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Soil C and N minimum detectable changes and treatment differences in a multi-treatment forest experiment

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Abstract

Detecting changes in forest soil C and N is vital to the study of global budgets and long-term ecosystem productivity. Identifying differences among land-use practices may guide future management. Our objective was to determine the relation of minimum detectable changes (MDCs) and minimum detectable differences between treatments (MDDs) to soil C and N variability at multiple spatial scales. The three study sites were 70–100-year-old coniferous forests in Washington and Oregon. Area- and volumetric-based soil measurements were made before implementation of 7 treatments on 2-ha experimental units, replicated in 3 or 4 blocks per site. In the absence of treatment effects, whole-site MDCs are ~10% for mineral soil C and N masses and concentrations and ~40% for O-horizon C and N masses. When treatment differences occur, MDDs are ~40% for mineral soil and ~150% for O-horizon. MDDs are reduced as much as two-thirds by evaluating change from pre- to post-treatment rather than only post-treatment values, and by pairing pre- and post-treatment measurements within small subplots. The magnitude of MDD reduction is quantitatively related to pre-treatment soil variability at multiple spatial scales, with the greatest reductions associated with the largest within-block:within-plot and within-plot:within-subplot variability ratios. These quantified benefits can be weighed against costs and challenges to make informed decisions when selecting the most appropriate sampling design.

Keywords: Soil nitrogen; Soil carbon; Minimum detectable change; Minimum detectable difference; Change detection

1. Introduction

Detecting change in forest soil C and N and differences between treatments is paramount to understanding alterations in soil fertility, C sequestration, and N impacts on C cycling (Homann et al., 2001b; Johnson and Curtis, 2001; Post et al., 2001; Conen et al., 2003; Swanston et al., 2004; Lal, 2005; Jandl et al., 2007; Woodbury et al., 2007). In investigations of these issues, minimum detectable changes (MDCs) in soil properties and minimum detectable differences between treatments (MDDs) provide valuable information during all phases of study design, implementation, and interpretation. During study design, MDCs and MDDs based on previous studies or low-intensity preliminary sampling can guide experimental and sampling designs, including issues of replication and sampling intensity. Following experimental layout, MDCs and MDDs from comprehensive pre-treatment sampling, combined with estimates of rates of change (Conen et al., 2003; Smith, 2004), can guide timing, intensity, and design of post-treatment sampling. After termination of an experiment, MDCs and MDDs indicate magnitudes of change or differences that could have occurred but remain undetected (Homann et al., 2001b).

Forest soil C and N MDCs and MDDs have been determined for several experimental designs. MDCs have been quantified for *single* experimental units, such as an individual plot, stand or watershed (Huntington et al., 1988, O-horizon and mineral soil C and N) and *single* treatments represented by *multiple* experimental units (Conant et al., 2003, mineral soil C). Substantial differences in MDCs exist between these two experimental designs (Yanai et al., 2003, O-horizon C). MDDs have been determined for more complex experiments that

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compare *multiple* treatments represented by *multiple* experimental units (Garten and Wullschleger, 1999, mineral soil C; Homann et al., 2001a, and Rothe et al., 2002, O-horizon and mineral soil C and N).

MDCs and MDDs are typically large for forest soils (Johnson et al., 1990; Homann et al., 2001a; Conant et al., 2003; Yanai et al., 2003). Large MDCs and MDDs may be reduced by increasing the number of observational or experimental units (Johnson et al., 1990; Conant et al., 2003; Yanai et al., 2003). However, detecting changes and differences on the order of 20 to 30% may require a substantial, and often impractical, number of observations (Johnson et al., 1990; Conant et al., 2003; Yanai et al., 2003; Schoning et al., 2006).

MDCs and MDDs may also be reduced by selecting advantageous experimental and sampling designs (Homann et al., 2001a; Conant et al., 2003; Yanai et al., 2003), but results have varied among studies and sites. Considerable decreases in MDCs were forecast for resampling the same experimental units vs. sampling an independent set of experimental units (Ellert et al., 2002; Yanai et al., 2003), but Conant et al. (2003) found substantial decreases in only three of four sites, which they attributed to differences in soil spatial variability. In examining change, Yanai et al. (2003) suggested the resampling of established subplots would presumably increase statistical power (i.e., lower MDC) compared with sampling an independent set of subplots, but did not have information to test this presumption. In comparing treatments, Homann et al. (2001a) demonstrated a broad range of reductions in MDDs resulting from pre- and post-treatment sampling vs. only post-treatment sampling, a pattern attributed to differences in soil spatial variability. These sampling strategies are implicitly linked to the spatial dependence of forest soil variability, i.e., that proximal points tend to be more similar than distant points (Grigal et al., 1991; Kirwan et al., 2005; Schoning et al., 2006). However, a quantitative assessment between multi-scale variability and sampling strategies is lacking for forest soils.

