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Pyrogenic carbon controls across a soil catena in the Pacific Northwest

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ABSTRACT

Since turnover times of pyrogenic carbon (PyC) are substantially slower than those of other organic carbon input to soil, it is considered an important constituent of the global C cycle acting as a C sink. In the Pacific Northwest vegetation fires regularly produce PyC, but its accumulation in soils is poorly quantified. Using mid-infrared spectroscopy (MIR) and partial least-squares (PLS) analysis in conjunction with ultraviolet photo-oxidation followed by nuclear magnetic resonance spectroscopy (UV-NMR) techniques, PyC contents were quantified for samples from soil profiles along a vegetation gradient. Sample locations included different forest types as well as sites under agricultural use. While PyC was most prevalent in the first 0.2 m with 7–24% of total soil organic C (SOC), it could be found in the subsoil of all locations. However, PyC concentrations did not change consistently with soil depth. Stock sizes were lowest at the Turkey Farm (0.71 kg m^{-2}; 10% of SOC) and Organic Growers Farm (1.14 kg m^{-2}; 8% of SOC) sites, presumably due to the pervasive combustion of grass and cereals. Among the forested sites, lower stocks were observed at sites with higher mean annual temperature (MAT) and lower mean annual precipitation (MAP) such as Metolius (1.71 kg m^{-2}; 15% of SOC) and Juniper (1.89 kg m^{-2}; 26% of SOC). In contrast, the highest PyC stocks were found under cooler and moister conditions at Cascade Head dominated by Douglas Fir (*Pseudotsuga menziesii* (Mirb.)) (5.66 kg m^{-2}; 16% of SOC) and Soapgrass Mountain (4.80 kg m^{-2}; 15% of SOC). PyC was only moderately related to non-PyC SOC, which comprises plant residues, their decomposition products and soil biota ($r^2 = 0.61$ and 0.44 for SOC with and without PyC, respectively), suggesting largely independent processes influencing production and disappearance.

1. Introduction

Fire has always been a factor of significant disturbance in forests and grasslands ecosystems in North America and affects between 273 and 567 Mha of grassland, savannah, and forest per year (Hicke et al., 2003). It is considered to be among one of the crucial driving forces of ecosystem processes and the global carbon (C) cycle (Hicke et al., 2003). Soil organic C (SOC) constitutes the largest organic C component in the global C cycle, and yet the largest uncertainty in predicting C turnover is the soil (Friedlingstein et al., 2006). During fires, part of the organic C is transformed into pyrogenic carbon (PyC) due to incomplete combustion (Forbes et al., 2006). This altered form of biomass C has a highly aromatic structure with few oxygenated functional groups which makes it a less preferred energy source for microbial decay (Preston and Schmidt, 2006). Therefore, it is considered to mineralize significantly slower than other litter input (Ansley et al., 2006). Hence, there is a strong potential for PyC to act as a significant C sink from the more rapid bio-atmospheric C cycle to the slower (long term) geological C cycle (Forbes et al., 2006). But information about the amounts of PyC in soils is still scant (Krull et al., 2008).

In the Pacific Northwest, the frequent occurrence of fire, mostly caused by dry lightning, is an integral factor in forested areas (Campbell et al., 2007) and can be understood as a persistent ecological process. For instance, under natural (unmanaged) conditions the Douglas fir forest in the Oregon Coastal Range has a fire regime of infrequent yet stand-replacing fires (Agee and Huff, 1987). Climate parameters are also likely to affect fire. The region is characterized by a Mediterranean climate where cool, wet winters provide abundant precipitation to grow forests while hot, dry summers bring about annual droughts which guarantee conditions for fire to spread easily even in years that prove wetter than average (Whitlock et al., 2003). In 2011 the Oregon Department of Forestry has calculated a running 10-year average of 388 fires burning nearly 13,000 acres (Oregon State Fire Statistics, 2011).

Between Oregon's forested mountain ranges lies a valley landscape, which prior to European settlement was dominated by wetland prairies and open oak savannah (Johannessen et al., 1971). While soils and climate of the region would be amenable to forest growth (Franklin and Dymess, 1988), the native Kalapuya people maintained the grassland

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by setting fire annual during the dry season (late summer to early fall) in order to increase the growth of food plants and to facilitate hunting (Boyd, 1986). In the nineteenth century, settlers converted most of the valley to agriculture. While fire was mostly suppressed at first, grassland farmers have rediscovered burning as part of their production in the 1940s. They commonly used fire as a management practice for disease, insect and weed control as well as improving ease of tillage and reducing immobilization of N fertilizer by decomposing plant litter. Regulated by the Oregon Department of Agriculture, the burning of cereal grain stubble has usually occurred between June and October when weather conditions are favorable for smoke dispersal. Information how such varied fire histories affects the distribution of PyC in landscapes is not known (Oregon Department of Agriculture, 2009).

Therefore, the objective of this study was to determine the spatial distribution of PyC stocks in soils across a landscape with different fire histories in order to understand its landscape scale distribution.

