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Influence of Recommended Agricultural Management Practices on Enhancing Soil Carbon Sequestration

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ABSTRACT

Climate change in India threatens food security due to the tropical monsoon climate and the poor cropping capacity of small and marginal farmers. The Intergovernmental Panel on Climate Change (IPCC) has projected a global mean surface temperature rise of 1.1–6.4 °C by 2100. Soil carbon sequestration refers to the ability of agricultural lands and forests to reduce the amount of carbon dioxide in the atmosphere. Healthy soils can help combat climate change because soils with high organic matter have a greater CO_2 sequestration potential. Improper soil and crop management practices have led to a continuous loss of soil carbon. Agricultural practices primarily responsible for soil carbon loss include improper tillage operations, inadequate crop rotation, poor residue management, excessive fertilization, and low use of organic fertilizers, all resulting in an ongoing loss of soil organic matter in the form of CO_2. In the last two decades, there has been a growing interest in the adoption of recommended agricultural practices aimed at improving the sustainability of agricultural lands among smallholder farmers in developing countries. This paper aims to understand the factors that influence the adoption of technologies that enhance soil carbon sequestration. The adoption of recommended agricultural management practices (RAMP) enhances carbon sequestration while reducing the rate of atmospheric CO_2 enrichment. Such an increase can result from practices that include improved conservation agriculture, which focuses on crop residue management, manure and compost application, and employs several techniques like no-tillage, lay farming, precision agriculture, and other carbon-rich resources that sustain soil health and increase SOC sequestration. The challenges for this study include high costs, substantial infrastructure investments, and public concerns about the safety of CO_2 storage. To mitigate these challenges, there is a need to further improve the RAMP, which is happening continuously.

Keywords: *Atmospheric CO2, Carbon Sequestration, Crop Residue Management, Recommended Agricultural Management Practices, Soil health, Soil organic carbon.*

1. Introduction

In the process of photosynthesis, plants absorb CO_2, store it in biomass both above and below ground, and contribute litter to the soil for the accumulation of soil organic carbon. The process by which plants absorb and store CO_2 in the long-term storage of plant biomass and soil organic carbon is called carbon sequestration [31]. Among the various forms of carbon are plant biomass, soil organic matter, and air and seawater-dissolved CO_2. Mainly comprising SOM, soil organic carbon (SOC) can be divided into stable and labile fractions [55]. The contribution of soil organic matter is crucial for the humification process, the creation of stable humus fractions, and fertilization management. Intensive agriculture usually results in considerable soil degradation and carbon depletion, because intensive soil utilization is essential in the present agriculture and human food chain. Still, it is very imperative, so it should be followed and coupled with appropriate conservation practices.

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Approximately 30% of greenhouse gas emissions worldwide are attributed to the agricultural sector. The primary cause of this loss of soil carbon is improper crop and soil management practices. The atmosphere's carbon content has increased by 30% in the last 150 years [55]. The biotic pool also plays a role in the increase in atmospheric CO_2 concentration, contributing approximately 1.6 Pg C per year due to land use, conversion factors, and deforestation [56]. Historically, agriculture has contributed to soil carbon decreases of up to 60–75% and soil carbon losses of more than 50 Gt (1 Gt = 1 billion tonnes) [33]. There is a 9.9 Pg C annual total of anthropogenic CO_2 emissions; of this, 4.2 Pg C is absorbed by the atmosphere and 2.3 Pg C by the ocean, with the remaining Pg C potentially being absorbed by unnamed terrestrial sinks. Approximately 456 Pg of soil carbon is stored in above-ground vegetation and dead organic matter, while 1417 Pg is stored globally in the first-meter soil depth. 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 [56]. The total estimated mass of the terrestrial C pool, which includes the biotic and pedologic C pools, is 3120 Pg [56]. The estimated carbon pool at a 1-meter soil depth is 2500 Pg, which is divided into two distinct forms: the soil inorganic C (SIC) pool, which is 950 Pg, and the soil organic C (SOC) pool, which is probably around 1550 Pg [4].

While the soil's organic C (SOC) pool is made up primarily of relatively inert charcoal C and highly active humus, the soil's inorganic C pool is primarily composed of elemental C and carbonate minerals, such as calcite, dolomite, and primary and secondary carbonates. An annual assessment of agricultural soils' worldwide carbon sequestration potential is usually conducted, with a range of 0.4 to 1.2 gigatons annually [30]. Enhancing Soil Carbon. The RAMP procedures employed in this study are equivalent to soil fertility management approaches that enhance soil quality by reducing carbon losses and sequestering carbon. The following actions cause the soil to release carbon dioxide into the atmosphere: deforestation, burning, plowing, and continuous cropping. The amount and quality of soil organic carbon (SOC) in agroecosystems influences the physical, chemical, and biological characteristics of the soil; hence, an increase in SOC increases soil productivity and sustainability. Loss of SOC pool can lead to soil degradation by nutrient and water imbalances, accelerated erosion, compaction, leaching, and acidification, and a decline in soil biodiversity. It is thus imperative that the land use systems and recommended agricultural management practices adopted enhance and/or sustain the SOC pool. RAMP practices that increase soil carbon include activities such as (i) tillage and residue management, (ii) soil fertility management, both inorganic fertilizers and organic waste products, (iii) crop rotation and cover crop (iv) ley farming (v) Agroforestry and Precession farming. The purpose of this paper is to collate, review, and synthesize available information on SOC sequestration by the adoption of RAMP; describe ecological processes and identify management practices that enhance SOC sequestration; and identify research and development priorities for increasing the potential of RAMP for SOC sequestration.

