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 a diverse array of natural farming methods and marketable products simultaneously. According to the 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 CO$_2$-equivalent per year, representing 14.5% of total anthropogenic GHG emissions. For example, an agroforestry system that deliberately integrates trees and crops with livestock in agricultural production could potentially increase carbon sequestration and decrease GHG emissions from terrestrial ecosystems, thus helping to mitigate global climatic change. Also, agroforestry is capable of generating huge amounts of bio-mass and is believed to be particularly suitable for replenishing soil organic carbon (SOC). SOC is a crucial indicator for soil fertility since the change in SOC can explain whether the land use pattern degrades or improves soil fertility. Moreover, SOC found in soil in the form of soil organic matter (SOM) helps to improve soil health either directly or indirectly. Thus, efforts should be made to convince farmers to increase their resource-use efficiency and soil conserving ability to get maximum benefits from agriculture. Therefore, this review aimed at clarification about carbon farming, modifications in carbon cycle and carbon sequestration during agricultural development, and 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 CO$_2$ in the environment while improving water use efficiency and soil quality at the same time. Different management practices affect the amount of organic matter in the soil, composition, and water retention capacity [1,2]. However, satisfying human needs and protecting environmental resources simultaneously is key to effective planning strategies. Soil quality research aims to understand the management of soil to take advantage of its inherent qualities. Therefore, it becomes necessary to recognize the factors affecting the health of soil, among which organic matter is critically important [3,4]. Easily manipulated by land management activities, organic matter is found in most agricultural settings. Because organic matter increases the water-retaining capacity and strengthens the soil structure [5,6], it helps to improve agricultural productivity, in addition to reduced incidences of drought and diseases [7,8]. Furthermore, agricultural activities that deposit organic matter into the soil are necessary to limit the environmental CO$_2$ [9,10].

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It has also been demonstrated that activities related to soil management are essential for conserving and restoring soil carbon. However, many farming fields, though not all, have substantial carbon deficiency because of soil erosion and breakdown [11,12]. It is widely accepted that various governments employ possible measures to incentivize ecologically sustainable farming methods to conserve soil carbon. 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 solve numerous agricultural challenges [13,14]. 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 the systems operating under agroforestry [15,16].

The density of forests constitutes another major factor influencing the soil carbon content. On the other hand, deforestation substantially affects the flow of rivers and land use patterns [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 gigatons of CO$_2$-equivalent per year, accounting for 14.5 percent of total anthropogenic GHG emissions, according to the Food and Agriculture Organization (FAO) [19]. Forests, however, provide significant scope for a net reduction in global warming (as a consequence of GHG emissions) through CO$_2$ sequestration [20]. Since injecting flue gas into aquifers for storage and disposal of CO$_2$ poses the risk of carbon leakage over time, it offers little economic advantage, making the carbon sequestration technique more attractive [21,22]. Furthermore, planning and management of forests must also consider how they relate to other aspects of the ecosystem. Besides, microalgae exhibit a highly productive photosynthesis, resulting in large amounts of CO$_2$ as organically bound carbon in their cells [23,24]. Therefore, for biomass sourced from fossil fuels, CO$_2$ pollution per unit may be lowered due to the CO$_2$ that is recycled and then reused by algae [25].

2. Material and Methods

The literature was systematically reviewed based on the PRISMA (Preferred Reporting Items for Systematic Meta-Analysis) approach [26]. The research goals were investigated through related studies using Google Scholar with the keywords: carbon farming and soil management, carbon foot-printing and carbon economy, carbon sequestration, carbon farming and challenges. Further, the studies were investigated for the years 2000–2020. In total, 360 documents were analyzed, out of which 190 papers were found relevant for the present review (Figure 1). Finally, the research papers published in journals with an impact factor were carefully selected, and their findings are reported in this review.

![Identification of research database using Google Scholar](total 360 documents)

![Screening of relevant documents or research papers published in journals with impact factor (190 documents)]

![Removal of irrelevant documents or research papers not particularly related to carbon farming (47 documents)]

Final inclusion of documents (143 documents)

Figure 1. The methodological framework of research analysis.

3. Low Carbon Agriculture

Minimal soil disturbance, consistent soil coverage, and crop rotation are essential for soil conservation practices [27]. According to their availability, managing diverse plant
species (allocating nutrients at varying levels) allows for sustainable nutrient management in nutrient-depleted soils [28,29]. Agroforestry, in this context, has been found to be useful in creating environmental, economic, and ecological values for agricultural areas in temperate and tropical ecosystems [30]. These may include an increase in nutrient utilization, creating habitats for plants, insects, and animals, and protecting soil from erosion in hilly locations [31,32]. Furthermore, litter and tree roots constitute a highly sustainable way of forming and enhancing the quality of soil organic matter (SOM) in agroforestry ecosystems [33,34]. Restoration systems have proven successful because of their capacity to improve soil structure and biomass stores in the long term [35]. Further, it has been observed that, in hot regions, organic matter tends to degrade quickly, with corresponding changes in the chemical, physical, and biological composition of soil [36]. In these regions, appropriate soil conservation and crop management are predicated on using little or no-tillage for crops with higher residue production [37,38].

An agroforestry or alley cropping system, in general, combines trees and grassland farming. The trees are used to make quality wood products while also providing forage and shelter at the same time. On the other hand, grasslands can serve to preserve biodiversity [39]. Most treeless savanna systems can sequester carbon, in addition to extraction or remediation of nutrients [40]. Alley cropping has been used in temperate and tropical regions to grow trees and coffee, cocoa, and livestock [41,42]. Cultivated vegetation in alley cropping systems has been shown to improve soil nutrient cycling [43], reduce nutrient losses [44], promote fauna activity [45], enhance fertility [46], and control soil erosion [47]. Besides, interest in developing alleys as alternative crops and as a carbon sink has risen because of the development of species like Robinia pseudoacacia, as a great potential to offset GHG emissions [48]. Improving soil characteristics due to N2 fixation and increasing SOM in the litterfall may contribute to R. pseudoacacia’s overall success [49,50]. Therefore, integrating three elements, i.e., farming, livestock, and forestry via agroforestry with various conservation practices, revitalize soils while increasing carbon sequestration in the long term [51,52]. 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 [53,54]. These systems maximize total production, lower the real risk, and increase the cultivation alternatives rendering them economically favourable to monoculture [53,55]. However, some researchers have suggested that alley cropping systems may influence soil use efficiency [56]. The labile organic fraction also decreased with the continued use of alley cropping [46,57]. Therefore, more research needs to be done in order to discover the possible impacts of agroforests on the quality of soils in different ecosystems. Also, studies of the annual litterfall and non-tree elements of alley-based agriculture should be done.

4. Carbon Cycle in Agriculture

The main sources of carbon circulating actively in the ecosystem are atmospheric CO2, biomass (generally vegetation), soil organic matter, and the oceans [58,59]. Among these, the oceans comprise the most extensive carbon reserves. However, most of the carbon lies in deep ocean layers (not involved in active carbon circulation) [60,61]. Carbon stocks in biomass or biota are less certain, however, they are almost equivalent to the atmospheric sources [62]. About 75% of biomass is found in forests [63]. Plants found in the ocean, primarily algae, possess less than 1% global carbon biomass [64].

Furthermore, the largest source of carbon circulating actively in the terrestrial ecosystem is the soil [65]. It contains carbon in different organic forms, such as plant litter, charcoal, or fossils [66]. About one-third of the organic carbon in soil is found in forests, another one third in savannas and grasslands, and the rest in wetlands and other biomes [67].

All of these carbon sources, i.e., the atmosphere, the vegetation, the soil, and the oceans, are interconnected. Atmospheric CO2 enters the terrestrial bio-mass through photosynthesis in plants. However, about half of the CO2 is released through respiration [68].
The amount of CO$_2$ left or net primary production (NPP) is stored provisionally in vegetative tissues, which eventually enters the soil after attaining senescence [69]. Simultaneously, heterotrophic respiration performed mainly by soil micro-organisms and other anthropogenic activities returns roughly equivalent NPP to the atmosphere, closing the loop [69]. CO$_2$ exchange between the atmosphere and the ocean is even more prominent. Some of this occurs by physical processes involving the CO$_2$-carbonate equilibria, but a surprisingly large exchange also occurs via biological processes [70].