Our goal in this study was to quantitatively relate MDCs and MDDs for forest soil C and N to soil variability at multiple spatial scales. Our analysis is based on comprehensive pre-treatment sampling from a large-scale, complex, multi-treatment experiment at three coniferous forests of the Pacific Northwest USA (Homann et al., 2001a). We compare several relevant MDCs and MDDs (Fig. 1):

MDC_{unit}—minimum detectable change over time in a single unreplicated experimental unit.
MDC_{treat}—minimum detectable change in a single treatment with replicated experimental units.
$MDC_{multiple}$—minimum detectable change in multiple treatments, when magnitude of change does not differ between treatments.
MDD_{change}—minimum detectable difference between treatments, when magnitude of change does differ between treatments, based on pre- and post-treatment sampling of independent subplots.
$MDD_{change*}$—minimum detectable difference between treatments, when magnitude of change does differ between treatments, based on pre- and post-treatment sampling of the same subplots.
MDD_{post}—minimum detectable difference between treatments for a single post-treatment sampling.

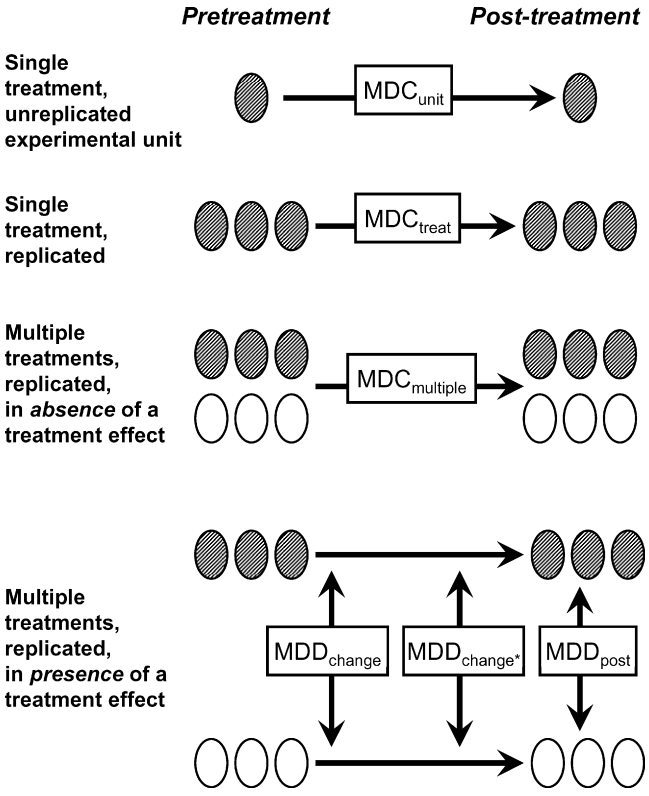

Fig. 1. Conceptual types of minimum detectable change (MDC) and minimum detectable difference between treatments (MDD) considered in this analysis. MDD_{change} and $MDD_{change*}$ differ in their subsampling designs.

These MDCs and MDDs were chosen to represent possible sampling designs and outcomes of our experiment, to allow comparison with less complex experiments, and to address several specific questions. Our presentation of MDC_{unit} and MDC_{treat} allows comparison with evaluations of basic experimental designs (Yanai et al., 2003). Our unique analysis of a more complex multi-treatment experiment recognizes multiple possible outcomes. If there is no difference between treatments, then change can be assessed across all treatments simultaneously ($MDC_{multiple}$). Conversely, if there is a difference between treatments, detecting the difference in change may be affected by sampling design (MDD_{change}, $MDD_{change*}$). Finally, rather than evaluating change, treatment differences may be evaluated at a single post-treatment point in time (MDD_{post}).

In carrying out our assessment, we provide quantitative answers to the following specific questions: What is the relation of MDCs for experimental designs that have different scopes of inference: an unreplicated experimental unit vs. a single treatment with multiple experimental units vs. multiple treatments with multiple experimental units (MDC_{unit} vs. MDC_{treat} vs. $MDC_{multiple}$)? How much is MDD reduced by examining change vs. quantifying only post-treatment properties