2. Carbon Sequestration and Its Importance:

Carbon sequestration is the process by which atmospheric CO_2 is captured and stored in the ocean, geologic basalt, vegetation, and soil for a specific period [31]. The act of capturing CO_2 from the atmosphere into the soil through crop leftovers and other organic solids such that it can remain there for a longer amount of time and in a form that is not readily released again is known as soil C sequestration. By raising the amount of soil organic matter, carbon sequestration in soil contributes significantly to both increased productivity and improved soil quality (SOM). The process of sequestering carbon involves moving atmospheric CO_2 into long-lived C pools and keeping it safe to prevent its instant re-emission. Consequently, soil C sequestration refers to the process of boosting soil organic C (SOC) and soil inorganic C stocks via sensible land use and suggested management techniques such as crop rotation, stubble retention, and nutrient management [30,31]. Different strategies can achieve carbon sequestration in soils, oceans, and deep geological strata. As used in agriculture, C sequestration involves plants absorbing atmospheric CO_2 and storing it in the soil as organic matter. Carbon sequestration can occur mainly through biotic, abiotic, and mechanical processes (Fig. 1). The two main processes affect soil C sequestration: (i) biomass input to the soil, and (ii) decomposition of SOM [48]. C sequestration occurs through the biotic processes of plants removing atmospheric CO_2 through photosynthesis and creating biomass and storing it in the terrestrial carbon pool. SOC can be improved by increasing biomass production and input into soils; this is mostly dependent on cultural practices and soil management techniques.

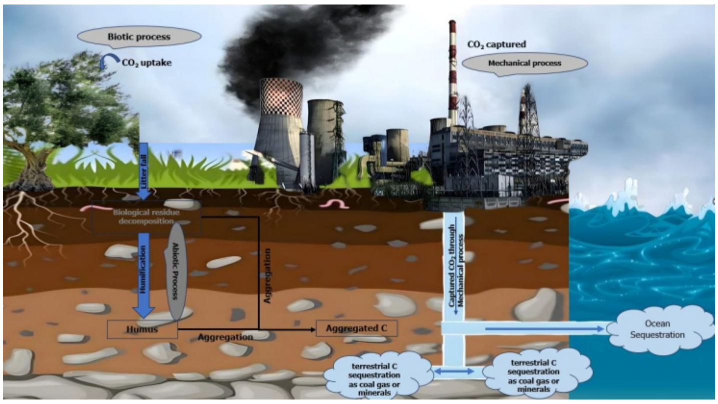

Fig. 1: Schematic representation of the processes involved in carbon sequestration

The "sequestering" of carbon has a major impact on absorbing atmospheric CO_2, which is mostly released through the burning of fossil fuels and other sources of carbon emissions. It also improves soil quality and productivity. There are two different approaches to sequestering C. Two types: (1) biotic and (2) abiotic (including ocean injection, geological sequestration, etc.). The photosynthetic mechanism fixes atmospheric CO_2 into terrestrial or aquatic ecosystems in an environmentally beneficial and economical biotic strategy. First of all, this C is kept in the roots, leaves, branches, and trunks of plants. Then, the activities of various soil organisms, which are the functional groups of the soil ecosystem, incorporate these materials into the soil. Microbial populations control the incorporation of biomass C into the soil by using C exudates from roots, trash, and other sources. In addition to its role in reducing greenhouse gas emissions, carbon sequestration enhances the physical characteristics and productivity of soil, contributing to the attainment of sustainability. In addition to being a potential sink for atmospheric CO_2, soil can also function as a source (Fig. 2) when appropriate management techniques are used.

