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The effects of topography on forest soil characteristics in the Oregon Cascade Mountains (USA): Implications for the effects of climate change on soil properties

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ABSTRACT

Forest soil measurements were made at over 180 sites distributed throughout the H.J. Andrews Experimental Forest (HJA) in the Oregon Cascade Mountains. The influences of both elevation and aspect on soil variables were measured in the early (1998) and late summer (1994). Increased elevation significantly increased soil moisture, mean annual precipitation, soil organic matter, labile C and mineralizable N, microbial activities, extractable ammonium, and denitrification potentials. In contrast, bulk density, pH and soil temperature (1998 only) were significantly lower at the higher elevations. Relative to labile C, mineralizable N was preferentially sequestered at higher elevations. Aspect significantly affected annual mean temperature and precipitation, soil moisture and temperature, soil organic matter, mineralizable N, extractable ammonium, denitrification, and microbial activities. There were no significant higher statistical interactions between elevation and aspect on climatic or soil factors. Soil organic matter (SOM) accumulation at higher elevations is likely driven by a reduction in decomposition rates rather that an increase in primary productivity, however, SOM accumulation on north facing slopes is probably due to both a decrease in decomposition and an increase in primary production. Models of climate change effects on temperate forest soils based on elevational studies may not apply to aspect gradients since plant productivity may not respond to temperature–moisture gradients in the same way across all topographical features.

1. Introduction

Predicting global climate change impacts on forest soils posses a significant challenge to forest ecologists and soil scientists. Soils contain vast quantities of sequestered carbon and nitrogen that could potentially be mobilized with global warming and/or changes in precipitation. Both moisture and temperature are known to be primary drivers for plant growth and litter decomposition (Perry, 1994). The balance between these two processes influences the cycling of soil organic matter (SOM) and associated microbial processes (Kirschbaum, 1995).

Current estimates suggest that soils contain approximately three times the carbon found in above-ground biomass and twice that in the atmosphere (Eswaran et al., 1993). Soil warming experiments (Van Clev et al., 1990; Lukewille and Wright, 1997) and measurements along altitudinal and latitudinal gradients (Trumbore, 1997; Garten et al., 1999) have been made to predict the effects of climatic change on soil properties.

A number of studies have addressed the impact of elevation on forest soils in tropical (Schuur and Matson, 2001) and boreal and sub-arctic forests (Sveinbjörnsson et al., 1995; Fisk et al., 1998) but there have been relatively few studies in temperate forests (Morecroft et al., 1992; Kneopp and Swank, 1998) and even fewer in the carbon laden forests of the Pacific Northwest (Powers, 1990). Studies have generally been based on a limited number of sites that provide little or no information about how elevation and aspect influence forest soil properties within the same watershed. In general, these studies have shown that as soils are warmed decomposition rates increase resulting in increased CO_2 production. This effect is especially strong at cooler temperatures where Q_{10} values are greater than those found at higher temperatures (Kirschbaum, 1995).

H.J. Andrews Experimental Forest (HJA) was chosen for a number of reasons: (1) there is approximately 60 years of meteorological, hydrological, biological and silvicultural data for this site which provides a historical perspective to the current study, (2) it is representative of coniferous forests of the Pacific

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Northwest (Greenland, 1994), (3) there is a relatively wide elevation gradient and (4) because of the relatively unpolluted prevailing winds from the Pacific Ocean, nitrogen deposition should be low; this avoids complications caused by high nitrogen deposition rates found in other mountain ranges such as those on the east Coast of the USA (Garten et al., 1999). Within the HJA, there is sufficient topographical variation to impact both mean annual temperature (4.6–9.7 °C) and precipitation (200–317 cm) which either directly or indirectly influenced SOM which ranged from 11.4 to 58.7% (1994) and 7.4 to 58.4% (1998).

The main objective of this study was to measure the effects of both elevation and aspect on forest soil properties. More specifically, our objectives were to demonstrate the effects of topography on the following carbon cycle components; SOM, litter depth, water soluble organic C, labile C, and field respiration as well as the following nitrogen cycle components; mineralizable N, extractable ammonium, and denitrification potentials. Since these factors are all influenced by microbial activity, we measured soil basal respiration rates, substrate-induced respiration (SIR), and β-glucosidase activities. A secondary objective was to measure these variables in a large spatial array over a large mountainous watershed so that krieged data maps of these variables could be generated. It is possible that these spatial arrays would show relationships that were not apparent from standard statistical analyses. At present, there is no similar study published that addresses our research objectives.

