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Soil Carbon Sequestration through Agronomic Management Practices

Sikander Khan Tanveer, Xingli Lu, Shamim-Ul-Sibtain Shah, Imtiaz Hussain and Muhammad Sohail

Abstract

Improper soil and crop management practices have resulted in loss of soil carbon. Worldwide, about 1417 Pg of soil carbon is stored in first meter soil depth, while 456-Pg soil carbon is stored in above–below ground vegetation and dead organic matter. Healthy soils can be helpful in combating the climate change because soils having high organic matter can have higher CO₂ sequestration potential. Main agronomic practices responsible for soil carbon loss include improper tillage operations, crop rotations, residue management, fertilization, and similarly no or less use of organic fertilizers that have resulted in the loss of soil organic matter in the form of CO₂. The share of agriculture sector in the entire emissions of global GHGs in the form of CO₂, N₂O, and CH₄ is about 25–30%. Studies have shown that by adapting proper tillage operations, the use of such kind of crop rotations that can improve soil organic matter and similarly the application of organic fertilizers, i.e., FYM, compost, and other organic amendments such as humic acid, vermicompost, etc., can be useful in soil carbon sequestration.

Keywords: soil carbon, agronomic practices, tillage, crop rotation, crop residues, organic fertilizers

1. Introduction

Soil carbon (C) sequestration implies the removal of atmospheric CO₂, by plants and storage of the fixed C through incorporation into soil organic matter [1]. Carbon exists in a variety of forms, mainly as plant biomass, soil organic matter, and gas carbon dioxide (CO₂) in atmosphere and dissolved in sea water. Soil organic carbon (SOC), which is a main component of SOM, can be separated into stable and labile fraction [2], and soil organic matter and its contribution play a very vital role during its humification formation of stable humus fraction and in the management of fertilization [3]. Worldwide, about 1417 Pg of soil carbon is stored in first meter soil depth, while 456-Pg soil carbon is stored in above–below ground vegetation and dead organic matter. The Earth's soils include approximately 1500 Pg of C, which is about 2–3 times larger than the amount of C stored in Earth's vegetation [4, 5]. The atmospheric carbon pool contains ~800 Pg of CO₂-C and is escalating at the rate of 4.2 Pg C per year, 0.54 percent per year. Over the past 150 years, the amount of carbon in the atmosphere has enlarged by 30%. An increase in the atmospheric concentration of CO₂ from 280 ppm from the pre-industrial era to 390 ppm in 2010 (an enrichment of 39%) and other greenhouse gases (GHGs) has changed the

Earth's mean temperature and precipitation [6]. There is much interaction among the terrestrial and atmospheric C pools through the processes of photosynthesis and respiration. Due to land use, conversion factors, and deforestation, biotic pool also contributes in the rise of atmospheric CO₂ concentration at the rate of ~1.6 Pg C per year. Different anthropogenic sources include the combustion of fossil fuel, deforestation, land use conversion, soil tillage, animal husbandry, cement manufacturing, etc. According to an estimate, 8.3 Pg C year⁻¹ is emitted by combustion of fossil fuel [6, 7], and 1.6 Pg C per year is emitted by deforestation, land-use change, and soil cultivation. It is anticipated that terrestrial ecosystems have contributed as much as half of increases in CO₂ emissions from human activity in the past two centuries [4, 8], and about 50 Pg CO₂ additions to the atmosphere has been contributed by cultivated soils [9], through the process of mineralization of soil organic carbon (SOC). Terrestrial C pool is estimated approximately 3120 Pg, which is the combination of both pedologic and biotic C pools.

Historically, agricultural soils have lost more than 50 Gt (1 Gt = 1 billion tons) of carbon and agriculture is responsible for soil carbon reductions up to 60–75% [9]. Total anthropogenic emission of CO₂ is 9.9 Pg C per year, of which 4.2 Pg C per year is absorbed by atmosphere and 2.3 Pg C per year by the ocean while remaining may be absorbed by unidentified terrestrial sinks.

