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Modeling the dynamics of protected and primed organic carbon in soil and aggregates under constant soil moisture following litter incorporation

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A B S T R A C T

Incorporating plant litter into soil can replenish soil organic carbon (SOC) through physical protection mechanisms, such as formation of mineral-organic complexes and aggregates. Meanwhile, plant litter input may stimulate the decomposition of native SOC, known as the priming effect. It remains unclear how these physical protection mechanisms affect the priming effect, which further affects the SOC dynamics. Here, we present a novel model that can predict the dynamics of protected and primed organic carbon in soil and aggregates (PROCAAS). The PROCAAS model assumes that microbial activity will control the dynamics of both aggregate turnover and the priming effect following litter incorporation, and that litter-derived SOC will prime the decomposition of the native SOC pool as they are in the same location and in the same pool, either occluded in soil pores or associated with minerals. The PROCAAS model was well calibrated and validated using independent datasets of aggregate mass proportion and aggregated SOC contents in literature as well as soil respiration and the priming effect measured here during 76-day incubation with and without ^{13}C labeled litter. The model results showed that litter-derived SOC was protected predominantly through occlusion in macroaggregates, while the priming effect was originated mainly from mineral-associated SOC in macroaggregates. The dynamics of priming effect could be explained by the soil structural change from soil disaggregation during litter incorporation, via the formations of macroaggregates and microaggregates within macroaggregates, to the aggregate stability during litter decomposition. Our proof-of-concept model can form the base for incorporating these biophysical mechanisms underlying soil aggregation and the priming effect into future ecosystem models.

1. Introduction

Globally, agricultural lands produce more than five million tons of plant litter annually (Cherubin et al., 2018). If part of plant litter inputs can replenish soil organic carbon (SOC) of agricultural lands by just a few parts per thousand (4‰) each year, it would significantly increase food production, alleviate soil erosion and drought induced by climate change, and mitigate anthropogenic greenhouse gas emissions (Chabbi, 2017; Rumpel et al., 2018; Soussana et al., 2019). Although tillage applied for litter incorporation could destroy soil aggregates, litter decomposition can later promote the formation of stable aggregates and physically protect SOC through mineral-organic association and occlusion within pores of aggregates (Tisdall and Oades, 1982; Oades, 1984). These physical protection mechanisms play a significant role in governing the long-term dynamics of SOC (Balesdent et al., 2000; Schmidt et al., 2011; Dungait et al., 2012). Meanwhile, fresh litter C inputs can stimulate the decomposition of native SOC, known as the priming effect. The priming effect is often explained by microbial co-metabolism in which fresh C inputs provide readily bioavailable nutrients and energy for microbes to grow on SOC (Hamer and Marschner, 2005). A few

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