5. Effects of Plant Residue Quality on Carbon Dynamics

The added plant residue, microbial biomass, mineralization, and organic matter production rates are important in different ecosystems [71,72]. The quality of plant residues and, essentially the soil mineralogy (such as acidity, biological readiness and mineral contents) are mainly determined by the rates of residual mineralization [73,74]. The plant residues are also affected by variations in their biochemical compositions [75,76]. The composition of residue minerals 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 decay [77,78]. Further, various studies have revealed that plant species with distinct abilities are especially important for agricultural systems with limited fertilizer inputs [79,80]. The amount, location, and bio-degradability of plant residues significantly affect the SOC [81,82]. Therefore, the adequate management of plant residues is necessary to increase the processing of biological nutrients and minerals in the soil.

However, plant residue management alone may not be sufficient to ensure enough carbon reserves in the soil since it is also associated with the physical soil structure [83,84]. It has been found that the soil carbon levels decreased considerably as a result of conversion of the forest land to agricultural land [85,86]. The loss in soil inputs, nutrients, and decomposition can be attributed to changes in forest carbon and ecosystem disturbance [87,88]. The carbon isotope composition in the soil is a valuable technique for quantifying the rate of organic and/or non-biological processes [89]. A number of ecosystems have been investigated using C-isotopic techniques for SOM concentrations. Most of these studies have investigated the 13C (isotopic) properties of SOM that have emerged through vegetation changes between the C3 plants and the C4 plants [90,91]. Changes in the 13C concentration of these fractions can, thus, tell us about SOM consumption rates and provide helpful information about the different control systems of management. Depending on the location and environmental exposure, different results are obtained.

6. Carbon Sequestration

As a matter of environmental concern, there has been increased interest in carbon sequestration techniques for reducing CO$_2$ emissions. Human activities are known to have substantial effects on the terrestrial carbon cycle (approximately 50% CO$_2$ sequestration) both directly and indirectly [92,93]. The burning of fossil fuels constitutes a significant proportion of total anthropogenic CO$_2$ emissions [94,95], and with the demand for energy increasing rapidly, particularly in developing countries, such emissions are expected to increase even more. The overwhelming body of scientific evidence has indicated that elevated CO$_2$ levels in the atmosphere are highly detrimental to the environment [96,97]. According to researchers, increased CO$_2$ levels in environment produce greenhouse effect resulting in increased temperatures and hence global warming [98,99]. The oceans, in this regard, can provide a solution since they are known to absorb about a quarter of all the anthropogenic CO$_2$ emissions [100,101]. This could be beneficial, but at a cost, since increased CO$_2$ levels in seawater forms carbonic acid [102,103]. It is worth mentioning here 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 [101,102]. Additional increases in oceanic acidity are believed to hasten the demise of marine life. Therefore, stringent post-combustion
carbon sequestration management will be required to meet the energy demand while minimizing CO\textsubscript{2} emissions.

Carbon capture and storage is a process that absorbs CO\textsubscript{2} from flue gaseous emissions and stores it for extended periods \cite{104,105}. Carbon is found in all biological media, including peat and seawater \cite{106,107}. Besides, organic carbon can be produced by autotrophic organisms through photosynthesis which involves the reduction of CO\textsubscript{2} \cite{108,109}. Carbon sequestration is defined as the deliberate or intentional separation and disposal of CO\textsubscript{2} as a by-product of combustion in non-atmospheric reservoirs \cite{110}. It has been further defined as increasing natural processes, such as CO\textsubscript{2} absorption by living organisms, to offset any additional CO\textsubscript{2} emitted \cite{21,111}. Energy crops such as biofuels, in this context, may be used in a variety of ways \cite{112,113}. CO\textsubscript{2} can be recycled during the biofuel production, and biomass can be potentially used in place of fossil fuels \cite{114,115}. If the process is carried out properly, it will result in massive amounts of value-added biomass and materials that can be further used to make bio-ethanol. In addition to these carbon management strategies, the biological carbon mitigation technology (BCM) in CO\textsubscript{2} sequestration has also been investigated (as is the applicability of microalgae) to ascertain the fate of mitigated carbon \cite{21,116}. Thus, appropriate carbon management is necessary to ensure that biomass can be used for various commercial purposes while also sequestering additional carbon simultaneously in biological media to keep the air safe.

7. Carbon Foot Printing

To reduce GHG emissions and increase GHG sinks in a particular system, carbon footprint (CF) identifies the source, quantity, and sink of GHGs released from on-farm and off-farm activities \cite{117}. A CF takes into account all the inputs and processes within the confines of a defined system. The friction coefficient is calculated within a system limit, a hypothetical line based on the activity and materials used \cite{118}. Although the findings of CF research may provide helpful information to make effective choices, the methods used to calculate CF for agricultural systems are, at present, lacking in consistency \cite{119}. For instance, in several areas, consistency including the choice of functional units, system limits and emission factor specificity (EFS) is missing. Moreover, it is difficult for a variety of reasons to estimate soil GHG emissions from diverse farm activities. There are significant variations amongst other factors in soil carbon (C), global and field-scale estimates \cite{120}. In addition, the dynamics and interactions of labile and recalcitrant carbon stores give a combined strategy to develop consistent methods and models for site-specific information. Adewale et al. quantified carbon loss and gained in soil, and found that 13% of CF net soil emissions were produced from a small production of vegetables \cite{117}. Therefore, a full CF assessment must cover carbon (CO\textsubscript{2} released or sequestered) and the net GHG emissions of a particular farm or farm product or field operations \cite{121} to determine whether agricultural techniques can help implement a GHG reduction strategy successfully. Organic agriculture, in this regard, is a beneficial subset of CF agriculture since it involves the conservation of natural resources and annual certification \cite{122}. Numerous studies were carried out to determine the environmental impacts of organic farming, most of which demonstrated advantages over conventional farming methods, including increased soil content, lowering nutrient performance and lower consumption of energy \cite{123,124}.

However, whether organic farming produces more or less GHGs than conventional farming is not answered since the findings vary depending on the product and farm activity. According to a study, organic farming techniques emit more ammonia, nitrogen and N2O per Product Unit than conventional farming systems \cite{125}. Organic dairy and organic pig farmers are often responsible for more GHG emissions by a unit than conventional systems, while organic beef production generates fewer GHGs per kilogram of meat \cite{126}. Due to many results, satisfactory conclusions cannot be drawn regarding the CF of different systems. However, many studies advocate using Tier3 EFS to improve the precision and usefulness of methods for estimating agricultural GHGs \cite{127}. 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 an agricultural system 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 [128]. Any such factor could be critical in determining systems differentiation or the most effective CF prevention and reduction strategies.

Furthermore, agricultural operations need adequate monitoring so that farmers can make informed decisions regarding equipment and use of fuel and soil carbon changes [129]. Organic farming frequently has a lower carbon footprint (CF) than conventional agriculture when measured by area and sometimes by-product unit [121]. The future use of certified organic farms as a longitudinal national or global population study would be justified due to their potential benefits and the annual inspection and certification process. In this direction, the representative concentration pathway (RCP) is a GHG concentration trajectory approved by the Intergovernmental Panel on Climate Change (IPCC). In 2014, the IPCC’s fifth assessment report took four distinct climate modelling and research [130]. The paths illustrated possible climate futures, and each is considered plausible considering CO₂ generated in the coming years. RCP2.6, RCP4.5, RCP6.0, and RCP8.5 refer to radiative forcing values for the year 2100 (Figure 2).

![Figure 2. Anthropogenic total CO₂ emissions (PgC yr⁻¹) from farming and its projection until 2100.](Image)

**8. Carbon Economy**

Instead of colonizing the governance spaces created by calculating a product’s carbon footprint, retailers establish new corporate responsibility regimes to measure and manage carbon emissions. Here, certain behaviors are encouraged, legitimized, and/or eliminated in order to force individual suppliers to become active participants in their own governance [131,132]. Similar is the case for carbon reduction from agricultural products, with the values and ambitions of their supply chain partners. Concerning climate change, retailers take on a more significant 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 license to operate [133]. While global retailers have received plaudits for their role in mitigating climate change, the actual responsibility of such climate change mitigation programs and the risk associated with them is positioned with the government [134]. However, 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 [132,133]. Retailers reframe their supply chain models by looking into the product’s entire life cycle through carbon footprinting and
introducing new norms and priorities into the existing relationships [135,136]. In carbon footprint printing, suppliers have independently adopted new measurement techniques, collected and disclosed data, and made corresponding carbon reductions.