In 1-m soil depth, estimated carbon pool is 2500 Pg, in two diverse forms including soil organic C (SOC) pool which is likely about 1550 Pg and soil inorganic C (SIC) pool at 950 Pg [10]. Soil inorganic C pool mostly consists of elemental C and carbonate minerals, i.e., calcite, dolomite, and likewise primary and secondary carbonates, whereas soil organic C (SOC) pool contains highly active humus and relatively inert charcoal C. According to United Nations Framework Convention on Climate Change (UNFCCC), carbon sequestration is the process of removing C from atmosphere and depositing it in a reservoir. It entails the transfer of atmospheric CO₂ and its secure storage in long-lived pools [11].

The estimation of global carbon sequestration potential of agricultural soils is typically made for sequestration on annual basis, and its range is from 0.4 to 1.2 gigatons per year [1]. Land use, land use change, and forestry (LULUCF) activities can be a relatively cost-effective ways to offset emissions through increasing removals of greenhouse gases from the atmosphere (e.g., by planting trees or managing forests) or through dropping emissions (e.g., by deforestation) [12]. Likewise, emissions of CO₂ from soil can be reduced by the adoption of such practices that can increase C input in soils and similarly can lessen the decomposition potential of soil organic matter. These kinds of practices have a vital role in storage and in release of C within terrestrial C cycle [13]. Nowadays, intensive agriculture usually results in a considerable soil degradation and soil carbon depletion [14], because in present agriculture and human's food chain, intensive soil utilization is very essential but it is very imperative so it should be followed and coupled with appropriate conservation practices [15]. Agriculture sector is responsible for the emissions of about 30% global greenhouse gases emissions, and primarily, inappropriate soil and crop management practices have resulted in the loss of soil carbon. In agricultural soils, C sequestration means the increase of soil C storage.

Main agronomic and related practices that can be helpful in SOC sequestration include:

- adoption of no-tillage (NT) or minimum tillage;
- adoption of environmental and soil health friendly farming systems;
- incorporation of cover crops;

- use of mulch either in the form of crop residues or synthetic materials;
- minimization of soil and water losses by surface runoff and erosion;
- adoption of integrated nutrient management practices for the increase of soil fertility;
- use of organic amendments; and
- promotion of farm forestry.

Benefits of soil carbon sequestration include the following:

- It can be helpful in the reduction of CO₂ emissions.
- It can reduce the emissions of different GHGs.
- It can be helpful in the reduction of atmospheric temperatures.
- It helps in maintaining suitable biotic habitat.
- It decreases nutrients losses.
- It can improve soil health and productivity.
- It can increase water conservation.
- It can promote and sustain root growth.
- It can reduce soil erosion.

Agriculture sector can be supportive in the lessening of emissions of GHGs, and if suitable agronomic practices are to be adopted, then agricultural soils have the potential to act as a sink for CO₂ sequestration. Healthy soils can be supportive in combating the climate change because soils having high organic matter can have higher CO₂ sequestration potential.

2. Agronomic practices

Different agronomic and related practices that can be supportive in CO₂ sequestration are given below.

2.1 Tillage

The main aim of tillage is the physical disturbance of upper soil layers for the preparation of soil bed, incorporation of fertilizers, crop residues, and similarly to control weeds. Tillage methods in world vary depending upon the soil, climate, crop management, and availability of technology. The relationship between tillage, soil structure, and soil organic matter dynamics is essential to C sequestration ability of agricultural soils. Tillage effects on soil carbon dynamics are complex and often variable [16]. Global reductions in natural SOC due to cultivation by humans are obvious, and it is estimated to cause a loss of 60 (temperate regions) to 75%

(temporal regions) of the original SOC [17]. Conventional tillage practices led to decline in soil carbon from 30 to 50% globally [18] to low as 20% [19]. Plowing is the basic cause of SOC oxidation and emissions of CO₂ to the atmosphere [20], and when NT, CP, and MP are under a nonsteady state, all these types of tillage systems may fail in the sequestration of significant amount of soil organic carbon [21]. The large losses of C typically follow initial cultivation [22, 23]. Moldboard plow, followed by secondary tillage operations, is commonly used in world, which is basically intensive tillage practice, but over the several years, intensive tillage has replaced by less intensive tillage in which soil is minimum disturbed. No tillage often increases the stability and numbers of soil aggregates, but conventional tillage is detrimental to soil structure, which increases the decomposition of soil organic matter. Conservation tillage systems keep more crop residues on the soil surface and have a higher SOC concentration in surface layer than conventional tillage [24, 25].

