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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*

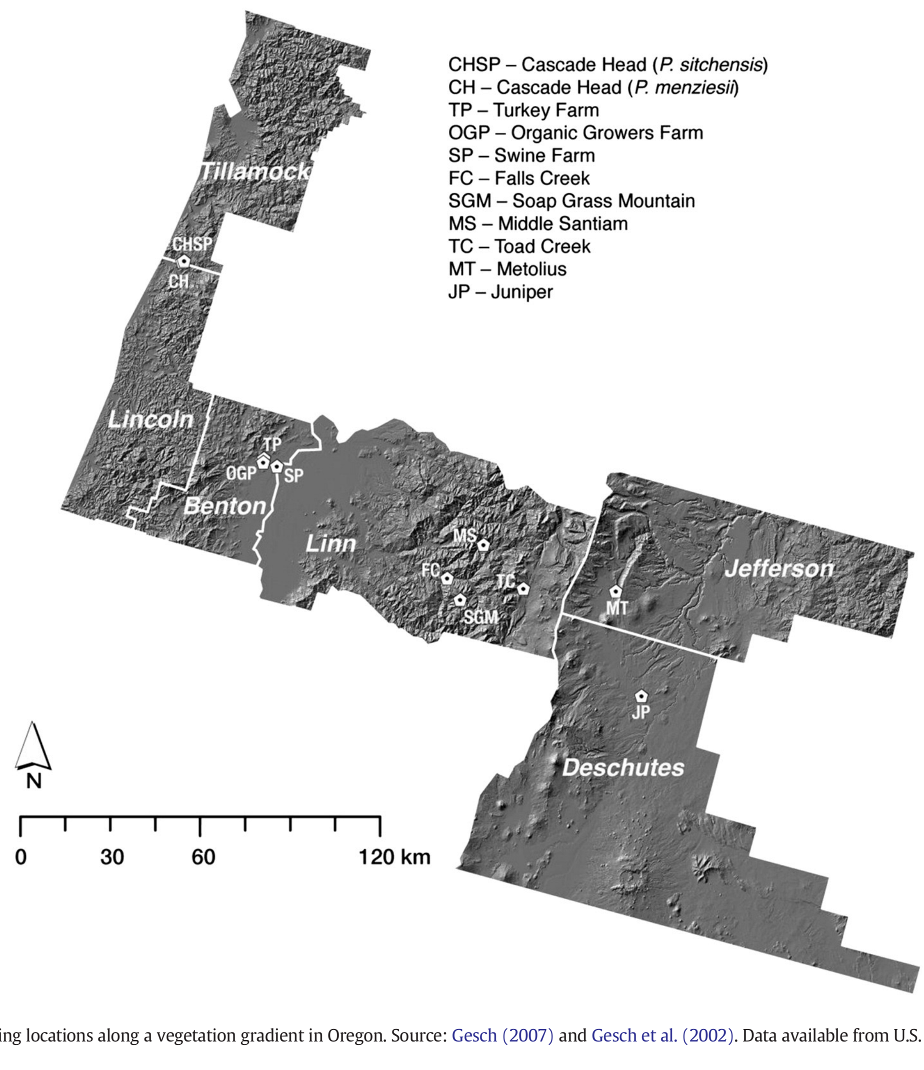

Fig. 1. Soil sampling locations along a vegetation gradient in Oregon. Source: Gesch (2007) and Gesch et al. (2002). Data available from U.S. Geological Survey.

Table 1
Climate, soil organic carbon (SOC) and pyrogenic carbon (PyC) stocks for the full soil profile in Oregon soils calculated by two different methods and auxiliary site related attributes.

