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Tea Gardens, A Potential Carbon-Sink for Climate Change Mitigation

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Abstract

The necessity to identify ecosystems with high carbon sink capacity as an alternative mitigation approach to terrestrial carbon sequestration has increased due to hazards such as global warming from emissions of Green House Gases mainly due to anthropogenic activities. Tea is an intensively managed perennial cash crop planted beneath a canopy of shade trees. They provide a prospect for the reduction of climate change while providing economic incentives so much so that some states and the country are dependent on the plantations and the revenue generated out of the tea gardens. Tea and shade trees together can store a significant quantity of atmospheric CO2 in the plants and the soil. The area of the gardens and the shade trees that grow in them makes it very necessary to estimate the amount of carbon sequestered in tea agroforestry systems and define their role as carbon sinks countering the climatic changes and the mitigation of the same.

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Introduction

The IPCC report predicts that the warming in the 21st century will probably reach 1.5°C. In order to prevent this, greenhouse gas emissions must roughly be decreased by 50% from 2019 levels between 2030 and 2035 then eventually decreasing to zero by 2050.[1-4] Ecosystems are growing less robust to the fluctuations of climate change resulting in the continual decline of biodiversity, which may make it more and more challenging to realize the potential for mitigation as has been stated by the AFOLU.[5] The IPCC report emphasizes the fact that numerous innovations required to keep global warming below 1.5°C already exist and are frequently more affordable than burning fossil fuels. Political willingness is the need of the hour since it has not been very impactful to make way for deep and lasting changes in compelling decarbonization.[6] Human actions like burning fossil fuels and deforestation are thought to have accelerated the steady increase in atmospheric carbon dioxide (CO2) concentration.[7] Urban green areas are a useful expansion of carbon sinks in human-dominated environments to amplify the mitigation of climate change. Few studies have

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been done on the advantages that are provided by urban green space, even though many have been done on the detrimental impacts of urbanization.[8] In the context of climate change caused by humans, accurate carbon budget estimation has gained importance. The land use systems that rely on woody perennials have a comparatively high capacity for absorbing and storing atmospheric CO2 in plants, soils, and biomass products.[9] Urban green areas are a useful expansion of carbon sinks in human-dominated environments to amplify the mitigation of climate change. The potential for climate change caused by the atmosphere's rapidly rising carbon dioxide level [2ppm yr-1] is one of the main causes of current global carbon (C) concern. The average global surface temperature has risen by 0.6–0.2 0 C as a result of rising amounts of CO2 and other greenhouse gases (GHGs) in the atmosphere.[1] According to Houghton (2007), managing terrestrial ecosystems, particularly in the areas of forestry, land use, and land use change, is crucial for mitigating human-caused climate change (LULUCF).[10] The era post-Kyoto Protocol garnered a lot of attention for its role in stabilizing the atmosphere's CO2 concentration and promoting a variety of land use schemes as C sinks as the world is fast becoming an urban place as nearly two third of the world's population is expected to live in urban areas by 2025.[11]

Review

Outside of the four billion hectares of closed-canopy forests, nearly one-third of the world's three billion trees grow.[9] Woody perennials are purposefully utilized on the same land management unit as agricultural crops and/or animals in some kind of spatial arrangement or temporal sequence, an approach known as agroforestry. In an agroforestry system there are both ecological and economic interactions between the various components.[10] In the years 2010 to 2019, the AFOLU (managed land) sector, on average, generated 13-21% of the total amount of greenhouse gas (GHG) emissions worldwide by the anthropogenic activities.[11] Terrestrial ecosystems, both managed and unsupervised, served as a carbon sink at the same time, absorbing approximately a third of anthropogenic emissions of carbon dioxide.[2] These trees outside of forests (TOF) are very significant in terms of their potential ecosystem services such as microclimate modification, biodiversity conservation, biogeochemical cycle strengthening, and carbon sequestration.[12] The largest portion of the economic (up to USD100 tCO2-eq-1) AFOLU mitigation potential is located in forests and other natural ecosystems between 2020 and 2050, subsequently followed by agriculture and necessitate-side measures.[2] A significant majority of these reside in agriculture, rangelands, and agroforestry systems, with only a small proportion living in urban and peri-urban zones.[4] For a long time people have believed that agroforestry and more trees on agricultural land are the best strategies to improve agricultural production systems15.With several environmental, ecological, and socioeconomic advantages, these land use methods are also now being taken into account to decrease carbon emissions, sequester extra carbon, and limit the environmental effect of agricultural production, potentially contributing to at least nine of the 17 SDGs.[16] Agroforestry systems, along with afforestation/reforestation and carbon sequestration in grass and croplands, are regarded as one of the top three agriculture, forestry, and land use for the mitigation of the ongoing climatic change. In climate change mitigation scenarios, agroforestry practices have been discovered to have significantly greater potential than peat land and coastal wetland restoration, improved forest management, and biochar.[3] To accurately quantify the amount of vegetation biomass and carbon stored in urban and other non-forest areas, regular monitoring, inventories, and accounting of these areas are necessary. This information will help policymakers create regional or national programs that are environmentally responsible and beneficial to citizens.[17] The quick onset of climate change effects and rising understanding of the sector's significance in suggested worldwide adaption and mitigation efforts have raised the importance of trees and agroforestry systems in debates in several international venues.[15,18,19] The REDD+ agreement, the Convention on Biological Diversity, the UN Sustainable Development Goals (SDG), as well as the FAO and the World Bank have been some noted international forums.[20] A growing understanding of how important agroforestry and more trees on agricultural land are to the fight against climate change[21] is also evident in the recent IPCC report.[2] Similarly, there is a significant increase in citations of agroforestry that are found in National Adaptation

