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Frequent Applications of Organic Matter to Agricultural Soil Increase Fungistasis

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ABSTRACT

Soil-borne plant pathogens are among the most important limiting factors for the productivity of agro-ecosystems. Fungistasis is the natural capability of soils to inhibit the germination and growth of soil-borne fungi in the presence of optimal abiotic conditions. The objective of this study was to assess the effects of different soil managements, in terms of soil amendment types and frequency of application, on fungistasis. For this purpose, a microcosm experiment was performed by conditioning a soil with frequent applications of organic matter with contrasting biochemical quality (*i.e.*, glucose, alfalfa straw and wheat straw). Thereafter, the fungistasis response was assessed on four fungi (*Aspergillus niger*, *Botrytis cinerea*, *Pyrenochaeta lycopersici* and *Trichoderma harzianum*). Conditioned soils were characterized by measuring microbial activity (soil respiration) and functional diversity using the BIOLOG EcoPlates™ method. Results showed that irrespective of the fungal species and amendment types, frequent applications of organic matter reduced fungistasis relief and shortened the time required for fungistasis restoration. The frequent addition of easily decomposable organic compounds enhanced soil respiration and its specific catabolic capabilities. This study demonstrated that frequent applications of organic matter affected soil fungistasis likely as a result of higher microbial activity and functional diversity.

Key Words: biological control, disease suppression, microbial activity, microbial functional diversity, organic C, soil-borne pathogens

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INTRODUCTION

The productivity of agro-ecosystems is often limited by the activity of soil-borne plant pathogens. Such destructive microbes are often difficult to control with conventional approaches such as the use of fungicides and resistant crop varieties (McDowell and Woffenden, 2003). The ban of methyl bromide and other soil fumigants (Martin, 2003), coupled with the progressive restriction on the use of fungicides by European Union (EU) policy, promoted the research for alternative disease control methods. In this context, the use of organic amendments such as animal and green manure (Himmelstein *et al.*, 2014), organic wastes (Croteau and Zibilske, 1998), composts (Noble and Coventry, 2005), and more recently biochar (Bonanomi *et al.*, 2015) has been proposed as a reliable and cost effective approach for control of soil-borne pathogen. Different mechanisms have been proposed to explain organic amendment suppression of soil-borne plant diseases, including increase of soil microbial activity (Hoitink and Boehm, 1999), enhanced competition for resources that cause fungistasis (Lockwood, 1977), release of fungitoxic compounds during organic matter decomposition (Tenuta and Lazarovits, 2004), and induction of systemic resistance in the host plants (Zhang *et al.*, 1998). Unfortunately, the suppressive capability of organic amendments is often inconsistent and many studies report an increase of disease incidence after organic matter application (Bonanomi *et al.*, 2007). To eliminate these inconsistencies and successfully apply organic amendments it is necessary to understand the ecological factors that affect the spread of pathogenic as well as antagonistic microbes.

Fungistasis is defined as the capability of soils to inhibit the germination and growth of soil-borne fungi when optimal abiotic conditions (*e.g.*, temperature, moisture, pH, redox potential, *etc.*) occur (Watson and Ford, 1972). Studies on fungistasis have focused on the sensitivity of different soil fungi (Lockwood, 1977), the magnitude of fungistasis of different soil types (Xu *et al.*, 2004), the role of volatile inhibitory compounds

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(Zou *et al.*, 2007) and the relationships between soil microbial diversity and fungistasis (De Boer *et al.*, 2003; Wu *et al.*, 2008; Bonanomi *et al.*, 2014). Two mutually non-exclusive hypotheses have been proposed to explain fungistasis in soil: (i) the presence of inhibitory compounds with antifungal activity (Berendsen *et al.*, 2012), including volatiles (Smith, 1973), and (ii) the depletion of labile organic C compounds and nutrients due to the intense competition among soil microbes (Steiner and Lockwood, 1970).