Soil profile	Location	Elevation (m a.s.l.)	MAP (mm yr^{-1})	MAT (°C)	Fire return interval (years)	SOC Stocks (kg m^{-2})	PyC stocks constant (kg m^{-2})	PyC stocks spline λ=0.1 (kg m^{-2})	Diff. (%)	PyC[2] (% of SOC)
Juniper	44° 13' 24"; −121° 23' 53"	975	220	8.5	71–80	6.8	1.89	1.86	1.61	25.8
Metolius	44° 29' 24"; −121° 37' 53"	921	1980	8.1	21–25	13.0	1.71	1.69	1.18	14.9
Toad Creek	44° 25' 35"; −122° 1' 54"	1210	2040	7.6	126–150	20.1	2.87	2.43	1.65	15.4
Soapgrass Mountain	44° 20' 54"; −122° 17' 26"	1199	2760	6.1	201–300	28.2	4.80	4.85	−1.03	18.0
Middle Santiam	44° 30' 52"; −122° 15' 22"	477	1500	10.3	>1000	27.1	4.63	3.38	36.98	17.1
Falls Creek	44° 23' 46"; −122° 22' 46"	501	2010	10.3	301–500	22.1	1.44	1.54	−6.49	7.9
Organic Grower's Farm	44° 33' 55"; −123° 14' 27"	67	1143	11.7	21–30	10.2	1.14	1.12	1.17	8.1
Turkey Farm	44° 34' 33"; −123° 18' 20"	92	1143	11.7	21–30	9.2	0.71	1.08	−52.71	9.6
Swine Farm	44° 33' 54"; −123° 18' 13"	84	1143	11.7	21–30	21.2	4.93	4.91	0.38	24.0
Cascade Head (*P. menziesii*)	45° 2' 44"; −123° 54' 10"	275	2510	10.1	501–1000	24.8	3.91	3.93	−0.63	15.8
Cascade Head (*P. sitchensis*)	45° 2' 30"; −123° 54' 29"	210	2510	10.1	501–1000	34.6	5.66	5.61	0.92	15.7

[1]Natural fire interval classes for the region if fire was not suppressed (The National Map LANDFIRE, 2006b).
[2]PyC calculated using constant concentration within a horizon.

amabilis Douglas ex J. Forbes) at the site suggests a cryic soil temperature regime.

Geomorphology indicates the presence of a former cirque basin glacier at the Soapgrass Mountain site. The well-drained soil has an organic horizon (0–0.06 m), four horizons with umbric (0.06–0.95 m) and one horizon with cambic (0.95–1.29 m) properties. Total profile depth amounts to more than 1.41 m. Very smeary to moderately smeary organic matter could be found to a depth of 0.24 m. Next to Douglas fir, noble fir grows at the site and suggests a highly frigid to cryic soil temperature regime.

The Middle Santiam site is situated on a stream terrace. The soil is well-drained, 1.14 m deep (roots to a depth of 0.54 m) and has a silty loamy to fine sandy loamy texture. Two organic horizons could be distinguished; the first (0–0.05 m) comprises dark brown fibric material, the second (0.05–0.09 m) dark reddish brown sapric woody material. In the subsurface horizon, macroscopic pieces of char were found at 0.8 m depth. Oregon grape (*Mahonia aquifolium* (Pursh) Nutt.) dominates the undergrowth at the site.

At the Falls Creek site, the well-drained, fine loamy soil is covered by an organic horizon (0–0.05 m) that consists of slightly decomposed plant material. The two surface horizons possess umbric properties. Spherical Fe/Mn concretions were found between a depth of 0.18 and 0.28 m and comprised 60 to 35% (v/v). The soil profile is more than 1.65 m deep. Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) dominates the undergrowth at this Douglas fir stand.

Geomorphologically all three field sites in between the two mountain ranges lie on flood plains and valley terraces of the Willamette River. Drainage at the three locations is very variable from well drained (Organic Growers' Farm) to poorly drained (Turkey Farm) to moderately well drained (Swine Farm). The Organic Grower's Farm site has a slightly darker surface horizon (0–0.06 m) and two barely weathered subsurface horizons (0.06–0.4 m and 0.4–0.8 m). At the Turkey Farm site three surface horizons could be distinguished in the 0.25 m deep profile. The Swine Farm site is 1.2 m deep and shows the most developed soil profile: Under the surface horizon, a transitional horizon shows eluvial features. Beneath them three different argic horizons could be discerned. While the Organic Growers' Farm site lies next to fields of cultivated crops and irrigated agriculture, the areas surrounding the Turkey Farm and the Swine Farm site are surrounded by pasture. This may explain the predominance of annual graminoids at the first site and of perennial graminoids at the other two locations.