2. Materials and methods

2.1. Site descriptions

The HJA is located in the Oregon Cascade Mountains of Western Oregon with a relatively mild Mediterranean climate (Greenland, 1994). Its soils are derived from volcanic parent materials (Sollins et al., 1980) and includes a major drainage basin with elevations ranging from about 500 to >1500 m. Douglas fir (*Pseudotsuga menziesii* [Mirb] Franco) and western hemlock (*Tsuga heterophylla*) dominate below 1000 m while Mountain Hemlock (*Tsuga mertensiana* [Bong.] Carr.) and Pacific silver fir (*Abes amabilis*) dominate at elevations above 1000 m (Franklin and Dyrness, 1988). Stand ages ranged from old growth (typically 200–500 years) to recently harvested stands <15 years. When old growth is cut, remaining slash and debris were usually subjected to a light burn, thus leaving burnt stumps and old, decayed logs. These sites are typically replanted within 2 years with Douglas-fir, which represented the majority of trees present in all age classes. Two studies were conducted using essentially the same 180+ locations (Fig. 1). Sample sites were typically located at 0.5-km intervals along all accessible roads forming a sampling array representing all aspects, elevation, soil and vegetation types, and stand ages found on the HJA (Fig. 1). The first study was conducted in August 1994 (late summer) during the hottest and driest season when microbial activity should be at a minimum. The second study was conducted from 15 June to 7 July 1998 (early summer) when soils had higher moisture and were cooler than in August (Tables 1 and 2).

2.2. Sampling techniques

In 1994, one soil sample was collected and one set of field measurements were made at each location. In 1998, multiple samples were taken at 5-m intervals along a 45-m transect parallel to the road. This spacing was chosen because we previously determined from semivariograms that 5-m spacing provided statistically independent samples (Griffiths

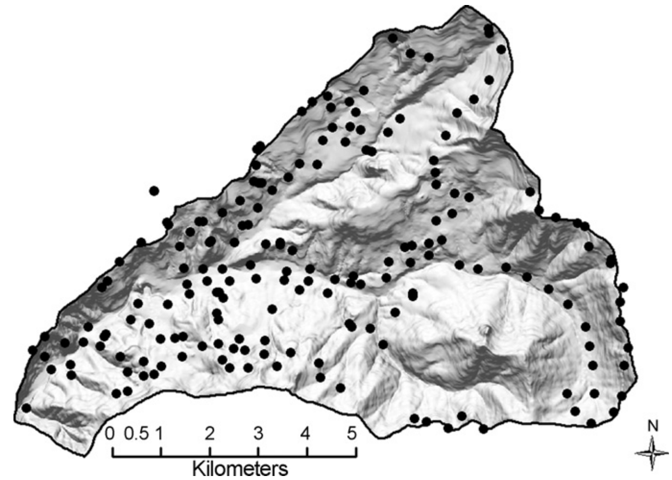

Fig. 1. Sampling locations on a topographical map of the H.J. Andrews Experimental Forest.

Table 1
Effects of elevation on forest floor and soil characteristics; 1994 late summer study

Variable	Units	Elevation		
		Low	Medium	High
Soil temperature	°C	14.5	15.3	14.6
Mean ann. temp	°C	9.2c	8.3b	6.2a
Moisture	%	33.8a	35.0a	48.9b
Mean ann. prec.	cm	217.1a	232.3b	283.8c
pH	pH	5.10b	4.99ab	4.88a
Bulk density	gdm/cm^3	0.62c	0.54b	0.46a
SOM	%	19.8a	23.8b	33.2c
WEOC	μgC/gdm	0.47	0.51	0.52
Field resp.	gC/m^2 day	1.45	1.32	1.53
Labile C	μgC/gdm	218a	238a	388b
Mineralizable N	μmolN/gdm	4.24a	4.64a	6.78b
Labile C:Min N		40.3	42.6	45.8
Extrac. ammon	μmolN/gdm	0.25a	0.30a	0.41b
Basal resp.	μgC/gdm h	0.13a	0.15ab	0.22b
SIR	μgC/gdm h	0.26	0.27	0.37
Denitrification	ngN/gdm h	4.39a	1.54a	7.52b
Alder sites	%	5.3	2.8	5.7

Low, medium and high elevation ranges were <1000 m, 1000–1500 m, and >1500 m, respectively.
Within a row, values that are significantly different at the $p < 0.05$ level are followed by different letters.

Table 2
Effects of elevation on forest floor and soil characteristics; 1998 early summer study

Variable	Units	Elevation		
		Low	Medium	High
Soil depth	cm	29.4	29.8	31.8
Soil temperature	°C	11.8c	10.0b	9.2a
Moisture	%	49.4a	50.8a	75.7c
pH	pH	5.14	5.15	5.14
Bulk density	gdm/cm^3	0.84c	0.75b	0.62a
Litter depth	cm	5.3	5.1	4.9
SOM	%	18.7a	21.7b	32.3c
Field resp.	gC/m^2 day	27.4	25.8	26.3
Labile C	μgC/gdm	281ab	284b	259a
Mineralizable N	μmolN/gdm	6.9a	7.5a	16.4b
Labile C:Min N		39.0b	38.3b	17.1a
Extrac. ammon	μmolN/gdm	0.16a	0.21a	0.91b
β-Glucosidase	μg/gdm h	0.100a	0.118ab	0.122b
Denitrification	ngN/gdm h	3.18a	1.70a	8.48b

Low, medium and high elevation ranges were <1000 m, 1000–1500 m, and >1500 m, respectively.
Within a row, values that are significantly different at the $p < 0.05$ level are followed by different letters.