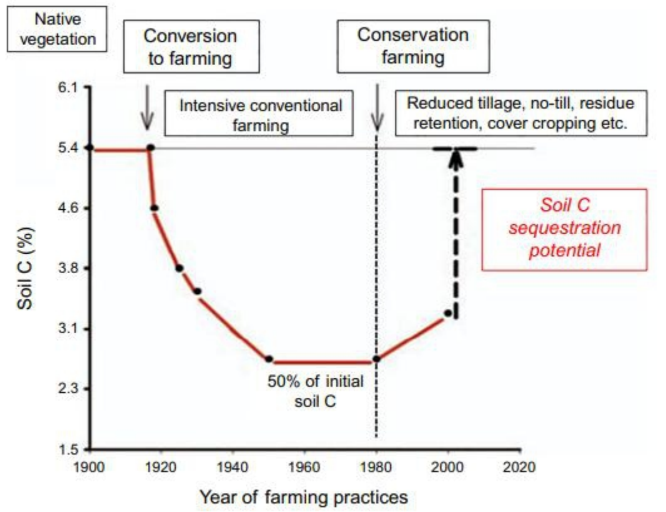

Fig. 2: Conceptual diagram showing carbon sequestration potential of soil

3. Adoption of Recommended Agricultural Management practices

Soil can be a sink or source of atmospheric carbon dioxide (CO_2). The necessity to improve land use and management techniques to sequester more carbon in agroecosystems is therefore well acknowledged. When land is converted to agriculture, the average yearly rate of SOC depletion is frequently far higher than the rate at which SOC is sequestered upon the use of recommended agricultural management principles (RAMP) [24]. [44] indicated that SOC sequestration is attributed to those management systems that: (1) minimize soil disturbance and erosion, (2) maximize crop residues retained in soil, and (3) maximize water and nutrient use efficiencies of the crop production system. Adopting reduced or no-till methods, using organic manures or biosolids, growing cover crops, and using N fertilizer promote SOC sequestration in agricultural soils [34]. Adopting recommended management practices has increased soil carbon sequestration rates by 0.05 to 1.0 Mg C ha^{-1} $year^{-1}$ [31,19]. [29] estimated that in the US adoption of management practices may lead to sequestration of 75 to 208 MMT (million metric tons) C $year^{-1}$, of which 50% is due to conservation tillage and residue management, 6% to supplemental irrigation and water table management, and 25% to adoption of improved cropping systems. Traditional techniques such as agroforestry, afforestation, and soil management are being pushed to sequester soil carbon. Under these management techniques, the amount of C sequestration is determined by the net balance between increased C input and output [32].

Table 1: Rate of Carbon Sequestration through land use change and adoption recommended agricultural management system

Management Practices	Rate of C sequestration (Mg C ha^{-1} $year^{-1}$)	Source
Crop rotation	0.02	[40]
Cover Crop with Non-Legume	0.17	[39]
Management of Irrigated Land	0.2-0.3	[30]
Straw return	0.57-0.61	[26,37,10]
Erosion control	0.05	[30]
Residue Incorporation	0.10	[40]
Lay Farming	0.30	[45,10]
Cover Crop with Legume with high N supply	0.43	[39]
Cover Crop with Legume with low N supply	0.41	[39]
Animal manure	0.58	[40]
Secondary Carbonates	0.11	[30]
Straw return with inorganic fertilizer	0.47	[54,10]

3.1. Tillage: A conservation tillage system (CT) maintains 30% of the soil surface covered by residue after planting to prevent water erosion; or in areas where wind erosion is a major concern, maintain a minimum of 1000 kg of small grain residue equivalent on the surface during the critical wind erosion period. Among the different tillage systems, conventional tillage hurts Carbon sequestration whereas conservation tillage (no-till or minimum till) has a positive role in C sequestration in soils [62,10]. It is advised to use conservation techniques to reduce SOC and plant nutrient losses. By switching from a plough-till to a no-till system, the peak rate of SOC may grow in 5–10 years, and the SOC will achieve its new equilibrium in 15–20 years [59]. Globally, conventional tillage methods caused a 30 to 50% decrease in soil carbon [56]. Conventional tillage damages soil structure and accelerates the decomposition of soil organic matter; no-tillage frequently increases the stability and quantity of soil aggregates. Moving from reduced tillage (RT) to no-tillage (NT) improved the rate of carbon sequestration in China's paddy soils (0–30 cm layer) by 93–147 kg C ha^{-1} yr^{-1} [60]. When switching from a Plow-till to a no-till system, the SOC may increase at its highest rate in 5–10 years, reaching a new equilibrium in 15–20 years [24]. Conservation tillage or no-till techniques raise the concentration of SOC, whereas cultivation and tillage cause a decrease in SOC. Worldwide, there are roughly 1.5 billion hectares of agriculture [16]. Currently, conservation tillage is only being used on a very tiny portion of this area. Thus, by 2020, converting even one-third of cropland to conservation tillage can significantly increase SOC sequestration [29]. No-till farming may have site- or soil-specific advantages for SOC sequestration, and in fine-textured and poorly-drained soils, the improvement in SOC may not always be consistent [58].

3.2. Crop Rotation: Crop rotation, as opposed to continuous monoculture or farming a varied sequence of crops, is the intentional succession of crops cultivated on the same land in a regularly occurring succession. Crop rotation impacts soil quality, growth, and yield of succeeding crops in a variety of ways, such as variations in SOC concentration, soil aggregation and structure, nutrient cycling, and insect incidence. Crop rotations, when combined with minimum or no-till management, can improve SOM, sequester SOC, and lessen soil erosion [34]. Therefore, the selection of crop or cropping system has a significant impact on soil C inputs. Crop rotation works better than monoculture to retain C and N in the soil [5]. More SOC has sequestered than in grain-legume rotations thanks to the combined effects of reduced tillage, surface residue maintenance, and high residue-producing continuous sorghum in the first rotation and continuous maize in the second [20,24]. Similar results were found by [43], reporting higher SOC under continuous corn as opposed to corn under corn-soybean rotation. In fertilized monoculture wheat, the rate of SOC sequestration was 50 g cm^{-2} yr^{-1}, while in a three-year corn/wheat/clover rotation, it was 150 g cm^{-2} yr^{-1} [8,52]. The SOC sequestration depends on the tillage systems to the soil through crop rotation (Table.2). According to [9], crop rotation can lead to an improvement in agronomic production and the possibility of SOC sequestration. Enhancing rotation complexity can sequester an average 20 ± 12 g C m^{-2} yr^{-1}, excluding a change from continuous corn (Zea mays L.) to corn-soybean [59]. The aforementioned illustrates how choosing suitable crop rotations based on soil and environmental factors can aid in the sequestration of carbon, improving soil fertility while lowering CO_2 emissions into the atmosphere and boosting farmer income, all while keeping economic considerations in mind.