West of the valley, two more forested sampling sites were established in the Oregon Coastal Mountain Range. Even though they are not more than 2 km apart, the vegetation is very different, with one site being dominated by a Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), the other by a Sitka spruce (*Picea sitchensis* (Bong.) Carriére) forest. At both sites, soils are more than 2.0 m deep, well drained and have a thin organic horizon (0–0.03 m). Yet organic matter of smeary consistency can be found throughout the surface horizons to a depth of 0.3 m. Texture varies from silty loam in the surface horizon to silty clay (Sitka spruce stand) and clayey loam (Douglas fir stand) in the deeper horizons. While Fe/Mn nodules and concretions (2–5 mm in diameter) were found in the subsoil of the Douglas fir site, the subsoil at the Sitka spruce site merely showed common Fe/Mn stains. Both soil profiles showed umbric (0.03–0.56 m) and cambic (0.56–1.01 m) properties. Western hemlock was found in the undergrowth together with red and black huckleberry (*Vaccinium parvifolium* Sm.; *Vaccinium membranaceum* Douglas ex. Torr.).

2.2. Analyses

Soil profiles were divided into horizons based on morphological soil properties. A bulk sample was taken at the horizon midpoint from the face of the soil pit at each site. Sixty-seven collected samples were air dried, finely ground and subsequently analyzed for PyC content by CSIRO Adelaide, Australia. Finely ground samples (Retsch Ball Mill, MM400, Haan, Germany) were analyzed using mid-infrared spectroscopy where distinctive vibrations of molecules are associated with particular chemical functional groups (Janik et al., 2007). Spectra from 4000 to 500 cm^{-1} were recorded with a rapid scanning Fourier Transform spectrometer (Bio-Rad 175C) with an extended range KBr beam splitter and DTGS detector. Based on algorithms according to Haaland and Thomas (1988) partial least-squares (PLS) analysis of PyC was carried out with the PLSplus/IQ™ (Thermo-Electron GRAMS™) software package. The PLS calibration was derived from a standard set of soils that had previously been analyzed for PyC using ultraviolet photo-oxidation and HF treatment followed by solid-state ^{13}C nuclear magnetic resonance (NMR) spectroscopy (Janik et al., 2007). In terms of reliability, PyC was well predicted with an $R^2 = 0.86$ ($n = 121$) although when fifteen random samples were removed from the calibration set the prediction of those excluded samples using the new calibration set dropped slightly to $R^2 = 0.78$. Considering the small number of samples used in the calibration, this is an encouraging result. As PyC has a very specific chemical structure different to most other C species making up total SOC, the predictions are relatively robust. It must be noted that the calibration data set comprises only Australian soils and therefore may not be fully representative of samples collected from ecological zones found outside the Australian continent. An F-statistic based on Mahalanobis distance was used to determine how well the samples taken from the Oregon field sites were characterized in terms of the calibration set. No samples were significantly different from predictions based on the calibration set, although there were slight differences in significance for topsoils ($F \geq 1$) and subsoils ($F \geq 3$).

When calculating PyC stocks, measurements from the bulk sample are assumed to represent the average value for the soil over the depth interval from which it is sampled. However, soil attributes are rarely evenly distributed throughout a horizon. Consequently, horizon data appear to be inadequate in accurately representing depth functions of a given soil attribute (Jenny, 1941). The true soil attribute values are assumed to vary smoothly with depth. In order to receive more accurate predictions, equal-area quadratic splines have been tested on a variety of soil profile properties, including SOC, and found to be the best predictors of soil depth functions. The function f(x) is estimated from the point data choosing the f(x) which minimizes $\frac{1}{n}\sum_{i=1}^{n}\left(y_i-\bar{f}_i\right)^2+\lambda\int_{x_0}^{x_n}f'(x)^2dx$ (Bishop et al., 1999). The shape of the spline depends on the parameter λ, which balances fidelity to the measured data and the smoothness of the curve. The smaller λ is chosen the less weight is attached to the derivative of the minimizing function. That means the spline will remain closer to the measured data. Choosing a λ value that provides an acceptable compromise between fidelity and smoothness is indispensible (Bishop et al., 1999). In the context of this study λ values of 1, 0.1 and 0.01 were tested. Stocks were calculated by assuming that for each horizon the area under the spline estimates are equal to the percentage of PyC multiplied by the horizon thickness. Afterwards, the bulk density was taken into account, which was determined for each field site at every depth level using the STATSGO database (U.S. General Soil Map, 2006).

