesticides to avoid in direct energy consumption
Mechanism C: Increase renewable energy production to avoid carbon emissions
Cultivate annual crops for biofuel production, such as ethanol from maize and sugarcane
Cultivate annual and perennial crops, such as grasses and coppiced trees, for combustion and electricity generation, with crops replanted each cycle for continued energy production
Use biogas digesters to produce methane, so substituting for fossil fuel sources

Table 2: Mechanisms and measures for increasing carbon sinks and reducing carbon dioxide and other greenhouse gas emissions in agricultural systems.

Climate information and policies are very fundamental to deal with the impacts of climate variability on development, and resource management problems. Carbon sequestration describes long-term storage of carbon dioxide or other forms of carbon to either mitigate or defer global warming and avoid dangerous climate change.

Grassland soil carbon stock is mainly a result of belowground carbon in roots and soil organic matter. The farming system in Ethiopia can be classified into five major categories the highland mixed farming system, lowland mixed agriculture, the pastoral system, shifting cultivation and commercial agriculture. Climate-smart agriculture is an approach to help guide actions to transform and modernize agricultural systems to effectively and sustainably support development and food security under a changing climate. Cropland with climate smart agriculture had the second highest soil carbon stock of 229.4 ton/ha, attributed to crop residues. Climate change may decrease national gross domestic product (GDP) by 8–10% by 2050, but adaptation action in agriculture could cut climate shock-related losses by half.

The energies to increase terrestrial carbon sequestration are based on the premise that reforestation adds to the planet's net carbon storage and helps moderate global warming by slowing the growth of carbon emissions in the atmosphere. Climate smart agriculture, does not advocate use of a narrow carbon lens to address agricultural and climate change challenges. Therefore, special attention will be given to the regeneration of natural resources as well as soil and water conservation and environmental protection as a matter of great importance of increased and promoted climate smart agriculture. For the next, reviewer will incorporate sustainable climate change adaptation, mitigation intensified and diversified biodiversity conservation to conducive environment is the valuable figure.

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