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The effects of fresh and stabilized pruning wastes on the biomass, structure and activity of the soil microbial community in a semiarid climate

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ABSTRACT

The incorporation of organic amendments from pruning waste into soil may help to mitigate soil degradation and to improve soil fertility in semiarid ecosystems. However, the effects of pruning wastes on the biomass, structure and activity of the soil microbial community are not fully known. In this study, we evaluate the response of the microbial community of a semiarid soil to fresh and composted vegetal wastes that were added as organic amendments at different doses (150 and 300 t ha^{-1}) five years ago. The effects on the soil microbial community were evaluated through a suite of different chemical, microbiological and biochemical indicators, including enzyme activities, community-level physiological profiles (CLPPs) and phospholipid fatty acid analysis (PLFA). Our results evidenced a long-term legacy of the added materials in terms of soil microbial biomass and enzyme activity. For instance, cellulase activity reached 633 μg and 283 μg glucose g^{-1} h^{-1} in the soils amended with fresh and composted waste, respectively. Similarly, bacterial biomass reached 116 nmol g^{-1} in the soil treated with a high dose of fresh waste, while it reached just 66 nmol g^{-1} in the soil amended with a high dose of composted waste. Organic amendments produced a long-term increase in microbiological activity and a change in the structure of the microbial community, which was largely dependent on the stabilization level of the pruning waste but not on the applied dose. Ultimately, the addition of fresh pruning waste was more effective than the application of composted waste for improving the microbiological soil quality in semiarid soils.

1. Introduction

Soil degradation is one of the main threats to arid and semiarid ecosystems and is characterized by loss of organic matter (OM) as a consequence of scarce vegetal growth (García et al., 1996). Yet organic matter plays a central role in maintaining key soil functions and global biochemical cycles. Furthermore, it is an essential determinant of soil fertility and resistance to erosion (Ros et al., 2006; Fonte et al., 2009). In scenarios of soil degradation, the application of organic wastes to the soil constitutes an environmental and agricultural means to maintain soil organic matter, reclaim degraded soils and supply plant nutrients. The fresh organic matter present in organic wastes stimulates the development and activity of the soil microbial community (Yang et al., 2003; Bonilla et al., 2012) and can incorporate also exogenous microbes to the soil environment. Moreover, organic matter improves the physical structure of the soil and contributes to carbon sequestration (Foley and Cooperband, 2002; Ros et al., 2006). Nevertheless, the biostimulant capacity of organic amendments depends on their chemical composition (Ajwa and Tabatabai, 1994).

Agricultural and gardening activities produce large quantities of vegetal residues and by-products. These residues cause serious environmental and visual pollution such as formation of pests that can move to new crops, gas emissions, toxic particle accumulation, and so on (Blázquez et al., 2011); particularly in agricultural areas like southeast Spain. A sustainable valorization of this vegetal waste is therefore need. It has been observed that the incorporation of green wastes derived from pruning into soil may improve long term soil fertility and quality (Doran et al., 1988). Moreover, composting these vegetal wastes can also help to reduce waste production. Composting is one of the best known processes for the biological stabilization of solid organic wastes. It involves the accelerated degradation of organic matter by microorganisms under controlled conditions, in which the organic material

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undergoes a characteristic thermophilic stage that allows for sanitization of the waste through the elimination of pathogenic microorganisms (Lung et al., 2001). For this reason, compost is considered to be an environmentally safe and agronomically advantageous organic amendment that stimulates soil microbial activity and crop growth (García et al., 1994; Pascual et al., 1997; Van-Camp et al., 2004). Changes in the properties of organic amendments after composting may directly affect the composition and activity of the soil microbial community (Bastida et al., 2008; Pérez-Piqueres et al., 2006; Cross and Sohi, 2011). However, despite the fact that the restoration of arid and semiarid lands with organic wastes has been a hot topic in recent years, the long-term impact of pruning wastes on the microbial community remains poorly understood.

Several microbial and biochemical indicators are commonly used for evaluating the effects of organic amendments on the soil microbial community. For instance, phospholipid-fatty acid analysis (PLFA) is often used as an indicator of microbial biomass and community structure in soil (Frostegard et al., 1993; Bastida et al., 2008; Williams and Hedlund, 2013). Moreover, community-level physiological profiles (CLPP) are useful for detecting the functional responses of soil microbial communities to a variety of organic amendments (Bastida et al., 2013; Ng et al., 2014).

Soil enzymes play key roles in the biochemical functions of organic matter decomposition and nutrient cycling (Nannipieri et al., 1990; Waldrop and Firestone, 2004). Hence, it has been suggested that soil enzyme activity can be used as an indicator of soil fertility and microbial activity (Badiane et al., 2001) and for evaluating the influence of organic amendments on soil properties (Ng et al., 2014). A better understanding of the enzymes involved in carbon cycling is necessary to improve our knowledge concerning the processes leading soil restoration after application of organic amendments. Given the chemical complexity of soil organic matter contained in plant wastes, including polymeric carbon sources (i.e., cellulose, lignin, etc.), a suite of soil enzymes are involved in organic matter transformation and should be considered in restoration studies. For instance, polyphenol oxidase is involved in lignin degradation and plays an important role in soil C stabilization by favoring humic substance formation through the catalysis of polyphenol oxidation reactions (Weand et al., 2010). Cellulase breaks down cellulose into cellobiose, a sugar composed of two glucose units; and β-glucosidase, which hydrolyzes polymers of plant residues such as cellobiose.