Table: 2 Effect of C-sequestration rates under several cropping systems worldwide

Cropping System	Tillage System	Location	C-sequestration (Mg C ha^{-1} $year^{-1}$)	Source
Wheat-Corn	Conventional Tillage	Gto, Mexico	1.05	[13]
Wheat-Corn	Zero Tillage	Gto, Mexico	-0.03	[13]
Wheat-Vetch	-	ICARDA, Syria	0.87	[25]
Wheat-Lentil	-	ICARDA, Syria	0.71	[25]
Wheat-Maize	Rotary Tillage	North China	0.78	[62]
Wheat-Maize	Conventional Tillage	North China	0.79	[62]
Wheat-Maize	No-Tillage	North China	1.02	[62]
Rice-mustard-sesame	-	WB, India	0.25	[38]
Wheat-Chickpea	-	ICARDA, Syria	0.75	[25]
Wheat-Fallow	-	ICARDA, Syria	0.45	[25]
Rice-wheat-fallow	-	WB, India	0.06	[38]
Wheat-Fallow	Zero Tillage	Nebraska, U.S. A	0.18	[13]
Groundnut-wheat	-	Gujarat, India	0.20	[38]
Paddy- Wheat	-	MP, India	0.13	[38]

3.3. Crop residues: Crop residues are plant parts that are left over after crops are grazed or harvested, such as stems, leaves, roots, and chaff. Worldwide, the annual production of crop residues is about 3.4 × 109 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 [56]. Globally, 84% of residues are produced by seven major crops: wheat, rice (Oryza sativa L.), corn, sugar cane (Saccharum officinarum L.), barley, cassava (Manihot esculenta L. Crantz), and soybeans [29]. In agricultural soils, crop residues are the primary source of carbon and typically account for 45% of the element on a dry-weight basis [29]. A crop's ability to return a certain amount of residue to the soil varies (Table 3). Crop residue management done right can improve water retention, lower summer soil temperatures, and lessen runoff and soil erosion.

When crop residues are applied to the soil's surface, they reflect light, shield the soil from heat waves, and prevent water from evaporating [17,49] and are beneficial to enhancing soil fertility and SOC concentration [23,24]. [18] also noted higher SOC build-up in the top 15 cm soil layer under crop residue treatment coupled with no-tillage. The long-term experiments showed an increase in SOC concentration from straw-treated plots compared to nontreated/control [53].

Table 3: Potential of Soil Carbon Sequestration by Crop Residues

Crops	Yield (t ha^{-1})	Input C with Residues (t ha^{-1})	SOC Sequestration (kg C ha^{-1})
Barley	2.44	1.65	247
Potato	16.0	1.80	270
Cassava	10.7	3.35	503
Rice	3.96	2.67	401
Sorghum	1.31	0.88	133
Sugarcane	65.3	7.35	1102
Corn	4.33	1.95	292
Wheat	2.69	1.82	272
Oats	2.05	0.92	138

Source: [24]

3.4. Cover crop and Green manure: A cover crop is defined as a "crop that provides soil protection, seedling protection, and soil improvement between periods of normal crop production, or between trees in orchards and vines in vineyards". Conversely, the definition of "green manure" is "a plant material incorporated into the soil while green or at maturity, for soil improvement". [42] reported that sequestering soil organic carbon (SOC) has been observed when cover crops are used in intensive row crop rotations with varying tillage regimes. A cover crop may be referred as green manure when ploughed under and incorporated into the soil. Cover crops enhance soil protection, soil fertility, groundwater quality, pest management, SOC concentration, soil structure, and water-stable aggregates [47,12]. Cover crops promote SOC sequestration by increasing the input of plant residues and providing a vegetal cover during critical periods [7]. According to [29], tall fescue (Festuca arundinacea Scherb.) and smooth bromegrass (Bromus inermis Leyss.), two types of cover crops grown in Ohio, were found to be the most effective for sequestering SOC, enhancing soil structure, and micro-aggregation. This is because these plants have deeper root systems than other types of cover crops. According to [22], the addition of cover crops doubled or tripled the amount of labile SOC pool and coarse organic debris, while the overall SOC pool grew by 20%. Green manuring in a maize-wheat cropping system captured more carbon than applying FYM in addition to green manure [28].

3.5. Animal manure and compost application: Compost, which is mostly made up of decomposed organic matter and is used to fertilize and condition agricultural soil, is different from animal manure, which is animal excreta that is collected from livestock farms and barnyards and used to enrich the soil. The application of FYM in conjunction with NPK boosted C sequestration in the rice-wheat cropping system as compared to the application of NPK alone [41]. In an irrigated maize-wheat cropping system, the addition of organic wastes (filter cake or MSW) has the best potential for improving SOC retention, WUE, and wheat yield. This was demonstrated by the application of various organic wastes, such as 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 [50]. Long-term studies in Europe have demonstrated that both manure and fertilizer raise the concentration of SOC, but gains are greater when organic manure is applied than when chemical fertilizers are used [52,53] According to [11], over 100 years, manure application in Askov, Denmark, increased SOC by 10% in the 0–30 cm soil level compared to inorganic fertilizers. In the Norwegian studies, the rate of SOC sequestration by combining use of fertilizer and manure ranged from 68 to 227 kg ha^{-1} yr^{-1}, while only fertilizer applications ranged from 68 to 84 kg ha^{-1} yr^{-1} [52].

