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Accounting for soil inorganic carbon in the ecosystem services framework for United Nations sustainable development goals

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ABSTRACT

Soil inorganic carbon (SIC) is currently not included in the list of key soil properties related to ecosystem services (e.g., provisioning, regulating, cultural, and supporting services). Soil inorganic carbon is a dynamic key soil property used in soil classification, taxonomy and fertility, therefore its inclusion in the framework of ecosystem services is important. With soils rapidly changing due to human use and climate change, the ecosystem services framework should include not only soil organic carbon (SOC), but SIC as well since it is of global importance to soil fertility and the long-term carbon (C) cycle, especially in semiarid and arid climates where SIC comprises the largest C pool. The objective of this study is to assess the value of SIC in the 12 soil orders of Soil Taxonomy at the country scale (continental United States (U.S.)) and at the farm scale (the Cornell University Research Farm) within the context of ecosystem services, specifically provisioning and supporting services. At the country scale, the total estimated midpoint value of SIC storage within the upper two meters of soil is \$5.17 T (i.e., 5.17 trillion U.S. dollars). The soil orders having the highest total value of SIC storage (based on an average 2014 price of \$10.42 per U.S. ton of $CaCO_3$ lime in the U.S.) are: 1) Mollisols (\$2.22 T), 2) Aridisols (\$1.23 T), 3) Alfisols (\$523B, i.e., 523 billion U.S. dollars), and 4) Entisols (\$489B). In terms of SIC content (i.e., value per square meter), the soil orders are ranked: 1) Vertisols (\$2.22 m^{-2}), 2) Aridisols (\$1.52 m^{-2}), 3) Mollisols (\$1.10 m^{-2}), and 4) Inceptisols (\$0.49 m^{-2}). At the farm scale, based on variable measured and reported soil sample depths, the soil orders having the highest total value of SIC (based on an average 2014 price of \$10.88 price per U.S. ton of $CaCO_3$ for the State of New York (NY)) were: 1) Alfisols, 2) Inceptisols, and 3) Entisols. However, the farm-scale estimates varied greatly depending on whether the values were based on field-derived vs. SSURGO-derived data. The results of this study begin to provide an estimated value of the importance of SIC when assessing ecosystem services. The potential impacts on society from this research include adding SIC into the ecosystem services framework for the United Nations (UN) Sustainable Development Goals. Future research should identify and quantify other important ecosystem services that SIC may provide on a variety of spatial and temporal scales, as well as the potential need of including total C (TC) and interactions between SIC and SOC pools.

1. Introduction

Soil inorganic carbon (SIC) is a part of total carbon (TC) in soils, however, it is currently not included with the key soil properties related to ecosystem services (e.g., provisioning, regulating, cultural, and supporting services) (Fig. 1). Soil inorganic carbon is an integral part of terrestrial carbon, which can either be a source or sink of carbon (C).

The United Nations (UN) adopted 17 Sustainable Development Goals as guidelines to enhance the sustainability of global human societies (Keestra et al., 2016). Soil functions are critical to the United Nations Sustainable Development Goals because soils provide clean water, clean air, and food for global societies (Keestra et al., 2016). The UN Sustainable Development Goals that relate to soil functions include: “2. End hunger, achieve food security, and improve nutrition and promote sustainable agriculture, 3. Ensure healthy lives and promote well-being for all at all ages, 6. Ensure availability and sustainable management of water and sanitation for all, 13. Take urgent action to combat climate change and its impacts, 15. Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and biodiversity loss” (Keestra et al., 2016).

Ecosystem services exemplify how the ecosystem benefits society through commodities and services (Costanza et al., 2014). Ecosystem services are broken down into four main categories: 1. provisioning

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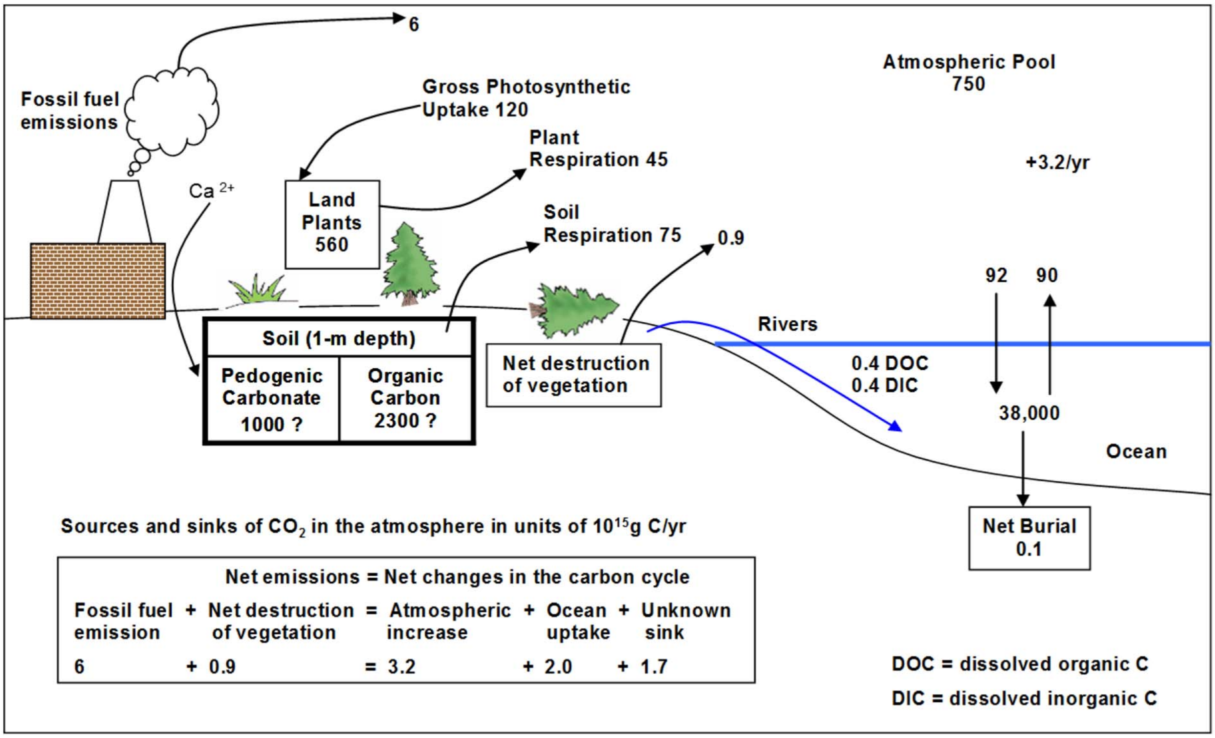

