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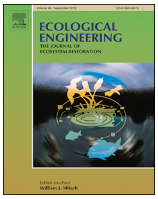

Short communication

Indications of soil properties on dissolved organic carbon variability following a successive land use conversion

Xiao Pu[a,b], Hongguang Cheng[b,*], Mats Tysklind[c], Jing Xie[d], Lu Lu[e], Shengtian Yang[f]

[a] Beijing Key Laboratory of Resources Environment and Geographic Information System, College of Resource Environment and Tourism, Capital Normal University, Beijing 100048, China
[b] School of Environment, Beijing Normal University, Beijing 100875, China
[c] Department of Chemistry, Umeå University, Umeå 90187, Sweden
[d] Chinese Academy for Environmental Planning, Beijing 100012, China
[e] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[f] State Key Laboratory of Remote Sensing Science, School of Geography, Beijing Normal University, Beijing 100875, China

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ABSTRACT

In seasonal freeze-thaw zones of NE China, the policy-oriented land management has caused successive land use conversions of native woodland, dry cropland and paddy field for food security. Controls of soil property factors on soil dissolved organic carbon (DOC) dynamics might vary with deforestation. This study aimed to test performance of soil properties interpreting DOC variability along soil profile following a vegetation succession of native forest, rainfed crops (maize-soybean rotations) and paddy rice in an observation area of the Sanjiang Plain. The linear mixed effects model evaluated relative importance of soil properties with comparisons of adjusting and not adjusting for random effects of land use and soil depth as subject variables. The modeling results revealed presence of consistent soil property factors indicating DOC dynamics before and after deforestation. When excluding interferences of land uses and soil layers, interpretations of soil properties were weakened. Soil moisture and bulk density predominantly accounted for DOC variability across land uses, presenting greater estimated effects (0.69 and −0.64, respectively) over those of total nitrogen, soil organic carbon and hydrolyzable nitrogen (0.49, 0.44 and 0.31, respectively). But no soil property factor indicated DOC variability with soil depth. Further research is needed to understand why indications of soil moisture and bulk density on DOC dynamics would differ between horizontal and vertical.

1. Introduction

The movement of soil dissolved organic carbon (DOC) is a crucial component of carbon (C) cycling and balance in terrestrial ecosystems (Kaiser and Kalbitz, 2012; Kindler et al., 2011). A better understanding of DOC variability in soils is conducive to reliable estimates of ecosystem C budgets. A variety of factors reportedly contribute to DOC dynamics (Kalbitz et al., 2000). Herein, soil physico-chemical properties importantly control DOC quality and quantity (Filep and Rékási, 2011; Kothawala et al., 2009). Soil properties, combined with local climatic and pedogenic conditions, could modulate microbial processing through altering microbial community characteristics and enzyme activities (Brockett et al., 2012). Meanwhile, the forms and sorptive capacity of soil minerals (e.g. pedogenic oxides and oxyhydroxides and phyllosilicate clay minerals) could also change with varying soil properties (Kothawala et al., 2009). Thus, several parameters in soil properties are recommended as indicators for DOC dynamics (Filep and Rékási, 2011; Kalbitz et al., 2000). However, effects of soil properties on DOC in previous studies are not entirely consistent due to differences in investigating approaches, analytical methods and data processing (Filep and Rékási, 2011). Besides, influences of environmental factors (e.g. land use) increased the complexity in understanding the correlation of soil properties and DOC. Land use conversion significantly affects degree and direction of soil C fluxes and variations (Deng et al., 2016; Kindler et al., 2011; Liu et al., 2016; Wang et al., 2015). Comprehensive analysis is essential for evaluating basic soil parameters that govern DOC dynamics subject to the land use conversion.