In a recent review, Garbeva *et al.* (2011) suggest that the manipulation of soil fungistasis can be a powerful mechanism for limiting soil invasion by plant pathogenic microbes, and consequently become an useful tool for control of plant pathogens. In this regard, a potential strategy is to enhance fungistasis strength so that germination and growth of pathogens is reduced even in the presence of a host plant. This should be achieved by the application of organic amendments, increasing the capability of microbial community to withdraw soil resources and reduce the window of opportunity for soil-borne plant pathogens in bulk soil and rhizosphere. However, translating this ecological concept into a practical application is challenging. In fact, from the farmer perspective, the use of organic amendments may appear as a non-profitable strategy to strengthening soil fungistasis because this property, in the short-term, is reduced or even lost after pulse organic matter applications (Adams *et al.*, 1968; Lewis and Papavizas, 1977). In this regards, Bonanomi *et al.* (2013), by using 42 organic matter types, showed that the quality of organic amendments is a major controlling factor of soil fungistasis. In detail, a dramatic relief of soil fungistasis was observed when soil was amended with lignin-poor, but labile C-rich substrates. Indeed, the interplay between organic amendments, fungistasis and disease suppression is complex and remains obscure because few studies explored the effects of the quality and application frequency of organic matter on such a soil property.

A large variety of organic matter types including composts, crop residues, peats and organic wastes are widely used as soil amendments. However, the majority of published studies investigated the immediate biological and agronomic effects of organic amendments by adding them only once at the start of the experiment, or by repeating the treatment usually once a year in long-term field trials (Diacono and Montemurro, 2010). This likely resembles the ordinary agricultural practices; *i.e.*, organic amendments are added once or twice in growing season. In contrast, in natural ecosystems, leaf and root litters are continuously delivered during the plant cycle, although a large inter-season variability can occur (Incerti *et al.*, 2011). In agroecosystems, organic C inputs follow complex dynamics in relation to soil management which varies with crop successions, types and application frequency of organic amendment. The few studies concerning the legacies between application frequency of soil amendments with soil functions investigated the effect on basal respiration (Nett *et al.*, 2012), enzymatic activities (Stark *et al.*, 2008), C and N mineralization (Mallory and Griffin 2007; Duong *et al.*, 2009), often using organic compounds as a model. Previous studies demonstrated that soils subject to frequent applications with organic amendments, compared with unamended soils, have a higher and more active microbial biomass (Kandeler *et al.*, 1999) and enhanced enzymatic activities (Dick *et al.*, 1988). For instance, decomposition of newly added organic amendments was differentially affected by soil amendment history (SH) in relation to the biochemical quality of the substrates. A limited effect was reported for high-quality, fast decomposing materials, but a strong influence was observed in case of recalcitrant, slow-decomposing substrates (Nett *et al.*, 2012). The rationale behind this model is that recalcitrant substrates require a more active and specialized microbial community, whereas easily decomposable materials can be rapidly decomposed by generalist microbial communities (Balser and Firestone, 2005). However, because of the lack of experimental studies, it is not known whether and how the application frequency of organic amendments affects fungistasis. The aforementioned considerations about basic soil processes and SH suggest that conditioning soil with repeated organic matter input, by stimulating the activity of the resident microbial community, can positively affect soil fungistasis. In other words, it can be expected that a soil frequently amended with organic matter can become an ecosystem where organic C and nutrients are more efficiently utilized by the resident biotic members. As a result, the large but transient resource pools that occur after a pulse organic matter application can be reduced in amount (*i.e.*, reduced fungistasis relief) and availability in time (*i.e.*, increased fungistasis restoration) so that the windows of opportunity for pathogens are reduced.

The objective of this study was to assess the effects of different soil management, in terms of soil amendment types and frequency of application, on fungistasis. For this purpose, a microcosm experiment was performed by conditioning a soil with different amounts and types of organic matter with contrasting biochemical qualities. Thereafter, the fungistasis response