

Review

Carbon Farming: Prospects and Challenges

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Abstract: Carbon farming is a capable strategy for more sustainable production of food and other related products. It seeks to produce the diverse array of natural farming methods and marketable products simultaneously. In agroforestry system, carbon sequestration is done by incorporating carbon dioxide (CO₂) into plant biomass via photosynthesis. Carbon is, thus, stored in reserves of above-ground biomass, such as timber or branches, and below-ground biomass such as roots, or organic carbon in the soil. In addition to the significance of carbon sequestration in climate change mitigation, soil organic carbon (SOC) is an imperative indicator for the soil health as well as fertility. The change in SOC can explain whether the land use pattern degrades or improves the soil fertility. SOC, found in the soil in the form of soil organic matter (SOM), helps to improve soil health either directly or indirectly. Its direct consequence is related to the process of mineralization. Further, agroforestry is highly capable of generating huge amounts of bio-mass. In fact, agroforestry is believed to be particularly suitable for replenishment of SOC. Therefore, efforts should be made to convince farmers for their resource-use efficiency and soil conserving ability in order to get maximum benefits out of agriculture. According to food and agriculture organization (FAO,) agriculture, forestry, and other land use practices account for 24% of global greenhouse gas (GHG) emissions, and total global livestock emissions of 7.1 gigatons of CO₂-equivalent per year, representing 14.5% of total anthropogenic GHG emissions. Agroforestry system that deliberately integrates trees and crops with livestock in the agricultural production could potentially increase carbon sequestration and decrease GHG emission from the terrestrial ecosystems, thus, helping in global climatic change mitigation. This study, therefore, aimed at clarification about carbon farming, modifications in carbon cycle and carbon sequestration during agricultural development in addition to benefits of agroforestry.

Keywords: carbon farming; carbon foot printing; low carbon agriculture; carbon sequestration; carbon economy

1. Introduction

Novel approaches to cropping systems and soil management are being developed to cope with the abundance of CO₂ in the environment, while at the same time improving water use efficiency and soil quality. In low-input areas, agroforests struggle to increase crop productivity and help farmers maintain soil quality. In combination with crops, particular tree species in agroforest-management systems may be feasible to provide solutions to numerous agricultural challenges [1,2]. The satisfaction of human needs and protection of environmental resources is key to effective planning strategies. Different management practices are known to affect the amount of soil organic matter, the soil composition, and water retention capacity [3,4]. Soil quality research aims to understand how

to manage soil to take advantage of its inherent qualities in the environment. It is necessary to recognize the various factors that affect the health of the soil, among which organic matter is critically important [5,6]. Easily manipulated by land management activities, organic matter is found in most of the agricultural settings. As organic matter increases the ability to retain water and strengthens the soil structure [7,8], it increases agricultural productivity along with the environment's resistance to drought and disease while simultaneously reducing the costs and the impact of epidemics [9,10]. Agricultural activities that deposit organic matter into the vegetation, are necessary in order to limit the environmental CO₂ [11,12]. It has been demonstrated that activities related to soil management are essential in conserving and restoring soil carbon. However, many, though not all, farming fields on the planet have substantial carbon deficiency because of soil erosion and breakdown [13,14]. It is widely accepted that various governments employ measures to curb this practice and incentivize the use of ecologically sustainable methods. Another government project is the implementation of environmental policies that attempt to maintain a low carbon footprint. In addition to traditional tillage, terracing, and no-mulching systems, farmers are advised to use other systems such as biofertilizers, no-till, and vegetal mulch, along with systems operating under agroforestry [15,16].

Forests are essential for maintaining biodiversity. Deforestation has a substantial impact on the flow of rivers and land use pattern [17,18]. Agriculture, forestry, and other land use practices account for 24 percent of global greenhouse gas (GHG) emissions, with total global livestock emissions of 7.1 gigatonnes of CO₂-equivalent per year, accounting for 14.5 percent of total anthropogenic GHG emissions, according to the Food and Agriculture Organization (FAO) [19]. Therefore, planning and management of the forests must consider how they relate to other aspects of ecosystem. Further, there is a significant scope for net reduction in global warming as a consequence of CO₂ sequestration [20]. Although injecting flue gas into aquifers poses the risk of carbon leakage over time, it offers little economic advantage, this carbon sequestration technique is more attractive [21,22]. Microalgae exhibit a highly productive photosynthesis, resulting in the release of large amounts of CO₂ as organically bound carbon and accumulating it in their cells [23,24]. And if biomass was sourced from fossil fuels, CO₂ pollution per unit would be lowered due to the CO₂ that is recycled and then reused by algae [25].

