Journal of Arid Environments 122 (2015) 37–45

Contents lists available at ScienceDirect

Journal of Arid Environments

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

Carbon and nitrogen mineralization of semi-arid shrubland soils exposed to chronic nitrogen inputs and pulses of labile carbon and nitrogen

George L. Vourlitis*, John S. Fernandez

Department of Biological Sciences, California State University, San Marcos, CA 92096, USA

ARTICLE INFO

Article history:
Received 15 March 2014
Received in revised form
7 February 2015
Accepted 10 June 2015
Available online 20 June 2015

Keywords:
Atmospheric N deposition
Chaparral
Coastal sage scrub
Microbial respiration
N retention
N saturation
Urban ecosystems

ABSTRACT

Semi-arid shrublands experience chronic anthropogenic nitrogen (N) inputs and episodic pulses of N and carbon (C). Chronic N deposition can cause N saturation, leading to soil acidification and N loss; however, some ecosystems experience acidification and N loss before N saturation while others exhibit an increase in N retention with prolonged N deposition. These divergent responses may be due to variations in soil N and C availability and microbial activity. We tested whether labile C and/or N pulses affected microbial activity (respiration and net N mineralization) in soil exposed to chronic N input. We hypothesized that C pulses would increase microbial activity, but that pulsed and chronic N enrichment would decrease activity. We found that a C pulse stimulated microbial respiration and net N immobilization, while pulsed and/or long-term N enrichment significantly increased N accumulation but not microbial respiration. Nitrate retention was highest in soil exposed to a C pulse and chronic N enrichment, indicating substantial capacity for microbial N retention with sufficient labile C availability. Our data suggest that N retention in semi-arid shrublands is driven more by spatial and temporal variations in labile C availability than exceedance of N storage capacity.

1. Introduction

Atmospheric N deposition adds an estimated 25–45 kgN ha^{-1} yr^{-1} to semi-arid shrublands of the South Coast Air Basin of southern California, which includes parts of Los Angeles, San Bernardino, and Riverside counties (Padgett et al., 1999; Fenn et al., 2003a). These high N inputs increase N availability through direct fertilization and N mineralization (Michalski et al., 2004; Sirulnik et al., 2007; Vourlitis and Zorba, 2007; Vourlitis et al., 2007, 2009). Increases in N availability also cause tissue and litter N-enrichment and a decline in C:N ratios (Fenn et al., 2003b; Vourlitis and Fernandez, 2012), an increase in net primary production (NPP) (Pasquini and Vourlitis, 2010; Vourlitis, 2012), and changes plant species composition (Zavaleta et al., 2003; Vourlitis and Pasquini, 2009). However, there may be a threshold of N input, or a "critical load" (Cresser, 2000), where the ecosystem capacity to utilize and immobilize N is exceeded (Groffman et al., 2006). Under such conditions, ecosystems are thought to be N-saturated (Fenn et al., 1998), with additional N inputs resulting in soil acidification and large N losses from gaseous (NO, N_2O) efflux and NO_3^- leaching (Skeffington et al., 2007; Fenn et al., 2008; Homyak and Sickman, 2014).

Finding these thresholds has been elusive because the ecosystem capacity to store and process N inputs depends on a variety of factors such as climate, vegetation and soil type, topography, interactions with other nutrients, disturbance history, and soil C storage and availability (Cresser, 2000; Goodale et al., 2005; Lovett and Goodale, 2011). For some ecosystems, N leaching and acidification have been shown to increase immediately after N addition (Vourlitis and Fernandez, 2012) even though NPP and N storage continue to increase (Vourlitis, 2012), while for others, NO_3 losses have consistently declined over decades even though anthropogenic N deposition continues (Goodale et al., 2005).

One mechanism that may help explain these divergent trends is the interaction between soil N and C availability and microbial N retention. For example, NO_3^- losses in stream flow reportedly decline rapidly with an increase in dissolved organic C concentrations (Goodale et al., 2005), and ecosystem N retention is positively correlated with mineral soil C concentration and C:N ratio across

* Corresponding author.
E-mail address: georgev@csusm.edu (G.L. Vourlitis).

http://dx.doi.org/10.1016/j.jaridenv.2015.06.007
0140-1963/

diverse ecosystems (Templer et al., 2012). Litter inputs have been shown to increase microbial activity but lead to a decline in net N mineralization because of an increase in microbial N demand (Miller et al., 2005; Biudes and Vourlitis, 2012). The addition of labile C can also reduce nitric oxide (NO) and nitrous oxide (N_2O) emissions (Sanchez-Martin et al., 2008) because of microbial N immobilization.

Resource availability in southern California is highly variable, and often N, C, and water become available as a rapid and ephemeral pulse that is driven by episodic rainfall events (Miller et al., 2005). This is especially true for N inputs from anthropogenic N deposition, because most of these N inputs (90%) are in the form of dry deposition that rapidly becomes available as a pulse following the first rainfall event (Fenn et al., 2003a). Here though, resource variations are happening at two different frequencies, one is a short-term *pulse* where C, water, and N are changing rapidly as a function of rainfall variation, while the other is a chronic *press* where soil resources (N) are increasing cumulatively over time (Smith et al., 2009). Pulse and press perturbations in soil resources are likely to affect microbial activity and ecosystem N retention differently. For example, microbial responses to short-term soil water or C pulses result in large but transient increases in microbial respiration, especially in semi-arid and arid ecosystems (Miller et al., 2005; Borken and Matzner, 2009; Jenerette and Chatterjee, 2012). However, frequent soil wetting and drying (Miller et al., 2005; Borken and Matzner, 2009) or increases in soil C (Jenerette and Chatterjee, 2012) act to diminish the microbial response to soil resource pulses, suggesting that there is an interaction between pulse and press perturbations in soil resource availability. Pulses of labile C and nutrients may cause rapid increases in microbial growth, and therefore C use efficiency, but over time the pulse-driven increase in C use efficiency can decline because the maintenance costs associated with growth increase (Sinsabaugh et al., 2013). Thus, it is unknown whether soil microorganisms would respond to C and N pulses in a similar manner under chronically high versus low N inputs (Smith et al., 2009).

