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Review

Different plant types for different soil ecosystem services

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ABSTRACT

Sequestration of atmospheric carbon (C) and erosion prevention are two ecosystem services that can be provided by plants through their impact on soil aggregation and organic matter. We propose a conceptual model aimed at generalizing the effect of plant material decomposition on C sequestration and soil water-stable macroaggregation (WSMA). We characterized plant material mineralization using a first order exponential plus linear equation in which parameter *b* describes the mineralization rate of the labile C pool, followed by a low mineralization rate of the non-labile C pool (parameter *k*). We propose that there are two selected types of plant materials that have differential positive effects on soil organic C (SOC) or soil WSMA: type-*B* and type-*K* plant materials. During decomposition in soil, type-*B* plant materials present a high *b* parameter followed by low *k* and have a positive effect on SOC, whereas type-*K* plant materials show an inverse mineralization pattern and favor longevity of soil WSMA. In our field and laboratory experiments, the model for type-*B* plant material was pigeon pea [*Cajanus cajan* (L.) Millsp.] which was characterized by high lignin and N contents, and the model for type-*K* plant material was mature corn (*Zea mays* L.) residue which contained high levels of pentoses, the main component of hemicellulose. According to this model, type-*B* plants would be adequate in strategies aiming primarily at soil C sequestration, while type-*K* would be more appropriate in reducing a soil's susceptibility to physical degradation. Cropping or reclamation systems involving both plant types would contribute to both ecosystem services.

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1. Introduction

Plants can play a significant role in mitigating or preventing soil degradation and climate change through their effects on soil properties. Plants can reduce soil erodibility by stabilizing soil aggregates and can improve the sequestration of atmospheric C by increasing soil organic matter content, which is also a key parameter of soil fertility. Plants are successfully used for reclaiming degraded areas, such as eroding stream banks and unstable slopes (Polster, 2002). In agriculture, there are circumstances where the use of plants, such as winter cover crops, becomes a unique and efficient way to manage soil organic matter and associated physical properties, such as under no-tillage (NT) systems. Therefore, the use of plants for improvement of key soil attributes, apart from their potential economic value, can represent a strategy of increasing the benefits of NT.

The choice of plant species as part of management strategies aiming at increasing both soil aggregation and SOC content in terrestrial ecosystems has often been considered (e.g., Angers et al., 1999; Bhattacharyya et al., 2009). Plants represent the primary resource for SOC formation (Kögel-Knabner, 2002; Cotrufo et al., 2013) and the decomposition of their residues stimulates biochemical and biological processes contributing to soil aggregation (Martins et al., 2013). Many experimental studies have been conducted to study plant effects on SOC content

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(e.g., Bayer et al., 2000; Conceição et al., 2013) and soil aggregation (e.g., Angers et al., 1999; Bandyopadhyay et al., 2010). However, there is still a need for a unifying conceptual model describing plant effects on SOC accumulation and soil aggregation. A general model would contribute to the development of adequate mitigation/prevention strategies involving choices of plant type for addressing specific issues such as soil physical degradation or soil C depletion or both.

In the present study, we seek to synthesize recent findings on the dynamics of plant-induced changes in soil WSMA and soil organic matter properties through a conceptual model based on key biochemical attributes of plant tissue composition.

2. Model

Our conceptual model is based on a first order exponential plus linear equation characterizing plant C mineralization (Fig. 1). This equation has two parameters describing two different plant material organic pools: the mineralization rate of the labile C pool (parameter *b*), followed by the mineralization rate of the non-labile C pool (parameter *k*) (Martins et al., 2013). We propose that there are two contrasting types of plant materials that would have differential positive effects on SOC and soil WSMA: type-*B* and type-*K* plant materials. During decomposition in soil, the type-*B* plant material presents high *b*, followed by low *k*, whereas type-*K* plants present an inverse mineralization pattern, i.e., low *b* followed by high *k*. According to this classification, type-*B* plants would be adequate in soil management strategies aimed at C sequestration, whereas type-*K* plants would be more useful at reducing soil physical degradation via soil erosion.

The model implies that (i) the sustained decomposition of type-*K* plant residues during the latter period of decomposition stimulates long-lasting WSMA; (ii) there is selective preservation of organic C derived from the intense initial transformation of N-rich substrates of type-*B* plant materials and characterized by microbial residue accrual; (iii) the persistence of these effects would be dependent on the constant renewal of C input from plants; (iv) the effects of substrate biochemical composition on SOC retention and aggregation are decoupled and aggregate size-dependent processes.