In this experiment, vegetal pruning wastes and compost made from this material were applied as organic amendments in different doses (150 and 300 t ha^{-1}) to a semiarid soil five years ago. We aim to evaluate the long-term effects of these vegetal wastes at different doses and with distinct levels of stabilization (fresh or composted) on the chemical and microbiological properties of a semiarid soil. For this purpose, several indicators of microbial biomass and activity are used in this study. We hypothesized that compost would improve microbial activity and biomass more than fresh waste in the long-term because compost contains a more-stabilized organic matter. Moreover, we expected greater microbial biomass and activity in the plots amended with the highest dose of organic amendments. High doses would incorporate a higher amount of organic carbon and nutrients in soil and promote a most-intense development of the microbial community.

2. Methods and materials

2.1. Study area, experimental design and soil sampling

This study was developed in an experimental field located in Santomera, in the Province of Murcia (southeast Spain) (38° 10′ 91.5″ N; 1° 03′ 79.8″ W), in an area that is greatly affected by soil degradation processes. The area is subjected to a semiarid climate with a mean annual rainfall of less than 300 mm and a mean annual temperature of 18 °C. The soil is classified as Haplic Calcisol (FAO, 2006) and its texture is clay-silt-loam. The pH of the soil is 8.5, its electric conductivity is 250 μS cm^{-1}, its water holding capacity is 40.2 g 100 g^{-1} and the bulk density is 2.57 g cm^{-3}. There was no vegetation growing on the soil at the beginning of this study. The soil was abandoned from agriculture use 20 years ago. This factor, together with inadequate climate conditions of the area and water scarcity, leads soil degradation processes in SE-Spain (López Bermúdez and Albaladejo, 1990). These processes are strongly related to a loss of organic matter (García et al., 1994).

In November of 2008, 15 experimental plots (16 m^2 each) were established in the experimental area. The following treatments were established in replicate plots ($n = 3$): 1) soil with fresh vegetal waste at 150 t ha^{-1} (VW150); 2) soil with fresh vegetal waste at 300 t ha^{-1} (VW300); 3) soil with composted vegetal waste at 150 t ha^{-1} (CVW150); 4) soil with composted vegetal waste at 300 t ha^{-1} (CVW300); and 5) soil without the addition of organic wastes (Control). The chemical properties of the organic amendments are presented in Table 1. Organic materials were incorporated into the first 15–20 cm of soil with a rotovator. The green waste originated mainly from pruning from urban parks. Compost was produced with this type of pruning waste mixed with pig slurry at 3:1 (w:v), for decreasing C/N ratio. For each soil sampling, six subsamples per plot were randomly collected with hand-driven probes to a depth of 15 cm in March of 2014. These subsamples were then mixed to constitute a single sample per plot. The samples were sieved to <2 mm and stored at 4 °C until analysis. Samples were analyzed within one month after sampling.

2.2. Chemical parameters, basal respiration and enzyme activities

Total organic carbon (TOC) was determined using a C analyzer (Thermo Finnigan Flash EA 1112). Water-soluble carbon (WSC) was determined through soil extraction (2 h shaking with a soil:distilled water ratio of 1:5), followed by centrifugation, filtration, and analysis of the extract solution on a C analyzer for liquid samples (Shimazdu 5050 A). An aqueous solution 1:5 (w:v) was used to measure pH in a pH meter (Crison mod.2001, Barcelona, Spain).

Humic substances were extracted with a 0.1 M, pH 9.8 sodium pyrophosphate solution (w/v ratio = 1:5) by mechanical shaking for

Table 1
Characteristics of organic amendments added (VW: fresh vegetal waste; CVW: composted vegetal waste).

	VW	CVW
pH	7.90	8.88
Electrical conductivity (mS)	718.33	787.67
Carbohydrates (ppm)	1671.82	309.13
Water soluble C (ppm)	9601.19	2659.29
Total organic C (%)	34.22	19.32
Humic acids (mg kg^{-1})	1617.01	5241.57
Fulvic acids (mg kg^{-1})	2188.67	1527.34
Polyphenols (μg coumaric ac g^{-1} soil h^{-1})	1300.80	258.75
NH_4 (mg kg^{-1})	<2.5	<2.5
Available P (mg kg^{-1})	135.9	141.40
Total P (g 100 g^{-1})	0.06	0.13
NO_3 (mg kg^{-1})	<5.0	<5.0
N (g 100 g^{-1})	0.87	1.03
Available K (meq 100 g^{-1})	4.65	14.13
Total K (g 100 g^{-1})	0.38	0.75
Cd (mg kg^{-1})	<0.5	0.50
Cu (mg kg^{-1})	14.0	59.60
Cr (mg kg^{-1})	2.7	17.40
Ni (mg kg^{-1})	1.1	7.20
Pb (mg kg^{-1})	1.9	30.50
Zn (mg kg^{-1})	70.6	149.80
(Cellulose + hemicellulose + lignin) (g 100 g^{-1})	35.15	6.76