The product carbon footprint necessitates the suppliers to take responsibility for the environmental and social impacts of the products they deliver to the next stage of the supply chain [137,138]. Suppliers at all the levels and tiers of a product’s supply chain are encouraged to collect and share their best carbon footprint data [139,140]. Furthermore, the priorities, ambitions, and responsibilities assumed by multinational corporations, from halting deforestation to reducing carbon emissions, have a profound impact on the lives of consumers, suppliers, society, and global ecologies [132,141]. In the absence of well-defined and well-enforced international environmental standards, these actors are increasingly defining sustainability in corporate terms [142]. 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 [143,144]. Therefore, it becomes inevitable to address the fundamental questions relating to consumption (at the expense of global environmental changes) and the expanding power of these corporate citizens in creating a sustainable market for low-carbon products.

9. Challenges in Carbon Farming

The carbon farming initiatives (CFI) demand agro-environmental policies to incentivize farmers to adopt best farm management practices. However, it is usually difficult to get farmers involved in such programs mainly because of the complex scheme-design and its implementation or conflicting targets of policy-makers and the farmers [145]. Various other factors are also known to affect the adoption and implementation of new farm management practices, which include personal interests of landholders, farm or land features [146,147]. Some of the barriers in carbon farming are directly associated with the landholders’ interests, in addition to inadequate skills or management abilities. Political instability also substantially affects the acceptance and implementation of such practices [148]. Besides, uncertainty about environment related impacts and lack of awareness of such schemes and policies may also undermine their adoption [149,150]. Farmers have agreed that they have insufficient access to information regarding available options for carbon farming [150,151]. In fact, many farmers don’t understand the exact meaning of carbon farming, and they lack detailed information about the pros and cons of carbon farming. The situation was further exaggerated by high input costs and apprehensions regarding the effect of carbon farming on yield and farm productivity.

CFI’s other significant barriers are lack of approved methods and procedures, higher administrative expenses, and difficulty in getting certification as a qualified carbon offset provider [152,153]. 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 [150,154]. Some other barriers that need specific mention here include: instability in carbon prices [155]; uncertainty regarding benefits from carbon farming [156]; difficulty in monitoring the progress of such initiatives [157]; uncertainty regarding carbon market selling practices [158]; and the financial consequences of participation [159]. Farmers also stated that the sale of products from tree plantations is difficult, indicating their reluctance to implement carbon farming as they consider it to be dissenting with other objectives [151,153]. Moreover, some farmers believe that the carbon farming policy rewards them with an antiquity of improper land management, preventing their involvement [160,161]. This suggests that farmer’s interests or sentiments may offer a participation barrier to CFI along with the other barriers mentioned above. In such a scenario, encouragement through financial incentives for increased participation in CFI does not seem to be sufficient to tackle the barriers that farmers generally face.
10. Discussion

Carbon farming involves, as discussed in this review, the management of carbon content in soils. Carbon farming presents an opportunity to maintain biodiversity, economic and social co-benefits along with terrestrial carbon abatements (Figure 3). The review emphasizes some of the important factors that must be considered to implement carbon farming and other reforestation policies. However, its effective implementation primarily relies on appropriate institutional provisions and sufficient information dissemination. Landholders are required to be provided with clear information about the relative outcomes and benefits of adopting carbon farming, including precise information on carbon abatement, expected financial returns in the carbon market, variations in carbon yields depending upon soil type, possible impacts on property value, and farm productivity [162]. Evans et al. highlighted the possibility of carbon farming to be adopted as a feasible land use practice in agricultural lands of north-eastern Australia. The research, in particular, illustrated the potential of carbon farming as a cost-effective alternative for agrarian production capable of sequestering carbon and restoring biodiversity simultaneously [154].

Further, changes in land-use pattern remain, arguably, the most compelling threat to biodiversity conservation which requires utmost attention. Therefore, we have presented an approach to enumerating the impacts of carbon farming across various ecosystem components and exploring synergies to minimize the adverse effects through careful implementation. Generally, the mechanisms involved in carbon farming help restore the lost functions of the ecosystem and strengthen ecosystem services delivery. This mainly includes soil health and water quality (services significant for environmental well-being), in addition to improved farm productivity [163].

![Figure 3. Environmental and socio-economic advantages of carbon farming](image)

11. Conclusions

Given the increasing human demands and subsequent effects on the environment, sustainable practices of agricultural production are being encouraged. The dependence of the agricultural output on climatic change can be stabilized by using less-intensive and judiciously organized farming methods. The agro-environmental parameters must be considered thoroughly to discover farming systems that can control the delicate balance between climatic change and agricultural productions. Carbon farming, in this context, offers an all-inclusive and sustainable land-use management method, beneficial for both environment and the society. The combination of forest vegetation with crop farming and livestock production through agroforestry improves net agricultural production and food security. It is also known for reduced GHG emissions and carbon sequestration which depend mainly upon climate conditions, soil characteristics, vegetation, and land-use practices. Agroforestry ecosystems might be estimated with various environmental indicators de-
pending on energy use, the yield and productivity, and production processes. However, the silvopastoral system is generally found to be more effective in relation to carbon sequestration and GHG emissions reduction than the agroforestry system. Besides, carbon farming systems are highly efficient at retaining organic carbon stocks in the soil. These systems are capable of accumulating more significant amounts of SOC as compared to mono-cropping, thereby improving soil quality. However, in spite of so many advantages, carbon farming is not well-appreciated by farmers due to a number of reasons. Therefore, well-informed advisory services are required to encourage farmers to adopt CFI for agricultural production and soil management and reduce the unsustainable farming practices.

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References

1. Aranda, V.; Ayora-Cañada, M.J.; Dominguez-Vidal, A.; Martin-Garcia, J.M.; Calero, J.; Delgado, R.; Verdejo, T.; González-Vila, F.J. Effect of Soil Type and Management (Organic vs. Conventional) on Soil Organic Matter Quality in Olive Groves in a Semi-Arid Environment in Sierra Máginga Natural Park (S Spain). Geoderma 2011, 164, 54–63. [CrossRef]

2. Fageria, N.K. Role of Soil Organic Matter in Maintaining Sustainability of Cropping Systems. Commun. Soil Sci. Plant Anal. 2012, 43, 2063–2113. [CrossRef]

3. Bolan, N.S.; Adriano, D.C.; Kunhikrishnan, A.; James, T.; McDowell, R.; Senesi, N. Dissolved Organic Matter: Biogeochemistry, Dynamics, and Environmental Significance in Soils. Adv. Agron. 2011, 110, 1–75.

4. Scotti, R.; Bonanomi, G.; Scelza, R.; Zoina, A.; Rao, M.A. Organic Amendments as Sustainable Tool to Recovery Fertility in Intensive Agricultural Systems. J. Soil Sci. Plant Nutr. 2015, 15, 333–352. [CrossRef]

5. Karami, A.; Homaee, M.; Afzalinia, S.; Ruhipour, H.; Basirat, S. Organic Resource Management: Impacts on Soil Aggregate Stability and Other Soil Physico-Chemical Properties. Agric. Ecosyst. Environ. 2012, 148, 22–28. [CrossRef]

6. Tisdall, J.M. Formation of soil aggregates and accumulation of soil organic matter. In Structure and Organic Matter Storage in Agricultural Soils; CRC Press: Boca Raton, FL, USA, 2020; pp. 57–96.