3.6. Ley Farming: Ley farming is a method that intensifies the crop-fallow system by growing grasses and/or legumes in short-term crop rotation and grazing them [36]. According to [2] leys based mostly on annual legumes and cereal crops had higher SOC concentrations, which were accompanied by improvements in the stability of the soil aggregate, a drop in bulk density, and an increase in the rate of water infiltration. The ley farming technique in Mali was found to have a beneficial effect on SOC concentration [6]. This was attributed to the infusion of ley roots and the animal recycling of crop leftovers. Ley farming is a good substitute for clearing a field by burning crop waste, which is a typical practice in Africa and results in a significant loss of soil organic carbon [3]. According to Norwegian data, ley farming had the biggest impact on SOC sequestration. More SOC was sequestered by a rotation comprising two years of spring grain and four years of ley than by all grain rotation over 37 years [57].

3.7. Agroforestry: Agroforestry is the term used to describe a group of land-use systems where woody perennials (trees, shrubs, etc.) are grown alongside herbaceous plants (pastures, crops) or animals, either in a rotational pattern, in a spatial arrangement, or both. Compared to traditional crops, agroforestry systems are much more effective in conserving soil because trees maintain soil organic matter (SOM) through litter and root leftovers. [61] underlined the importance of agroforestry in tropical ecosystems and the following strategies that could enable such reductions in greenhouse gas emissions: (1) trees on farms absorb carbon; (2) SOC grows; and (3) the supply of fuel wood, timber and other forest products to farms reduces the need for forest clearing. Agroforestry systems in India have been found to have a carbon sequestration capacity of 0.25–19.14 Mg C ha^{-1} year^{-1} in biomass and 0.003–3.98 Mg C ha^{-1} year^{-1} in soil [14,19]. According to [15], in Canada's intermediate areas, a tree-based intercropping agroforestry system has a significant potential for reducing N_2O emissions and sequestering SOC. Afforestation via the establishment of multipurpose tree plantations is a crucial technique for SOC sequestration in the dryland ecosystems of West Asia and North Africa [34]. The carbon sequestration potential by agroforestry is estimated up to 9, 21, 50, and 63 Mg C ha^{-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.

3.8. Biochar: Biochar is carbonized biomass, which is obtained from sustainable sources and sequestered in soils. It can also be obtained by pyrolysis synthetically. Application of Biochar can also improve 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. It has been reported that Biochar can improve carbon sequestration in soil due to prolonged residence time [38]. Biochar could be considered as both chemically and biologically stable C pool [35], properties of which depend upon different factors such as type of OM used, site and process of pyrolysis, heating temperature, and time etc. Biochars' long-term stability in the soil would undoubtedly reduce CO_2 emissions into the atmosphere and, by storing carbon in the soil, aid in the mitigation of climate change [1]. They not only add to carbon sequestration, but they also reduce the emissions of N_2O and CH_4, offer a good way to manage forestry and agricultural waste, improve soil sustainability, reduce fertilizer needs, produce renewable energy, and have numerous other positive environmental effects [19]. When it comes to the long-term storage of carbon trapped in biomass, applying biochar to soil is thought to be the most promising method of soil carbon sequestration. According to reports, Australia's natural biochar sink absorbs over 21 million tonnes of carbon dioxide a year [19]. The mechanism of carbon sequestration using biochar can be understood in the observation of Fig. 3. Recently, there has been increased interest in using biochar for carbon sequestration from the atmosphere and then applying it to the soil.

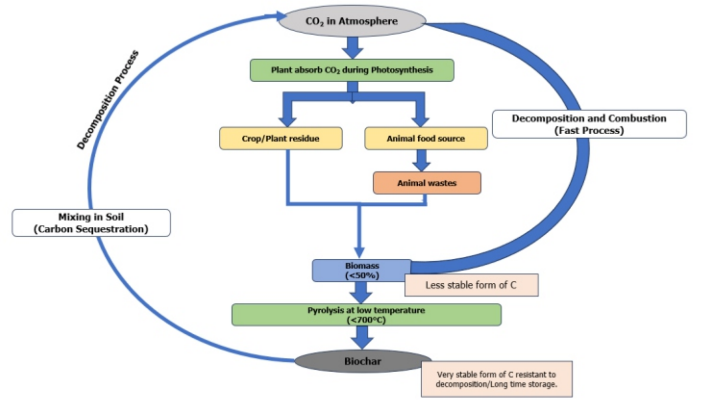

Fig. 3. The process by which biochar sequesters carbon

3.9. Precision farming: Precision farming is a technique that uses the best available technologies to tailor soil and crop management to fit specific conditions found within an agricultural field. Precision farming is a unique tool to combine production and environmental needs in agriculture [7]. In precision farming, management practices are applied on a soil-by-soil basis, improving energy and material flow efficiencies. Based on detailed information and a program for the specific site, precision farming is the management system that matches production expectations with environmental requirements, including SOC sequestration.

4. Future Research Needs

Soil acts as a primary sink as well as a source of atmospheric C and raises the soil C content with the aid of suitable agricultural management techniques. As a broad knowledge base about soil management and its effects on SOC sequestration is developing, there is a need to greatly improve the rates of SOC sequestration for different cropping systems and geographical regions. Details are required regarding the characteristics of various storage forms of sequestered SOC. Much more research is needed to determine the rates of aggregate formation, their stability and longevity, the connections between their formation and tillage techniques, soil properties, and residue quality. It is necessary to know the rates at which SOC pools accumulate and degrade, which pools and chemical forms are the most resistant, and what procedures are involved in the physical protection of SOC. Sustaining or restoring SOM levels could serve as a long-term indicator of how well conservation measures are working to preserve soil productivity and even raise producers' net income. Information is required regarding how above-ground residue resources, including the impact of different crop types, influence the amount of soil organic carbon (SOC) sequestered due to soil management practices. Additional details are required at both local and state levels regarding the rates of soil organic carbon sequestration associated with the Conservation Reserve Program and the soil types and types of vegetation being planted. Similar information is required for different types of crop rotations and winter cover crops. The advancement of better management systems for utilizing crop residues is crucial, as is the reduction of soil erosion (water and wind) resulting from irrigated farmland. Much more needs to be known about SOC sequestration under irrigated agricultural systems.

