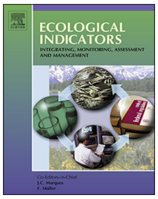
Ecological Indicators 93 (2018) 196–200

Contents lists available at ScienceDirect

Ecological Indicators

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



Original Articles

Indicator value of trees for soil reaction in cool-humid forests

O.T. Bouman

Department of Biology, Cape Breton University, Sydney, Nova Scotia B1P6L2, Canada

ARTICLE INFO

Keywords:
pH
Ca
Acid rain
Sea salt
Homoeostasis
Cape Breton Island

ABSTRACT

Acid rain, soil mineral weathering, and the interception of dust and sea salt still obscure the evaluation of tree effects on soil reaction in mature natural forests. The null hypothesis that tree species and size do not differentiate soil pH was tested in four ways: (i) comparison of an evergreen conifer ecosystem with a history of elevated exposure to acidifying emissions *vs.* a deciduous angiosperm ecosystem in a rural area; (ii) soil trenching to exclude mineral nutrient and water uptake by trees in the two ecosystems; (iii) comparisons of soil pH and the accumulation of decomposed organic material on the soil surface (O_h) beneath boreal angiosperms, boreal conifers, and temperate angiosperms at the landscape level; and, (iv) stand-level comparisons of large trees and small trees as a proxy for cumulative ecosystem effects. Results show for mature mixed forests on acid soils below pH 5 that tree species and size do not differentiate soil pH although varying tree species composition among forest stands differentiates the magnitude of acid rain impacts and indicates the disturbance history of forest vegetation at the landscape level. Low exchangeable base cation pools compared to annual turnover in foliage corroborates the notion of homoeostasis in mixed and structurally diverse natural forests. Natural conifer admixture in northern hardwoods moderates spring soil warming and thereby slows down element cycling. However, conifer admixture does not exacerbate biogenic soil acidification. Significantly reduced soil pH beneath ruderal angiosperms at the landscape level suggests a high vulnerability of cool-humid forests on acid soils to biogenic acidification caused by the destruction of the forest canopy.

1. Introduction

Imbalances between proton-producing and proton-consuming processes cause soil acidification most commonly indicated by a decreasing pH of the soil. Controlled agronomic experiments have shown that the magnitude of proton imbalances determine the rate of soil acidification and its impacts on soils (Bouman et al., 1995). As a master variable, soil pH also indicates the nutritional milieu for plant growth in soils most notably a depletion of base cations and mobilization of potentially toxic metals. Monitoring and manipulating the pH of a soil in keeping with specific crop optima and tolerance levels has become a common practice in agriculture but also gained currency in forestry with the expansion of tree plantations; increased utilization of forest biomass; and, most prominently in the context of soil acidification due to human-induced air pollution (Ludwig et al., 2002). Thus, the agricultural concept of nutrient budgets and associated practices of replenishing "harvested" and "lost" soil nutrients is now competing with the ecological concept of biotic control of *quasi* closed nutrient cycles and retention within forest ecosystems thus ecosystem homoeostasis (Covington, 1981; Hamburg et al., 2003; Séguin et al., 2004). The notion of a steady state of mineral nutrition in mature natural forests due to high rates of internal cycling relative to low rates of geochemical throughputs is however, supported by well-known phenomena such as physiological translocation, extreme longevity of numerous forest tree species, and ecosystem research (Dijkstra and Smits, 2002). Forest trees also show functional convergence of shoot architecture and rooting patterns conducive to homoeostasis (Chang and Matzner, 2000; Thomas et al., 2015). Moreover, long-term forest dynamics suggest a diversity of tree species facilitates mineral nutrient retention (Bouman, 2015). Botanists have however, characterized the local distribution of common tree species on acid soils in a cool-humid region like Nova Scotia (Canada) primarily on the basis of soil moisture regime and drainage as opposed to soil reaction (Roland and Smith, 1969). Ellenberg et al. (2001) did not assign indicator values for soil reaction to common European tree species due to their wide amplitude or inconsistent response to varying soil acidity across geographic regions. Correlations between tree species and soil chemistry have also been attributed to inherent differences in soil parent material rather than differential species effects (Dijkstra et al., 2003; Ste-Marie et al., 2007). Specific tree effects of species on soil acidity and associated depletion of base cations have often been tested following reforestation of open areas with high specific nutrient demands for canopy formation in mono specific planting trials rather than during mature canopy maintenance in mixed and gap-regenerated forests (cf., Reich et al., 2005). However, evergreen and deciduous