7. Altieri, M.A.; Nicholls, C.I.; Henao, A.; Lana, M.A. Agroecology and the Design of Climate Change-Resilient Farming Systems. Agron. Sustain. Dev. 2015, 35, 869–890. [CrossRef]

8. Garrett, K.A.; Forbes, G.A.; Savary, S.; Skelsey, P.; Sparks, A.H.; Valdivia, C.; Van Bruggen, A.H.C.; Willocquet, L.; Djurle, A.; Duveller, E. Complexity in Climate-Change Impacts: An Analytical Framework for Effects Mediated by Plant Disease. Plant Pathol. 2011, 60, 15–30. [CrossRef]

9. Hartmann, J.; West, A.J.; Renforth, P.; Kübler, P.; De La Rocha, C.L.; Wolf-Gladrow, D.A.; Dürr, H.H.; Scheffran, J. Enhanced Chemical Weathering as a Geoengineering Strategy to Reduce Atmospheric Carbon Dioxide, Supply Nutrients, and Mitigate Ocean Acidification. Rev. Geophys. 2013, 51, 113–149. [CrossRef]

10. Mceod, E.; Chmura, G.L.; Bouillon, S.; Salm, R.; Björk, M.; Duarte, C.M.; Lovelock, C.E.; Schlesinger, W.H.; Silliman, B.R. A Blueprint for Blue Carbon: Toward an Improved Understanding of the Role of Vegetated Coastal Habitats in Sequestering CO2. Front. Ecol. Environ. 2011, 9, 552–560. [CrossRef]

11. Kirkels, F.; Cammeraat, L.H.; Kuhn, N.J. The Fate of Soil Organic Carbon upon Erosion, Transport and Deposition in Agricultural Landscapes—A Review of Different Concepts. Geomorphology 2014, 226, 94–105. [CrossRef]

12. Xiao, H.; Li, Z.; Chang, X.; Huang, B.; Nie, X.; Liu, C.; Liu, L.; Wang, D.; Jiang, J. The Mineralization and Sequestration of Organic Carbon in Relation to Agricultural Soil Erosion. Geoderma 2018, 329, 73–81. [CrossRef]

13. Dewi, S.; Van Noordwijk, M.; Zulkarnain, M.T.; Dwiputra, A.; Hyman, G.; Prabhu, R.; Gitz, V.; Nasi, R. Tropical Forest-Transition Landscapes: A Portfolio for Studying People, Tree Crops and Agro-Ecological Change in Context. Int. J. Biodivers. Sci. Ecosys. Serv. Manag. 2017, 13, 312–329. [CrossRef]

14. Nair, P.K.R. Carbon Sequestration Studies in Agroforestry Systems: A Reality-Check. Agrofor. Syst. 2012, 86, 243–253. [CrossRef]

15. Chapagain, T.; Raizada, M.N. Agronomic Challenges and Opportunities for Smallholder Terrace Agriculture in Developing Countries. Front. Plant Sci. 2017, 8, 331. [CrossRef]
16. Chhabra, V.; Abdul Haris, A.; Prakash, V.; Upadhyay, H. Cropping systems and their effectiveness in adaptation and mitigation of climate change. *Plant Arch.* 2018, 18, 1175–1183.

17. Liu, Y.; Zhang, X.; Xia, D.; You, J.; Yong, Y.; Bakir, M. Impacts of Land-Use and Climate Changes on Hydrologic Processes in the Qingyi River Watershed, China. *J. Hydrol. Eng.* 2013, 18, 1495–1512. [CrossRef]

18. Tan, M.L.; Ibrahim, A.L.; Yusop, Z.; Duan, Z.; Ling, L. Impacts of Land-Use and Climate Variability on Hydrological Components in the Johor River Basin, Malaysia. *Hydrol. Sci. J.* 2015, 60, 873–889. [CrossRef]

19. FAO—News Article: Key Facts and Findings. Available online: http://www.fao.org/news/story/en/item/197623/icode/ (accessed on 23 July 2021).

20. Powlsion, D.S.; Whitmore, A.P.; Goulding, K.W. Soil Carbon Sequestration to Mitigate Climate Change: A Critical Re-Examination to Identify the True and the False. *Eur. J. Soil Sci.* 2011, 62, 42–55. [CrossRef]

21. Farrelly, D.J.; Everard, C.D.; Fagan, C.C.; McDonnell, K.P. Carbon Sequestration and the Role of Biological Carbon Mitigation: A Review. *Renew. Sustain. Energy Rev.* 2013, 21, 712–727. [CrossRef]

22. Zheng, J.; Chong, Z.R.; Qureshi, M.F.; Linga, P. Carbon Dioxide Sequestration via Gas Hydrates: A Potential Pathway toward Decarbonization. *Energy Fuels* 2020, 34, 10529–10546. [CrossRef]

23. Singh, S.K.; Sundaram, S.; Sinha, S.; Rahman, M.A.; Kapur, S. Recent Advances in CO$_2$ Uptake and Fixation Mechanism of Cyanobacteria and Microalgae. *Crit. Rev. Environ. Sci. Technol.* 2016, 46, 1297–1323. [CrossRef]

24. Moreira, D.; Pires, J.C. Atmospheric CO$_2$ Capture by Algae: Negative Carbon Dioxide Emission Path. *Bioresour. Technol.* 2016, 215, 371–379. [CrossRef] [PubMed]

25. Sun, L.; Wang, S.; Zhang, Y.; Wang, X.; Wang, R.; Lyu, W.; Chen, N.; Wang, Q. Conservation Agriculture Based on Crop Rotation and Tillage in the Semi-Arid Loess Plateau, China: Effects on Crop Yield and Soil Water Use. *Agric. Ecosyst. Environ.* 2018, 251, 67–77. [CrossRef]

26. El-Ramady, H.R. Integrated nutrient management and postharvest of crops. In *Sustainable Agriculture Reviews*; Springer: Berlin/Heidelberg, Germany, 2014; pp. 163–274.

27. Sommer, R.; Bossio, D.; Desta, L.; Dimes, J.; Kihara, J.; Koala, S.; Mango, N.; Rodriguez, D.; Thierfelder, C.; Winowiecki, L. Positive Long-Term Impacts of Crop Rotations. *J. Soil Water Conserv.* 2021, 76, 69–79. [CrossRef]

28. Williams, J.D.; Wuest, S.B.; Long, D.S. Soil and Water Conservation in the Pacific Northwest through No-Tillage and Intensified Crop Rotations. *J. Soil Water Conserv.* 2014, 69, 495–504. [CrossRef]

29. Gaujou, E.; Amiaud, B.; Mignonet, C.; Plantureux, S. Factors and Processes Affecting Plant Biodiversity in Permanent Grasslands. A Review. *Agron. Sustain. Dev.* 2012, 32, 133–160. [CrossRef]

30. López-Hernández, D.; Hernández-Hernández, R.M.; Hernández-Valencia, I.; Toro, M. Nutritional Stress in Dystrophic Savanna Soils of the Orinoco Basin: Biological Responses to Low Nitrogen and Phosphorus Availabilitys. In *Emerging Technologies and Management of Crop Stress Tolerance*; Elsevier: Amsterdam, The Netherlands, 2014; pp. 343–375.
41. Atangana, A.; Khasa, D.; Chang, S.; Degrande, A. Major agroforestry systems of the humid tropics. In *Tropical Agroforestry*; Springer: Berlin/Heidelberg, Germany, 2014; pp. 49–93.

42. Jose, S. Agroforestry for Conserving and Enhancing Biodiversity. *Agrofor. Syst.* 2012, 85, 1–8. [CrossRef]

43. Sauer, T.J.; Coblentz, W.K.; Thomas, A.L.; Brye, K.R.; Brauer, D.K.; Skinner, J.V.; Van Brahana, J.; DeFauw, S.L.; Hays, P.D.; Moffitt, D.C. Nutrient Cycling in an Agroforestry Alley Cropping System Receiving Poultry Litter or Nitrogen Fertilizer. *Nutr. Cycl. Agroecosyst.* 2015, 101, 167–179. [CrossRef]

44. Swieter, A.; Langhof, M.; Lamerre, J.; Greef, J.M. Long-Term Yields of Oilseed Rape and Winter Wheat in a Short Rotation Alley Cropping Agroforestry System. *Agrofor. Syst.* 2019, 93, 1853–1864. [CrossRef]

45. Marsden, C.; Martin-Chavez, A.; Cortet, J.; Hedde, M.; Capowiez, Y. How Agroforestry Systems Influence Soil Fauna and Their Functions-a Review. *Plant Soil* 2020, 453, 29–44. [CrossRef]

46. Cardinael, R.; Chevallier, T.; Barthes, B.G.; Saby, N.P.; Parent, T.; Dupraz, C.; Bernoux, M.; Chenu, C. Impact of Alley Cropping Agroforestry on Stocks, Forms and Spatial Distribution of Soil Organic Carbon—A Case Study in a Mediterranean Context. *Geoderma* 2015, 259, 288–299. [CrossRef]

47. Kremer, R.J.; Kussman, R.D. Soil Quality in a Pecan–Kura Clover Alley Cropping System in the Midwestern USA. *Agrofor. Syst.* 2011, 83, 213–223. [CrossRef]

48. Mosquera-Losada, M.R.; Freese, D.; Rigueiro-Rodríguez, A. Carbon sequestration in European agroforestry systems. In *Carbon Sequestration Potential of Agroforestry Systems*; Springer: Berlin/Heidelberg, Germany, 2011; pp. 43–59.

