

# Carbon in Agricultural Soil

Subjects: Soil Science  
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Carbon in agricultural soils is chemically classified as either soil organic carbon (SOC) or soil inorganic carbon (SIC). Globally, the naturally occurring SOC and SIC pools are estimated to be 1500 Gt C and 950 Gt C, respectively. The SOC includes humus, decomposed plant and animal residues, charcoal and microorganisms. The SIC pool includes primary and secondary carbonates, such as calcite (CaCO<sub>3</sub>) and dolomite (CaMg(CO<sub>3</sub>)<sub>2</sub>), and can be classified into lithogenic and pedogenic carbonates. Lithogenic carbonates are the primary carbonates that refer to the detrital particle derived from the carbonate bedrock (especially limestone) that are formed in marine environments. Pedogenic carbonates refer to the secondary carbonates formed in the soil and is further classified as calcitic pedogenic carbonates (formed by calcite remobilization) and silicatic pedogenic carbonates (formed by silicate weathering). Calcitic pedogenic carbonates are derived from pre-existing carbonates; hence, it does not result in net carbon sequestration. On the other hand, carbonation of alkaline earth elements derived from silicate minerals results in net positive sequestration through the formation of silicatic pedogenic carbonates.

Keywords: carbon sequestration ; enhanced rock weathering ; soil organic carbon ; pedogenic carbonates ; negative emissions ; carbon sink ; climate change mitigation

## 1. Soil Carbon Sequestration as SOC

Improved agronomic practices, including crop rotation, use of improved crop varieties and use of cover crops, increase the input of residual organic carbon into the soil, which leads to increased SOC stored content. BMPs, and their net CO<sub>2</sub> sequestration potential, are summarized in **Table 1**. The buildup of SOC takes many years, and the efficiency of the BMPs summarized in **Table 1** depends on the soil type, soil saturation and drainage practices and climatic conditions <sup>[1]</sup>. Hence, agricultural soils act as both net sources as well as sinks for GHGs, including atmospheric CO<sub>2</sub>.

**Table 1.** Techniques to enhance soil organic carbon (SOC) storage in agricultural soils <sup>[2][1][3][4][5][6][7][8][9][10][11][12]</sup>.

Practice	Example	CCS (t CO <sub>2</sub> ha <sup>-1</sup> year <sup>-1</sup> )	Acceptance <sup>a</sup>	Agreement <sup>b</sup>	Net GHG Emission (t CO <sub>2</sub> ha <sup>-1</sup> year <sup>-1</sup> )	Effect
Cropland Management	Reduced tillage	0.41	H	M	0.44	Reduced decomposition and weed control.
	Crop rotation	0.59	H	H	0.69	Reduced reliance on N inputs.
	Eliminate summer fallow	0.17	H	-	-	Reduces SOM decay.
	Nutrient management	0.27	M	H	0.48	Control on N <sub>2</sub> O release.
	Water management	1.14	L	L	1.14	Improves aeration.
	Increased productivity (e.g., fertilization, irrigation)	0.30	M	M	-	Stimulate N <sub>2</sub> O emission.
Grassland management	Grazing intensity improvement	0.45	L	L	0.46	Influence crop growth.

Practice	Example	CCS (t CO <sub>2</sub> ha <sup>-1</sup> year <sup>-1</sup> )	Acceptance <sup>a</sup>	Agreement <sup>b</sup>	Net GHG Emission (t CO <sub>2</sub> ha <sup>-1</sup> year <sup>-1</sup> )	Effect
Land restoration	Restore permanent grass or woodland	2.57	L	H	3.72	Improves soil fertility
Organic soil management	Use organic residues (manure, biosolids, crop residues)	1.83	M	H	2.17	High density C source
	Organic soil restoration	55.0	M	H	51.8	
Bioenergy	Energy crop plantation	0.42	M	H	0.44	CO <sub>2</sub> neutral sources

<sup>a</sup> 'Acceptance' denotes the likelihood of acceptance by farmers. <sup>b</sup> 'Agreement' denotes the relative degree of agreement in the literature. H = high, M = medium, and L = low. CCS: carbon capture and storage; GHGs: greenhouse gases.

