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Seasonal changes in multi-scale spatial structure of soil pH and related parameters along a tropical dry evergreen forest slope

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ABSTRACT

Seasonal changes in multi-scale spatial variation in soil chemical properties, which may be controlled simultaneously by biotic and abiotic factors, have not been studied in tropical dry forests. We evaluated the spatial variation of physico-chemical soil properties, plant litter and terrain attributes at multiple scales in a tropical dry evergreen forest using multivariate geostatistics. Soil samples were collected at different depths using nested interval sampling during 1- and 10-m intervals in both the wet and dry seasons. We measured pH, exchangeable cations (Ex-K^+ and Ex-Ca^{2+}), acidity (Ex-H^+ and Ex-Al^{3+}), particle size (clay and sand contents), and forest floor mass (O_i and O_a). Pronounced spatial variation in pH was observed in surface soil (0–5 cm) but not in deeper soil (5–55 cm). Multi-scale spatial structures with short (20 m) and long (86 m) ranges were observed in the auto- and cross-variograms of soil, litter and slope gradient. Pronounced multi-scale structures were observed simultaneously in pH and Ex-Ca^{2+} both in the wet and dry seasons. Only a short-range structure was observed in Ex-K^+ and $O_{a,}$ whereas a long-range structure was pronounced in sand contents and slope gradients. Although the variograms had similar shapes between wet and dry seasons for almost all variables, the short-range structure of the cross-variogram between O_a with pH and base cations was more pronouncedly developed in the wet season than in the dry season. Scale-dependent correlation coefficients suggest that a small-scale spatial variation in pH was connected to heterogeneous litter accumulation via base-cation input, whereas long-range spatial variation was simultaneously linked to particle size and slope gradient. This multivariate geostatistical approach applied within a stand detected biotic and abiotic factors controlling spatial variation in soil properties at both short and long distances.

1. Introduction

Large spatial variation in soil chemical properties often occurs in tropical forests (Richards, 1996). Spatial variation may occur on a scale of kilometers or hundred meters, or the properties may vary over distances of a few meters or less in tropical regions (Oline and Grant, 2002; Robertson, 1987; Robertson et al., 1988; Sun et al., 2003; Yavitt et al., 2009; Yost et al., 1982). Within a stand (intra-stand scale), an individual tree can affect this variation by throughfall, stem flow, and litterfall to the forest floor (Berg and McClaugherty, 2003; Swift et al., 1979) in addition to root uptake (Schlesinger et al., 1996). Meanwhile, particle size (sand, silt, and clay contents) also strongly regulates the pools of base elements in tropical forest soils via the cation exchange capacity of clay minerals (Ohta and Effendi, 1993; Sanchez, 1985). Slope topography has been regarded as one of the most important factors controlling pedogenic processes that affect soil chemical properties (e.g., Buol et al., 1997; McDaniel et al., 1992). These biotic and abiotic factors are thought to cause large and complex spatial variation at multiple scales in the soil properties of tropical forests because these factors may have different spatial structures and scales even within a stand. However, little is known about the effects of biotic and abiotic factors on multi-scale spatial structure at the intra-stand scale in tropical forests. A comprehensive understanding of multi-scale spatial variation in soil chemical properties controlled by biotic and abiotic factors is important to biogeochemical studies and forest management in tropical regions.

Multivariate geostatistics, described and evaluated in earlier papers (Dobermann et al., 1995; Goovaerts, 1994; Goovaerts et al., 1997; Goulard and Voltz, 1992), has been developed to detect important scales from relationships among many factors. In tropical regions, this approach has been used to distinguish between chemical

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and physical soil-forming factors at a scale of more than several kilometers (e.g., Holmes et al., 2005; Yemefack et al., 2005); in contrast, the intra-stand scale, which may encompass less than several hundred meters, might be an appropriate scale for simultaneously detecting the effects of individual trees, i.e., biotic factors, and soil particle size and topography, i.e., abiotic factors.

Tropical dry forests (tropical seasonal forest) are particularly important because about 40% of the earth's tropical and subtropical lands are dominated by open or closed forest, of which 42% is dry forest (Murphy and Lugo, 1986). The clear seasonality of climate produces distinct phenological patterns in plant growth, foliation, defoliation, and litter decomposition. Nutrient dynamics are also strongly affected by this seasonality via microbial activity or hydrological processes in the canopy, litter, and soil layers (Anaya et al., 2007; Lambert et al., 1980; Martinez-Yrizar and Sarukhan, 1990). This suggests that the spatial variation in soil chemical properties derived from biotic factors, which may have multi-scale structures, could change seasonally. However, the seasonal changes in multi-scale spatial variation in soil chemical properties have not been studied in tropical dry forests.

The objectives of the present study were 1) to detect multiple spatial scales of variation in soil chemical properties and 2) to clarify the biotic (forest floor mass) and abiotic (particle size distribution and slope topography) factors controlling this multi-scale spatial variation in both the wet and dry season in a tropical dry forest.