A Wilcoxon test for pair-wise comparison was applied to compare the results of both of these calculation methods. To see how PyC contents change within the soil profiles, a one-sided ANOVA was used. Depth function modeling with splines was implemented in MATLAB 8 (Mathworks, Natick, MA), while SPSS 20 (SPSS Inc, Chicago, IL) was used for statistical testing.

3. Results

PyC stocks varied greatly among the soil profiles; the highest overall value was found at the Cascade Head (*P. sitchensis*) site (5.66 kg m^{-2}), the lowest at the Turkey Farm site (0.7 kg m^{-2}) (Table 1). At all sites with exception of Turkey Farm and Organic Growers Farm, PyC stocks were highest in the topsoil and declined with depth, and PyC could be detected throughout the profile, in some cases to a depth of 1.4 m. However, this decrease is not continuous throughout all of the profiles (Fig. 2). Amounts for the topsoil were highest at the Soap Grass Mountain site, lowest at the Organic Growers Farm site. At five sample locations where the soil profile extended beyond a meter in depth, PyC values for the subsoil were highest at the Swine Farm and Cascade Head (*P. menziesii*) sites.

The variation of PyC stocks with depth was statistically examined using the results of the common calculation method that considers PyC to be constant throughout a given horizon. In order to compare PyC values in the subsoil with PyC values in the topsoil, the ratio of subsoil to topsoil values (Fig. 3a) was examined at each of four depth increments (0.2–0.3 m, 0.3–0.5 m, 0.5–1.0 m, 1.0–1.4 m) applying a one-way ANOVA, which showed that there was no significant difference between the groups ($p = 0.362$). The ratio of PyC to SOC was analyzed at five depth increments (Fig. 3b) by a one-way ANOVA indicating that there was no significant difference between the five depth groups ($p = 0.501$). In addition, a regression of PyC against SOC was examined. On the grounds that the subsoil contained lower SOC and PyC stocks compared to the topsoil, which would dominate the correlation, the regression analysis was restricted to the topsoil. The summary statistics indicate that SOC is merely a fair predictor for PyC. This appears to be true for total SOC ($R^2 = 0.61$) as well as for SOC with the PyC removed ($R^2 = 0.44$) (Fig. 4).

The 0.1 λ equal-area quadratic spline function appears to be preferable for approximating PyC with depth (Fig. 2). Using λ=1 resulted in a smooth curve but did not fit the measured data as well whereas λ=0.01 fit the measured data very closely but caused the curve to be substantially rougher (data not shown). To determine whether calculating PyC stocks by making use of the quadratic spline function yields statistically different results from calculating stocks assuming the measured PyC to be constant throughout the horizon, a Wilcoxon test for pair-wise comparison was chosen since the samples were dependent but not normally distributed. The pair-wise comparison showed that the results were statistically not significantly different from each other ($p = 0.509$). The difference between measured and modeled values was +/−1.75% on average (Table 1). However, at two sample sites the differences appeared to be considerably higher.

4. Discussion

4.1. Depth distribution of PyC

Several previous studies suggest that the amount of PyC as a proportion of total SOC increases with depth (Dai et al., 2005; Lehmann et al., 2008). This is typically explained by the fact that PyC mineralizes more slowly than uncharred litter (Ansley et al., 2006; Knicker, 2011). However, this trend could not be observed at the Oregon sites where the proportion of PyC in SOC did not change with depth. Apart from the Turkey Farm and the Swine Farm sites, where slightly higher concentrations of PyC could be detected in the subsoil compared to the topsoil, also the total stocks otherwise declined with depth in all profiles. Vertical movement of PyC may be explained by either leaching, bio- or argillipeloturbation. Downward movement of PyC is favored in coarse-textured soils or soils with low bulk density (Leifeld et al., 2007; Skjemstad et al., 1999). Bulk density at the Oregon sample sites varied widely from 0.82 to 1.31 g cm^{-3}, and the textures ranged from sandy loam to silty clay loam. However, no apparent relationships between texture or bulk density and PyC in the subsoil were found despite the substantial differences in bulk density or texture. We therefore speculate that differences in soil properties did not control subsoil PyC stocks, and rather landscape or climate played a role in determining PyC in subsoils studied here.