Plans and Nationally Determined Contributions.[3] Although AFOLU measures have a significant potential for mitigation from a biophysical and environmentally friendly standpoint, their viability is constrained by weak governance, unresolved permanency repercussions, scattered land ownership, lack of organizational support, and ambiguity about long-term addition and trade-offs. Despite these barriers AFOLU mitigation methods are successful and, with the right assistance, can lead to rapid decreases in emissions in the majority of countries.[5] The primary stakeholders for achieving the necessary level of tree cover in the nation may be thought of as agroforestry systems.[22] The amount of carbon sequestration is influenced by the species, agroforestry system type, and system management.[23] In Mei-tan County, the soil consolidation rate was 3.78 104 t/a, the carbon storage potential was 187.65 104 t/a, and water conservation was 0.61 million m3/a.[24] In India, tea agroforestry covers 563,980 hectares and has the potential to combine economic rewards with social services and environmental advantages. Although uncertainty in estimates of both the sources and the sinks of CO2 was highlighted, it was noted that the share of AFOLU to human-caused environmental GHG emissions had stayed largely unchanged since the IPCC Fifth Assessment Report (AR5) at 13-21% of total emissions of GHG.[6] This uncertainty was intense due to the ambiguity in the difference between natural and anthropogenic fluxes. The assessment takes into account the fact that land mitigation is predicted to account for around 25% of the 2030 mitigation commitments made in Nationally Determined Contributions (NDCs) under the Agreement of Paris, few nations have offered specifics on how this will be accomplished. From 2010-2019, average global the net anthropogenic GHG emissions from AFOLU were found to be 11.9 4.4 GtCO2-eq yr-1, or about 21% of total global anthropogenic GHG emissions.[25] The conversion of 630 million hectares of unproductive croplands and grasslands to agroforestry may sequester 1.43 and 2.15 Tg (1012g) of CO2 yearly by 2010 and 2040, respectively.[26] The estimated urban tree carbon (C) storage densities average 7.69 kg C m-2 while the sequestration densities averages 0.28 kg C m-2 of the total tree cover per year.[27] It was stated that realization would be extremely difficult due to the dependence of mitigation under AFOLU on a wide range of factors that includes overpopulation, technical and economic advancements, the effect of climate change amidst the mitigation efforts.[3] Agroforestry systems (AFS) can play a significant role in storing carbon in above- and below-ground biomass as well as in soil, even if this is not their primary purpose for planning appropriate management techniques to lower, stabilize, and stop CO2 emissions or to improve C-sinks, it is helpful to assess the stand's growth rate in order to assess its capacity to offset the emission of GHGs (Green House Gases).[28–30] Agroforestry systems (AFS) offer excellent chances to store carbon and reduce climate change.[22] The ability of carbon dioxide absorption and storage by these land use systems of woody perennials in vegetation, soils, and biomass products is rather high. Estimates for the overall C storage in an AFS's biomass compartments show higher values than for land without trees.[9] The Intergovernmental Panel on Climate Change (IPCC) estimates that over the next 50 years, AFS has the potential to mitigate 1.1–2.2 Pg C in terrestrial ecosystems.

