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The effect of landform on soil microbial activity and biomass in a Hyrcanian oriental beech stand

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ABSTRACT

Beech stands in Hyrcanian forests cover a hilly landscape with many topographical ridge–valley gradients or catenas. This study aims at providing important insights regarding the role of landscape shape and position on the drivers of soil microbial biomass and activity in these forest ecosystems. Variations in the depth profiles (0–15, 15–30 and 30–45 cm) of soil organic carbon (OC), total nitrogen (TN), soil water content (SWC), soil microbial respiration (SR), microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and metabolic coefficient (qCO_2) were evaluated at different slope positions (the summit, shoulder, back slope, foot slope and toe slope) along both concave (C-shaped) and convex-shaped (V-shaped) *catenas*. The results of our study evidenced that catena shape and slope position significantly influenced most of the parameters evaluated, confirming the importance of topography in creating heterogeneity in soil properties. In general, the significantly greater soil microbial biomass and activities observed in C-shaped with respect to V-shaped catenas, and in lower with respect to upper slope positions was related to higher SWC, OC and TN contents. We concluded that spatial variability in water and substrate availabilities are important components in determining microbial activities and the cycling of limiting nutrients for plant growth in different microsite ecosystems present in catenas.

1. Introduction

Soil properties are a product of soil-forming factors including topography, vegetation, climatic factors and ecosystem management. Soil biological and biochemical properties may respond more rapidly than physical and chemical properties to management activities and perturbations. The biological component of soil is responsible for many soil functions, including the decomposition of organic debris, nutrient cycling, stabilization of organic matter, and soil-atmosphere gas exchange (Paz-Ferreiro and Fu, 2016). Variations in microbial activity pose one of the greatest current uncertainties, and are particularly poorly understood in forest soils (McCarthy and Brown, 2006). The important role that soil microorganisms play in the nutrient and energy-flow relationships of natural, as well as anthropogenically influenced ecosystems, has given rise to the need for easily measured biological indicators of ecosystem development and disturbance. Microorganisms are involved in the mineralization of soil organic matter leading to carbon (C) loss by respiration, and incorporation into the soil microbial biomass pool. As the second largest C flux between terrestrial ecosystems and the atmosphere (Kuzyakov, 2006; Raich and Tufekcioglu, 2000), soil respiration plays an important role in regulating soil C pools and cycling in terrestrial ecosystems such as forests (Luo et al., 2001; McCarthy and Brown, 2006; Saiz et al., 2006). Representing CO_2 release from the soil surface combined by metabolic activity of roots and free living and symbiotic heterotrophs (Hogberg et al., 2001; Wan and Luo, 2003), soil respiration is influenced by soil temperature (Rustad et al., 2001), soil water content (SWC) status (Liu et al., 2002), plant growth (CurielYuste et al., 2004), and soil C and nitrogen (N) availability (FazFranzluebbers et al., 2002). Soil microbial biomass is considered as an important indicator of soil biological fertility (Powlson et al., 1987), and holds important implications on the biogeochemical cycling of C and N in terrestrial ecosystems (Jenkinson, 1988a, 1988b).

More recently, it has been demonstrated that at large scales the spatial variability of soil respiration and microbial activity is organized by topographic factors such as altitude, landscape morphology and structure (Riveros-Iregui and McGlynn, 2009), and influenced by changing patterns of precipitation, temperature and humidity (Paz-Ferreiro et al., 2010). Environmental perturbations that affect these biotic and abiotic factors can alter soil respiration and microbial activity, with consequent impact on terrestrial C cycling and feedbacks to climate change (Cox et al., 2000). Spatial heterogeneity is an intrinsic characteristic in terrestrial ecosystems (Hook and Burke, 2000). Topography is well documented to cause variability of soil temperature, SWC, plant growth, and soil C and N contents (Hook and Burke, 2000; Liu et al., 2007), and consequent variations in soil respiration and microbial activity with slope directions (Kang et al., 2006) or even with positions in the same slope (Ohashi and Gyokusen, 2007). Ridge-Hilly structures are

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two dominant landscape elements in catchments and generally have different SWC and groundwater table regimes, leading to differences in soil properties and vegetation characteristics (McGlynn and Seibert, 2003).

Numerous studies have evaluated the effect of landscape position and land management on physical, chemical and biological soil properties (Yimer et al., 2006; Udawatta et al., 2008; Paz-Ferreiro et al., 2009; Paz-Ferreiro et al., 2010; Abrishamkesh and Asadi, 2011). Past research has examined the spatial variability of soil microbial activity across landscapes and has revealed important spatial differences in CO_2 emissions. For example, altitude was found to be a significant factor that affected most soil biochemical properties (Yimer et al., 2006; Paz-Ferreiro et al., 2010), and microbial activity decreased with altitude (Margesin et al., 2009; Miralles et al., 2007). Soil water content is known to limit biological processes in soils (Li and Sarah, 2003), and also suppress the relative activity of certain groups of fungi, leading to a decrease in enzymatic activities and soil respiration (Allison and Treseder, 2008). Significant differences in soil respiration have been found between north- and south-facing slopes in the northern hemisphere (Kang et al., 2006), across wet and dry landscape positions (Pacific et al., 2009; Riveros-Iregui et al., 2008; Webster et al., 2008), and as a result of the distribution, quantity, and quality of organic matter (Webster et al., 2008).