Tillage and cropping systems can influence microbial activity, which ultimately affects SOC dynamics and stability [26, 27], and soil mineralization can be decreased by reducing or eliminating soil tillage and increasing cropping intensity and plant production efficiency. In case of no-tillage as litter accumulates at the soil surface, which reduces evaporation from the soil because surface residues [28] and similarly standing stubbles [29] decrease wind speed at the soil surface, which ultimately results in less turbulent exchange of water and heat. Reduction in soil temperature through the use of surface mulches and no-till practices is important for maintaining stocks of soil organic matter especially in tropical soils [30].

SOC is a prime determinant of biological activity and soil macro fauna, which controls most of the different soil functions, i.e., organic matter dynamics, nutrient release, soil structure, and its different associated physical properties [31, 32]. In no-tilled soils, there are generally higher densities of biota and especially microorganisms. A large number of studies have shown that no-tillage can increase soil carbon rapidly, particularly at the soil surface [33], and this increase is linked to increases in aggregation [34, 35]. Compared to the PT and RT systems, strong SOC gradients have been observed under NT systems in the surface to subsurface layers in paddy soil. Moreover, it has been observed that the impacts of tillage on SOC concentration are dependent on crop species and soil depth in paddy soil [36]. However, according to Grandy and Robertson [37], tilling a previously untilled soil quickly losses the previously reserved carbon gains by exposing carbon molecules to microbial attack due to the disruption of aggregates. This accelerated turnover also reduces the formation and stabilization of more recalcitrant organic matter fractions within micro aggregates that have a longer residence time in soil [38]. The results of a study, which was conducted to find out the influence of conservation tillage, land configuration, and residue management practices on soil health in a Pigeon pea+ Soybean intercropping system. The study consisted of six tillage systems, i.e., CT₁: conservation tillage with BBF and crop residue retained on the surface, CT₂: conservation tillage with BBF and the incorporation of crop residue, CT₃: conservation tillage with flatbed with crop residue retained on the surface, CT₄: conservation tillage with the incorporation of crop residue, CT₅: conventional tillage with the incorporation of crop residue, and CT₆: conventional tillage without crop residue. The conservation treatments significantly improved soil health. The pooled data of the study showed that all the conservation tillage systems, i.e., CT₁, CT₂, CT₃, and CT₄, had significantly higher soil organic carbon at 0–15 cm depth (0.62, 0.64, 0.60, and 0.62%, respectively) and at 15–30 cm depth (0.56, 0.56, 0.54, and 0.55%, respectively) in higher soil carbon sequestrations (15.07, 15.39, 14.58, and 14.72 t ha⁻¹, respectively), over conventional systems. The study also revealed that however biological soil quality, such as soil microbial biomass carbon

and nitrogen, was significantly higher in all the tillage systems except conventional tillage without crop residue [39]. It is estimated that the adoption of conservation tillage globally can sequester 25 Gt C over the next 50 years, which can be helpful in the stabilization of atmospheric carbon [40].

All this indicates that the adoption of conservation tillage practices can be helpful in the reductions of emissions of CO₂ into the atmosphere and similarly can be supportive in the sequestration of carbon in the soil.