5. Conclusion

Soil carbon sequestration may remove excess CO_2 from the atmosphere without jeopardizing the global food supply, it is a win-win solution. A vital instrument for soil C sequestration, effective agricultural management techniques have a strong impact on lowering greenhouse gas emissions, raising soil organic matter (SOC) levels, enhancing soil health, and establishing soil sustainability. The application of effective agricultural management techniques for soil carbon sequestration has a strong effect on reducing greenhouse gas emissions, increasing soil organic matter (SOC) levels, enhancing soil health, and establishing soil stability. Conservation tillage techniques, prudent application of fertilizers and manures, utilization of crop residues, varied crop rotations, and other soil/crop management techniques can sequester SOC. Compared to conventional systems, the adoption of conservation tillage has a large positive impact on soil carbon sequestration. Applying crop residues in conjunction with conservation tillage typically results in a higher build-up of soil carbon content, with the type of residue included playing a significant role in determining the amount of carbon accumulated in the soil. Mulching also raises SOC concentration, which is, for the most part, directly correlated with mulch quality and thickness. Numerous studies have noted that organic farming effectively improves soil structure and captures atmospheric carbon dioxide. This is because different cropping systems and land uses have dramatic effects on carbon sequestration. Therefore, it has been discovered that choosing appropriate land-use strategies that improve land cover and C input in the form of above-ground litterfall and root biomass helps build up resistant forms of soil C. Applying biochar as a soil amendment has been shown in numerous studies to be remarkably successful at retaining C in the soil for extended periods.

6. Future scope: The future scope for RAMP in enhancing carbon sequestration is promising, with potential directions including the integration of precision agriculture, soil health monitoring, and climate-smart agriculture. By promoting sustainable agricultural practices, RAMP can play a crucial role in mitigating climate change. The evolution of Carbon Sequestration from its origins in the oil and gas industry to a central tool for climate mitigation underscores its transformative capacity. Future efforts should focus on developing more efficient, less energy-intensive capture technologies, optimizing processes using artificial intelligence, and establishing a global carbon storage infrastructure. This approach is essential for countries with limited geological storage capacities. Tackling these challenges opens up pathways for innovation, ensuring that carbon sequestration remains central to global strategies for reducing greenhouse gas emissions and achieving climate goals. Emphasizing cost reduction, efficiency improvements, and renewable energy integration will enable carbon sequestration to fulfill its potential in a sustainable future.

7. Conflict of Interest: The authors state they have no conflicts of interest.

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References

1. Ahmad M, Ok YS, Kim BY, Ahn JH, Lee YH, Zhang M, Moon DH, Al-Wabel MI, Lee SS (2016) Impact of soybean stover- and pine needle-derived biochars on Pb and As mobility, microbial community, and carbon stability in a contaminated agricultural soil. Journal of environmental management 166: 131-139.

2. Angus JF, Kirkegaard JA, Peoples MB (2001) Rotation, sequence and phase: research on crop and pasture systems. In Proceedings of the 10th Australian Agronomy Conference, Hobart.

3. Bationo A, Mokwunye AU (1991) Role of manures and crop residue in alleviating soil fertility constraints to crop production: With special reference to the Sahelian and Sudanian zones of West Africa. Fertilizer research 29: 117-125.

4. Batjes NH (1996) Total carbon and nitrogen in the soils of the world. European journal of soil science 47(2): 151-163.

5. Biederbeck VO, Campbell CA, Zentner RP (1984) Effect of crop rotation and fertilization on some biological properties of a loam in southwestern Saskatchewan. Canadian Journal of Soil Science 64(3): 355-367.

6. Bosma RH, Bos M, Kante S, Kebe D, Quak W (1999) The promising impact of ley introduction and herd expansion on soil organic matter content in southern Mali. Agricultural systems 62(1): 1-15.

7. Bowman RA, Vigil MF, Nielsen DC, Anderson RL (1999). Soil organic matter changes in intensively cropped dryland systems. Soil Science Society of America Journal 63(1): 186-191.

8. Buyanovski HA, Wagner GH (1998) Carbon cycling in cultivated land and its global significance. Global Change Biol. 4: 131–141.

9. Campbell CA, McConkey BG, Zentner RP, Selles F, Curtin D (1996). Tillage and crop rotation effects on soil organic C and N in a coarse-textured Typic Haploboroll in southwestern Saskatchewan. Soil and Tillage Research, 37(1): 3-14.

10. Chowdhury S, Bolan N, Farrell M, Sarkar B, Sarker JR, Kirkham MB, Hossain MZ, Kim GH (2021). Role of cultural and nutrient management practices in carbon sequestration in agricultural soil. Advances in agronomy 166: 131-196.

11. Christensen BT (1996) The Askov long-term experiments on animal manure and mineral fertilizers In: Powlson DS, Smith P, J.U. Smith JU, editors. Evaluation of Soil Organic Matter: Models Using Existing Datasets, NATO, ASI 138, Heidelberg, Springer, pp. 301–312.