3. Discussion

Our model suggests that there can be decoupling between the formation of long-lasting WSMA and SOC accumulation under the influence of decomposing plant material. We argue that each process is favored by different types of plant material. Type-*B* plant material is more favorable to SOC accumulation, whereas type-*K* stimulates the persistence of WSMA. In our microcosm experiments, the model plant for type-*B* material was pigeon pea, a legume characterized by high lignin and N contents, and the model for type-*K* material was mature corn residues (Martins et al., 2013). As a grass, mature corn tissues present a hemicellulose fraction containing high levels of pentoses present as arabinoxylans (Schädel et al., 2010). It is a common observation that grasses provide higher soil WSMA compared to other crops under different soil and climatic conditions (e.g., Martens, 2002; Obalum and Obi, 2010; Martins et al., 2012a, 2013). On the other hand, many reports show that frequent inclusion of legumes in cropping systems contribute more to soil C sequestration compared to their less frequent use (e.g., Drinkwater et al., 1998; Bayer et al., 2000; Boddey et al., 2010).

In a recent study under field conditions, plant-induced differences in WSMA of an Oxisol under NT management were attributed to the presence of plant-derived pentose in the soil, rather than total SOC variation (Martins et al., 2012a). This observation was consistent with the results of a microcosm experiment showing that WSMA of the same soil was closely related to the soil pentose contents, with no relationship with the remaining SOC, after 180 days of incubation (Martins et al., 2013). These results are in agreement with Abiven et al. (2008) who suggested that the hemicellulose (which contains pentosans) is the organic fraction of the plant material that contributes to soil aggregate stability longevity. Therefore, we emphasize in our model that the influence of plant materials in the longevity of soil WSMA is controlled by decomposition of hemicellulose-derived pentosans.

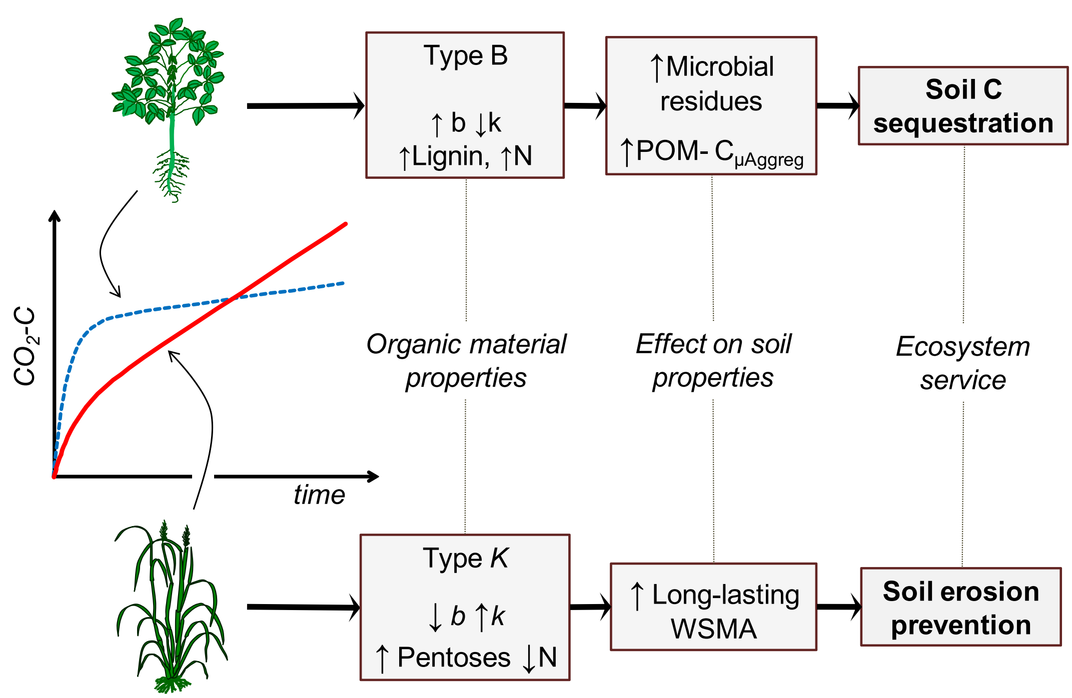

Fig. 1. Conceptual model for describing the plant-induced changes in soil organic C and water-stable macroaggregation (WSMA). This model is based on a first order exponential plus linear equation characterizing the C mineralization: $CO_2\text{-}C(t) = C_0[1 - \exp(-bt)] + kt$, where C_0 is the size of the labile fraction of plant material, *t* is time, *b* is the coefficient of the mineralization rate for the labile C pool, and *k* is the mineralization rate of the non-labile C pool of plant material. POM-$C_{\mu Aggreg}$: soil C present as particulate organic matter in microaggregates.