2. Carbon Foot Printing

Carbon footprint (CF) is a measurement of total product or system balance of GHG emissions and drops over the course of the product or system life [26]. A CF takes all inputs and processes within the confines of a defined system into account. The friction coefficient is calculated within a system limit, a hypothetical line based on the activity and materials used to calculate the friction coefficient [27]. While the findings of CF research may provide useful information in order to make effective choices the methods used to calculate CF for agricultural systems are at present lacking in consistency [28]. In several areas, consistency is missing, including the choice of functional units, system limits and emission factor specificity (EFS). If carbon is absorbed into the earth, it could significantly impact agricultural emissions of carbon dioxide (CO₂) [29]. Adewale et al. quantified carbon loss and gain in soil, and found that 13% of CF net soil emissions were produced from small production of vegetables [30]. Therefore, a full assessment must cover carbon (CO₂ or sequestered), on the net GHG emissions of a particular farm or farm product or field operations [31]. This is important to determine whether agricultural techniques can help implement a GHG reduction strategy successfully.

However, it is difficult for a variety of reasons to estimate soil GHG emissions from diverse farm activity. There are significant variations amongst other factors in soil carbon (C), global and field-scale estimates [32]. In addition, the dynamics and interaction of labile and re-calcitrant carbon stores give a combined effort to develop consistent methods and models for site-specific information. Organic agriculture is a beneficial subset of CF agriculture since it requires the conservation or improvement of natural resources along

with annual certification [33]. Numerous studies were carried out to determine the environmental impact of organic farming, most of which demonstrate advantages over conventional farming methods [34,35]. Organic farming, thus, offers a number of advantages per unit area, including increased soil content, lowering nutrient performance and lower consumption of energy [36].

However, whether organic farming produces more or less greenhouse gas emissions than conventional farming is not definitely answered since the findings vary by product and farm. According to a study, organic farming techniques emit more ammonia, nitrogen and N₂O per Product Unit than conventional farming systems [37]. Organic dairy and organic pig farmers are often responsible for more GHG emissions by unit than conventional systems, while organic beef production generates fewer GHG emissions per kilogram meat [38]. However, due to a large number of results, conclusions cannot be drawn regarding the CF of the different systems. Many studies advocate the use of Tier3 EFS to improve the precision and usefulness of methods of estimating agricultural GHGs [39]. As a result of the study, the case for the broad and consistent agricultural CF limits, including the inclusion of soil and carbon sequestration and the establishment of new agricultural EFS Tier 3 has been established and reinforced [39]. Given the potential to contribute significantly to GHG reduction efforts by organic fertilizers and technology, it is critically needed that Tier 3 EFs, particularly for organic inputs, be established. The limits of the agricultural system should include farm infrastructure and machinery, pesticides and other chemical inputs, soil-use changes, soil emissions and sequestration of carbon and livestock enteric fermentation, in combination with more traditional inputs such as fertilizer, fuel and electricity [40]. Any such factor could be critical in determining systems differentiation or the most effective strategies for CF prevention and reduction. Furthermore, agricultural operations need adequate monitoring so that farmers can make informed decisions regarding equipment and use of fuel and soil carbon changes [41]. Organic farming frequently has a lower carbon footprint (CF) than conventional agriculture when measured by area and sometimes by product unit [31]. The future use of certified organic farms as a longitudinal national or global population study will be justified due to the potential benefits and the annual inspection and certification process. In this direction, representative concentration pathway (RCP) is a greenhouse gas concentration trajectory approved by the Intergovernmental Panel on Climate Change (IPCC). In 2014, the IPCC's fifth assessment report took four distinct paths in climate modelling and research[42]. The paths illustrate possible climate futures, and each is considered plausible considering CO₂ generated in the coming years. RCP2.6, RCP4.5, RCP6, and RCP8.5 refer to radiative forcing values for the year 2100 (Figure 1).