2.2 Nutrient management

Chemical fertilizers are a source of emission of GHGs, especially N₂O. In addition to it, fertilizer production and its transportation are also associated with the emissions of GHGs. Judicious use of fertilizers increases crop yields and profitability, and about 50 Pg CO₂ additions to the atmosphere has been contributed by the cultivated soils [9], through the process of mineralization of soil organic carbon (SOC). The use of fertilizers has dramatically increased agricultural productivity, but studies reveal that the chronic use of nitrogen fertilization decreases soil microbial activity [41–44]. Continuous use of balanced fertilizers is necessary for sustainable soil fertility and productivity of crops [45]. Crop residues and nutrients, especially N, help in carbon sequestration up to 21.3–32.5% [46]. However, ultimate effects of continuous nitrogen fertilization on soils are complicated and remain unclear. For example, in the long-term experiments in Canada, SOC sequestration were 50–75 g cm⁻² per year in well-fertilized soils with optimum cropping systems [47]. Research in the Great Plains shows that SOC sequestration is improved by the application of N fertilization [48–52], but opposite to it, long-term experiments in the Northern Great Plains (ND) have also shown that N fertilizer increased crop residue returns but generally did not increase SOC sequestration [53]. Liu Enke et al. [54] reported the results of a long-term study which was initiated in Northwest China in 1979, to find out the effects of fertilization on SOC and SOC fractions for the whole soil profile such as (0–100 cm) soil depth. The experiment included six treatments, i.e., unfertilized (control), N fertilizer (N), nitrogen and phosphorous fertilizer (NP), straw plus N and P fertilizers (NP + S), Farmyard manure (FYM), and Farmyard manure (FYM) plus N and P fertilizers (NP+ FYM). Results showed that SOC storage in 0–60 cm in NP + FYM, NP + S, FYM, and NP treatments increased by 41.5, 32.9, 28.1, and 17.9%, respectively, as compared to control treatment. Application of organic manure plus inorganic fertilizer also enlarged labile pool in 0–60 cm soil depth. These results show that long-term applications of organic manure have the most beneficial effects in building carbon pools among the investigated types of fertilization.

The results of Morrow plots, which is the world's oldest experimental site under continuous corn (*Zea mays* L.), revealed that after 40–50 years of synthetic fertilization that exceeded grain N removal by 60–190%, a net decline occurred in soil C despite increasingly massive residue C incorporation, the decline being more extensive for a corn-soybean (*Glycine max* L.) or corn-oats (*Avena sativa* L.) rotations than for the continuous corn rotation and of greater intensity for the profile (0–46 cm) than the surface soil [55]. Nayak et al. (2012) [56] reported that the application of combined inorganic fertilizers with or without manure can sequester carbon in the 0–60 cm soil layer at the Indean Sub-Himalayas. Majumder et al. [57] reported the results of a study that was conducted in hot humid subtropical Eastern India. According to them after 19 years in a puddle rice-wheat (*Triticum aestivum* L.) system, NPK + FYM treated plots had 14% larger labile C pools compared with the control plots in the 0–60 cm soil depth.

It can be concluded that the appropriate use of fertilizers according to the soil condition can be helpful in the maximum sequestration of carbon along with maximum crops production and in the reductions of emissions of different GHGs.

2.3 Animal manure and compost application

Animal manure is animal's excreta which is collected from livestock farms and barnyards and is used to enrich the soil, while compost is the material which largely consists of decayed organic matter and is used for fertilizing and conditioning of agricultural soil. Application of manures is important for the maintenance of soil health [58, 59] and is the source of C, and its application to different crops fields has effects on C contents [60]. As compared with the application of only NPK, application of FYM along with NPK increased C sequestration in the rice-wheat cropping system [61], while green manuring, as compared with the application of FYM along with green manure, sequestered more C in a Maize-Wheat cropping system [62]. Composting not only increases the net primary production but also enhances the C contents of the soil [63]. It has been reported that decreasing of manures and organic fertilizers application influences not only stable organic compounds but also soil microorganisms and nutrient regimes [64, 65]. Liu et al. [53] supported the positive effect of incorporation of mineral fertilizers with organic manures. Similarly, application of different organic wastes, i.e., municipal solid waste (MSW), farm yard manure (FYM), sugar industry waste (filter cake), and maize cropping residues, at 3 t C ha⁻¹ alone and with a full or half dose of NPK mineral fertilizer showed that the addition of organic wastes (filter cake or MSW) has the best potential for improving SOC retention, WUE, and wheat yield in an irrigated maize-wheat cropping system [66].