---

E-mail address: thomas_bouman@cbu.ca.

https://doi.org/10.1016/j.ecolind.2018.05.004
Received 5 August 2017; Received in revised form 20 April 2018; Accepted 2 May 2018

species differ in their capacity to filter the atmosphere (Schrijver et al., 2007; Kowalska et al., 2016). Geochemical inputs due to acid rain, soil mineral weathering, and interception of dust and sea salt interception still obscure the nutrition of trees and related proton balances in forests (Hansen et al., 2007; Gonzalez-Arias et al., 2006; Talkner et al., 2010).

The purpose of this paper is to explore the relationship between trees and soil pH in mixed forests naturally regenerating on acid soils in a coastal region of Eastern Cape Breton Island, Nova Scotia, Canada. The null hypothesis that tree species and size do not differentiate soil reaction was tested in four ways: (i) ecosystem comparison between a boreal conifer ecosystem in the Springhill soil series (BoCS) with a history of elevated exposure to acidifying emissions *vs.* a temperate angiosperm ecosystem in the Thom series (TeAT) of the Nova Scotia Soil Survey (Cann et al., 1963); (ii) soil trenching to exclude mineral nutrient and water uptake by trees in the two ecosystems; (iii) comparisons of soil pH and the accumulation of decomposed organic material on the soil surface (O_h) beneath boreal angiosperms (BoA), boreal conifers (BoC), and temperate angiosperms (TeA) at the landscape level in four forested water supply areas with a history of limited vegetation disturbances in recent decades; and, (iv) stand-level comparisons of large trees and small trees as a proxy for cumulative ecosystem effects.

2. Materials and methods

2.1. Research sites

Research was conducted in six forests on Eastern Cape Breton Island in the Province of Nova Scotia, Canada, at northern latitudes 46°, 46°10′, 46°04′, 45°55′, 46°15′, and 46°12′ and western longitudes 60° 24′, 60° 5″, 60°09′, 60°01′, 60°08′, and 60°18′. The forests were situated within a distance of 2–17 km from the Atlantic coast and ranged in altitude from 15 to 90 m a.s.l. According to the original soil survey by Cann et al. (1963), "humo-ferric podzolic" soils are most common in the area (http://sis.agr.gc.ca/cansis/taxa/cssc3/chpt16.html) with pH 4.0 near soil surface increasing to 5.2 below 0.3 m depth for the three dominant soil series referred to as Thom, Shulie, and Springhill. Climate normals for the distinctly maritime region show a mean temperature of 5.9 °C and annual precipitation of 1517 mm for the 30-year period from 1980 to 2010 (http://climate.weather.gc.ca). The first research site dominated by temperate angiosperms in the Thom series (i.e., TeAT) formed part of large contiguous forest landscape. The second site dominated by boreal conifers in the Springhill series (i.e., BoCS) was located in an urban environment with long-term exposure to emissions from residential burning of coal, oil, and more recently wood pellets. The remaining four sites were located in protected forests of four public water supply areas within the Thom, Shulie, and Springhill series. On a continental scale, government agencies predicted a precipitation acidity of pH 4.6 in 1980 and pH 5.0 in 2000 for Eastern Cape Breton Island (https://ec.gc.ca).