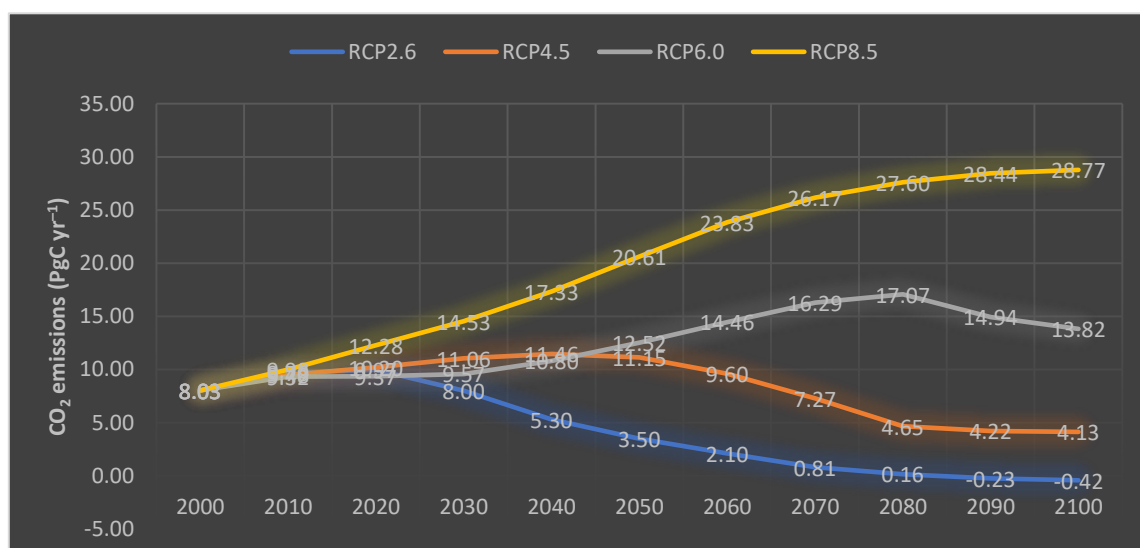


Figure 1. Anthropogenic total CO₂ emissions (PgC yr⁻¹) from farming and its projection until 2100.

2. Low Carbon Agriculture

In hot regions, organic matter tends to be quickly degraded, with corresponding changes in the chemical, physical, and biological composition [43]. In these regions, appropriate soil conservation and crop management is predicated on using little or no-tillage, with those crops that are higher on residue production [44,45]. Minimal soil disturbance, consistent soil coverage, and crop rotation are part of the conservation practices [46]. Management systems that include plantations, tree crops, and pastures must be applied to this context. Restoration systems have proven successful because of their capacity to improve soil and biomass stores in the long term [47]. Agro-forestation has proven useful in creating environmental, economic, and ecological value for agricultural areas in temperate and tropical ecosystems [48]. These may include increases in nutrient utilization and irrigation, creation of habitats for plants, insects, and animals; and protection from erosion in hilly locations [49,50]. Litter and tree roots constitute the highly sustainable way of formation as well as enhancing the quality of soil organic matter (SOM) in agroforestry ecosystems [51,52]. However, soil fertility is distinct in tropical agroforests, where they tend to have low organic matter due to high porosity and depth [53,54]. According to their availability, the management of diverse plant species allocating nutrients at varying levels, allows for sustainable nutrient management in nutrient-depleted soils [55,56].

An agro-forestation system combines trees and grassland farming. The trees are used to make quality wood products while also providing forage and shelter. Most treeless savanna systems can sequester carbon, as well as extract or remediate nutrients [57]. On the other hand, grassland areas can serve to preserve the biodiversity [58]. Advantages to reduced silviculture practices, include greater carbon sequestration and enhanced nutrient removal. Alley cropping has been used in both temperate and tropical regions to grow trees and coffee, cocoa, and livestock [59,60]. Cultivated vegetation in alley cropping systems has been shown to improve soil nutrient cycling [61], reduce nutrient losses [62], promote fauna activity [63], enhance fertility [64], and control soil erosion [65]. Interest in developing alleys as alternative crops and as a carbon sink has risen because of the development of species like *Robinia pseudoacacia*, also as a great potential to offset greenhouse gas emissions [66]. Improving soil characteristics due to N₂ fixation and increasing SOM in the litterfall may contribute to *R. pseudoacacia*'s overall success [67,68].

However, some researchers have suggested that alley cropping systems can replace soil use [69]. The labile organic fraction also decreased with the continued use of alley cropping [64,70]. The research needs to be done in order to discover the possible impacts of agroforests on tropical soils. Also, studies of the alley's forest or annual litterfall and non-tree elements of alley-based agriculture should be done. Integrating three elements (farming, livestock, and forestry), with various conservation practices aims to revitalize soils while increasing carbon sequestration in long-term [71,72]. In a crop-livestock system, forests are involved simultaneously as livestock-grazing land after the crops have been harvested. Moreover, an integrated crop-livestock-forest system may improve soil biodiversity, nutrient depletion, and nutrient recycling, as withstanding capacities [73,74]. These systems maximize total production, lower the total risk, and increase the cultivation alternatives, rendering them economically favourable to monoculture [73,75].