49. Wang, B.; Liu, G.; Xue, X. Effect of Black Locust (Robinia Pseudoacacia) on Soil Chemical and Microbiological Properties in the Eroded Hilly Area of China’s Loess Plateau. *Environ. Earth Sci.* 2012, 65, 597–607. [CrossRef]

50. Yülsek, T. The Restoration Effects of Black Locust (Robinia Pseudoacacia) Plantation on Surface Soil Properties and Carbon Sequestration on Lower Hillslopes in the Semi-Humid Region of Coruh Drainage Basin in Turkey. *Catena* 2012, 90, 18–25. [CrossRef]

51. Pacheco, A.R.; Chaves, R.d.Q.; Nicoli, C.M.L. Integration of Crops, Livestock, and Forestry: A System of Production for the Brazilian Cerrados. In *Ecо-Efficiency: From Vision to Reality*; Hershey, C.H., Neate, P., Eds.; CIAT: Cali, Colombia, 2013; pp. 51–61.

52. Peri, P.L.; Banegas, N.; Gasparri, I.; Carranza, C.H.; Rossner, B.; Pastur, G.M.; Cavallero, L.; López, D.R.; Loto, D.; Fernández, P. Carbon sequestration in temperate silvopastoral systems, Argentina. In *Integrating Landscapes: Agroforestry for Biodiversity Conservation and Food Sovereignty*; Springer: Berlin/Heidelberg, Germany, 2017; pp. 453–478.

53. Frison, E.A. From Uniformity to Diversity: A Paradigm Shift from Industrial Agriculture to Diversified Agroecological Systems. In *IPBES-Food*; IPBES: London, UK, 2016.

54. Lopes, M.A.; Faleiro, F.G.; Ferreira, M.E.; Lopes, D.B.; Vivian, R.; Boiteux, L.S. Embrapa’s Contribution to the Development of New Plant Varieties and Their Impact on Brazilian Agriculture. *Crop Breed. Appl. Biotechnol.* 2012, 12, 31–46. [CrossRef]

55. Bernués, A.; Ruiz, R.; Olazola, A.; Villalba, D.; Casasius, I. Sustainability of Pasture-Based Livestock Farming Systems in the European Mediterranean Context: Synergies and Trade-Offs. *Livestock Sci.* 2011, 139, 44–57. [CrossRef]

56. Tsonkova, P.; Böhm, C.; Quinkenstein, A.; Freese, D. Ecological Benefits Provided by Alley Cropping Systems for Production of Woody Biomass in the Temperate Region: A Review. *Agrofor. Syst.* 2012, 85, 133–152. [CrossRef]

57. Aguiar, A.d.C.F.; Carvalho, C.S.; Almeida, C.; Ribeiro, C.S.; Moreira, P.H.M.; de Moura, E.G. Organic Matter Fraction and Pools of Phosphorus as Indicators of the Impact of Land Use in the Amazonian Periphery. *Ecol. Indic.* 2013, 30, 158–164. [CrossRef]

58. Das, S.K. Carbon Sequestration and Climate Change. *Food Sci. Rep.* 2015, 1, 23–29. [CrossRef]

59. Ussiri, D.A.; Lal, R. Carbon Sequestration for Climate Change Mitigation and Adaptation; Springer: Berlin/Heidelberg, Germany, 2017.

60. Alves, E.Q.; Macario, K.; Ascough, P.; Bronk Ramsey, C. The Worldwide Marine Radiocarbon Reservoir Effect: Definitions, Mechanisms, and Prospects. *Rev. Geophys.* 2018, 56, 278–305. [CrossRef]

61. Cheah, W.Y.; Show, P.L.; Chang, J.-S.; Ling, T.C.; Juan, J.C. Biosequestration of Atmospheric CO₂ and Fluor Gas-Containing CO₂ by Microalgae. *Bioresour. Technol.* 2015, 184, 190–201. [PubMed]

62. Nielsen, U.N.; Ayres, E.; Wall, D.H.; Bardgett, R.D. Soil Biodiversity and Carbon Cycling: A Review and Synthesis of Studies Examining Diversity–Function Relationships. *Eur. J. Soil Sci.* 2011, 62, 105–116. [CrossRef]

63. Asner, G.P.; Clark, J.K.; Mascaro, J.; Galindo García, G.A.; Chadwick, K.D.; Navarrete Encinales, D.A.; Paez-Acosta, G.; Cabrera Montenegro, E.; Kennedy-Bowdoin, T; Duque, Á. High-Resolution Mapping of Forest Carbon Stocks in the Colombian Amazon. *Biogeosciences* 2012, 9, 2683–2696. [CrossRef]

64. Sayre, R. Microalgae: The Potential for Carbon Capture. *Bioscience* 2010, 60, 722–727. [CrossRef]

65. Johnson, M.G. The role of soil management in sequestering soil carbon. In *Soil Management and Greenhouse Effect*; CRC Press: Boca Raton, FL, USA, 2018; pp. 351–364.

66. Schrumpf, M.; Kaiser, K.; Guggenberger, G.; Persson, T.; Kögel-Knabner, I.; Schulze, E.-D. Storage and Stability of Organic Carbon in Soils as Related to Depth, Occlusion within Aggregates, and Attachment to Minerals. *Biogeosciences* 2013, 10, 1675–1691. [CrossRef]

67. Reichstein, M.; Bahn, M.; Ciais, P.; Frank, D.; Mehecha, M.D.; Seneviratne, S.I.; Zscheischler, J.; Beer, C.; Buchmann, N.; Frank, D.C. Climate Extremes and the Carbon Cycle. *Nature* 2013, 500, 287–295. [CrossRef]

68. MacBean, N.; Peylin, P. Agriculture and the Global Carbon Cycle. *Nature* 2014, 515, 351–352. [CrossRef]
69. Gougoulias, C.; Clark, J.M.; Shaw, L.J. The Role of Soil Microbes in the Global Carbon Cycle: Tracking the below-Ground Microbial Processing of Plant-Derived Carbon for Manipulating Carbon Dynamics in Agricultural Systems. *J. Sci. Food Agric.* 2014, 94, 2362–2371. [CrossRef] [PubMed]

70. Bendtsen, J.; Dellille, B.; Dieckmann, G.S.; Glud, R.N.; Kennedy, H.; Mortenstreu, J.; Papadimitriou, S.; Thomas, D.N.; Tison, J.-L. Sea Ice Contribution to the Air–Sea CO₂ Exchange in the Arctic and Southern Oceans. *Tellus B Chem. Phys. Meteorol.* 2011, 63, 823–830.

71. Hartley, I.P.; Hopkins, D.W.; Sommerkorn, M.; Wooker, P.A. The Response of Organic Matter Mineralisation to Nutrient and Substrate Additions in Sub-Arctic Soils. *Soil Biol. Biochem.* 2010, 42, 92–100. [CrossRef]

72. Kabiri, V.; Raisi, F.; Ghazavi, M.A. Tillage Effects on Soil Microbial Biomass, SOM Mineralization and Enzyme Activity in a Semi-Arid Calcareous. *Agric. Ecosyst. Environ.* 2016, 232, 73–84. [CrossRef]

73. Campos, A.; Suárez, G.; Laborde, J. Analyzing Vegetation Cover-Induced Organic Matter Mineralization Dynamics in Sandy Soils from Tropical Dry Coastal Ecosystems. *Catena* 2020, 185, 104264. [CrossRef]

74. Geisseler, D.; Miller, K.S.; Aegerter, B.J.; Clark, N.E.; Miyao, E.M. Estimation of Annual Soil Nitrogen Mineralization Rates Using an Organic-Nitrogen Budget Approach. *Soil Sci. Soc. Am. J.* 2019, 83, 1227–1235. [CrossRef]

75. Imaz, M.J.; Virtu, I.; Bescansa, P.; Enrique, A.; Fernandez-Ugalde, O.; Karlen, D.L. Soil Quality Indicator Response to Tillage and Residue Management on Semi-Arid Mediterranean Cropland. *Soil Tillage Res.* 2010, 107, 17–25. [CrossRef]

76. Kay, B.D. Soil Structure and Organic Carbon: A Review. Available online: https://www.taylorfrancis.com/ (accessed on 15 July 2021).