12. Dabney SM, Delgado JA, Reeves DW (2001). Using winter cover crops to improve soil and water quality. Communications in Soil Science and Plant Analysis 32(7-8): 1221-1250.

13. Dey, P., Singh, S.R. and Sekhon, B.S., 2024. Systems approach vis-à-vis carbon sequestration: issues and strategies. *Current Science (00113891)*, *127*(12).

14. Dhyani SK, Ram A, Dev I (2016) Potential of agroforestry systems in carbon sequestration in India. Indian J Agric Sci 86: 1103–1112.

15. Dyack BJ, Rollins K, Gordon AM (1998) A model to calculate ex ante the threshold value of interaction effects necessary for proposed intercropping projects to be feasible to the landowner and desirable to society. Agroforestry Systems 44: 197-214.

16. FAO (2000) Production Yearbook: 2000, Vol. 54. FAO, Rome, Italy

17. Franzluebbers AJ, Hons FM, Zuberer DA (1995). Tillage-induced seasonal changes in soil physical properties affecting soil CO_2 evolution under intensive cropping. Soil and Tillage Research 34(1): 41-60.

18. Ghimire R, Shah SC, Dahal KR, Duxbury JM, Lauren JG (2008). Soil organic carbon sequestration by tillage and crop residue management in rice-wheat cropping system of Nepal. Journal of the Institute of Agriculture and Animal Science 29: 21-26.

19. Gupta DK, Gupta CK, Dubey R, Fagodiya RK, Sharma G, Noor Mohamed MB, Dev R, Shukla AK (2020) Role of biochar in carbon sequestration and greenhouse gas mitigation. In: Singh JS, Singh C editors. Biochar applications in agriculture and environment management. Springer, pp.141-165.

20. Havlin JL, Kissel DE, Maddux LD, Claassen MM, Long JH (1990) Crop rotation and tillage effects on soil carbon and nitrogen. Soil Sci. Soc. Am. J. **54**: 448–452.

21. Hernandez-Soriano MC, Kerré B, Goos P, Hardy B, Dufey J, Smolders E (2016) Long-term effect of biochar on the stabilization of recent carbon: Soils with historical inputs of charcoal. Gcb Bioenergy 8(2): 371-381.

22. Hu S, Grunwald NJ, Van Bruggen AHC, Gamble GR, Drinkwater LE, Shennan C, Demment, MW (1997) Short-term effects of cover crop incorporation on soil carbon pools and nitrogen availability. Soil Science Society of America Journal 61(3): 901-911.

23. Jacinthe PA, Lal R, Kimble JM (2002) Carbon budget and seasonal carbon dioxide emission from a central Ohio Luvisol as influenced by wheat residue amendment. Soil and Tillage Research 67(2): 147-157.

24. Jarecki MK, Lal R (2003) Crop management for soil carbon sequestration. Critical Reviews in Plant Sciences 22(6): 471-502.

25. Jenkinson DS, Harris HC, Ryan J, McNeill AM, Pilbeam CJ, Coleman K (1999) Organic matter turnover in a calcareous clay soil from Syria under a two-course cereal rotation. Soil Biology and Biochemistry 31(5): 687-693.

26. Jin L, Li Y, Gao Q, Liu Y, Wan Y, Qin X, Shi F (2008) Estimate of carbon sequestration under cropland management in China. Sci. Agric. Sin. 41: 734–743.

27. Kimble JM, Follett RF, Cole CV (1998). The potential of US cropland to sequester carbon and mitigate the greenhouse effect. CRC Press, pp. 144

28. Kukal SS, Benbi DK (2009). Soil organic carbon sequestration in relation to organic and inorganic fertilization in rice–wheat and maize–wheat systems. Soil and Tillage Research 102(1): 87-92.

29. Lal R (1997) Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2-enrichment. Soil and tillage research 43(1-2): 81-107.

30. Lal R (2004) Carbon sequestration in dryland ecosystems. Environmental management 33:528-544.

31. Lal R (2004) Soil carbon sequestration to mitigate climate change. Geoderma 123(1-2): 1-22.

32. Lal R (2009) Challenges and opportunities in soil organic matter research. Eur. J. Soil Sci. 60: 158–169.

33. Lal R (2011) Sequestering carbon in soils of agro-ecosystems. Food policy 36: S33-S39.

34. Lal, R. (2001). World cropland soils as a source or sink for atmospheric carbon. Advances in Agronomy 71: 145-191.

35. Lehmann J, Czimczik C, Laird D, Sohi S. (2009) Stability of biochar in the soil. In: J. Lehmann, & S. Joseph (Eds.). Biochar for Environmental Management: Science and Technology. Earthscan. pp. 183–205.

36. Lloyd D, Smith KP, Clarkson NM, Weston EJ, Johnson B (1991) Sustaining multiple production systems. Tropical Grasslands 25: (181).

37. Lu F, Wang X, Han B, Ouyang Z, Duan X, Zheng HUA, Miao H (2009). Soil carbon sequestration by nitrogen fertilizer application, straw return and no-tillage in China's cropland. Glob. Chang. Biol. 15: 281–305.

38. Manna MC, Rao AS, Mandal A (2015). Impact of agricultural land management practices on soil carbon sequestration. Indian Journal of Soil Conservation 43(3): 204-212.

39. Mazzoncini M, Sapkota TB, Barberi P, Antichi D, Risaliti R (2011) Long-term effect of tillage, nitrogen fertilization and cover crops on soil organic carbon and total nitrogen content. Soil and tillage research 114(2): 165-174.