3. Effects of Plant Residue Quality on Carbon Dynamics

The amount, location and bio-degradability of the plant residues can significantly affect soil organic carbon [76,77]. Therefore, the added plant residue is important in different ecosystems, along with microbial biomass, mineralization, and organic matter production rates [78,79]. The quality of plant residues, weather and soil mineralogy, such as acidity, biological readiness and mineral contents, are mainly determined by the rates of residual mineralization [80,81]. The management of plant residues has been found to increase the processing of biological nutrients and minerals. Plant species with distinct abilities are especially important for agricultural systems with limited fertilizer input [82,83]. The residue is affected by the variations in chemical and biochemical characteristics

[84,85]. In addition, the composition of residue minéraux and their chemical profile in controlled environments decides the extent of decomposition or in other words, the biochemical composition of residue controls the rate of decomposition [86,87]. However, plant residue management alone may not be sufficient to ensure enough carbon reserves in the soil, it is associated with the physical soil structure also [88,89]. The soil carbon levels decreased considerably as a result of conversion of the forest land to agricultural land [90,91]. The loss in soil inputs, nutrients and its decomposition can be attributed to changes in forest carbon, and ecosystem disturbance [92,93].

The carbon isotope composition in the soil is a useful technique for quantifying the rate of organic and/or nonbiological processes [94]. A number of ecosystems have been investigated using C-isotopic techniques for SOM concentrations. Most of these studies have investigated the ^{13}C (isotopic) properties of SOM that have emerged through vegetation changes between the C3 plants and the C4 plants [95,96]. Depending on the location and environmental exposure, there are different results. Changes in the ^{13}C concentration of these fractions can thus tell us about SOM consumption rates and provide useful information about the different control systems of management. The crucial point is that the natural wealth and quantity data must be tracked for each of the system components. Some examples have been used for agricultural ecosystems of ^{13}C stable isotope analyses [97,98]. The scientists found that the maintenance of trees led to substantial improvements in the sequestration of carbon in the long run [99,100]. In conventional agriculture, it was discovered that soil water depletion was greater in the alley than in the trees [69,101].

4. Carbon Sequestration

There has been an increased interest in carbon sequestration techniques as a matter of environmental concern about global warming and CO_2 emissions. Human activity has an effect on the terrestrial carbon cycle (approximately 50% CO_2 sequestration) both directly and indirectly [102,103]. CO_2 emissions are commonly believed to be caused by the burning of fossil fuels [104,105]. With demand for energy increasing rapidly, particularly in developing countries, CO_2 emissions are expected to increase even more. The overwhelming body of scientific evidence indicates that elevated CO_2 levels in the atmosphere are detrimental to the environment [106,107]. According to the researchers, increased CO_2 levels produces greenhouse effect, resulting in increased temperatures and hence global warming [108,109]. Each year, the oceans absorb about a quarter of all the anthropogenic CO_2 emissions [110,111]. This could be beneficial, but at a cost since increased CO_2 levels in seawater rise, forming carbonic acid [112,113]. There have been numerous evidences to suggest that ocean acidity has increased by 30% since the industrial revolution began. Increased water acidity impairs the development of marine shells and skeletons, primarily affecting deep-sea organisms such as benthic and anadromous fauna [111,112]. Additional increases in oceanic acidity are believed to hasten the demise of marine life. Therefore, to meet the energy demand while minimizing CO_2 emissions, stringent post-combustion carbon sequestration management will be required.

Carbon capture and storage is a process that absorbs CO_2 from flue gaseous emissions and stores it for extended periods of time [114,115]. Carbon sequestration is defined as the deliberate or intentional separation and disposal of CO_2 as a by-product of combustion in non-atmospheric reservoirs [116]. It has been defined as the process of increasing natural processes, such as CO_2 absorption by living organisms, in order to offset any additional CO_2 emitted [21,117]. Organic carbon can be produced by autotrophic organisms and plants through photosynthesis, which involves the reduction of CO_2 [118,119]. Carbon is found in all biological media, including peat and seawater [120,121]. It is incorporated into the cells of these organisms via photosynthesis. Thus, appropriate carbon management is necessary to ensure that biomass can be used for a variety of commercial purposes while also sequestering sufficient carbon in biological media to keep the air safe. Energy crops such as biofuels may be used in a variety of ways, for instance, as a biofuel, fertilizer, food, and animal feed [122,123]. CO_2 can be recycled during the biofuel