The general linear model with standard ordinary least squares (OLS) method was widely used for parameter estimation in evaluations of soil properties (Filep and Rékási, 2011; Pu et al., 2012; Stielstra et al., 2015). A pivotal assumption of the OLS method is that samples are independent and have equal inclusion probabilities. But for the

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[*] Corresponding author at: No. 19, Xinjiekouwai Street, Haidian District, Beijing 100875, China.
E-mail address: chg@bnu.edu.cn (H. Cheng).

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geostatistical analysis, soil samples are usually systematically collected on grids or transects across landscapes and soil layers. Once the location of the origin and its orientation are determined, all sampling points have been specified, exhibiting a spatial dependence within a stratum of land use or soil depth. So, the OLS method is inappropriate for coefficient estimation. Instead, the linear mixed effects (LME) model with restricted maximum likelihood provides an alternative approach through treating all effects not adopted by explanatory variables as random (Lark and Cullis, 2004). It could ensure the accuracy of statistical inferences from the stratified sampling data by examining intraclass correlation and cross-level interaction and help drawing common conclusions regardless of stratums.

Located in the freeze-thaw zone of NE China, Sanjiang Plain is one of the most important agricultural regions of China, with the characteristics of high latitudes (45°01′ to 48°27′N), long frost periods (late October to early May) and vast areas of rice paddy cultivation (Pu et al., 2015). For boosting grain yields and food production, native vegetation of the plain was extensively converted to dry croplands in 1960s and most of dry croplands were then converted to rice paddy in 1990s driven by policy-oriented land use management, leading to a shift from mixed landscapes to sole agroecosystems (Pu et al., 2015; Wang et al., 2010). The construction of numerous artificial drainage ditches further resulted in landscape fragmentation and promoted water quality degradation (Lu et al., 2016; Wang et al., 2010). Studies on DOC dynamics as indicated by soil properties after deforestation are important in this area for its ecological vulnerability and sensitivity.

In this paper, we selected a site experiencing a succession of native forest, rainfed crops (maize-soybean rotations) and paddy rice with a cultivation history of more than 50 years. It was hypothesized that controls of soil properties on DOC dynamics might vary with deforestation. The objectives of this study were i) to examine consistency of soil properties indicating DOC variability along soil profile following a successive land use conversion and ii) to compare efficacies of adjusting for random effects of land use and soil depth as subject variables (LME) or not (OLS).

2. Materials and methods

2.1. Study site description

The sampling area (47°28′N–47°31′N, 133°59′E–134°04′E) is located at central Bawujiu Farm of Heilongjiang Province in northern Sanjiang Plain, NE China, characterized as a cold temperate sub-humid climate with annual mean air temperature, precipitation and frost-free period of 2.24 °C, 553 mm and 137 days (averages of 1956–2010), respectively. The soil type is lessive soil (Chinese soil taxonomy: Baijiang Soil; USDA: fine, illitic, frigid Mollic Albaqualfs; FAO: Albeluvisol) with the stratification of Ah-E-Bt-Cg horizons, and soil parent materials are weathering alluvial deposits of late Pleistocene to early Holocene (Pu et al., 2012). The sampling site encountered a successive land use conversion. Prior to reclamation, the site was vegetated with native forest till 1958 when a portion was exploited and cultivated as dry croplands. In 1989, parts of dry cropland were shifted to rice paddy fields.

2.2. Sample collection and analysis

A total of 84 intact soil cores were collected in the growing season (early August) with 6 depths (up to 60 cm with a 10 cm interval) at 14 individual sites which were separately selected in 14 square grids with an interval of 2 km in the sampling plot across 3 land uses (4 sites for native forest with predominant tree species of Dahurian larch [*Larix gmelinii* (Rupr.) Rupr.], Manchurian ash (*Fraxinus mandshurica* Rupr.), and white birch (*Betula platyphylla* Suk.); 5 for dry cropland with a 1-year-round soybean [*Glycine* max (L.) Merr.]-maize (*Zea mays* L.) rotation; and 5 for rice paddy (*Oryza satiua* L.) fields).

