Applied Soil Ecology 50 (2011) 27–36

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Resistance and resilience of the soil microbial biomass to severe drought in semiarid soils: The importance of organic amendments

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ARTICLE INFO

Article history:
Received 3 February 2011
Received in revised form 10 May 2011
Accepted 30 July 2011

Keywords:
Drought
Rewetting
Semiarid soils
Organic amendments
Microbiological properties
Soil enzymes

ABSTRACT

Changes in mean global air temperature and precipitation patterns, leading to longer drought periods and more extremely dry years, are predicted. The objective of this work was to assess whether a long period of severe drought can affect the growth and activity of the microbiota of a semiarid soil, as well as the effect of organic amendments on soil resistance and resilience to this severe drought. A soil incubation experiment was carried out over 60 days, under controlled conditions (25 °C and 60/80% day/night relative humidity), with two treatments: unamended (US) and amended (AS) with manure compost (100 t ha^{-1}). Two levels of irrigation were imposed: (1) well-watered (MUS and MAS), the soil being maintained at 60% of its water-holding capacity (WHC), and (2) dry, without irrigation (DUS and DAS). Then, a single level of irrigation was established for 37 days, dry soils being irrigated under the same conditions than well-watered soils, to assess soil resilience to this period of drought. Under well-watered conditions, the soil water-soluble nitrogen contents were 73 and 88% higher, the microbial biomass carbon 63 and 48% higher, alkaline phosphomonoesterase activity 46 and 32% higher, β-glucosidase activity 16 and 25% higher and urease activity 30 and 19% higher for the US and AS treatments, respectively, compared with the dry conditions at the end of the experimental period. Furthermore, the organic amendment helped the soil to retain moisture and encouraged the growth and activity of soil microbial populations. However, a 2-month drought seems insufficient to destroy the native microbial biomass in the arid soil used in this study, indicating that it is well adapted to adverse climate conditions. Thus, microbiological and biochemical parameters experienced a rapid recovery after soil rewetting, DUS and DAS showing values similar to MUS and MAS, after rewetting, highlighting the resilience of this type of soil against drought stress.

1. Introduction

In semiarid areas, such as those of Mediterranean regions, ecosystem functioning is adapted to the severe climatic conditions (high temperatures and scarce rain events). However, changes in mean global air temperature and precipitation patterns, leading to longer drought periods and more extremely dry years, are predicted (IPCC, 2001), and in these Mediterranean ecosystems the strongest effects of climate change may well be related to more-severe drought conditions, since water stress is already the principal constraint in these areas (IPCC, 2001; Sardans et al., 2006). Therefore, it is of interest to know whether the increasing severity of drought might affect the microbial biomass and activity in these drought-adapted soils of semiarid ecosystems and whether soil microbiota are able to recover after long periods of severe drought.

The soil microbial community is involved in numerous ecosystem functions, such as nutrient cycling and organic matter (OM) decomposition (Schimel, 1995; Sowerbya et al., 2005). Its potential for rapid growth and turnover means that the microbial community is a more-reactive component of a terrestrial ecosystem to external stress than plants and animals (Panikov, 1999). The study of multiple biological and biochemical properties is often suggested since, because they are very responsive, they act as indicators of soil disturbance and provide immediate and precise information on small changes occurring in soil (Dick and Tabatabai, 1993; Ros et al., 2003). There is increasing evidence that microbial activity has a direct influence on the stability and fertility of ecosystems, microbiological parameters being sensitive indicators of both the response of ecosystems to stresses, such as drought, and their recovery (Smith et al., 1993; Ros et al., 2003).

Soil microorganisms synthesise and secrete extracellular enzymes, which constitute an important part of the soil matrix. Enzymes play an important role in soil nutrient cycles and, consequently, factors influencing soil microbial activity will affect the

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doi:10.1016/j.apsoil.2011.07.014

production of the enzymes which control nutrient availability and soil fertility (Sinsabaugh et al., 1993). The decrease of enzyme activity in Mediterranean ecosystems due to more-severe drought conditions may have a negative effect on nutrient availability, which may compromise enzyme current structure (Sardans and Peñuelas, 2005).

The use of organic amendments to compensate for losses of organic matter is a common practice in semiarid soils and it will be especially relevant in the near future for Mediterranean ecosystems, where longer and more-severe droughts are expected (Sardans and Peñuelas, 2005), since it will improve soil water-holding capacity (WHC), porosity and water infiltration rate. In addition, organic amendments affect several critical soil functions, such as plant nutrient availability and the diversity and activity of soil organisms (Kütük et al., 2003; Pascual et al., 2007).