production process, and biomass may be used in place of fossil fuels [124,125]. This method enables the harvesting of a significant amount of CO₂-rich flue gas for cultivation. If the process is carried out properly, these will result in massive amounts of value-added biomass and materials that can be further used to make bio-ethanol. The issues surrounding CO₂ recovery from point sources, as well as the legislative and policy drivers must be examined in order to get maximum benefit. The biological carbon mitigation technology (BCM) in CO₂ sequestration has been discussed in detail, as is the applicability of micro-algae [21,126]. To ascertain the fate of mitigated carbon, the commercial applications of BCM technology are being investigated.

5. Carbon cycle in agriculture

The main sources of carbon circulating actively are atmospheric CO₂, biomass (generally vegetation), soil organic matter, and the oceans [127,128]. Among these, the oceans are known to comprise the largest carbon reserves, however most of the carbon lies in deep ocean-layers (not involved in active carbon circulation) (Alves et al., 2018; Cheah et al., 2015). Carbon stocks in biomass or biota are less certain to some extent, however, they are almost equivalent to the atmospheric sources [131]. About 75% of this, is found in forests [132]. Plants found in the ocean, mostly algae, possess less than 1% global carbon biomass [133]. The largest source of carbon circulating actively in the terrestrial ecosystem is the soil [134]. It contains carbon in different organic forms, such as plant litter or charcoal or fossils [135]. About one third of the organic carbon in soil is found in forests, another one third in savannas and grasslands, and the rest part in wetlands, and other biomes [136].

All of these carbon sources, viz. the atmosphere, the vegetation, the soil, and the oceans are interconnected. Atmospheric CO₂ follows photosynthesis to enter terrestrial bio-mass, however, almost half of the CO₂ is released through respiration in plants [137]. The amount of CO₂ left or net primary production (NPP) is stored provisionally in vegetative tissues, which eventually enters the soil after attaining senescence [138]. Simultaneously, heterotrophic respiration performed mainly by soil micro-organisms and other anthropogenic activities return roughly equivalent amount of NPP back to the atmosphere, closing the loop [138]. CO₂ exchange between the atmosphere and the ocean is even larger. Some of this occurs by physical processes, involving the CO₂-carbonate equilibria, but a surprisingly large exchange also occurs via biological processes [139].

6. Challenges in carbon farming

The carbon farming initiatives (CFI) demands for agro-environmental policies to incentivize farmers to adopt best farm management practices. However, it is usually difficult to get farmer's involvement in such programs mainly because of the complex scheme-design along with its implementation, or conflicting targets of policy-makers and the farmers [140]. Various factors are known to affect the adoption and implementation of new farm management practices which include personal interests of landholders, farm or land features [141,142]. Some of the barriers in carbon farming directly associated with the landholders' interests, along with inadequate skills or management abilities for the implementation of carbon farming programs or practices. Political instability also substantially affects the acceptance and implementation of such practices [143]. Uncertainty about environment related schemes and policies may significantly undermine their adoption, and may be aggravated by lack of awareness or knowledge of the concerned program [144,145].

It has been agreed by farmers that they have insufficient access to information regarding available options for carbon farming [145,146]. In fact, many farmers don't understand the exact meaning of carbon farming and they lack detailed information about pros and cons of carbon farming. This was further exaggerated by high input costs, and apprehensions regarding the effect of carbon farming on yield and farm productivity. Other major barriers in CFI were lack of approved methods and procedures, higher

administrative expenses, and difficulty in getting certification as a qualified carbon-offset provider [147,148]. In addition, the capital investment required for adopting new farm management strategies, unsuitability of carbon farming with existing farm management practices, and the probable impacts on the ability of farmers to obtain financial assistance from banks or other sources have been identified as important challenges to carbon farming [145,149].

Besides, other barriers that need specific mention include: instability in carbon prices [150]; uncertainty regarding benefits from carbon farming [151]; difficulty in measurements or monitoring the progress [152]; uncertainty regarding carbon market selling practices [153]; and the financial consequences of participation [154]. Farmers also stated that the sale of properties with tree plantations are difficult which indicates their reluctance to implement carbon farming as they consider it to be dissenting with other objectives [146,148]. The encouragement through financial incentives for increased participation in CFI does not seem to be sufficient to tackle the barriers that farmers generally face. Moreover, some farmers believe that the carbon farming policy rewards them with an antiquity of improper land management, which further prevents their involvement [155,156]. This suggests that farmer's personal interests or sentiments may offer a participation barrier to CFI, along with the other barriers mentioned above.