Field moist soil cores were sub-sampled for determination of gravimetric soil moisture after oven-drying at 105 °C and bulk density calculation with sample weights and volumes. Sub-samples were air-dried at room temperature, grounded and sieved through 0.15 mm mesh. After removal of organic matter by H_2O_2, soil texture (clay, $<$ 0.002 mm; silt, 0.002–0.063 mm; sand, 0.063–2 mm) was determined with a grain-size analyzer (Nicomp 380, PSS, USA). Cation exchange capacity (CEC) was measured via ammonium acetate method. Soil pH was measured in 0.01 M $CaCl_2$ by PB-10 pH meter (Sartorius, Germany) using a soil/solution ratio of 1:2.5 (w/v). With 0.1 M HCl fumigation, soil organic C (SOC) and total nitrogen (TN) were analyzed by a CN analyzer (Vario E1, Elementar, Germany). DOC was extracted from field-moist soil with 0.5 M K_2SO_4 (1:5, soil:extractant, w/v) on a reciprocating shaker at a constant temperature of 20 °C for 1 h at a speed of 200 rev min^{-1}. After centrifugation, the supernatant was decanted off. DOC in the supernatant was determined using a TOC analyzer (TOC-V, Shimadzu, Japan) with Pt catalyst after 680 °C combustion. DOC was adjusted to dry mass concentration so as for interfield comparisons. Alkaline hydrolysable N (HN) was determined in HCl titrations after extraction with NaOH and adsorption with H_3BO_3.

2.3. Statistical analysis

As soil samples were systematically collected on grids and transects in this study, the data of DOC and soil properties could be hierarchically structured within stratums of land use type and soil layer. Unlike the effects of land use and soil depth which were usually set as fixed factors in simple random sampling schemes in previous studies, random subject effects of them should be taken into consideration. The LME model was employed to reveal relationships of DOC and soil properties based on effect estimates. The comparisons of adjusting (OLS) and not adjusting (LME) for random effects of subject variables (land use and soil depth) were also conducted. Firstly, the LME model was operated without random effects of subject variable which was equivalent to OLS:

$$Z(y_{i,j}) = \alpha + \beta_{i,j} Z(x_{i,j}) + u_j + e_{i,j} \tag{1}$$

where $y_{i,j}$ represents DOC of the ith individual at the jth group; $x_{i,j}$ is the vector of soil property factors and covariates (land use and soil depth) of the ith individual at the jth group, and $\beta_{i,j}$ denotes the corresponding coefficient vector that signifies effect estimates of soil property factors; α is the overall intercept; u_j represents random intercept at the group level; $e_{i,j}$ is the random error which is assumed normality with the average of zero. Z means the Z-scale transformation processing on raw data for normality and heteroscedasticity. Next, the model (1) was operated with random effects of subject variables involved:

$$Z(y_{i,j}) = \alpha + \beta_{i,j} Z(x_{i,j}) + \beta'_j z'_j + u_j + e_{i,j} \tag{2}$$

where z'_j is the vector of subject variables at the jth group, and β'_j denotes the correlated coefficient vector at the jth group. The fixed and random effects at the individual level were soil property factors and residual error items, respectively. The fixed effects at the group level were the subject variables; the random effects at the group level were the random intercepts for model (1) and were the subject variables and random intercepts for model (2). The estimations of model coefficients and parameters of covariance matrix were completed applying restricted maximum likelihood (Lark and Cullis, 2004). The models (1) and (2) were primarily run with null hypothesis (the tested soil property factor was excluded and the other factors were involved) and secondly with all soil property factors introduced including the tested factor. The -2 restricted log likelihood (RLL) was compared using Pearson's Chi-square (χ^2) test to examine if introducing the tested soil property factor to the model significantly improved model fit. Comparisons between models (1) and (2) in goodness of fit were based on changes in RLL values which were statistically examined through χ^2 test for significance. One-way analysis of variance (ANOVA) was used