This all indicates that the use of animal manure, compost, etc. along with other inorganic fertilizers is beneficial for both soil health and environment.

2.4 Crop rotations

Crop rotations mean the sequence of crops grown in regularly recurring successions on the same area of land. The succeeding crops may be for 2 or more years. Differences in crop rotations, climates, soils, and different crop-related management practices also affect carbon sequestration. Intensive cropping systems result in the depletion of SOM, but the use of balanced fertilization with NPK, application of organic amendments, and similarly application of crop residues can increase carbon sequestration levels to 5–10 Mg ha⁻¹ per year because these amendments contain 10.7–18% C, which can also be helpful in the sequestration of carbon [67]. Different legume crops, such as peas, lentils, alfalfa, chickpea, sesbania, etc., can serve as substitute sources for nitrogen. Applications of crop rotations especially by using legume cover crops, which contain carbon compounds that are likely more resistant to microbial metabolism, can make soil carbon more stable [68]. Syswerda et al. [69] reported the results of a long-term study (over a 12-year period) of an organic management system that involved various crop rotations. According to them despite of extensive tillage for weed control, increase in soil carbon sequestration was recorded. The results of a long-term study, which was conducted in Dingxi, Northwest China, during 2013–2015, were shown in-spring wheat-field pea rotation in a rain-fed semi-arid environment. The treatments were: conventional tillage with stubble removed (T); no tillage with stubble removed (NT); no-till with stubble retained (NTS), and conventional tillage with stubble incorporation (TS). The SOC, microbial biomass carbon, and root biomass in NTS increased over T and NT, and similarly, average grain yield across the 3 years in NTS was better than T and

NT [70]. Recently, much attention has been given to alternate tillage and cropping systems as a means to mitigate the agricultural emissions of CO₂ [27, 71]. Different types of cropping systems, i.e., cover cropping, ratoon cropping, and companion cropping, can be helpful in carbon sequestration. Intercropping which includes row inter cropping, strip inter cropping, mixed cropping, and relay intercropping can increase the income and can also raise soil fertility [72]. Some of the examples of inter cropping are wheat and mustard, cotton and peanut, peanut and sunflower, wheat and chickpea, etc. [73]. Organic farming can also improve soil organic carbon as compared with the conventional farming [68, 74]. Research regarding the restoration of grassland also shows that through their biotic and biotic effects, legume species have more positive effects on the restoration of grasslands as compared with the application of mineral fertilizers [75].

This above shows that keeping in view the economic considerations, selection of appropriate crop rotations according to the soil and environmental conditions can be helpful in the sequestration of carbon, which not only improve soil fertility but also reduce the emissions of CO₂ into the atmosphere and increase farmer's income.

2.5 Residues management

Crop residues are detached vegetative parts of crop plants that are intentionally left to decay in agricultural fields after crop harvesting. Worldwide, the annual production of crop residues is about 3.4×10^9 tones, and if 15% of these total residues are applied to the soil, it can increase the C contents of the soil, because, for example, one ton of cereal residue contains 12–20 kg N, 1–4 kg P, 7–30 kg K, 4–8 kg Ca, and 2–4 kg Mg. Mulching is detached vegetation, which includes wheat straw, compost, or may be plastic sheets, which are spread around plants to protect them from excessive evaporation and cold stress and similarly to promote SOM contents in soil.