2.2. Research design and data collection

The ecosystem comparison between BoCS and TeAT began with a forest inventory to determine tree species composition and basal area within an area of 0.48 ha in 2001 and digging of 12 small soil pits in a regular grid to collect soil from 0 to 0.15 m and 0.15 to 0.3 m in June 2001. The soil sample was dried at 40° C for 72 h prior to sieve tests and determination of pH. Equal volumes of soil and distilled water were mixed to determine after 30 min, the pH of the supernatant of the slurry. In September 2015, soil was sampled for pH determination following the same procedure as in 2001. Throughfall (TF) beneath forest canopy and rainfall (RF) in open areas nearby were collected repeatedly following rain events in summer 2003, fall 2004, and fall 2016 (BoCS only) for determination of pH and element concentrations at the Analytical Services Laboratory of the Nova Scotia Department of Agriculture, Truro, Nova Scotia. Soil warming was monitored at 0.15 m using an electronic thermocouple during spring 2002. Gravel proportion and apparent density of the soil's fine earth (particle size < 2 mm) were determined by lining small soil pits with plastic and back filling them with a measured volume of water using a graduated cylinder. In spring 2003, two 3-by-3-m blocks between canopy trees were selected within each stand for soil trenching to exclude uptake of nutrients and water by trees. Soil blocks were wrapped with 0.5 mm thick PVC plastic and trenches were backfilled. Ceramic suction cup lysimeters manufactured by Soil Moisture Corp. were conditioned and installed in 0.1 m and 0.3 m depth at four stations in each stand to extract *in situ* soil solution. Solution was extracted repeatedly in 2003 and early 2004 to condition and settle the lysimeters. Following soil re-saturation in fall 2004, soil solution was extracted for determination of pH and element concentrations by the Agricultural Lab. In November 2010, a soil auger was used to extract soil from the top 0.15 m at 0.75 m off the original trenches. In each forest, a total of 12 cores were taken at random inside the two trenched soil blocks and 12 cores in adjacent un-trenched soil. Soil samples were submitted to the Agricultural Lab for determination of pH and element concentrations in the Mehlich-3 extract (Ziadi and Sen, 2008) to estimate the retention of base cations by the cation exchange complex in the two forest soils hence storage of exchangeable soil nutrient pools.

In summer 2015, line surveys along a total of 13 km were conducted in mixed hardwoods of the four protected public water supply areas comprising a total area of approximately 92 km^2. Along 1-km-long stretches of mixed hardwood with varying admixture of conifers, the species and tree dimensions of the apparently largest tree were recorded in 100-m intervals as well species and diameter at breast height (DBH) of a small tree. The soil was assessed for thickness of the Oh layer in two different spots close to the trunk base and crown periphery of the large tree and close to the base of the small tree. In the same three positions, soil was extracted from the top soil (0.15 m) and sub soil (0.15–0.3 m) for determination of pH in the lab.

2.3. Data analysis

Calculations of water and soil nutrient storage in BoCS and TeAT accounted for sampling depth, gravel proportion of bulk soil, and apparent density of fine earth. Our bulk soil sampling excluded stones which would reduce estimates of soil nutrient pools and water content. For analysis of line surveys, tree taxa were grouped based on their geographic range and phenology into TeA, BoA, and BoC. Data were organized in MS Excel and statistically analyzed using *F*-tests for homogeneity of variances and *t*-tests for significance of mean differences at a probability of $p < 0.05$. The null hypothesis was tested by comparing the following: repeated measurements of soil pH 2001 *vs.* 2015 and TF 2004 *vs.* 2016; element concentrations and ratios in soil solution extracted from trenched *vs.* un-trenched areas in 2004; element concentrations and ratios in Mehlich-3 extract of soil cores collected in trenched *vs.* un-trenched areas in 2010. The effect of large trees on soil pH and thickness of O_h was tested by comparing BoA *vs.* TeA, BoA *vs.* BoC, and TeA *vs.* BoC at the landscape level. The paired *t*-test option was selected to test for effects of tree size by comparing large *vs.* small trees at the stand level. Correlations among elements were ascertained by regressions analyses on TF and soil solution data.

3. Results

3.1. Ecosystem comparison

The soil slurry pH for the two ecosystems BoCS and TeAT differed significantly from TeAT to a depth of 0.3 m ($p < 0.05$; Fig. 1). Repeated pH measurements showed for BoCS a significant decrease of the top soil (i.e., 0–0.15 m) 14 years after the initial measurements in 2001. Similarly, the pH decrease was marginally non-significant in TeAT. The vertical pH gradients had become more pronounced in 2015 because