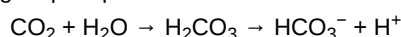
Another modern technique to store C as well as reduce N<sub>2</sub>O emissions includes the use of biochar as a soil amendment [13]. Biochar is porous with high carbon content and surface area, produced by pyrolysis of plant or waste feedstock [14]. Biochar contains stable forms of carbon, which are recalcitrant to degradation, hence mitigating CH<sub>4</sub> or CO<sub>2</sub> loss [15]. Thus, biochar can store carbon in the soil for as long as 1000 years [16][17] and thus contribute towards the reduction of anthropogenic CO<sub>2</sub> emissions. Additionally, biochar can minimize the use of N fertilizers, and indirectly contribute towards mitigating overall GHG emissions [18].

A series of studies from Syracuse University over the last decade has shown that the application of calcium silicate (wollastonite) can also help in increasing soil organic matter (SOM) in forested soil, as well as contributing to nutrient management by increasing exchangeable calcium, thereby improving the pH of the nutrient-depleted, acidic forest soil [19][20][21]. Wollastonite is used as a liming agent for the forest soil to improve the soil fertility, but these studies have not looked at inorganic carbon sequestration potential of this silicate mineral.

## 2. Soil Carbon Sequestration as SIC via Enhanced Weathering

The term 'enhanced weathering' refers to exposing milled minerals to the atmosphere, whereby the large specific surface area of fine powders aids in the rate of the weathering reactions, versus naturally occurring rocks that slowly weather [22]. Long-term atmospheric CO<sub>2</sub> sequestration in agricultural soils can be made possible through weathering of Ca silicates and Mg silicates, because the released Ca<sup>2+</sup> and Mg<sup>2+</sup> are precipitated as soil inorganic carbonates [23]. Formation of pedogenic carbonates offers a sink for carbon that is effectively permanent, and the amount of SIC presently held within soils has been estimated to be 720–950 Gt C [24][25]. These values can be augmented by addition of a variety of calcium and magnesium silicates, including wollastonite (CaSiO<sub>3</sub>), enstatite (MgSiO<sub>3</sub>), forsterite (Mg<sub>2</sub>SiO<sub>4</sub>), fayalite (Fe<sub>2</sub>SiO<sub>4</sub>), olivine ((Mg,Fe)SiO<sub>4</sub>), diopside (MgCaSi<sub>2</sub>O<sub>6</sub>) and serpentine ((Mg,Fe)<sub>3</sub>Si<sub>2</sub>O<sub>5</sub>(OH)<sub>4</sub>) [26].

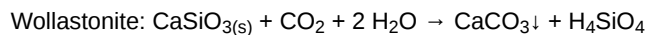
In enhanced weathering, firstly, CO<sub>2</sub> reacts with H<sub>2</sub>O to form bicarbonate (HCO<sub>3</sub><sup>-</sup>) and a proton (H<sup>+</sup>) (Equation (1)). Secondly, the metal ion from the mineral is liberated by the proton and ultimately reacts with the bicarbonate to precipitate as a carbonate (Equation (2)). Equations (3)–(6) represent some examples of mineral weathering [27][28][29] (under ambient conditions, magnesium carbonates are likely to occur as hydrated carbonates, such as nesquehonite (MgCO<sub>3</sub>·3H<sub>2</sub>O) or lansfordite (MgCO<sub>3</sub>·5H<sub>2</sub>O)). Carbonate solubility, and hence the transport of Ca<sup>2+</sup>/Mg<sup>2+</sup> and HCO<sub>3</sub><sup>-</sup>/CO<sub>3</sub><sup>2-</sup>, depends on the soil solution chemistry. Therefore, either in the longer term (as a result of soil porewater dilution by rainwater) or in the shorter term (as a result of intensive irrigation in some crops), CaCO<sub>3</sub> (for example) may be dissolved and instead of remaining in the soil profile, the ions (Ca<sup>2+</sup>, CO<sub>3</sub><sup>2-</sup>) may leach into the groundwater, and eventually into the oceans, where under more alkaline conditions they are again precipitated as calcium carbonates (Equation (7)) [30].



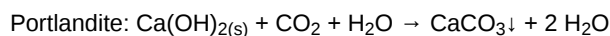
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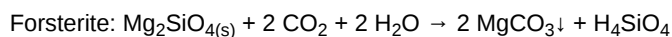
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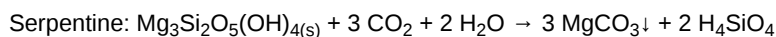
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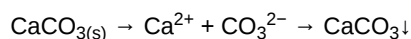
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