Crop residues play an important role in the SOC management and improvement of soil quality [76]. Mulching improves soil moisture, reduces soil erosion, and similarly reduces the loss of carbon from the soil and crop residues, which are incorporated into the soil to enhance the soil organic matter. A direct seedling mulch-based cropping system increases soil organic matter, as a result of increased carbon inputs and decreased soil disturbance [27]. Mulch can increase soil organic matter (SOM) and carbon sequestration in the top 0–5 cm soil depth. It improves soil's physical and chemical properties and can increase carbon sequestration in agricultural soils up to 8–16 Mg ha⁻¹ per year. Mulch-based cropping systems enhance the buildup of soil organic matter, principally as a result of increased carbon inputs and decreased soil disturbance [27]. Direct seedling straw mulch has the potential to ameliorate the heat stress, and it improves the infiltration rate, reduces evaporation [77, 78], and similarly increases soil organic carbon and N efficiency [79]. Increasing residues inputs to soils entails increasing net primary productivity (NPP). Many agricultural soils, which have been significantly reduced from their original C levels through cultivation, will show C gains in proportion to increases in C inputs. Soil C levels are governed by the balance between the inputs of C through plant residues and the losses of C basically through decomposition. Therefore, C can be increased in soil by increasing residues inputs and or reducing decomposition rates (i.e., heterotrophic soil respiration). Litter quality also affects rates of its decomposition [80]. The results of a 4-month study, which was conducted in a greenhouse controlled condition and in three rates of straw residue and farm yard manure, were added to uncultivated and cropland soils. Two treatments of straw residue and farm yard manure incorporation were used into: a soil surface layer and a 0–20 cm soil depth revealed that the application of organic matter,

especially the incorporation of farm yard manure, led to significant increase in the final soil organic carbon content, and higher amount of soil organic carbon were stored in the cropland soil than in the uncultivated soil. The results showed that carbon sequestration ranged farm yard manure > straw residue and cropland soil > uncultivated soil. The results revealed paying more attention to the role of organic residue management in carbon sequestration [81].

This all shows that the application of mulch and the use of crop residues can improve soil microbial activity, ameliorate the heat stress, and help in water storage and improvement of soil organic carbon.

2.6 Cover crops

Cover crop is grown for the benefit of soil rather than the crop yield. Cover crops improve soil quality by increasing soil organic carbon through biomass, by improving soil aggregates and stability, and by protecting the soil from surface runoff. Similarly, green manuring increases the biomass returned to the soil, which results in the form of enlarged soil carbon sink. Studies reveal that the adoption of cover crops is an efficient measure to mitigate climate change [82]. According to Olson 2010 [83], the use of cover crops in intensive row crop rotations with different tillage treatments has been found to sequester soil organic carbon (SOC). Kenneth et al. [84] reported the results of a study which included different kinds of tillages, i.e., no-till (NT), Chisel plow (CP), and moldboard plow (MP) with and without cover crops. The average annual corn and soybean yields were statistically same with or without cover crops. The average annual corn and soybean yields were statistically same for NT, CP, and MP systems with or without cover crops for the same soil depth layer and for tillage treatments. However, all tillage treatments, i.e., NT, CP, and MP, sequestered SOC with cover crops.

Keeping in view the cropping systems, suitable selection and planting of cover crops can be helpful in improving the soil organic carbon.

2.7 Use of improved crop varieties

Selection of improved varieties of different crops, which can improve both above and below ground biomass, can also improve the soil organic carbon. Machado et al. [85] reported that crop species that have massive rooting systems have the potential to improve SOC in soils under NT. Similarly, according to Kell [86, 87] by improving root growth in agricultural crops, soil carbon storage can match anthropogenic emissions for the next 40 years. This all indicates that the use of improved crop varieties having extensive root systems and better yields can increase both yields and soil fertility.

2.8 Soil biota management

Soil microbial activities can be helpful in the biological carbon sequestration because microbes improve the soil physical, chemical, and biological properties. The soil biota consists of a large number and a range of micro- and macro-organisms and is the living part of soils. They interact with each other and with plants, directly providing nutrition and other benefits. Their physical structure and products help a large to soil structure. They are also responsible for organic matter decomposition and for the transformations of organically bound nitrogen and minerals that are available to plants. Through biological control mechanisms, these organisms regulate their own populations and as well as those of incoming microorganisms. Micro- and macro-organisms are very crucial in maintaining

ecosystem function, and their populations are significantly affected by the different crop management practices. Microorganisms include bacteria, fungi, fungi, protozoa, and some nematodes. These also include a range of invertebrates such as micro- and macro-arthropods, termites, and earthworms. According to an estimate, micro-organisms constitute about one quarter of the total biomass on the Earth [88]. These organisms are affected by the management of soils in the agricultural and forest ecosystems. Soils also differ in their ability to support the survival and growth of different groups of micro- and macro-organisms. Research findings show that carbon sequestration was higher up to 49.9 g C kg^{-1} in soils which were rich in soil microbes such as soil bacteria and fungi [89]. Therefore, the use of different kinds of microbes, which are beneficial both for soil and environment, will increase soil carbon sequestration and improve the crops yields.