77. Kaleeem Abbasi, M.; Mahmood Tahir, M.; Sabir, N.; Khurshid, M. Impact of the Addition of Different Plant Residues on Nitrogen Mineralization–Immobilization Turnover and Carbon Content of a Soil Incubated under Laboratory Conditions. *Solid Earth* 2015, 6, 197–205. [CrossRef]

78. Le Guillou, C.; Angers, D.A.; Maron, P.A.; Leterme, P.; Menasseri-Aubry, S. Linking Microbial Community to Soil Water-Stable Aggregation during Crop Residue Decomposition. *Soil Biol. Biochem.* 2012, 50, 126–133. [CrossRef]

79. Damon, P.M.; Bowden, B.; Rose, T.; Rengel, Z. Crop Residue Contributions to Phosphorus Pools in Agricultural Soils: A Review. *Soil Biol. Biochem.* 2014, 74, 127–137. [CrossRef]

80. Kallenbach, C.; Grandy, A.S. Controls over Soil Microbial Biomass Responses to Carbon Amendments in Agricultural Systems: A Meta-Analysis. *Agric. Ecosyst. Environ.* 2011, 144, 241–252. [CrossRef]

81. Saljnikov, E.; Cakmak, D.; Rahimgalieva, S. Soil Organic Matter Stability as Affected by Land Management in Steppe Ecosystems. *Soil Process. Curr. Trends Qual. Assess.* 2013, 7, 5772.

82. Ukałska-Jaruga, A.; Klimkowicz-Pawlas, A.; Smerczak, B. Characterization of Organic Carbon Fractions in the Top Layer of Soils under Different Land Uses in Central-Eastern Europe. *Soil Use Manag.* 2019, 35, 595–606. [CrossRef]

83. Naresh, R.K.; Singh, S.P.; Chauhan, P. Influence of Conservation Agriculture, Permanent Raised Bed Planting and Residue Management on Soil Quality and Productivity in Maize–Wheat System in Western Uttar Pradesh. *Int. J. Life Sci. Biotechnol. Pharma Res.* 2012, 1, 27–34.

84. Turmel, M.-S.; Speratti, A.; Baudron, F.; Verhulst, N.; Govaerts, B. Crop Residue Management and Soil Health: A Systems Analysis. *Agric. Syst.* 2015, 134, 6–16. [CrossRef]

85. Deng, L.; Zhu, G.; Tang, Z.; Shangguan, Z. Global Patterns of the Effects of Land-Use Changes on Soil Carbon Stocks. *Glob. Ecol. Conserv.* 2016, 5, 127–138. [CrossRef]

86. Wei, X.; Shao, M.; Gao, W.; Li, L. Global Pattern of Soil Carbon Losses Due to the Conversion of Forests to Agricultural Land. *Sci. Rep.* 2014, 4, 1–6. [CrossRef]

87. Clarke, N.; Gundersen, P.; Jönsson-Belyazid, U.; Kjønaas, O.J.; Persson, T.; Sigurdsson, B.D.; Stupak, I.; Vesterdal, L. Influence of Different Tree-Harvesting Intensities on Forest Soil Carbon Stocks in Boreal and Northern Temperate Forest Ecosystems. *For. Ecol. Manag.* 2015, 351, 9–19. [CrossRef]

88. Luo, Z.; Wang, E.; Sun, O.J. Soil Carbon Change and Its Responses to Agricultural Practices in Australian Agro-Ecosystems: A Review and Synthesis. *Geoerda* 2010, 155, 211–222. [CrossRef]

89. Gallagher, T.M.; Breecker, D.O. The Obscuring Effects of Calcite Dissolution and Formation on Quantifying Soil Respiration. *Glob. Biogeochem. Cycles* 2020, 34, e2020GB006584. [CrossRef]

90. Jou, R.M.; Macario, K.D.; Pessenda, L.C.; Pereira, M.G.; Lorente, F.L.; Pedrosa, R.; da Silva Neto, E.C.; Fallon, S.; Muniz, M.C.; Cardoso, R.P. The Use of Carbon Isotopes (13C, 14C) in Different Soil Types and Vegetation Coverage in a Montane Atlantic Forest Region, Southeast Brazil. *Quat. Geochronol.* 2021, 61, 101133. [CrossRef]

91. Roy, B.; Ghosh, S.; Sanyal, P. Morpho-Tectonic Control on the Distribution of C3–C4 Plants in the Central Himalayan Siwaliks during Late Plio-Pleistocene. *Earth Planet. Sci. Lett.* 2020, 535, 116119. [CrossRef]

92. Luo, Y.; Weng, E. Dynamic Disequilibrium of the Terrestrial Carbon Cycle under Global Change. *Trends Ecol. Evolut.* 2011, 26, 96–104. [CrossRef]

93. Schmitz, O.J.; Raymond, P.A.; Estes, J.A.; Kurz, W.A.; Holtgrieve, G.W.; Ritchie, M.E.; Schindler, D.E.; Spivak, A.C.; Wilson, R.W.; Bradford, M.A. Animating the Carbon Cycle. *Ecosystenes* 2014, 17, 344–359. [CrossRef]

94. Dutcher, B.; Fan, M.; Russell, A.G. Amine-Based CO₂ Capture Technology Development from the Beginning of 2013—A Review. *ACS Appl. Mater. Interfaces* 2015, 7, 2137–2148. [CrossRef] [PubMed]

95. Holtsmark, B. Quantifying the Global Warming Potential of CO₂ Emissions from Wood Fuels. *Geb Bioenergy* 2015, 7, 195–206. [CrossRef]
96. Goepert, A.; Czaun, M.; Prakash, G.S.; Olah, G.A. Air as the Renewable Carbon Source of the Future: An Overview of CO₂ Capture from the Atmosphere. *Energy Environ. Sci.* 2012, 5, 7833–7853. [CrossRef]

97. Manalisidis, I.; Stavropoulou, E.; Stavropoulos, A.; Beztizoglou, E. Environmental and Health Impacts of Air Pollution: A Review. *Front. Public Health* 2020, 8. [CrossRef]

98. Anderson, T.R.; Hawkins, E.; Jones, P.D. CO₂, the Greenhouse Effect and Global Warming: From the Pioneering Work of Arrhenius and Callendar to Today’s Earth System Models. *Endeavour* 2016, 40, 178–187. [CrossRef]

99. McCulloch, M.; Falter, J.; Trotter, J.; Montagna, P. Coral Resilience to Ocean Acidification and Global Warming through pH Up-Regulation. *Nat. Clim. Change* 2012, 2, 623–627. [CrossRef]

100. Gattuso, J.-P.; Magnan, A.; Billoé, R.; Cheung, W.W.L.; Howes, E.L.; Joos, F.; Allemand, D.; Bopp, L.; Cooley, S.R.; Eakin, C.M.; et al. Contrasting futures for ocean and society from different anthropogenic CO₂ emissions scenarios. *Science* 2015, 349, aae4722. [CrossRef]

101. Tang, Q.; Chen, C.-T.A.; Yu, K.; Dai, M.; Zhao, M.; Ke, C.; Wong, G.T.; Chai, F.; Wei, G.; Zhou, L. The Effects of Ocean Acidification on Marine Organisms and Ecosystem. *Chin. Sci. Bull.* 2013, 58, 1307–1314. [CrossRef]

102. Buth, J.M. Ocean Acidification: Investigation and Presentation of the Effects of Elevated Carbon Dioxide Levels on Seawater Chemistry and Calcareous Organisms. *J. Chem. Educ.* 2016, 93, 718–721. [CrossRef]