2. Materials and methods

2.1. Study sites

To gain a better understanding of how much PyC can be found in soils of this highly fire-affected landscape, soil samples were taken by horizon from eleven pits (Fig. 1). Soil properties and vegetation were described in the field. Fire-related data were obtained from The National Map LANDFIRE (2006a, 2006b). Geomorphological information was derived from the U.S. General Soil Map (Soil Survey Staff, Natural Resources Conservation Service. United States Department of Agriculture, 2006). Table 1 provides information regarding geographical position, elevation, mean annual temperature (MAT), mean annual precipitation (MAP) and fire return interval for all eleven locations. Further details concerning soil condition, vegetation and landscape features are described below.

The most eastern site is a Juniper (*Juniperus occidentalis* Hook.) shrubland located beyond the piedmont of the Cascade Mountains on a lava plain of layered flood basalt from the late Miocene. The well-drained soil has a loamy sandy to sandy texture and is more than 0.84 m thick. An ochric surface and a cambic subsurface horizon were discerned. Many fine to medium roots can be found throughout the pedon. Aside from Juniper, sagebrush (*Artemisia tridentata* Nutt.) and various grasses grow at the site.

Close to the Metolius River, another research site was established in a Ponderosa Pine (*Pinus ponderosa* Douglas ex C. Lawson) forest with scattered sagebrush and wild strawberry (*Fragaria vesca* L.) in the undergrowth. The soil depth is 1.22 m, well drained, of sandy to loamy sandy texture and has a distinct organic horizon with fibric material (0–0.02 m). Pumice gravel could be observed in all horizons with amounts between 1 and 4%. Roots were found to a depth of 0.67 m.

Four additional sites in the Cascade Mountains represent low- and high- elevation Douglas fir (*Pseudotsuga menziesii* (Mirb.)) stands. The Toad Creek site is situated on a glacial plain. The soil profile is more than 1.36 m deep and has a gravelly silt loamy surface texture. An organic (0–0.05 m), two umbric (0.05–0.18 m and 0.18–0.42 m) and two cambic (0.42–0.83 m and 0.83–1.02 m) horizons could be distinguished. The presence of noble fir (*Abies procera* Rehd.) and Pacific silver fir (*Abies

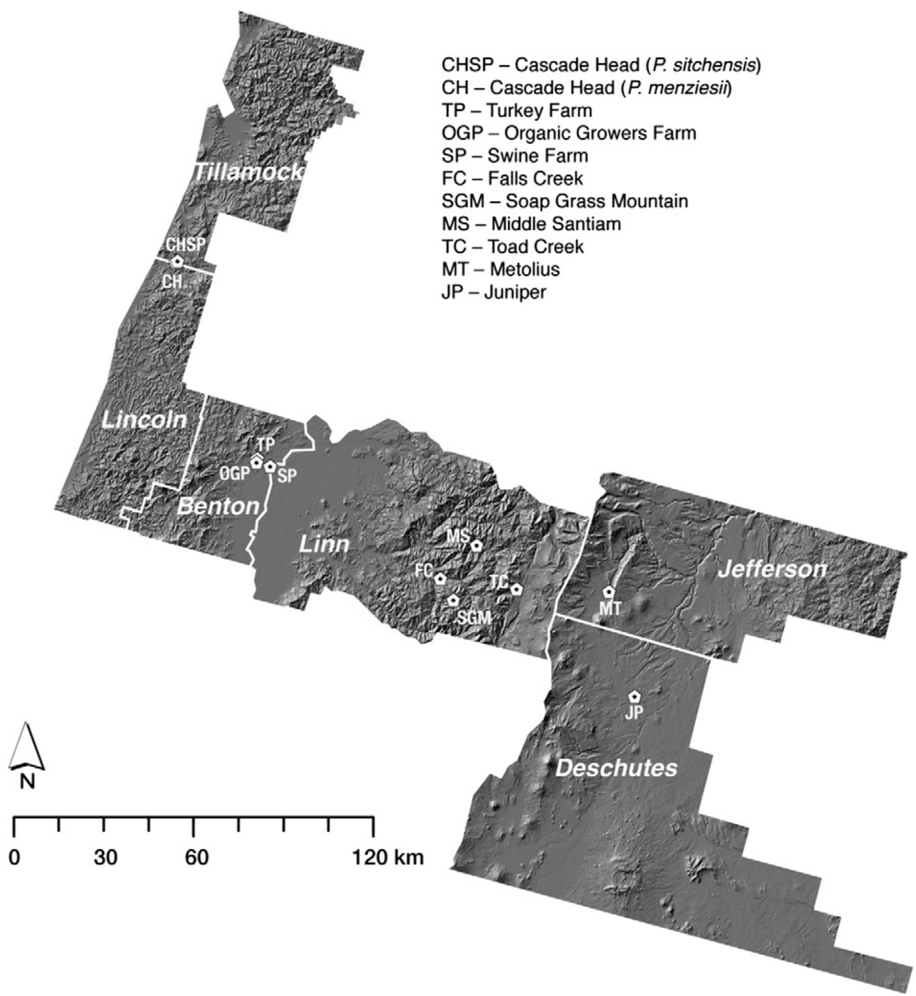

Fig. 1. Soil sampling locations along a vegetation gradient in Oregon. Source: Gesch (2007) and Gesch et al. (2002). Data available from U.S. Geological Survey.