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Carbon Farming: A Pathway to Climate Change Mitigation

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Abstract

A promising Climate Smart Agriculture (CSA) strategy to slow down global warming is carbon farming, which increases soil carbon storage and lowers greenhouse gas emissions. This strategy incorporates a number of land management techniques, including cover crops, conservation agriculture, grazing management, conservation tillage, agroforestry, crop rotation, and the restoration of wetlands and peatlands. In addition to improving biodiversity and soil health, these methods also support sustainable agriculture by reducing carbon losses and boosting organic carbon storage. No-till and conservation tillage farming minimize soil disturbance and maintain soil organic carbon (SOC), whereas agroforestry combines crops and trees to improve carbon storage. This review emphasizes how carbon farming may enhance soil health and agricultural sustainability while reducing the effects of climate change. Carbon stock monitoring and quantification heavily rely on advanced technologies, especially remote sensing technology. Additionally, carbon credits produced by carbon farming methods provide farmers a financial chance to lower greenhouse gas emissions and diversify their sources of income. Carbon farming has several advantages, but it also has drawbacks, such as complicated regulations, low awareness, expensive initial investment expenses, and trouble validating carbon credits. Better awareness campaigns, financial incentives, and well-designed agro-environmental laws are needed to remove these obstacles.

Keywords: Carbon Farming; Mitigation; Carbon Sequestration; Satellite

Abbreviations

CSA: Climate Smart Agriculture; SOC: Soil Organic Carbon; CO2: Carbon Dioxide; UV: Ultraviolet; OC: Organic Carbon; CA: Conservation Agriculture.

Introduction

Terrestrial ecosystems "breathe" in carbon dioxide (CO_2) through photosynthesis and release carbon (C) into the atmosphere through respiration and therefore play an important role in the global C cycle and the Earth's climate [1]. Carbon dioxide (CO_2) which is a primary greenhouse gas retains heat in the atmosphere contributing significantly to global warming. This in turn causes a threat to the survival of the worldwide species. The deleterious consequences of climate change, including land degradation, the extinction of various species, and the depletion of groundwater levels, are influenced by abrupt changes in temperature, precipitation, sea level, and ultraviolet (UV) radiation. According to the IPCC report released in 2018, approximately 6% of invertebrates, 8% of plants, and 4% of vertebrates among the 105,000 species under research would become extinct if temperatures rose by 1.5 degrees Celsius in the future [2]. Simultaneously, poorer subsistence societies would be impacted by climate change as farm yield and quality shrinks with the rise in crop pests and illnesses, ultimately disrupting culture [3].

On a global scale, a crucial role in the carbon (C) cycle is played by soil which acts as a large sink of C stores about 3 times more C than the atmosphere and 4.5 times than the biotic pool [4]. Again, soil acts as the most significant long-term organic carbon (OC) stored in terrestrial ecosystems [5]. The soils can assist in eliminating the high levels of CO_2 from the atmosphere by having a considerable ability to store carbon [6]. Planting trees on a large scale provides a natural way to absorb and store CO_2 from the atmosphere (carbon farming). Remote sensing has been widely used to study the terrestrial C cycle by quantifying ecosystem C fluxes and stocks and examining the impacts of global change on C dynamics and the feedbacks to the climate [7,8]. With the aid of satellite observations, it has become easy to ascertain the magnitude, interannual variability, spatial patterns, and long-term trends of ecosystem C dynamics at regional and global scales [9].

Carbon farming is a Climate Smart Agriculture land management approach that allows carbon absorption in soil and plants, reducing greenhouse gas emissions. As compared to alternative approaches, carbon farming may be easier to maintain and less disruptive one. Its reversibility and the potential to “green” degraded lands make it an attractive option [10]. Carbon farming is emerging as a promising solution for the climate crisis, offering a natural way to reduce atmospheric carbon dioxide and its detrimental effects [11]. There are two benefits of carbon farming. The first is to reduce emissions through sequestration and the latter is enhancing soil health to support climate-resilient agriculture.