While progress has been made in understanding the key factors controlling soil microbial activity, our understanding of the changes in soil microbial properties in different *catena* shapes and positions is still limited. Hyrcanian forests are ridge valley structures with combined topographic convergence and divergence, contrasting aspects, multiple landscape elements, variable groundwater dynamics (Fazlollahi Mohammadi et al., 2016b) and, this heterogeneity in topography results in a heterogeneous land cover. This study therefore aims at providing important insights regarding the role of landscape shape and position on the drivers of soil microbial biomass and activity in these forest ecosystems. We tested the hypothesis that topography, in particular catena shape and slope position, may influence SWC, soil organic C (OC) and total N (TN) contents, consequently regulating soil microbial biomass and activity.

2. Material and methods

2.1. Study area

This research was carried out within the TMU (Tarbiat Modares University) Experimental Forest Station located in a temperate forest of the Mazandaran province in northern Iran, between 36°31′56″ N and 36°32′11″ N latitude and 51°47′49″ E and 51°47′56″ E longitude. The region has a humid-temperate climate based on Köppen classification, with mean annual temperature, rainfall and relative humidity of 10.5 °C, 858 mm and 75.2%, respectively. The parent material is limestone and dolomite limestone (Sagheb Talebi et al., 2014), which belongs to the upper Jurassic and lower Cretaceous periods. Soils in the site were classified as Typic Endoaqualfs (Soil Survey Staff, 2014). Average cation exchange capacity of topsoils ranged from 10 to 12 $cmol_{(+)}kg^{-1}$, pH ranged from 6.0–7.5, and soil textures varied from silty clay loam to loam. Solum depths ranged from 87 to 150 cm depending on slope position. Although all soil profiles were generally characterized by O, A and B (Bt or Bht) horizons, those at the lower slope positions were more developed. Detailed soil profile descriptions for the site were provided elsewhere (Fazlollahi Mohammadi et al., 2016a).

Vegetation cover is characterized by a multistoried, multi-aged beech stand, dominated by *Fagus orientalis* Lipsky., *Carpinus betulus* L., *Alnus subcordata* C.A.Mey., and to a lesser extent, *Acer velutinum* Boiss. and *Tilia platyphyllos* Scop. Other tree species present in the area include *Quercus castaneifolia* C.A.Mey., *Cerasusavium* Moench., *Fraxinus excelsior* Bovéex. and *Acer cappadocicum* Gled. The density of the three dominant tree species was highest at lower slope positions and tended to decrease upslope (Fazlollahi Mohammadi et al., 2016b).

2.2. Data and sample collection

In the summer of 2013, we established a total of 30 quadrats at the site that encompassed two *catena* shapes and five catena positions. First we selected six catenas, three with a concave slope (called C-shaped hereafter) and three with a convex slope (called V-shaped hereafter). For each catena, five slope positions were located (the summit, shoulder, back slope, foot slope and toe slope), along a transect 20 m in width (Fig. 1). Aspect values were assigned to one category: northeast, in order to standardize aspect direction. At each of the five positions, a central point was delineated using a Garmin GPS model. Once transects were established, the elevation and slope of each position were recorded to verify field observations. From each slope position we collected composite soil samples from three depths (0–15, 15–30 and 30–45 cm). Samples were mixed completely, and roots and organic debris removed by hand. An aliquot was air dried and ground to < 2 mm for the determination of physical and chemical properties.

2.3. Soil analyses

Soil water content was determined on fresh soils by measuring weight loss after drying at 105 °C for 24 h. Soil OC was determined on air dried samples using the Walkley-Black method (Allison, 1975), while TN was determined using a semi-Micro-Kjeldahl technique (Bremner and Mulvaney, 1982). For the determination of soil respiration, soil microbial biomass C and N the collected fresh soils were kept at 4 °C until analysis. Soil microbial respiration (SR) was determined by trapping the CO_2 evolved over a 3 day incubation at 25 °C in a 0.05 M NaOH solution, and titrating against 0.1 M HCl (Alef, 1995). Soil microbial biomass C and N (MBC and MBN respectively) were determined using the chloroform fumigation-extraction method (Brookes et al., 1985). Soil microbial respiration and MBC were used to calculate the metabolic quotient (qCO_2), which is the amount of CO_2–C produced per unit of microbial biomass carbon (Anderson and Domsch, 1986).

2.4. Data processing

Prior to statistical analyses, normality and equality of variances were assessed for the calculated dependent variables using the Kolmogrov-Smirnov and Levene tests. The effects of *catena* shape and slope position on measured parameters were analyzed with three-way ANOVA utilizing a split-plot design using the F-test in SPSS Ver. 20 software. The Duncan's test at $P < 0.05$ was used to compare means of the dependent variables significantly affected by slope position. Correlations between soil characteristics were determined by calculating Pearson's correlation.

3. Results

3.1. Statistical analysis

The results of our study indicated that *catena* shape, slope position and soil depth generally influenced most of the soil characteristics analyzed. Mean and range of values obtained are reported in Table 1. All soil characteristics evaluated (SWC, OC, TN, SR, MBC and MBN) except qCO_2 showed significant differences with *catena* shape, catena position and soil depth (Table 2). Moreover, for all soil parameters except qCO_2 there was a significant interaction between *catena* shape and slope position. Significant interaction between *catena* shape and soil depth was observed for SWC and N. In addition, the variations in TN, MBN and MBC were influenced by the interaction between slope position and