ELSEVIER

Soil Biology & Biochemistry 37 (2005) 1419–1426

Soil Biology & Biochemistry

www.elsevier.com/locate/soilbio

Seasonal variations in enzyme activity and organic carbon in soil of a burned and unburned hardwood forest

R.E.J. Boerner*, J.A. Brinkman, A. Smith

Department of Evolution, Ecology, and Organismal Biology, Ohio State University, 1735 Neil Avenue, Columbus, OH 43210, USA

Received 25 June 2004; received in revised form 16 December 2004; accepted 20 December 2004

Abstract

This study examined variations in soil organic C content and the activity of acid phosphatase, α-glucosidase, phenol oxidase, chitinase, and L-glutaminase in ultisols of burned and unburned areas in *Quercus*-dominated forests in Ohio, USA. The low intensity, prescribed fires were conducted in April 2001, with temperature 10 cm above the forest floor averaging 160–240 °C. Sampling was conducted throughout the six month growing season (May–October) of 2003, two years after the fire. Organic C content in these ultisols varied between 20 and 30 g C/kg soil, and varied little through the growing season, except for a late season increase to ∼32 g C/kg soil in the burned areas. When enzyme activity was expressed per unit soil organic C, there was no statistically significant variation among sample dates in soil enzyme activity except L-glutaminase, which demonstrated a distinct maximum in activity in spring. Non-metric multidimensional scaling (NMS) ordination resulted in no clear separation of burned and unburned sample areas based on soil organic C and enzyme activity. When the growing season was divided into three segments (early spring, late spring/early summer, and late summer/early autumn), there was again a lack of separation between burned and unburned areas in the earlier two segments, whereas in the late summer/early autumn segment the burned and unburned areas were clearly separated on the basis of differences in soil organic C and L-glutaminase activity. As environmental factors (e.g. soil temperature, moisture) and substrate availability do not vary in parallel through the growing season in this region, seasonal patterns often differ among enzyme systems based on their predominant control mechanism. Sampling time during the growing season appears to have little effect on holistic judgments of fire effects based on soil enzymes, except under restrictive conditions.

Keywords: Acid phosphatase activity; α-Glucosidase activity; Phenol oxidase activity; Chitinase activity; L-glutaminase activity; Fire; Hardwood forest

1. Introduction

The history of the use of prescribed fire for forest management, restoration, and conservation dates to the 1940s, and is almost as long ago as the history of the policy and practice of fire suppression that led to the need for prescribed fire. In the late 1940s prescribed fire was adopted as an understory density and wildfire fuel management tool in coniferous forests in the southeastern US (Riebold, 1971). Since that time, the use of prescribed fire has grown to be continent-wide in extent and far more diverse in intent, with applications for purposes as diverse as wildlife conservation, wildfire hazard reduction, and ecosystem restoration. As the use of fire for restoration and conservation has grown, so has the need for robust, quantitative metrics of the effects of fire on the ecosystem as a whole, including soil quality and functioning.

Previous studies have demonstrated that soil biochemical parameters such as soil enzyme activities are sensitive indicators of stress on such ecosystems and have the potential to serve as robust measures of the health and sustainability of managed ecosystems (e.g. Bergstrom et al., 1998; Dick, 1994; Dick and Tabatabai, 1992). These enzymes serve as indicators of the activities of fungi, bacteria, and other soil organisms over periods of weeks prior to the soil being removed from the field. As such, they represent a holistic view of the acclimation response of the microbial assemblage to the suite of organic matter types and environmental conditions of the site over an ecologically-significant period of time.

* Corresponding author. Tel.: +1 614 292 6179; fax: +1 614 292 2030.
E-mail address: boerner.1@osu.edu (R.E.J. Boerner).

0038-0717/$ - see front matter
doi:10.1016/j.soilbio.2004.12.012

Fire often results in effects on organic matter and microbial community structure that can be detected by quantifying enzyme activity. For example, acid phosphatase activity, as an indicator of overall microbial activity, often decreases as a consequence of fire (e.g. Saa et al., 1993; Eivasi and Bayan, 1996; Boerner et al., 2000). Our previous studies of soil enzyme activities in forested ecosystems of southern Ohio (USA) demonstrated strong spatial patterns of variation within watersheds (Decker et al., 1999) and short-term effects of fire in some sites (Boerner et al., 2000). To date, however, we had not determined the degree to which these spatial and fire-induced variations were stable as soil microclimate and weather change through the cool, temperate growing season. Thus, the specific objectives of this study were to investigate (a) organic C content and activity of various enzymes variations through the growing season, and (b) the effects of a single, low intensity prescribed fire on organic C and enzyme activities as influenced by season of sampling.

