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Review

A review on the role of organic inputs in maintaining the soil carbon pool of the terrestrial ecosystem

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A B S T R A C T

Among the numerous sources of greenhouse gases, emissions of CO_2 are considerably affected by changes in the extent and type of land use, e.g., intensive agriculture, deforestation, urbanization, soil erosion, or wetland drainage. As a feasible option to control emissions from the terrestrial ecosystems, the scientific community has explored the possibility of enhancing soil carbon (C) storage capacity. Thus, restoration of damaged lands through conservation tillage, crop rotation, cover cropping, reforestation, sub-soiling of compacted lands, sustainable water management practices, and organic manuring are the major antidotes against attenuation of soil organic C (SOC) stocks. In this research, we focused on the effect of various man-made activities on soil biotic organics (e.g., green-, farm-yard manure, and composts) to understand how C fluxes from various sources contribute to the establishment of a new equilibrium in the terrestrial ecosystems. Although such inputs substitute a portion of chemical fertilizers, they all undergo activities that augment the rate and extent of decay to deplete the SOC bank. Here, we provide perspectives on the balancing factors that control the mineralization rate of organic matter. Our arguments are placed in the background of different land use types and their impacts on forests, agriculture, urbanization, soil erosion, and wetland destruction.

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1. Introduction

Soil is the largest and the most active terrestrial pool of the carbon (C) cycle (Janzen, 2004). Soil organic matter (SOM) can be defined as the accumulated decaying debris of biota living on or in the soil. It is heterogeneous, encompassing everything from the most recent root exudates to old aged persistent humified material (Amundson, 2001). SOM holds about 1500 Pg C to a depth of 1 m as the major pool of terrestrial C to regulate its biogeochemical processes. In terms of the C storage capacity, the soil system triples and quadruples those of the atmosphere and all living terrestrial plants and marine life forms (especially corals), respectively (Ware et al., 1991; Silva et al., 2008). However, intensive agricultural activities have had a detrimental effect on soil such as rapid mineralization of soil organic carbon (SOC). This has resulted in transformation of the excess C into soil air increasing CO_2 levels in the atmosphere while depleting the soil C stock. In particular, arable agriculture leads to depletion of soil C with the harvesting of a large proportion of photosynthetically-fixed C, while returning less plant litter. Such activity is expected to expedite biological decay of OM by disrupting soil aggregates and mixing fresh litter into the soil. Consequently, it should help intensify erosion to displace C-rich surface soil (Janzen, 2006).

Along with routine agricultural activities, overgrazing and overharvesting of forests and grasslands (identified as C sinks) can seriously degrade terrestrial ecosystems (Everendilek et al., 2004). Annually, about 120 Pg C is removed by global ecosystems from the atmosphere, while about 119 Pg C is re-emitted into the atmosphere through plant respiration (60 Pg C), soil respiration (55 Pg C), and biomass burning (4 Pg C) (Dirmeyer et al., 2010). Because of this natural feedback, sinks and sources of C in ecosystems can generally maintain a dynamic balance. Moreover, the combined effects of various processes (e.g., (1) net primary (and secondary) productivity, (2) humification, decomposition, and mineralization of SOM, and (3) anthropogenic disturbances) exert an influence on the source–sink interactions of C. A rapid and large-scale shift in land use and land cover is considered the primary cause that disturbs C cycling in soil. Over the past few decades, ~200 Pg C was estimated to have been released into the atmosphere due to undesirable changes in land use (Scholes and Noble, 2001).

The atmospheric concentration of CO_2 has risen from 280 ppm in 1750 to 397 ppm in 2014. Without appropriate action, current projections suggest that the concentration should continue to rise by as much as 500–1000 ppm by the year 2100 (Kuske et al., 2013). Furthermore, over the same period, atmospheric concentrations of CH_4 and N_2O have increased from about 700 to 1745 ppb and from 270 to 314 ppb, respectively (Kuske et al., 2013). Presently, the average atmospheric increase in C is 4 Pg year^{-1}, and the global mean temperature is rising in excess of the critical rate of 0.1 °C per century beyond which the earth system cannot adjust (Fig. 1) (Taub, 2010). Concurrently, surface precipitation is increasing at a rate of 0.5–1% per decade in the mid- and high latitudes of the Northern hemisphere and decreasing at a rate of 0.3% per decade in the subtropics (Lal, 2004). Such abnormalities have also contributed to denudation of the SOC pool. Sudden changes in the precipitation characteristics have made the soil more prone to water erosion, disrupting the biogeochemical cycles of water and other components (C, N, P, and S).

Organic inputs play a vital role in managing the soil C pool by replenishing the SOC stock depleted via harmful agricultural practices. Moreover, restoration and rejuvenation of grassland and forest ecosystems should substantially improve the SOC pool, thereby compensating for C loss through mineralization. In addition, bioenergy-based products have considerable ecological benefits by improving soil and water quality and increasing the net economic return to an agrarian society, while reducing net emission of greenhouse gases as an indirect effect (McLaughlin et al., 2002; Liebig et al., 2005). However, less diverse agricultural activities have a negative impact on soil quality. Furthermore, some sophisticated technologies (such as crop residue management, conservation tillage practices, and legume-based cropping systems) are useful strategies in terms of sequestration of C sinks in arable lands.

In light of a significant interaction between organic inputs and SOC dynamics, the strategic importance of organic agriculture in mitigating the buildup of atmospheric CO_2 has been established. Therefore, this review describes the significance of various organic inputs in association with diverse strategies that can be implemented to effectively sequester C in the soil pool. In this context, the review is organized as follows:

- Land use and SOC dynamics (subsections: forestry, agriculture, industrialization, and urbanization)
- Effect of soil erosion and land degradation on the SOC pool
- Organic inputs and their significance from the perspective of plant science (green/farm yard manure, compost, and biofertilizers)
- Relation between soil physicochemical properties and organic inputs (soil physical properties, nutrient composition, soil organic carbon, and humic substances).

2. Land use and SOC dynamics

The net changes in current land use patterns are expected to contribute to about 1.1 ± 0.8 Pg C year^{-1} to the atmosphere (Fig. 1). The combined effects of land use patterns and their changes can influence SOM content considerably, as they exert control on common factors determining the soil system (e.g., quality of biomass input, biomass decomposition rates, and pace of organic matter stabilization) (Gelaw et al., 2014). Due to the alteration of land use patterns, the atmospheric emission of CO_2 in the US tripled in 2012 (37.8 Tg) compared to 1990 (USEPA, 2014). According to Janssesns et al. (2003), the terrestrial biomes in Europe contributed to the absorption of about 7–12% of the total anthropogenic emission of CO_2. In contrast, net C sequestration of 979.3 Tg CO_2 Eq. was recorded in the US at the same time (due to land use, land use change, and forestry activities). This accounts for an offset of 18.2%