Biological Carbon Sequestration, which comes in three forms viz., Soil Carbon Sequestration, Ocean Carbon Sequestration & Forest Carbon Sequestration [12]. Soil Carbon Sequestration is related to agriculture in which the Sequestration of carbon in the ground takes place through the process of photosynthesis and is stored in the earth in the form of organic carbon (SOC) or carbonates. Ocean Carbon Sequestration is similar to geological carbon sequestration where CO_2 is captured and is then injected directly into water forming bicarbonates [13]. Forest Carbon Sequestration is related to forestry where utilization of appropriate practices (e.g., thinning followed by prescribed burning) helps sequestrated CO_2 accumulates in the form of forest soil, litter, biomass, and deadwood [14].

Common Practices in Carbon Farming

There are various practices of carbon farming which enhances soil carbon sequestration and ultimately contributing to climate change mitigation. These carbon farming practices have a massive effect on nutrient availability, soil health, and total agricultural output. The carbon sequestration rates of various practices obtained from the findings of the “Interreg North Sea Region Carbon Farming” funded by European Regional Developmental Fund (https://northsearegion.eu/carbon-farming/) have been given in the Table 1.

Sl. No	Carbon Farming Practices	Carbon Sequestration Rates
1	Cover crops	100- 460 kg C ha/ year in the topsoil 10- 320 kg C ha/ year in the subsoil
2	Crop rotations	Integrating grass-clover: 500 kg/ha C, replacing root crops by cereals 100 kg C/ ha
3	Grassland management	4 t C/ha per year in the topsoil in temperate grasslands
4	Agroforestry	1.5 t/ha C per year,
5	Tillage practices	500–1000 kg/ha/year in croplands

Table 1: Carbon sequestration rates of various practices.

Tillage Practices

Tillage is one of the most important parameters for carbon farming. Conservation tillage, one of the most prominent tillage technique in which the overall condition of the soil is considered.

Conservation tillage along with no tillage help decrease soil disturbance and aids in the preservation of soil organic carbon (SOC) levels [15]. These methods reduce the danger of erosion, increase the soil’s capacity to withstand irrigation and nutrient loss, and preserve significant amounts of soil carbon. By offering a continuous soil cover, reduced tillage techniques can lessen erosion and lower the chance of groundwater pollution from fertilizers [15]. There are certain advantages to no-till farming over traditional farming. Some of them are, more predictable surface hydrology, reduced sediment loads and increased carbon sequestration [16]. Another crucial component of low tillage systems that encourages soil carbon storage is the retention of crop leftovers [17].

Agroforestry: Agroforestry has received considerable interest as a potential method of sequestering carbon. The intentional growth of shrubs, crops, or animals in related combinations is referred to as agroforestry [18]. By maximising carbon contributions from improved biomass efficiency and limiting carbon losses, it can enhance soil organic matter and reduce climate change by delivering carbon from the atmosphere to the soil [19].

Crop Rotation: Crop diversity and rotation have a significant role in the soil organic carbon levels. In rotation systems, covering crops can improve SOC stocks by substituting active carbon assimilation periods for fallow ones [20]. A variety of cropping techniques, such as polycultures and perennials, boost the amount of carbon stored in the soil [21]. Biodiversity and ecosystem services are positively affected by crop diversification [22]. Non-significant impact of chickpea on SOC in wheat-chickpea rotation was also observed [23].

Conservation Agriculture: A sustainable agricultural method that increases soil health, biodiversity, and climate change resistance is conservation agriculture (CA). Minimum soil disturbance (no-till farming), permanent soil cover (mulching or cover crops), and varied crop rotations are its three main principles. Together, these methods lessen environmental deterioration and provide a more productive and sustainable agriculture system. The enhancement of soil health is one of CA's main advantages. The soil structure is preserved when ploughing is minimized, which improves water retention, lowers erosion, and increases organic matter. In addition to preventing erosion, permanent soil cover preserves moisture and offers a home for important soil organisms. Crop diversity improves soil fertility, breaks pest cycles, and lessens reliance on chemical pesticides and fertilizers through intercropping and rotation. Because they require less work, use less fuel, and rely less on artificial fertilizers and pesticides, farmers that use conservation agriculture frequently have lower input costs. Over time, conservation agriculture increases soil fertility and resistance to drought and other adverse weather events, which leads to better and more consistent crop yields.