4.2. Landscape distribution of PyC

Among all forested locations, the Metolius and the Juniper sites have the lowest, the Cascade Head (*P. sitchensis*) and the Soapgrass Mountain sites the highest PyC stocks. In comparison, both the Metolius and the Juniper sites exhibit a low mean annual temperature while mean annual precipitation greatly differs by 1760 mm between the very dry Juniper site and the much wetter Metolius site, whereas both Cascade Head (*P. sitchensis*) and the Soapgrass Mountain sites have the highest mean annual precipitation (overall weak correlation of MAP vs. PyC: $r^2 = 0.22$; $n = 11$; $p = 0.141$). Abiotic oxidation and biotic mineralization of PyC is usually accelerated by higher temperatures (Cheng et al., 2006; Nguyen et al., 2010) and reduced by water-logged conditions (Nguyen and Lehmann, 2009). The Soapgrass Mountain site is located in a basin left behind by a cirque glacier in the Holocene. While it is not underlain by permafrost anymore, the soil still exhibits a cryic soil temperature regime, which is likely to reduce microbial activity (Knicker, 2011). While high mean annual precipitation increases plant biomass production and presumably fuel load for fires, wet conditions may contribute to lower mineralization (Nguyen and Lehmann, 2009). Wetter conditions may also reduce PyC combustion by subsequent burning events thereby promoting its accumulation (Glaser and Amelung, 2003; Kane et al., 2007).

Generally, vegetation provides fuel for fires, which determines its intensity and thus PyC production. However, the influence of fire on individual plant species is highly variable (Heyerdahl et al., 2001). It is therefore likely that not only the quantity but also the nature of the undergrowth at a given forest location affect the amount of PyC that is produced. Due to a higher combustion intensity, the conversion rate for non-woody biomass to PyC is known to be small if fuel loads are similar (Czimczik et al., 2003; Forbes et al., 2006), thus the lowest PyC stocks are expected to be found at the agricultural sites. This is corroborated by PyC stocks at the Organic Growers Farm and Turkey Farm sites, but not by those at the Swine Farm site. A possible reason for this discrepancy may be that the former locations underwent burning management more frequently and with higher intensity than the Swine Farm site, possibly resulting in re-burning and subsequent oxidation at these

