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Short Communication

Stabilization of oxidative enzymes in desert soil may limit organic matter accumulation

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Abstract

Phenol oxidase and peroxidase activities in desert grassland soils at the Sevilleta Long Term Ecological Research site in central New Mexico (USA) are far greater than those of temperate soils. Activity is uniformly distributed across particles ranging from >1 mm to <38 μm and is unaffected by autoclaving, in contrast to hydrolase activities. The sorbed enzymes are readily extractable and inactivated by boiling. High soil pH, high stabilized oxidative enzyme activity, and carbonates create optimal conditions for degradation of phenols which increase decomposition potentials and limit soil organic matter accumulation.

Keywords: Soil enzyme activity; Phenol oxidase; Peroxidase; Desert grassland; Soil carbon

1. Introduction

The low concentrations of organic matter in desert soils are thought to result from low rates of net primary productivity (NPP) as a consequence of low precipitation. However, across latitudinal gradients, soil organic matter (SOM) concentrations reflect differences in decomposition potential relative to NPP (Horwath, 2007). Tundra ecosystems have annual NPP rates comparable to those of deserts, but accumulate large stores of SOM because decomposition rates are lower than NPP. Tropical forests have high rates of NPP but low SOM because decomposition potentials equal or exceed organic matter inputs.

Recent studies suggest that the decomposition potential of desert ecosystems has been underestimated. Because of photodegradation and physical disturbance, rates of surface litter decomposition are comparable to those of temperate ecosystems despite narrow opportunities for microbial growth (Austin and Vivanco, 2006; Gallo et al., 2006; Brandt et al., 2007). These processes also reduce the incorporation of surface litter into soil, contributing to low SOM stocks.

Another factor contributing to low SOM may be high soil oxidative potentials. Stursova et al. (2006) measured phenol oxidase and peroxidase potentials in desert grassland soils that were an order of magnitude greater than those reported for other biomes. These extreme values are related to soil pH. Because of carbonate accumulation, the pH of arid soils can reach 8 or above, which is optimal for these enzymes. However, pH alone may not account for the extreme values, given the low values for SOM and microbial biomass. To further characterize these activities, we conducted a series of trials to examine the distribution of oxidative potentials within the soil matrix and differentiate mineral from enzymic catalysis.

2. Site description

Soil samples were collected on Sevilleta National Wildlife Refuge (SNWR) in central New Mexico USA (34.58°N, 106.65°W). The site is desert grassland dominated by C_4 perenial grasses. Mean annual temperature is 13.2 °C; mean annual precipitation is 250 mm; aboveground net primary production averages 51 g m^{-2} y^{-1} (http://sev.lternet.edu). The soils are Typic Haplargids derived from piedmont alluvium. Soil texture in the upper 20 cm is 67.9% sand,

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22.5% silt and 9.5% clay, with 2% calcium carbonate (Kieft et al., 1998).

3. Sample collection

Soil (top 5 cm) was collected on 20 March 2007 from several locations and mixed to obtain a 5 kg composite sample, which was sieved through 2 mm mesh prior to further analyses. The water content of the soil collected was 0.5%. Subsamples of bulk soil were autoclaved twice for 30 min. Other subsamples were sorted through nested sieves (1000, 600, 355, 250, 150, 106, 75, 63, and 38 μm mesh).

4. Physical and chemical analyses

For fresh, autoclaved and size-sorted soils, moisture and organic matter content were determined by oven drying at 100 °C and combusting at 500 °C. Bulk soil pH was measured after overnight equilibration in 1:2 suspensions of air dry soil and and deionized water. For fresh and autoclaved soil, extractable phenols were assayed by adding 15 g soil to 30 mL of 50 mM, pH 8.2, bicarbonate buffer, and tumbling the suspensions on an orbital mixer for 1 h. After centrifuging the tubes at 3000*g* for 10 min, aliquots of the supernatant were pipetted into microplate wells for Folin–Ciocalteu assay (Zhang et al., 2006).