2.9 Bio char

Bio char is carbonized biomass, which is obtained from sustainable sources and sequestered in soils. It can also be obtained by pyrolysis synthetically. Application of Bio char can also improve the soil health through carbon sequestration, because it improves the crop yield and maintains the cation exchange capacity, water holding, and nutrient retention capacity of the soil. It remains stable for thousands of years and thus reduces the release of terrestrial C to the atmosphere in the form of CO_2 [90]. It has been reported that Bio char can improve carbon sequestration in soil due to prolonged residence time [91]. Another study also reveals that the application of Bio char reduces the co-localization of polysaccharides-carbon and aromatic carbon by reducing the carbon metabolism due to carbon stabilization in Bio char-activated soil [92]. It has also been reported that soil management by using different kinds of organic amendments and their incorporation by earthworms can also support micro-aggregates formation, C, and N retention in agricultural soils [93].

2.10 Agroforestry

Agroforestry is the combination of agriculture and forestry in which perennial trees and shrubs are grown in combination with agricultural crops. Planting of different kinds of trees, including orchards, fruit plants, and woodlands into the croplands, can improve soil carbon sequestration. Agroforestry has an enormous potential for carbon sequestration in croplands [94] because agroforestry practices accumulate more C than forests and pastures because they have both forest and grassland sequestration and storage patterns active [95–97]. Young [98] have also reported the estimated potential of C gains from agroforestry. Agricultural soils can sequester more quantities of carbon by the adoption of agroforestry. The carbon sequestrations potential of agroforestry systems is estimated between 12 and 228 Mg ha^{-1} , so on the Earth's total suitable area for crop production, a total of about 1.1–2.2 Pg C can be sequestered in the agricultural soils in the next 50 years [99]. The results of a meta-analysis from 53 published studies, regarding changes in soil organic carbon (SOC) stocks at 0–15, 0–30, 0–60, 0–100, and $0 \geq 100 \text{ cm}$, after land conversion to agroforestry, revealed a significant decline in the SOC stocks of 26 and 24% in land-use changes from forest to agroforestry at 0–15 and 0–30 cm, respectively. The transition from agriculture to agroforestry significantly enhanced the SOC stock of 26, 40, and 34% at 0–15, 0–30, and 0–100 cm, respectively. The results also showed that conversion from pasture/grassland to agroforestry produced significant SOC stock increases at 0–30 cm (9%) and 0–30 cm (10%). Switching from uncultivated/other land-uses to agroforestry increased SOC by 25% at 0–30 cm, while a decrease was observed at 0–60 cm (23%) [100].

The carbon sequestration potential by agroforestry is estimated up to 9, 21, 50, and 63 Mg Cha⁻¹ in semiarid, subhumid, humid, and temperate regions, respectively; however, it has been reported that intensively managed agroforestry practice in combination with annual crops is like conventional agriculture, which does not contribute in carbon sequestration [101].

Agroforestry also helps in the optimization of water use, and similarly, it improves the farmer's income. So, the promotion of agroforestry keeping in view the soil condition, climate, and along with crops production is beneficial for soil, environment, as well as the farmers.

3. Conclusion

CO₂ is increasing at the rate of 2.3 ppm per year, which is resulting in the increase of global warming and environmental pollution. Agriculture sector is responsible for up to 30% emission of GHGs. Sustainable agriculture is essential for the survival of humankind. Adoption of different agronomic management practices can be helpful in the sequestration of carbon. Such practices include no-tillage or reduced tillage, nutrient management, cover crops, crop rotations, green manuring, application of animal manures, agroforestry, etc. Adoption of these different agronomic practices will not only improve the crops yields but will also improve farmer's income.

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