103. Drupp, P.S.; De Carlo, E.H.; Mackenzie, F.T. Forewater CO₂–Carbonic Acid System Chemistry in Permeable Carbonate Reef Sands. *Mar. Chem.* 2016, 185, 48–64. [CrossRef]

104. Pires, J.C.M.; Martins, F.G.; Alvim-Ferraz, M.C.M.; Simões, M. Recent Developments on Carbon Capture and Storage: An Overview. *Chem. Eng. Res. Des.* 2011, 89, 1464–1460. [CrossRef]

105. Raza, A.; Gholami, R.; Rezaee, R.; Rasouli, V.; Rabiei, M. Significant Aspects of Carbon Capture and Storage–A Review. *Crit. Rev. Plant Sci.* 2011, 30, 58–77. [CrossRef] [PubMed]

106. Brouns, K.; Verhoeven, J.T.; Hefting, M.M. The Effects of Salinization on Aerobic and Anaerobic Decomposition and Mineralization in Peat Meadows: The Roles of Peat Type and Land Use. *J. Environ. Manag.* 2014, 143, 44–53. [CrossRef]

107. Raven, J.A. Praeger Review: Effects on Marine Algae of Changed Seawater Chemistry with Increasing Atmospheric CO₂. *Biol. Environ. Proc. R. Irish Acad.* 2011, 111B, 1–17. [CrossRef]

108. Hu, G.; Li, Y.; Ye, C.; Liu, L.; Chen, X. Engineering Microorganisms for Enhanced CO₂ Sequestration. *Trends Biotechnol.* 2019, 37, 532–547. [CrossRef] [PubMed]

109. Hügler, M.; Sievert, S.M. Beyond the Calvin Cycle: Autotrophic Carbon Fixation in the Ocean. *Annu. Rev. Mar. Sci.* 2011, 3, 261–289. [CrossRef]

110. Gaur, N.; Narasimhulu, K.; PydiSetty, Y. Recent Advances in the Bio-Remediation of Persistent Organic Pollutants and Its Effect on Environment. *J. Clean. Prod.* 2018, 198, 1602–1631. [CrossRef]

111. Leung, D.Y.; Caramanna, G.; Maroto-Valer, M.M. An Overview of Current Status of Carbon Dioxide Capture and Storage Technologies. *Renew. Sustain. Energy Rev.* 2014, 39, 426–443. [CrossRef]

112. Koçar, G.; Civaš, N. An Overview of Biofuels from Energy Crops: Current Status and Future Prospects. *Renew. Sustain. Energy Rev.* 2013, 28, 900–916. [CrossRef]

113. Valentine, J.; Clifton-Brown, J.; Hastings, A.; Robson, P.; Allison, G.; Smith, P. Food vs. Fuel: The Use of Land for Lignocellulosic ‘next Generation’ Energy Crops That Minimize Competition with Primary Food Production. *Geb Bioenergy* 2012, 4, 1–19. [CrossRef]

114. Graves, C.; Ebbesen, S.D.; Mogensen, M.; Lackner, K.S. Sustainable Hydrocarbon Fuels by Recycling CO₂ and H₂O with Renewable or Nuclear Energy. *Renew. Sustain. Energy Rev.* 2011, 15, 1–23. [CrossRef]

115. Raheem, A.; Azlina, W.W.; Danquah, M.K.; Harun, R. Thermochemical Conversion of Microalgal Biomass for Biofuel Production. *Renew. Sustain. Energy Rev.* 2015, 49, 990–999. [CrossRef]

116. Hyseni, S. Carbon Capture and Storage as a Method to Mitigate Climate Change. *Inquiries J.* 2017, 9, 3.

117. Adewale, C.; Higgins, S.; Granatstein, D.; Stöckle, C.O.; Carlson, B.R.; Zaher, U.E.; Carpenter-Boggs, L. Identifying Hotspots in Carbon Footprint of a Small Scale Organic Vegetable Farm. *Int. J. Prod. Econ.* 2012, 138, 43–50. [CrossRef]

118. Sundarakani, B.; De Souza, R.; Goh, M.; Wagner, S.M.; Manikandan, S. Modeling Carbon Footprints across the Supply Chain. *J. Environ. Manag.* 2019, 234, 1–14. [CrossRef]

119. Rebolledo-Leiva, R.; Angulo-Meza, L.; Iriarte, A.; González-Araya, M.C. Joint Carbon Footprint Assessment and Data Envelopment Analysis for the Reduction of Greenhouse Gas Emissions in Agriculture Production. *Sci. Total Environ.* 2017, 593, 36–46. [CrossRef] [PubMed]

120. Paustian, K.; Collier, S.; Baldock, J.; Burgess, R.; Creque, J.; DeLonge, M.; Dungait, J.; Ellert, B.; Frank, S.; Goddard, T. Quantifying Carbon for Agricultural Soil Management: From the Current Status toward a Global Soil Information System. *Carbon Manag.* 2019, 10, 567–587. [CrossRef]

121. Adewale, C.; Reganold, J.P.; Higgins, S.; Evans, R.D.; Carpenter-Boggs, L. Improving Carbon Footprinting of Agricultural Systems: Boundaries, Tiers, and Organic Farming. *Environ. Impact Assess. Rev.* 2018, 71, 41–48. [CrossRef]

122. Padmavathy, K.; Poyyamoli, G. Alternative farming techniques for sustainable food production. In *Genetics, Biofuels and Local Farming Systems*; Springer: Berlin, Germany, 2011; pp. 367–424.

123. Gomiero, T.; Pimentel, D.; Paoletti, M.G. Environmental Impact of Different Agricultural Management Practices: Conventional vs. Organic Agriculture. *Crit. Rev. Plant Sci.* 2011, 30, 95–124. [CrossRef]
124. Pimentel, D.; Burgess, M. An environmental, energetic and economic comparison of organic and conventional farming systems. In *Integrated Pest Management*; Springer: Berlin/Heidelberg, Germany, 2014; pp. 141–166.

125. Clark, M.; Tilman, D. Comparative Analysis of Environmental Impacts of Agricultural Production Systems, Agricultural Input Efficiency, and Food Choice. *Environ. Res. Lett.* 2017, 12, 064016. [CrossRef]

126. Cederberg, C.; Hedens, F.; Wisenius, S.; Sonesson, U. Trends in Greenhouse Gas Emissions from Consumption and Production of Animal Food Products–Implications for Long-Term Climate Targets. *Animal* 2013, 7, 330–340. [CrossRef]

127. Flynn, H.C.; Canals, L.M.I.; Keller, E.; King, H.; Sim, S.; Hastings, A.; Wang, S.; Smith, P. Quantifying Global Greenhouse Gas Emissions from Land-Use Change for Crop Production. *Glob. Change Biol.* 2012, 18, 1622–1635. [CrossRef]

128. Zuazo, V.H.D.; Pleguezuelo, C.R.R.; Flanagan, D.; Tejero, I.G.; Fernández, J.L.M. Sustainable land use and agricultural soil. In *Alternative Farming Systems*, Biotechnology, Drought Stress and Ecological Fertilisation; Springer: Berlin/Heidelberg, Germany, 2011; pp. 107–192.

129. Capalbo, S.M.; Antle, J.M.; Seavert, C. Next Generation Data Systems and Knowledge Products to Support Agricultural Producers and Science-Based Policy Decision Making. *Agric. Syst.* 2017, 155, 191–199. [CrossRef]

130. Van Vuuren, D.P.; Edmonds, J.A.; Kainuma, M.; Riahi, K.; Weyant, J. A Special Issue on the RCPs. *Clim. Change* 2011, 109, 1–4. [CrossRef]

131. Ormond, J. New Regimes of Responsibilization: Practicing Product Carbon Footprinting in the New Carbon Economy. *Econ. Geogr.* 2015, 91, 425–448. [CrossRef]

132. Boot-Handford, M.E.; Abanades, J.C.; Anthony, E.J.; Blunt, M.J.; Brandani, S.; Mac Dowell, N.; Fernández, J.R.; Ferrari, M.-C.; Gross, R.; Hallett, J.P. Carbon Capture and Storage Update. *Energy Environ. Sci.* 2014, 7, 130–189. [CrossRef]

133. Hartmann, F.; Perego, P.; Young, A. Carbon Accounting: Challenges for Research in Management Control and Performance Measurement. *Abacus* 2013, 49, 539–563. [CrossRef]

134. Haslam, C.; Butlin, J.; Andersson, T.; Malamatenios, J.; Lehman, G. Accounting for Carbon and Reframing Disclosure: A Business Model Approach. In *Proceedings of the Accounting Forum*; Taylor & Francis: Abingdon, UK, 2014; Volume 38, pp. 200–211.