2. Materials and methods

2.1. Site description

The study was conducted at the Sakaerat Environmental Research Station (SERS) located in northeastern Thailand (14°30′N, 101°55′E). The 79.6-km^2 area comprises 42.3 km^2 of dry evergreen forest (DEF), 11.8 km^2 of dry deciduous forest, and 17.2 km^2 of plantation forest. The climate of the region is classified as tropical savannah (Aw) according to Koppen's classification. Mean annual temperature and precipitation from 2000 to 2008 was 25.5 °C and 1407 mm, respectively. The period between December and February is extremely dry, with monthly precipitation less than 50 mm. The area is underlain by sandstone formed from the Triassic to the Cretaceous and is classified in the Khorat geological group (Moormann and Rojanasoonthorn, 1972). The area ranges in elevation from 250 to 762 m above sea level and has a mountainous topography with 10–30% slopes. The representative landform is the cuesta-like table mountain. The main soil type is Orthic Acrisols, with additional Humic Acrisols, Dystric Cambisols, and Lithosols, according to the Soil Map of the World (FAO, 1979). The total basal area of trees in the study plot was 28.5 m^2 ha^{-1}, and the dominant species were *Shorea henryana*, *Ficus altissima*, and *Walsura trichostemon* (Yamashita et al., 2010).

2.2. Soil and litter properties

We established a rectangular study plot spanning the slopes on either side of a stream in a small first-order catchment of DEF (35 ha; Figure 1). The plot measured 40×350 m and included grid plots at 10-m intervals and a 350-m line transect through the center (Figure 2). We collected soil samples at the grid points of the plot ($n = 180$) and at 1- or 2-m intervals on the line transect ($n = 163$). Mineral soil samples were collected from 0–5-cm depth late in the wet and dry seasons (November and March, respectively). The sampling points in the wet season are 1-m away in the same direction from the points in the dry season. Additional soil samples were also taken from 5–15- and 45–55-cm depths using an auger. These were collected from almost all points in a 10-m-interval grid for 5–15 cm depths ($n = 178$) and from randomly selected points in a 10-m-interval grid for 45–55 cm depths ($n = 44$) because the soil depth was less than 15 cm or 55 cm at some points, and little spatial variation was expected at 45–55 cm.

We immediately analyzed samples for pH (1:2.5, soil:water ratio). We measured 1 M KCl-exchangeable H^+ (Ex-H^+) and Al^{3+} (Ex-Al^{3+}) using the titrimetric method (Bertsch and Bloom, 1996). Exchangeable base cations (Ex-Na^+, Ex-K^+, Ex-Ca^{2+}, and Ex-Mg^{2+}) were extracted with 1 M ammonium acetate buffered at pH 7, and their concentrations were determined by atomic absorption spectrophotometry. Effective cation *exchange* capacity (ECEC) was calculated by summing the exchangeable base cations and KCl acidity, and base saturation was calculated from the quotient of the sum of exchangeable base cations and ECEC. The particle size distribution of soil (mesh size: clay, silt, and sand) was determined using the pipette method (Gee and Bauder, 1986) for wet season samples only, because particle size should not change on a seasonal time scale. For the additional soil samples (5–15 and 45–55 cm depth), we reduced the number of samples for all analyses except that for pH because little spatial variation had been observed in pH.

Before sampling soils, forest floor mass was measured at the same sampling points in both the wet and dry seasons. Samples were taken

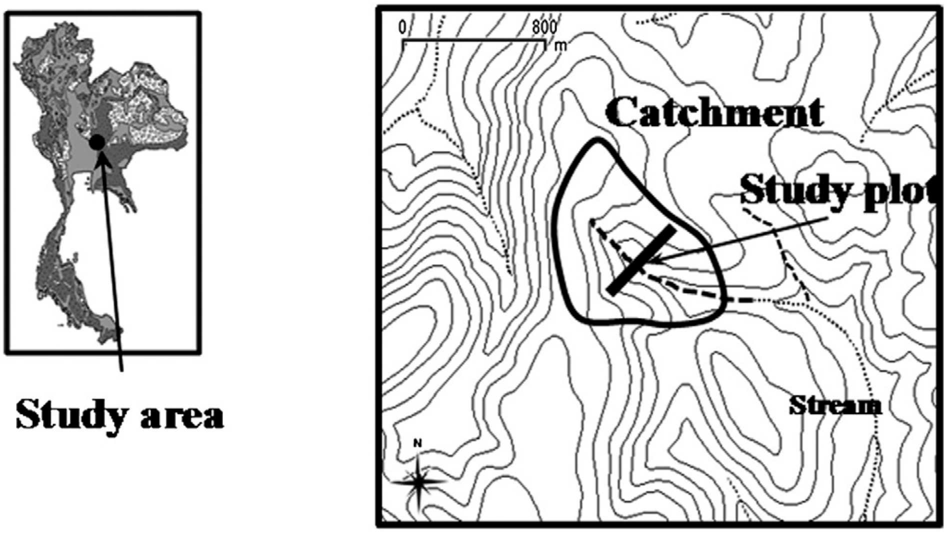

Fig. 1. Location of the Sakaerat Environmental Research Station and the study plot.