7. Carbon economy

Instead of colonizing the governance spaces created by calculating a product's carbon footprint, retailers are establishing new regimes of corporate responsibility requirements to measure and manage carbon emissions in which certain behaviours are encouraged, legitimized, and/or eliminated in order to force individual supply chain partners to become active participants in their own governance [157,158]. In this case carbon reduction, with the values and ambitions of their supply chain partners [159,160]. Suppliers at all levels and tiers of a product's supply chain are encouraged to collect and share their best carbon footprint data [161,162]. While global retailers assume responsibility for creating the market conditions and infrastructure (e.g., the tools), and have presumably received platitudes for their role in mitigating climate change, the actual delivery of these climate change mitigation programmes and risk associated with them is positioned as the specific responsibility of the government [158]. This exportation of climate mitigation duty and risk across a product's supply chain, with merchants achieving their headline-grabbing objectives at the expense of their workforces now ensconced in new accountability regimes [158,163].

With respect to climate change, retailers take on a larger and more extensive role in measuring and reducing the carbon footprint of the products in order to strengthen their place in society, ensuring their long-term viability and licence to operate [164]. By taking this approach, retailers have sparked a radical reimagining of the carbon economy due to their size and ubiquity at the intersection of daily consumption–production practices [158,164]. Retailers reframe what their supply chains must care about by looking beyond their direct operations to the entire life cycle of their product through product carbon foot printing, introducing new norms and priorities into existing and new relationships [165,166]. In contrast to previous models of supply chain responsibility, the footprint is established as a regime of responsibilities in which suppliers assume self-governance and retailers enact measurement, reductions, and, ultimately, governance of their supply chain behaviours [167]. In the case of product carbon foot printing, suppliers have independently adopted new measurement techniques, collected and disclosed data, and made carbon reductions.

The product carbon footprint responsibility could be a potentially new tool for retailers and other leaders to empower their suppliers to take responsibility for the water, waste, and ultimately environmental and social impacts embedded in the products they deliver to the next stage of the supply chain [168,169]. The priorities established, ambitions set, and responsibilities assumed by multinational corporations have a profound impact

on the lives of consumers, suppliers, society, and global ecologies. From halting deforestation to reducing carbon emissions, multinational corporations' priorities, ambitions, and responsibilities radically affects the lives of suppliers, consumers, society, and global ecologies at large [158,170]. In the absence of well-defined and well-enforced international environmental standards, these actors are increasingly defining sustainability in corporate terms [171]. When it comes to mitigating climate change, this has resulted in retailers gradually reimagining the transition to a low-carbon economy in ways that align with their commercial and risk-averse interests [163,172]. However, there is an unavoidable risk of failing to truly tackle the more fundamental questions relating to consumption, at the root of global environmental changes, as well as the rapidly consolidating and expanding power of these now sustainable corporate citizens in the process of creating a market for low-carbon products.

8. Conclusion:

Agroforestry has developed as an all-inclusive land-use management practice beneficial for both environment and the society. Combination of forest vegetation with crop farming and livestock production through agroforestry improves net agricultural production, along with food security. GHG emissions and carbon sequestration in agroforestry depend upon many biophysical and biochemical factors including climate conditions, soil characteristics, water management, vegetation, and the land use management practices. However, silvo-pastoral system was generally found to be more effective in relation to both carbon sequestration and GHG emissions reduction as compared to the agroforestry system which includes annual cropland farming. Interventions such as enrichment planting along with organic amendments of the soil to prevent the release of nutrients are also site-specific for their effectiveness. Agroforestry ecosystems might be estimated with various environmental indicators depending upon the energy use, the yield and productivity, and the production processes. There is a great possibility of implementing environment-friendly practices of cultivation in agricultural productions. Moreover, the agricultural production resilience on climatic change can be stabilized by using less-intensive and judiciously organized methods of farming. In this context, the above mentioned agro-environmental parameters may prove useful to decision-makers looking for farming systems which can control the delicate balance between climatic change and agricultural productions. Advisory services should be provided to farmers to encourage them to adopt soil or land management and tree planting practices, and to reduce the unsustainable practices. In conclusion, agroforestry systems are highly efficient at retaining organic carbon stocks in the soil. These systems are capable of accumulating greater amounts of soil organic carbon stocks as compared to mono-cropping, thereby improving soil quality.

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