As a result, both in developed and developing nations, agroforestry has generated high hopes as a C sequestration approach. Its acceptance as a C sequestration activity under the afforestation and reforestation activities of the Kyoto Protocol, and the various forms of agroforestry drew particular interest as a C sequestration technique. By preserving and enhancing land-based carbon sinks, agroforestry has a significant potential for Eco restoration of degraded lands and limiting the buildup of carbon as CO2 in the atmosphere. Recent attention has been drawn to the agroforestry system because of its vast potential carbon pools that lower carbon emissions to the atmosphere.[9] Future climate change mitigation strategies must include long-term carbon management through ecosystem services provided by multifunctional forests and agroforestry, coupled with yield enhancement.[23]

In Southeast Asia and certain African nations, tea is one of the main plantation crops. India is the world's second-largest tea producer after China. In India, there are three distinct areas where tea is grown.[32] These three regions—Darjeeling ,Terai and Dooars (West Bengal, India), Assam (Far North-East India), and Nilgiri (South India)—are geographically distinct and produce very diverse teas in terms of both flavor and style. In addition to the three distinct tea-growing regions mentioned above, tea is also grown in Kerala, Karnataka, Himachal Pradesh, Uttaranchal, Sikkim, Orissa, Bihar, Arunachal Pradesh, Tripura, Manipur, Nagaland, Mizoram, and Meghalaya. Robert Bruce found the untamed tea plants in the upper Brahmaputra Valley in 1823, and the first Indian tea was delivered to the United Kingdom for sale in 1838. The "Ching" or Tea Classic, which was written by Lu Yu and published around the year 780 A.D., documented different types of tea, cultivation and manufacturing techniques, quality, and distribution in China.[32] The previously studied tea growth characteristics in Sri Lanka were in terms of flushing and dormancy. The "dormancy index" concept was later created.[33] In North East India, Barua and Das (1979) investigated the growth properties of a wide variety of clones. Investigations were made into the blooming and fruiting of seed trees in North East India.[32,34] Many statistical tools and methodologies implemented in order to study the short and the long term climatic scenario of the tea sectors showed detrimental effects of climate change in the yield also indicating habitat unsuitability in parts of West Bengal and Sri Lanka.[35–38]

Tea is grown with dispersed sunshine, which is provided by shades.[32,39] In tea agroforestry systems, shade trees have an impact on the underlying mechanism of tea growth. Permanent shade trees and temporary shade trees are the two basic categories of shade trees. Permanent shade trees take a while to grow and give the best possible shade, temporary shade is planted alongside them for the first four to five years.[39] The shade trees are also used as fuel wood, lumber, edibles, medicines and gums by the people with other services like erosion prevention, living fences, ornaments, and environmental protection coming as an addition.[40] The organic matter that shade trees add to the soil is another benefit. So, in addition to the effect of temperature on net photosynthesis, a canopy of moderate shadow is necessary for circumstances to boost tea yields when the leaf temperature exceeds 350°C and virtually stops between 390°C and 420°C.[39,32] The first tree utilised as a shade tree was *Albizia chinensis.* A simultaneous introduction of more leguminous species, including *Albizia odoratissima, Dalbergia assamica, Erythrina indica,* etc.[32] *Albizia chinensis, Accacia lenticularis, Albizia odoratissima, Albizia moluccana, Albizia lebbeck, Albizia procera, Albizia lucida, Adenanthera pavonina, Derris robusta, Dalbergia sericea* and others are common shade tree species in North East India. Indonesia and Sri Lanka, two of the world's major producers of tea, followed the example of North East India and initiated the incorporation of the shade tree in the plantations. Kalita *et al.* (2016) found that the entire carbon stock in tea gardens is split between shade trees and tea plants, 70.66% and 29.34%, respectively. The shade trees are an essential component of tea gardens and, depending on their type, they have a tremendous ability to absorb atmospheric carbon dioxide.[41] The tea agroforestry system could be seen as "an interesting compromise" in the quest for a better "balance between the development of agriculture, economic gain, and the fight against deforestation.".[42] Reports suggest that shade trees in the tea gardens of northeast India sequestrated 4037.4 ± 589.9 kg CO2 ha yr-1 from the atmosphere and a decrease of 35-44 % will be seen by reducing the density of the shade trees by 50 %.[43,44] Due to the variations in urbanization, planning, and vegetation cover, as well as the different sizes of study sites, sizes of sampling, estimation procedures, and tree characteristics, it is not possible to forecast or even compare the estimates of sequestered carbon to the outcomes of these studies.[8] It was also discovered that the soil organic carbon sequestration in the tea gardens of West Bengal's Terai zone was 10.45 Mg ha-1.[45] Researchers like Li (2008a), Li (2008b) and Jing *et al.* (2010) have qualitatively described the ecosystem services of Chinese tea gardens which mainly include direct production value, social security function, organic matter accumulation, nutrient cycling, water conservation, soil immobilization and climate regulation. (Li 2008b) also found that the total service value of the tea garden system in China was about 130.17 billion yuan. InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) has been used to evaluate the ecological benefits of tea gardens in the Meitan County of China. It was estimated that the water conservation of tea gardens was 0.61 million m3 yr-1, carbon storage capacity was 187.65 x 104 Mg yr-1 and soil consolidation was 3.78 x 104 Mg ha-1.[24]