135. Higgins, V.; Dibden, J.; Cocklin, C. Private Agri-Food Governance and Greenhouse Gas Abatement: Constructing a Corporate Carbon Economy. *Geoforum* 2015, 66, 75–84. [CrossRef]

136. Derqui, B. Towards Sustainable Development: Evolution of Corporate Sustainability in Multinational Firms. *Corp. Soc. Responsib. Environ. Manag.* 2020, 27, 2712–2723. [CrossRef]

137. McKinnon, A.C. Product-Level Carbon Auditing of Supply Chains: Environmental Imperative or Wasteful Distraction? *Int. J. Phys. Distrib. Logistics Manag.* 2010, 40, 42–60. [CrossRef]

138. Rissman, J.; Bataille, C.; Malamatenios, J.; Lehman, G. Accounting for Carbon and Reframing Disclosure: A Business Model Approach. In *Proceedings of the Accounting Forum*; Taylor & Francis: Abingdon, UK, 2014; Volume 38, pp. 200–211.

139. Rissman, J.; Bataille, C.; Malamatenios, J.; Lehman, G. Accounting for Carbon and Reframing Disclosure: A Business Model Approach. In *Proceedings of the Accounting Forum*; Taylor & Francis: Abingdon, UK, 2014; Volume 38, pp. 200–211.

140. Robinson, O.J.; Tewkesbury, A.; Kemp, S.; Williams, I.D. Towards a Universal Carbon Footprint Standard: A Case Study of Carbon Management at Universities. *J. Clean. Prod.* 2017, 149, 1–10. [CrossRef]

141. Robinson, O.J.; Tewkesbury, A.; Kemp, S.; Williams, I.D. Towards a Universal Carbon Footprint Standard: A Case Study of Carbon Management at Universities. *J. Clean. Prod.* 2017, 149, 1–10. [CrossRef]

142. Dauvergne, P.; Lister, J. Big Brand Sustainability: Governance Prospects and Environmental Limits. *Corp. Soc. Responsib. Environ. Manag.* 2018, 25, 1–19. [CrossRef]

143. Oppenheim, J.; Dyvik, C. Unleashing the power of financial markets for the green transition. In *Standing Up for a Sustainable World*; Edward Elgar Publishing: Cheltenham, UK, 2020.

144. Ormond, J.; Goodman, M.K. A New Regime of Carbon Counting: The Practices and Politics of Accounting for Everyday Carbon through CO2e. *Glob. Environ. Change* 2015, 34, 119–131. [CrossRef]

145. Salas Castelo, E.M. The Role of Factors That Influence the Adoption of the Australian Carbon Farming Initiative-Emissions Reduction Fund: A Mixed Methods Study. Ph.D. Thesis, James Cook University, Douglas, Australia, 2017.

146. Liu, T.; Bruins, R.J.; Heberling, M.T. Factors Influencing Farmers’ Adoption of Best Management Practices: A Review and Synthesis. *Sustainability* 2018, 10, 432. [CrossRef]

147. Valdivia, C.; Barbieri, C.; Gold, M.A. Between Forestry and Farming: Policy and Environmental Implications of the Barriers to Agroforestry Adoption. *Can. J. Agric. Econ. Rev. Can. Agroecon.* 2012, 60, 155–175. [CrossRef]

148. Conant, R.T.; Ogle, S.M.; Paul, E.A.; Paustian, K. Measuring and Monitoring Soil Organic Carbon Stocks in Agricultural Lands for Climate Mitigation. *Front. Ecol. Environ.* 2011, 9, 169–173. [CrossRef]

149. Funk, J.M.; Field, C.B.; Kerr, S.; Daigneault, A. Modeling the Impact of Carbon Farming on Land Use in a New Zealand Landscape. *Environ. Sci. Policy* 2014, 37, 1–10. [CrossRef]

150. Toensmeier, E. *The Carbon Farming Solution: A Global Toolkit of Perennial Crops and Regenerative Agriculture Practices for Climate Change Mitigation and Food Security*; Chelsea Green Publishing: London, UK, 2016.

151. Ingram, J.; Mills, J.; Dibari, C.; Ferrise, R.; Shailey, B.B.; Hansen, J.G.; Iglesias, A.; Karaczyn, Z.; McVittie, A.; Merante, P. Communicating Soil Carbon Science to Farmers: Incorporating Credibility, Salience and Legitimacy. *J. Rural Stud.* 2016, 48, 115–128. [CrossRef]

152. Dhanda, K.K.; Hartman, I.P. The Ethics of Carbon Neutrality: A Critical Examination of Voluntary Carbon Offset Providers. *J. Bus. Ethics* 2011, 100, 119–149. [CrossRef]
153. Macintosh, A.; Waugh, L. An Introduction to the Carbon Farming Initiative: Key Principles and Concepts. *Environ. Plann. Law J.* 2012, 2, 439–461.

154. Evans, M.C.; Carwardine, J.; Fensham, R.J.; Butler, D.W.; Wilson, K.A.; Possingham, H.P.; Martin, T.G. Carbon Farming via Assisted Natural Regeneration as a Cost-Effective Mechanism for Restoring Biodiversity in Agricultural Landscapes. *Environ. Sci. Policy* 2015, 50, 114–129. [CrossRef]

155. Narassimhan, E.; Gallagher, K.S.; Koester, S.; Alejo, J.R. Carbon Pricing in Practice: A Review of Existing Emissions Trading Systems. *Clim. Policy* 2018, 18, 967–991. [CrossRef]

156. Alexander, P.; Paustian, K.; Smith, P.; Moran, D. The Economics of Soil C Sequestration and Agricultural Emissions Abatement. *Soil* 2015, 1, 331–339. [CrossRef]

157. Renwick, A.; Ball, A.S.; Pretty, J.N. Economic, biological and policy constraints on the adoption of carbon farming in temperate regions. In *Capturing Carbon and Conserving Biodiversity*; Routledge: Oxfordshire, UK, 2013; pp. 197–218.

158. Kragt, M.E.; Dumbrell, N.P.; Blackmore, L. Motivations and Barriers for Western Australian Broad-Acre Farmers to Adopt Carbon Farming. *Environ. Sci. Policy* 2017, 73, 115–123. [CrossRef]

159. Lo, A.Y. Challenges to the Development of Carbon Markets in China. *Clim. Policy* 2016, 16, 109–124. [CrossRef]

160. Tesfahunegn, G.B. Farmers’ Perception on Land Degradation in Northern Ethiopia: Implication for Developing Sustainable Land Management. *Soc. Sci. J.* 2019, 56, 268–287. [CrossRef]

161. Wang, X.; VandenBygaart, A.J.; McConkey, B.C. Land Management History of Canadian Grasslands and the Impact on Soil Carbon Storage. *Rangeland Ecol. Manag.* 2014, 67, 333–343. [CrossRef]

162. Evans, M.C. Effective Incentives for Reforestation: Lessons from Australia’s Carbon Farming Policies. *Curr. Opin. Environ. Sustain.* 2018, 32, 38–45. [CrossRef]

163. Lin, B.B.; Macfadyen, S.; Renwick, A.R.; Cunningham, S.A.; Schellhorn, N.A. Maximizing the Environmental Benefits of Carbon Farming through Ecosystem Service Delivery. *BioScience* 2013, 63, 793–803. [CrossRef]

164. Baumber, A.; Metternicht, G.; Cross, R.; Ruoso, L.-E.; Cowie, A.L.; Waters, C. Promoting Co-Benefits of Carbon Farming in Oceania: Applying and Adapting Approaches and Metrics from Existing Market-Based Schemes. *Ecosyst. Serv.* 2019, 39, 100982. [CrossRef]