Given the potentially strong controls of available C and N on microbial activity and N retention, and the temporally variable soil resource dynamics in southern California shrublands, the objective of this investigation was to quantify how pulses of soil N and C availability affect short-term variations in microbial activity in soils exposed to chronic low and high N inputs. To fulfill this objective, we conducted a short-term (14 day) laboratory C and N resource pulse experiment using soil that was exposed to ambient and elevated N inputs for over 7 years. We hypothesized that pulses of labile C would increase microbial respiration and N retention, but that short-term (pulse) and long-term (7 year) N enrichment would decrease microbial respiration and N retention.

2. Materials and methods

2.1. Site descriptions and field experimental design

Soil used for the laboratory incubation experiment was collected from plots that are part of a long-term field experiment designed to assess the effects of chronic dry season N enrichment on ecosystem C and N cycling of semi-arid chaparral and coastal sage scrub (CSS) shrublands (Vourlitis et al., 2009; Vourlitis and Fernandez, 2012). Field plots were located at the Santa Margarita Ecological Reserve (SMER: 33°29′N: 117°09″W) and the Sky Oaks Field Station (SOFS: 33°21′N: 116′34W). SMER is a CSS stand located in the SW Riverside County, California, USA at an elevation of 338 m (Vourlitis et al., 2009). The main vegetation consists of the semi-deciduous shrubs *Artemisia californica* Less. (California sage) and *Salvia mellifera* Greene (Black sage), which account for 96% of the total aboveground biomass (Vourlitis and Pasquini, 2009). Soil is a sandy clay loam of the Las Posas Series derived of igneous and weathered Gabbro material with an average bulk density of 1.22 g/cm^3 (Vourlitis et al., 2009). The site receives an average of 36 cm of precipitation annually, most of which is rainfall that falls between December and April. The most recent fire occurred approximately 40 years ago. SOFS is evergreen chaparral stand located in NE San Diego County, California, USA at an elevation of 1418 m. The stand was consumed by a lightning-induced fire in July 2003, and pre- and post-fire vegetation was composed of the evergreen shrub *Adenostoma fasciculatum* H. & A. (Chamise), with *Ceanothus greggii* A. Gray (Desert Ceanothus) as a sub-dominant. Together, these two species account for approximately 98% of the total biomass, with chamise accounting for most (90%) of the total biomass (Vourlitis and Pasquini, 2009). The site receives an average of 53 cm of precipitation annually consisting of rain with occasional snow that occurs during the winter and spring. The soil is sandy loam derived of the Sheephead Series with a bulk density of 1.34 g cm^{-3} (Vourlitis et al., 2009).

The field experimental layout at each site consisted of a randomized design where four-10 × 10 m plots received 50 kgN ha^{-1} yr^{-1} as granular NH_4NO_3 (2003-06), $(NH_4)_2SO_4$ (2007-09), or urea (2010-present) and an additional four-10 × 10 m plots served as un-manipulated controls (Vourlitis et al., 2009; Vourlitis and Fernandez, 2012). Estimated background levels of atmospheric N deposition are 6–8 kgN ha^{-1} y^{-1} (Tonnesen et al., 2007), with most (90%) accumulating as dry deposition during the summer and fall (Fenn et al., 2003a). Beginning in September 2003, N fertilizer has been applied once per year in September–October using a handheld spreader. At the time that the soil was collected, plots exposed to added N had been fertilized for 7 years and received a cumulative N input of 350 kg N/ha above ambient (Vourlitis and Fernandez, 2012).

2.2. Laboratory experiments

A 14 day laboratory incubation experiment was performed to assess the short-term response of microbial activity to exogenous N and C pulses. Soil samples were retrieved in January 2011 from the field plots (n = 2 subsamples/plot) and returned to the lab. Soil collected from each site was essentially dry at the time of collection (i.e., gravimetric soil water content = 0.30%). Soil was processed 2–3 days after collection by sieving subsamples through a 2 mm mesh to remove large organic and inorganic debris and mixing and homogenizing the subsamples to obtain one bulk sample per field plot. Ten grams of soil (fresh weight) was weighed into a sterile microcosm (50 ml Falcon centrifuge tubes, Becton, Dickinson and Company, Franklin Lakes, New Jersey), for a total of 5 microcosms per pulse treatment factor per field plot (a total of 20 per field plot).

The pulse experiment consisted of a fully-factorial design with four treatment factors: control (1.2 ml of DI water only; hereafter referred to as the W, water only, pulse treatment), N only (50 mgN/kg dry soil in the form of NH_4NO_3; hereafter referred to as the +N pulse treatment), C only (1.0 gC/kg dry soil in the form of sucrose; hereafter referred to as the +C pulse treatment), and a combination of the N and C levels above (hereafter referred to as the +C+N pulse treatment). The +C, +N, and +C+N treatments were added to the soils by dissolving the N and/or C into 1.2 ml of DI water, so each treatment combination had the same soil water content as the W pulse treatment. These treatment levels were selected based on observations from the experimental field plots. For example, the addition of 1.2 ml of DI water/tube brought the gravimetric soil water content to 12%, which is the typical soil water content observed during the wet season for these study sites (Vourlitis et al., 2009). The +N treatment level is based on that used in the