5. Extracellular enzyme assays

Phenol oxidase (EC 1.10.3.2) and peroxidase (EC 1.11.1.7) activities in soil suspensions and soil extracts were assayed using L-3,4-dihydroxyphenylalanine (DOPA) and DOPA + 0.3% H_2O_2, respectively (Stursova et al., 2006), and expressed as $\mu mol\,h^{-1}\,g\,OM^{-1}$. Enzymes sorbed to soil particles were solubilized in three sequential extractions, following the procedure described above for extraction of phenols. To compare the stability of oxidative enzymes to that of hydrolases, triplicate subsamples of fresh and autoclaved soil were also assayed for alkaline phosphatase (EC 3.1.3.1), β-1,4-glucosidase (EC 3.2.1.21), and leucyl aminopeptidase (EC 3.4.11.1) as described in Stursova et al. (2006).

6. Results

Soil characteristics were typical of those reported in previous studies (Kieft et al., 1998; Stursova et al., 2006; Crenshaw et al., 2007; Zeglin et al., 2007): pH 8.11, SOM 1.2%, texture 70% sand and 30% silt, inorganic carbon 1.5% (Table 1). No phenols were detected in extracts of fresh or autoclaved soil.

In bulk soil, potential activities for phenol oxidase and peroxidase averaged 288 and 416 $\mu mol\,h^{-1}\,g\,OM^{-1}$, respectively (Table 1). These values were in the low end of the range reported from previous studies of the Sevilleta grassland, which collectively encompass several sites and seasons over a 3-year period (1016 ± 1103 (S.D.) and $3056 \pm 3644\,\mu mol\,h^{-1}\,g\,OM^{-1}$, respectively, $n = 87$). Although the coefficients of variation (CV) appear high (109% and 119%, respectively), they are similar to the mean within-ecosystem CV for soil phenol oxidase (160%) and peroxidase (116%) activities, as calculated from a database that includes 40 sites across a broad range of biomes (Sinsabaugh et al., in preparation).

Table 1
Soil mass, organic matter content (OM) and potential activities of phenol oxidase (POX) and peroxidase (PER) by particle size

Size fraction	% Mass	% OM	POX	PER
Bulk soil	100	1.20	288 (86)	416 (37)
>1 mm	4.4	0.76	548 (135)	932 (82)
0.6–1 mm	13.6	0.69	416 (101)	764 (73)
355–600 μm	18.9	0.67	558 (131)	1148 (122)
250–355 μm	14.2	1.06	548 (71)	879 (65)
150–250 μm	22.3	1.23	266 (57)	488 (108)
106–150 μm	8.4	1.16	236 (67)	513 (109)
75–106 μm	10.0	1.47	400 (83)	367 (82)
63–75 μm	3.2	1.69	254 (99)	270 (112)
38–63 μm	3.5	1.98	73 (48)	173 (70)
<38 μm	1.4	3.37	318 (107)	312 (120)

Activities are mean values (±S.D.) in units of $\mu mol\,h^{-1}\,g\,OM^{-1}$ ($n = 7$).

Phenol oxidase and peroxidase activities per g OM were generally highest in the sand fractions (Table 1). When weighted by dry mass distribution, enzyme activities were similar across particle size classes: 71% of total soil phenol oxidase activity and 78% of total peroxidase activity was associated with particles >0.15 mm, which represented 73% of soil dry mass. This distribution is somewhat anomalous in that soil enzyme activities, particularly oxidative activity, is generally skewed toward the smallest particles, which have the largest sorptive surface area per unit mass.

Autoclaving had no effect on oxidative enzyme potentials of bulk soil, nor did it affect the extractability of sorbed enzymes (Table 2). In contrast, autoclaving inactivated 92.6%, 96.5% and 95.4% of alkaline phosphatase, β-glucosidase, and leucyl aminopeptidase activities, respectively. Oxidative enzyme activity extracted from autoclaved soils was destroyed by boiling, indicating that catalytic activity was enzymatic.

Peroxidase activity was more readily solubilized than phenol oxidase (Table 2). Extracted soil, after air drying and rewetting, had less phenol oxidase activity, but more peroxidase activity than the original sample. Because of steric hindrance and noncompetitive inhibition, enzymes sorbed onto particles may lose ~90% of their potential activity, so solubilization of a small fraction of sorbed enzyme can have a large effect on activity within a hydrated soil matrix (Quiquampoix et al., 2002).

7. Discussion

The oxidative potential of Sevilleta grassland soil is not only high compared to activities measured in other