The evaluation of above-ground standing biomass stock and C-dynamics, as well as the vegetation's reaction to environmental variables including increased temperature, increased solar radiation, CO_2 fertilization, and nitrogen enrichment, are all based on the long-term inventory of permanent plots. The latest state of the global C cycle is linked to increasing atmospheric CO_2.[46] It is considered to be the boundary between the organic and inorganic worlds since it is directly related to the cycles of water and nutrients, photosynthetic biomass production, and the earth's climate. By fundamental biological processes of photosynthetic carbon absorption, trees pump atmospheric CO_2 into biomass and soil. On a dry matter basis, a sizeable portion of the tea crop is made up of elemental carbon, which comes from the action of sunlight combined with the leaf's chlorophyll causing atmospheric CO_2 to accumulate in plant tissues. According to the growth characteristics of tea, root and shoot growth stages alternated and root growth is controlled by the physical and chemical features of the soil, the presence of an impervious zone, rainfall and the depth of the permanent water table, among other factors.[13,47] A typical yearly rainfall of more than 2000 mm, the northeastern alongside the eastern regions of India receive more rainfall than other parts of India resulting in the soils being more acidic and does tend to have higher Soil Organic Carbon levels.[48,49] Previous studies also reported higher SOC accumulation in the top soil layer of urban green space and a decline in SOC with increasing soil depth.[8,51,52] If all other factors are equal, the diameter growth rate should be inversely proportional to wood density since biomass increment associated with a given diameter increment is directly proportional to wood density.[53] According to Chave *et al.* (2009) and Flores & Coomes (2011), one major functional characteristic of woody plant species is wood density, which has a significant impact on ecosystem activities, including the estimation of the carbon stock.[54,55] While examining the universal functional features in plants and calculating their global carbon reserves, wood density has recently gained importance.[56] Wood specific gravity is a crucial factor in the estimate of biomass.[57] It is possible to determine a species' growth under various environmental conditions by examining plant characteristics like wood density.[54] As each system differs based on site factors, tree species, the density and productivity of shade trees, as well as their longevity and the afterward use in processing systems, the generation of litter, the rate of decomposition and how it is absorbed in the soil matrix as soil carbon, nutrient cycling, and soil respiration, uncertainties in estimates of carbon stocks in various AFS would be expected.[13] Investigations into the carbon sequestration potential of various alternative agroforestry and plantation systems in Indonesia revealed that there were differences among the various agroforestry systems in terms of carbon sequestration, with coffee multi-cropping systems having the greatest potential.[58] Additionally, each system's management strategy plays a crucial role in determining how much carbon is added to and removed from each system. Retaining the forest cover, reforesting them, and planting trees on bare land can all help to mitigate the effects of global climate change.[13] Molecular, cellular, and organ structural changes are closely related to wood density in trees .Wood density can be used to predict species differences in tropical trees, and it can be regarded as the second-most crucial characteristic for predicting tree biomass after tree diameter.[54,59]

While much is understood regarding the effectiveness and tea management the entire biomass production and carbon sequestration of the plant have received little consideration. The few known research are only concerned with areas where tea and Shade tree species are frequently investigated in conjunction with one another.[60,61] The overall quantity of carbon stored within biomass, litter, and soil is 83.3 Tg C (1 Tg = 1012 g C), 8.0 Tg C, and 225.0 Tg C, respectively, according to a study of C density and C pools associated with the biomass, litter, and soil of tea plantations in China.[58] The capacity of Sri Lankan tea plants to sequester carbon has been calculated in relation to environmental conditions wherein the key physiological mechanisms were evaluated which were in charge of determining the tea yield.[43,62] The research show the allometric equations for estimating tea biomass and the relationship between major nutrient intake and carbon stock with increasing tea age and genotype.[63] According to reports, tea seedlings and clonal cultivars see a rise in C stocks that are different in size as tea farms get older. The Sonitpur District of Assam in their assessment of tea bush health using remote sensing technology has demonstrated another method for examining the capacity of the agroforestry system for nutrient uptake and productivity.[60]