Cover Crops: Cover crops are employed by farmers to improve carbon absorption. The term "cover crop" refers to "a crop that is predominantly employed to help in reducing erosion, improving soil health, enhancing the accessibility of water, smothering weeds, controlling diseases and pests, and increasing biodiversity" [24]. In addition to controlling nutrients like nitrogen, cover crops benefit fields by reducing erosion, increasing water penetration, and harvesting crops for grazing animals [13]. Organic systems tend to have a lower carbon footprint incorporated with cover crops [25]. The carbon footprint of organic viticulture, which uses cover crops, is lower than that of conventional techniques [26].

Grazing Management: Grazing management is also one of the important practices of carbon farming. Moderate grazing can increase SOC while overgrazing causes deterioration and carbon loss in temperate grasslands [27]. In order to increase agricultural efficiency and absorb and store carbon, silvopasture involves feeding cattle in the forests as opposed to on farms. The amount of carbon in silvopasture soil can be up to five times that of controlled grazing soil [13]. Grazing areas may sequester more carbon through management techniques including fertilizer application, livestock rotation, and stocking rate maintenance [28]. The report claims that turning 3.6 million hectares into silvopasture may first absorb 5.6 teragrams of carbon annually and then 1.1 teragrams over the next 25 years. Moreover if this land is left to grasslands, 3.1 Teragram of $CO2$ would have been sequestered per year [13]. Studies have revealed that rotational grazing systems lead to improvements in performance of animals, including weight gain, milk production, and overall health if managed properly [29].

Wetland and Peatland Restoration: A key environmental tactic for restoring damaged ecosystems, increasing biodiversity, and slowing down climate change is wetland and peatland restoration. Wetlands, such as bogs, marshes, and swamps, serve as organic carbon sinks, flood control systems, and water filters. Peatlands, a kind of wetland with partially degraded plant matter, store twice as much carbon as all of the world's forests put together. Rewetting drained regions, eliminating invasive species, returning native vegetation, and enhancing land management techniques are all part of the process of restoring wetlands and peatlands. Carbon sequestration rises as a result of their natural activities being restored, which lowers greenhouse gas emissions. By supporting agriculture, tourists, and fisheries, wetlands also benefit nearby people. The contribution of wetland restoration towards the carbon sequestration was demonstrated earlier [30].

Application of Advanced Tools in Carbon Farming

Since remote sensing offers precise and effective methods for tracking and measuring changes in carbon stores and fluxes in soil and plants, it may be utilized extensively to support carbon farming. In order to achieve this, remote sensing may be used to estimate plant cover, above-ground biomass, and other vegetation properties, greenhouse gas concentration in the atmosphere [31-47].

Satellite Remote Sensing: Landsat time series images can be used to give field-level tillage information [38]. Additionally, it also enabled field-level tillage mapping at broad scales and offering a solution to the Landsat SLC-off data problem for tillage assessment applications. The application of multi-temporal Sentinel-2 data in crop monitoring was demonstrated in several studies [31-34]. The Moderate-resolution Imaging Spectroradiometer (MODIS) sensor was launched in late 1999 and installed on NASA's Earth Science Enterprise's Terra platform. MODIS LAI datasets is employed to take a spatial, temporal, or hybrid combination of weighted LAI and produce smoother and more spatiotemporally consistent outputs. It offers a practical technique for monitoring extensive grazing and doing additional evaluations of the grassland ecology [40]. Spatially co-located measurements of Earth reflectance in three different spectral bands are performed by CarbonSat [41]. CarbonSat is made to provide high spatial resolution (2 x 2 km^2) and adequate spatial coverage (500 km swath width) in order to retrieve the dry column amounts of CO_2 and CH_4 at high spatial resolution and temporal sampling [42].