The response of an ecosystem to any stress has two components, resistance and resilience, whose combined effects determine what ecologists refer to as "ecosystem stability". Resistance is the inherent capacity of the system to withstand disturbance, whereas resilience is the capacity to recover after disturbance (Seybold et al., 1999; Griffiths et al., 2001). Several reports have described the resistance of organically amended soils to wet/dry cycles in incubations assays (Magid et al., 1999; Mamilov and Dilly, 2002; Pascual et al., 2007). However, to the best of our knowledge, studies on the effect of long drought periods on microbiological parameters are scarce and there are no studies of the capacity of the soil microbiota to recover after long periods of severe drought. Therefore, the objectives of this work were: (1) to assess, under laboratory conditions, whether a long period of severe drought can affect the growth and activity of the microbiota of a semiarid soil, as well as the influence of organic amendments on soil resistance to this severe drought and (2) to assess the capacity of these amended and unamended soils to recover after drought. In order to achieve these objectives, water stress was evaluated by measuring physicochemical (pH and EC), chemical (such as COT, WSC and WSN), general biological and biochemical parameters such as microbial biomass carbon (Brookes, 1995), basal respiration and ATP or ecophysiological quotients (Anderson and Domsch, 1993), as well as specific biochemical properties such as hydrolytic soil enzymes related to C, N and P cycles (Nannipieri et al., 1990; Ros et al., 2006). The use of these biological and biochemical properties is often suggested because they are very responsive and provide immediate and precise information on small changes occurring in soil (Dick and Tabatabai, 1993; Ros et al., 2003). There is increasing evidence that such parameters are also sensitive indicators of ecology stress, such as drought, suffered by a soil and its recovery, since microbial activity has a direct influence on the stability and fertility of ecosystems (Smith et al., 1993; Ros et al., 2003).

2. Materials and methods

2.1. Soil and compost

The soil used is a Calcic Kastanozem (FAO Soil survey staff, 1998), sampled in an experimental field located in Santomera (SE Spain). This area is affected by soil degradation processes such as hydrological erosion. Soil was sampled in the upper layer (0–15 cm), air-dried, and sieved to 2 mm. The main characteristics of the soil are shown in Table 1. The compost applied originated from the organic fraction of sheep manure composted in static horizontal reactors in which the material was ventilated mechanically.

2.2. Experimental design

The semiarid agricultural soil (400 g), sieved through a 2-mm sieve, was placed in 500-ml pots and amended with manure compost at rate of 100 t ha^{-1} (3.3 g compost/100 g soil) (Table 1). Two batches, including the unamended (US) and amended (AS) soil, were set out, moistened to 60% of the soil WHC and incubated for 60 days. One of the batches was watered periodically to maintain the WHC at 40–60% (watered soils, MUS and MAS). The other batch was left to dry without watering (non-watered soils, DUS and DAS). Pots were randomly placed in an incubation chamber with controlled temperature (25 °C) and humidity (60/80% days/night) conditions with three replicates per treatment and sampling time. Soil moisture was determined in all treatments along the experimental period. The soils were sampled destructively at the start of the experiment and after 6, 12, 20, 30, 45 and 60 days. After this dry period of 60 days, pots without irrigation (DUS and DAS) were rewetted to 60% of their WHC and then, both series of soils (watered and non-watered) were incubated for 37 days under irrigation conditions, watering periodically both series of soils (watered and non-watered) to maintain moisture at 40–60% of soil WHC as in the first incubation. Soil samples were collected for analysis after 2, 6, 13, 27 and 37 days. After sampling, the soil samples from both batches were homogenised thoroughly, sieved and stored at 4 °C for analysis. Chemical, microbial and biochemical parameters indicative of soil quality were measured in all these samples.

Table 1
Characteristics of the soil and compost employed in the experiment.

Parameters	Unit	Soil	Compost
pH_{H_2O}	–	8.56	8.99
Electrical conductivity	dS m^{-1}	0.33	2.46
Total carbonates	g kg^{-1}	553.50	ND
Active carbonates	g kg^{-1}	150.00	ND
Total organic carbon	g kg^{-1}	21.50	302.00
Total nitrogen	g kg^{-1}	1.40	20.50
Available phosphorus	mg kg^{-1}	74.15	623.00

ND, not determined.

2.3. Chemical, biochemical and microbiological analyses

The organic C (OC) content was assessed after oxidation with $K_2Cr_2O_7$ in concentrated H_2SO_4; the excess dichromate was determined with $(NH_4)_2Fe(SO_4)_2$ (Walkey and Black, 1934). Water-soluble carbon (WSC) and water-soluble nitrogen (WSN) was extracted by shaking for 2 h a mixture of soil and distilled water, at a 1:10 solid:liquid ratio, and then measured in a Shimadzu TOC5050A Total Organic Carbon Analyzer, after centrifuging and filtering through ash-less filter paper (Albet 145 110) (Walkey and Black, 1934). Total nitrogen content (N_T) was measured in a Leco Truspec CN.

Microbial biomass C (Cmic) was determined by the fumigation-extraction method (Vance et al., 1987). Ten grams of sample were fumigated with chloroform and another 10 g were not fumigated. Carbon was extracted with 40 ml of 0.5 M K_2SO_4, from fumigated and non-fumigated samples, and measured in the centrifuged and filtered extract using a soluble-organic C analyzer (Shimadzu TOC-5050A).

The basal respiration (BR) was analysed by placing 30 g of each soil sample, moistened to 50–60% of the WHC, in a hermetically sealed flask (closed flow system) equipped with a rubber septum for gas sampling. The samples were then incubated at 28 °C for 22 days and the CO_2 evolved was measured at given time intervals, with an infrared gas analyzer (Toray PG 100, Toray Engineering Co. Ltd., Japan) (Hernández and García, 2003).

The metabolic quotient (qCO_2) was obtained by dividing basal respiration by soil Cmic.

Adenosine triphosphate (ATP) was extracted from the soil using the Webster procedure (Webster et al., 1984) and measured as