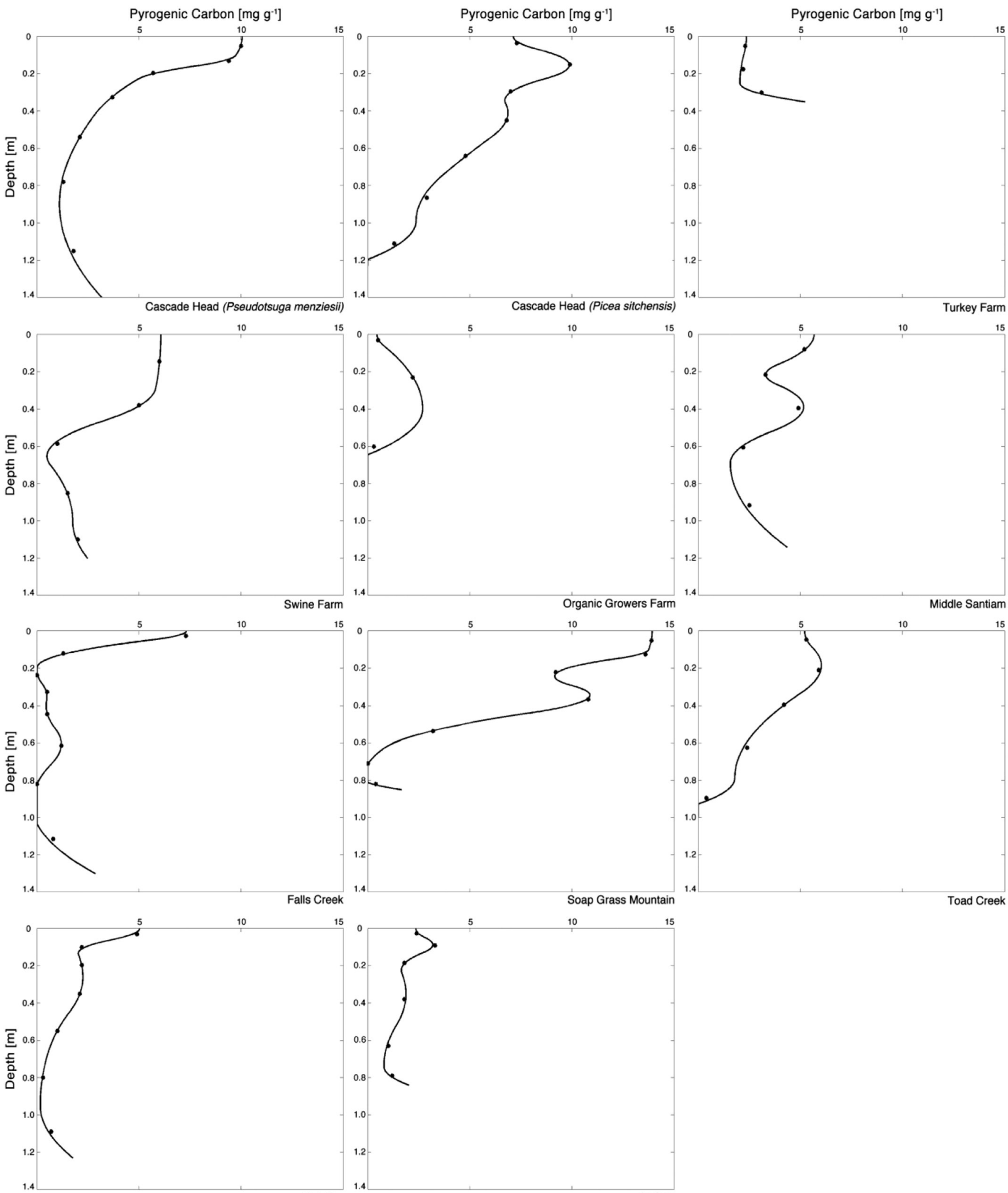

Fig. 2. Pyrogenic carbon concentrations in soil profiles of a catena in Oregon. The lines represent equal-area quadratic splines calculated to improve interpolation of PyC stock data, as explained in the Method section.