2. Materials and methods

2.1. Study site and sampling design

The site of this study was located in Zaleski State Forest (82°22′W, 39°21′N) in Vinton County on the unglaciated Allegheny Plateau of southern OH, USA. The climate of the region is cool, temperate and continental with mean annual temperature and precipitation of 11.3 °C and 1024 mm, respectively (Sutherland and Hutchinson, 2003). The site was a block of approximately 140 ha of contiguous mixed-oak forest that developed following clear-cutting for charcoal production 100–150 years ago, and has not been managed or disturbed since that time (Sutherland and Hutchinson, 2003). The canopy was dominated by oak species (e.g. *Quercus alba*, *Quercus velutina*, *Quercus rubra*) and the subcanopy/understory by a combination of red maple (*Acer rubrum*), American beech (*Fagus grandifolia*) and black gum (*Nyssa sylvatica*).

The soils sampled in this study were predominantly Gilpin series silt loams (Ultisol: typic halpludult) formed in residuum and colluvium from Pennsylvanian age sandstones, siltstones, and shales (Boerner and Sutherland, 2003). These A horizons of these soils are strongly acidic (pH range 3.8–5.2), have low Ca:Al molar ratio (range 0.01–3.50), and this region is also subject to heavy chronic N deposition in precipitation (Boerner and Brinkman, 2003, 2004).

The study site was divided into four treatment units of 25–35 ha each, and treatment units were randomly allocated to four treatments: control, dormant season prescribed fire, thinning to pre-settlement basal area, and the combination of prescribed fire and thinning. We sampled each treatment unit for a full growing season prior to the imposition of treatments, and found no significant difference among the four treatment units in a range of physical, chemical, and biochemical soil properties (Boerner and Brinkman, 2004). The research described here took place in the control and prescribed fire units only, as the focus was on quantifying seasonality in these forests soils rather than assessing the full range of treatments. The effects of all four treatments one and four years after application on soil properties, vegetation, and wildlife are being analyzed as part of a national scale study replicated in thirteen areas across North America (National Fire and Fire Surrogates Network Study, www.ffs.fed.us) and will be published elsewhere in the near future.

Each watershed-scale treatment unit was stratified using a GIS-based integrated moisture index (hereafter, IMI) developed by Iverson et al. (1997) for this region. The IMI stratification was achieved through integration of elevation, aspect, hill shade profile, solar radiation potential, downslope flow accumulation, soil depth, soil water holding capacity, and curvature profile (Iverson et al., 1997). Areas occupying three IMI classes (xeric, intermediate, and mesic) were delimited within each treatment, and three 0.1 ha random, permanent sampling plots were established within each IMI class in each treatment unit ($N=9$ per treatment unit). For this study, only the sampling plots located in the intermediate IMI classes were used ($N=3$ per treatment unit), and all were located in midslope positions on SE or E facing slopes. In addition we restricted the sampling to the intermediate IMI class plots in order to focus on seasonality without confounding effects of landscape position. Analysis of the influence of landscape position and the interaction of landscape position and fire on soil properties based on 1–2 sampling dates/growing season are given by Decker et al. (1999), Boerner et al. (2000), and Boerner and Brinkman (2003, 2004).

The prescribed fire was conducted in April 2001, and maximum fire temperatures at 10 cm above the forest floor in the areas near we sampled were 160–240 °C (Iverson, unpublished data). This low intensity fire was designed to recreate natural dormant-season fires that characterized this system until fire suppression was introduced in the 1930s (Sutherland and Hutchinson, 2003).

From just before the deciduous trees came into leaf (mid-May) through litterfall (early October) of the 2003 growing season, soil samples were taken from each of the four corners of each sampling plot in the control and prescribed fire units. The four samples taken around each sample plot were separated by distances of 20–54 m, and sample plots were separated by random distances of 150–200 m. As previous studies of soil chemical and biochemical properties in this and neighboring sites have demonstrated that samples taken >10 m apart are spatially uncorrelated in soil organic matter content and microbial activity (Boerner and Brinkman, 2004), the four samples taken around a given sample plot were considered to be independent of each other. In addition, as the prescribed fire at this site was patchy in intensity and duration (Iverson, unpublished data),