It is seen that SOC (Soil Organic Carbon) content dropped with soil depth while the soil BD (Bulk Density) did not alter substantially between depths. Thus, by reducing soil depth, OC (Organic Carbon) was sequestered to a lower level. By ageing the tea crop, from 1.67 to 0.49 Mg/Ha/y/1-m depth between the ages of 9 and 21 years, the SOC sequestration rate lowered.[64] It is through the root exudates, which were equal to 5.9 to 8.6% of the CO2 assimilation, that tea bushes release organic C. These secreted root exudates raise organic C levels in soil used for growing tea by 44–48 kg ha–1 year–1.[65] However, as the age of the tea crop rose from 9, to 21, and to 36 years old, respectively, the carbon sequestration under the tea plantation's canopy improved by 1.50, 1.71, and 1.79 times compared to the secondary forest. Despite the tea leaves being frequently collected, it appears that tea farming can stifle OC.[64]

Tea plants can store 50.8 to 10.5% of the atmospheric CO2 that has been ingested in their biomass. According to estimates, tea plants can exude up to 44–48 kg of organic cha per plant into the soil. As a result, tea plantations function as an efficient biological system to convert atmospheric CO2 to plant biomass and soil. High-yielding tea cultivars, particularly during their mature growth stage, are more efficient than quality tea cultivars in this context at sequestering carbon to the biosphere and lithosphere. Therefore, it could be concluded that growing high-yielding tea cultivars rather than quality tea cultivars may be more effective for environmental sustainability.[66] SOC considerably decreased at each crop age when soil depth was increased from the top 20 cm to 80 cm. This is because, in contrast to below-ground sources like root exudates and senescence, the OM source is primarily derived from the above soil surface, particularly plant litter. As a result, the topsoil's SOC was higher than that of the lower depths. This is consistent with the findings that the SOC stock in the soil profile depleted with depth in either dry or wet areas underneath the humid tropical region.[64]

In Bangladeshi tea soils, microbial biomass C and N have been examined.[67] It has been reported on the main soil chemical characteristics of the main tea-growing regions in India.[68–70] Research on soil fertility and physicochemical qualities in various tea-growing regions of West Bengal, tea garden belts of Golaghat district of Assam, and tea plantations of Cachar district have been investigated.[71,72,69] The annual impact on SOC is rapid in a system that has been intensively managed, like the tea AFS, with numerous treatments including ploughing, fertilizer application, and irrigation. The fluctuation in soil texture, land cover, and vegetation factors generally has an impact on the dynamic range of soil moisture. The extent of SOC after afforestation is influenced by abiotic factors such as site preparation, past land use, climate, soil texture, site management, and harvesting.[73] The tea is grown beneath a canopy of trees that partially shade the area. Shade trees mimic the type of forest that is thought to be tea's native environment. These tree species protect the soil from erosive forces and the effects of rainfall, increase the organic matter and fertility of the soil through leaf litter, and support a wide variety of flora and fauna, particularly a large number of bird species. Being deep-rooted plants, shade trees don't obstruct the tea plant's root system.[41]

Conclusion

The study of carbon sequestration in tea gardens and Agroforestry systems has not been explored intensively. The Shade tree, the bushes and soil of the tea garden together make a very solid aspect to be explored as a carbon sink for climate change mitigation. Research on the assessment of biomass and C in several other AFS with comparable structural compositions and management techniques has come forward in the recent years. The estimation of aboveground biomass of shade trees and coffee (*Coffea arabica* L.) bushes have been studied in Costa Rica.[74] Allometric equations have also been reported for coffee biomass estimation in Ethiopia.[75,76] The estimated carbon stock in bamboo species' ecosystems (44.46-163.28 Mg ha) and biomass (8.1-135.53 Mg ha) is comparable to that of the world's agroforestry and forest ecosystems.[77] According to the meta-analysis, the primary element determining an agroforestry system's ability to store carbon is the growth and character of the various tree species used in agroforestry.[13] Additionally, there is a great deal of potential to use the silvopastoral system in rain fed regions to address issues like climate change and global warming via the increase in carbon capture thereby also preserving biodiversity.[78] The insights of the study provide a positive direction for Agroforestry especially the tea gardens as an alternative source of carbon capture and a step towards the mitigation of the climatic change by the sequestration of the carbon compounds.

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Conflict of Interest

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