Drone Technology: The International Civil Aviation Organization defines a drone, also referred to as an unmanned aerial vehicle (UAV), as an aircraft that is flown without a human pilot present [43]. Integrating a high-resolution (5 mm) drone model with multispectral satellite data enhance the accuracy [44].

Lidar (Light Detection And Ranging): The LiDAR principle was first introduced before the invention of the laser. Lidar sensors are popular due to their high spatial and temporal resolution, ability to observe the atmosphere under ambient conditions, and capacity to cover the height range from the ground to above 100 km altitude [45]. The models created using LiDAR data can generate good predictions and estimates for an Short Rotation Coppice crop, and they can be used as a management tool to enhance and optimize follow-up decisions pertaining to a commercial crop, based on the moderate to highly accurate estimates that were obtained [46]. Considering the outcomes, it may be profitable to acquire or buy low-density LiDAR data to help with energy plantation monitoring.

Climate Change Mitigation and Enhancing Ecosystem Health: Practices related to carbon farming serve as organic carbon sinks. By encouraging the development of plants and the buildup of soil organic matter, carbon dioxide is drawn out of the atmosphere and stored in plant biomass and soil. This lessens the effects of climate change by lowering the total atmospheric CO_2 concentration. Cover crops and no-till farming are two carbon farming techniques which raise the amount f organic matter in the soil and encourage the establishment of helpful soil bacteria. This eventually increases soil fertility by improving the soil's structure, ability to retain water, and nutrient availability. On the other hand crops become more resistant to drought due to organic matter rich medium, which is becoming a huge gain in many areas because of climate change. Higher crop yields and better agricultural productivity might result from healthy soil that contains more organic matter. Plants growing in healthy, fertile soil are naturally resistant to pests and diseases. This can minimize the need for chemical pesticides and fertilizers, fostering a more sustainable farming system. Increased plant diversity brought about by hedgerows and cover crops draws pollinators, such as bees and butterflies, which are essential for plant reproduction and the maintenance of healthy ecosystems. Farmers can sell carbon credits produced by carbon farming methods to businesses or organizations looking to reduce their carbon impact. For farmers that embrace sustainable techniques, this opens up a new source of income. To sum up, carbon farming presents an advantageous scenario for both farmers and the environment. Carbon farming creates the foundation for a more sustainable and climate-friendly agricultural future by storing carbon, boosting soil health, encouraging biodiversity, and strengthening climate resilience. The following list includes some benefits associated with carbon farming [47]:

- Farmers may increase water efficiency and diversify agricultural revenue sources, both of which are very helpful during "difficult times" like drought.
- Farmers can benefit from increased agricultural output and efficiency in combination with better soil health and lower salinity.
- Environmental benefits such as lower level of greenhouse gas emissions along with increased capacity of plants to store carbon.
- The quality of air is improved and a less likelihood of soil erosion.
- The health of the animals, their habitat, and the native plants has all enhanced.
- In general, soil health will improve; soil fertility will rise, while limiting soil salinity.

Challenges in Carbon Farming

Agro-environmental policies are required by the Carbon Farming Initiatives (CFI) in order to encourage farmers to implement optimum farm management practices. Adoption and implementation of novel farm management strategies are also known to be influenced by a number of other variables, such as landholders' personal interests and the characteristics of the farm. Political conflicts have a significant impact on the adoption and use of these techniques as well. Furthermore, ignorance of such programs and policies and doubts about their effects on the environment might also make it more difficult for them to be adopted. Many farmers are unaware of the precise definition of carbon farming and are not well-informed about its benefits and drawbacks. Other major obstacles for CFIs include the absence of authorized practices and processes, increased administrative costs, and the challenge of becoming certified as a qualified carbon offset provider. In addition, the capital investment required 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 significant challenges to carbon farming. Significant challenges to carbon farming have also been noted, including the required capital expenditure, the incompatibility of carbon farming with existing farm management techniques, and the potential effects on farmers' capacity to secure bank or other funding.

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