40. Morari F, Lugato E, Berti A, Giardini L (2006) Long-term effects of recommended management practices on soil carbon changes and sequestration in north-eastern Italy. Soil Use and Management 22(1): 71-81.

41. Naresh RK, Gupta RK, Minhas PS, Rathore RS, Dwivedi A, Purushottam VK, Singh O (2017) Climate change and challenges of water and food security for smallholder farmers of Uttar Pradesh and mitigation through carbon sequestration in agricultural lands: an overview. Int J Chem Stud 5(2): 221-236.

42. Olson KR, Ebelhar SA, Lang JM (2010) Cover crop effects on crop yields and soil organic carbon content. Soil Science 175(2): 89-98.

43. Omay AB, Rice CW, Maddux LD, Gordon WB (1997) Changes in soil microbial and chemical properties under long-term crop rotation and fertilization. Soil Science Society of America Journal 61(6): 1672-1678.

44. Paustian K (2001) Modelling soil organic matter dynamics-global challenges. In: Rees RM, Ball BC, Campbell CD, Watson CA. Sustainable management of soil organic matter. Wallingford UK: CABI. pp. 43-95.

45. Powlson, D., Johnston, J. (2015). Potential Soil Organic Matter Benefits From Mixed Farming: Evidence From Long-Term Experiments. From Sustainable Food Trust Meeting: What Role for Grazing. http://www.slideshare.net/ Sustainablefoodtrust/ davidpowlson. (Feb 2015 last accessed January 2020).

46. Rong YANG, Su YZ, Tao WANG, Qin YANG (2016) Effect of chemical and organic fertilization on soil carbon and nitrogen accumulation in a newly cultivated farmland. Journal of Integrative Agriculture 15(3): 658-666.

47. Sainju UM, Singh BP, Whitehead WF (2000). Cover crops and nitrogen fertilization effects on soil carbon and nitrogen and tomato yield. Canadian journal of soil science 80(3): 523-532.

48. Sanderman, J., Farquharson, R., Baldock, J. (2010). Soil Carbon Sequestration Potential: A Review for Australian Agriculture. CSIRO.

49. Sauer TJ, Hatfield JL, Prueger JH (1996). Corn residue age and placement effects on evaporation and soil thermal regime. Soil Science Society of America Journal 60(5): 1558-1564.

50. Shehzadi S, Shah Z, Mohammad W (2017). Impact of organic amendments on soil carbon sequestration, water use efficiency and yield of irrigated wheat. Biotechnol. Agron. Soc. Environ. 21(1): 36-49

51. Singh BR, Borresen T, Uhlen G, Ekeberg E (2019) Long-term effects of crop rotation, cultivation practices, and fertilizers on carbon sequestration in soils in Norway. In: Lal R, Kimble JM, Follet RF, Stewart BA editors. Management of carbon sequestration in soil. CRC Press. pp. 195-208.

52. Singh BR, Lal R (2005) The potential of soil carbon sequestration through improved management practices in Norway. Environment, Development and Sustainability 7: 161-184.

53. Smith P, Powlson SDS, Glendining MJ, Smith JU (1997) Potential for carbon sequestration in European soils: Preliminary estimates for five scenarios using results from long-term experiments. Global Change Biology **3**: 67–79.

54. Smith P, Powlson SDS, Glendining MJ, Smith JU (1997) Potential for carbon sequestration in European soils: Preliminary estimates for five scenarios using results from long-term experiments. Global Change Biology **3**: 67–79.

55. Sugiyanta, 2015. Rice straw management for food security support. In: Presentation at Soil Information to Support Sustainable Agriculture and Food Security in Indonesia. Australia Indonesia Center. P4W, Bogor (08 October 2015).

56. Sun Y, Huang S, Yu X and Zhang W (2013) Stability and saturation of soil organic carbon in rice fields: evidence from a long-term fertilization experiment in subtropical China. Journal of Soils and Sediments 13: 1327-1334.

57. Tanveer SK, Lu X, Hussain I, Sohail M (2019). Soil carbon sequestration through agronomic management practices. In CO2 sequestration. IntechOpen.

58. Uhlen G.O.T.F.R.E.D, Tveitnes, S.T.E.I.N.A.R. (1995) Effects of long-term crop rotation, fertilizers, farm manure and straw on soil productivity. Nor J Agric Sci 9: 143-161.

59. Wander MM, Bidart MG, Aref S (1998) Tillage impacts on depth distribution of total and particulate organic matter in three Illinois soils. Soil Science Society of America Journal 62(6): 1704-1711.

60. West TO, Post WM (2002) DIVISION S-6—SOIL & WATER MANAGEMENT & CONSERVATION. Soil Sci. Soc. Am. J 66: 1930-1946.

61. Xu S, Shi X, Zhao Y, Yu D, Li C, Wang S, Sun W (2011) Carbon sequestration potential of recommended management practices for paddy soils of China, 1980–2050. Geoderma 166(1): 206-213.

62. Young A (1997) Agroforestry for soil management (Ed. 2). CAB International. 320 p.

63. Zhang MY, Wang FJ, Chen F, Malemela MP, Zhang, HL (2013) Comparison of three tillage systems in the wheat-maize system on carbon sequestration in the North China Plain. Journal of Cleaner Production 54: 101-107.

64. Zhang S, Li Q, Leu Y, Zhang X, Liang W (2013) Contributions of soil biota to C sequestration varied with aggregate fractions under different tillage systems. Soil Biol. Biochem. 62: 147–156.