Fig. 1. The global carbon cycle (Adapted from Schlesinger, 2002).

services (food, fuel and fiber, raw materials, gene pool, fresh water/water retention), 2. regulating services (climate and gas regulation, water regulation, erosion and flood control, pollination/seed dispersal, pest and disease regulation, carbon sequestration, water purification), 3. cultural services (recreation/ecotourism, esthetic/sense of place, cultural heritage), and 4. supporting services (weathering/soil formation, nutrient cycling, provisioning of habitat) (Adhikari and Hartemink, 2016). The ecosystem services that relate to soil properties of organic carbon include provisioning services: food, fuel, and fiber, raw materials, and fresh water/water retention; regulating services: climate and gas regulation, water regulation, erosion and flood control, pest and disease regulation, carbon sequestration, and water purification; cultural services: recreation/ecotourism, esthetic/sense of place, and knowledge/education/inspiration; supporting services: weathering/soil formation, nutrient cycling, and provisioning of habitat (Adhikari and Hartemink, 2016).

Total carbon (TC) represents the summation of soil inorganic carbon (SIC) and soil organic carbon (SOC) in a terrestrial soil environment. Presently, SOC is included into the ecosystem services framework; however, SIC is not included, despite SIC's contribution within the ecosystem services framework (Keestra et al., 2016). The exclusion of SIC from the ecosystem services framework stems from the initial supremacy placed on SOC as the driver for soil fertility and its existence as a super colloid. Soil inorganic carbon is a major component of the global carbon cycle and is found in various forms such as, gaseous $CO_{2(g)}$, dissolved $CO_{2(aq)}$, carbonic acid $H_2CO_{3(aq)}$, bicarbonate $HCO_{3(aq)}^{-}$, carbonate $CO_{3(aq)}^{2-}$, and solid-phase carbonate (primarily $CaCO_3$) (Monger, 2014; Zamanian et al., 2016) Soil inorganic carbon forms, bicarbonate and carbonate, together comprise a larger terrestrial carbon pool than SOC (Monger et al., 2015). Furthermore, solid-phase calcium carbonate is divided two types: lithogenic carbonate and pedogenic carbonate (Monger et al., 2015). Lithogenic carbonates are formed in a marine environment and can be found as fragments in a terrestrial setting (Monger et al., 2015). Pedogenic carbonates are formed authigenically in a soil environment that is commonly under alkaline, arid conditions (Monger et al., 2015).

Soil inorganic carbon provides a significant contribution to ecosystem services, but it is currently overlooked. The objective of this study is to assess the value of SIC in the 12 soil orders of Soil Taxonomy at the country scale (the continental United States) and at farm scale (the Cornell University Research Farm) within the context of ecosystem services, specifically provisioning and supporting services.

2. Soil inorganic carbon and USDA Soil Taxonomy

Soil inorganic carbon has a variable distribution in the U.S. by soil order and depth. Using the State Soil Geographic Database (STATSGO), Guo et al. (2006) reported that half of the 12 soil orders in the conterminous U.S. have appreciable accumulations of SIC and ranked the soil orders by midpoint SIC storage in the following order: (1) Mollisols, (2) Aridisols, (3) Alfisols, (4) Entisols, (5) Inceptisols, and (6) Vertisols. Soils with "slight" and "intermediate" degrees of weathering tend to have more carbonates, whereas soils with a "strong" degree of weathering tend to have little to no accumulations of SIC. Mollisols, Alfisols and Vertisols are important soil orders globally due to high soil productivity for world crops (Liu et al., 2012). Soil inorganic carbon accumulations are identified at the suborder level (e.g. Calcids, Durids, Gypsids, etc.), and by lowercase letter symbols to designate subordinate distinctions within master horizons (e.g., k = accumulation of carbonates, c = concretions or nodules, etc.) (Soil Survey Staff, 2014). Uncertainty associated with STATSGO reported values for SIC is unknown, however Zhong and Xu (2011) reported that there were significant differences in soil organic matter (SOM) values when comparing STATGO to the more detailed SSURGO databases. Zhong and Xu (2011) concluded that the SSURGO values for SOM more closely matched field data and were more likely more accurate. This indicates that relying on STATGO for SIC estimates (Guo et al., 2006) can introduce an unknown quantity of error.

The spatial and vertical distribution of SIC is influenced by the amount of rainfall, which tends to decrease from east to west in the U.S. with more carbonate-rich soils found in the western part of the country. Because agricultural activity is influenced by soil pH and naturally