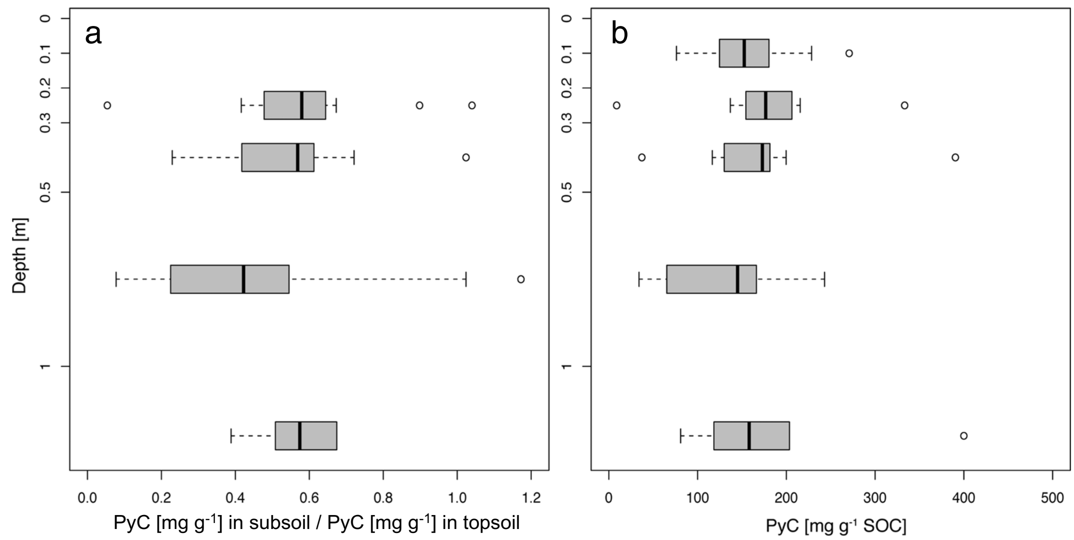

Fig. 3. Average pyrogenic carbon (PyC) of eight soil profiles in Oregon: (a) proportion of subsoil concentrations as a fraction of topsoil (0–0.2 m); (b) proportion of PyC as a fraction of total soil organic carbon (SOC).

sites (Czimczik et al., 2005). With regard to the high mobility of PyC and its susceptibility to erosion, the high stocks at the Swine Farm site may further be a result of deposition and accumulation of previously displaced material (Guggenberger et al., 2008; Major et al., 2010; Rumpel et al., 2006).

4.3. Relationship of SOC and PyC

Some studies have found PyC concentrations in the soil to be unrelated and highly variable with regard to total SOC contents (Lehmann et al., 2008; Leifeld et al., 2007). This may be expected as a greater PyC input through more frequent and more severe fires may result in lower non-PyC inputs. The Oregon field site samples indicate a weak but positive association between PyC and total non-PyC in soil. Glaser and Amelung (2003) obtained data from a Great Plain climosequence, which revealed a much closer relationship between PyC and SOC ($r^2 = 0.89$) than found in our study. This led to their conclusion that PyC accumulates together with dead biomass during fires. Furthermore, they suggest that some PyC is directly formed in the soil from SOC while the surface is burning. Our findings of a much weaker association between PyC and SOC ($r^2 = 0.61$ and 0.44 for SOC with and without PyC, respectively) suggest that while these processes may also occur at our field sites, input and/or output of PyC and non-PyC may be to a significant extent controlled by different processes.

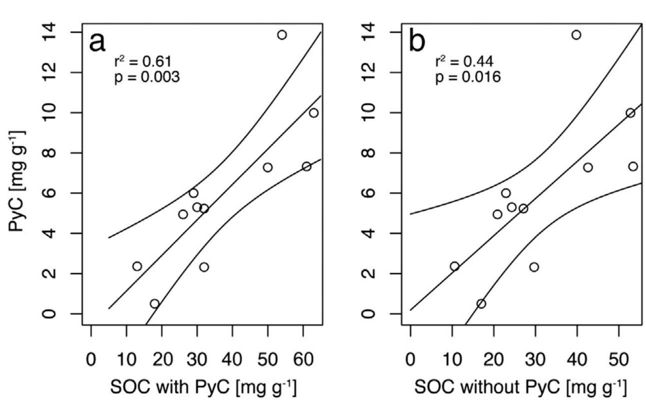

Fig. 4. Relationship between concentrations of soil organic carbon (SOC) and pyrogenic carbon (PyC) in the topsoil ($n = 11$): (a) total SOC; (b) SOC without PyC.

4.4. Calculation of depth distribution

Modeling PyC stocks using equal-area quadratic spline prediction following Bishop et al. (1999) did not yield results that are statistically different from the conventional stock calculation method. However, it must be noted that the small sample size may have influenced the results. A general mathematical problem with the technique stems from the fact that no boundary conditions are defined preventing the spline from assuming negative values. Yet on the whole, the method offers a suitable illustrative presentation of PyC distribution for a given soil profile.

5. Conclusion

PyC stocks in the studied soil catena in the Pacific Northwest are highly variable, both laterally and vertically in the soil profile. Apart from fire frequency, PyC formation appears closely related to vegetation, but no simple explanation for accumulation of PyC could be found. This suggests that the processes influencing production and fluxes of PyC are largely independent, as PyC stocks defy simple correlations with individual climate or soil properties and appear highly dependent on specific landscape conditions. Given the high spatial variability of PyC on this short but ecologically very diverse transect further studies examining fire behavior as well as vertical and lateral transport of pyrogenic carbon in the landscape are warranted. Likely only a full assessment of all source and sink processes of PyC will generate a landscape-scale understanding of PyC distribution.

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