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Developing a minimum data set for characterizing soil dynamics in shifting cultivation systems

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Abstract

The complexity of temporal and spatial changes of soil characteristics under shifting cultivation in the tropics and the expense of comprehensive data collection motivates the development of a minimum data set (MDS) for characterizing soil productivity status and potential. We define a multi-criteria quantitative procedure for MDS selection: (i) the development of selectors based on objective selection criteria; (ii) the transformation of these selectors into combinable scores; and (iii) the combination of transformed selectors scores into a single rating for each soil variable. Selectors are (a) the norm of the vector representing a soil property in the space spanned by the standardized principal components that explain most of the variance; (b) the coefficient of determination of a one-way ANOVA of land use change on a property; (c) time of earliest response; (d) recovery time; (e) expense of sampling and measurement. These are justified heuristically. The method was applied to a set of MDS candidates: 13 soil variables collected within a chronosequence of shifting cultivation system in southern Cameroon. In this case the method selected five soil properties (pH in water, exchangeable calcium, available phosphorous, bulk density and organic carbon). These can be used individually or in combination to assess the effect of this practice on soil condition. The selected variables were easily interpretable in terms of their relation to land management practices and land use changes. The procedure was robust to soil orders and depths at which properties were measured. This method of choosing a MDS is expected to work well for studies of soil dynamics in other agro-ecosystems.

Keywords: Minimum data set (MDS); Shifting cultivation; Soil dynamics; Southern Cameroon; Soil quality; Multi-criteria decision-making

1. Introduction

Shifting cultivation is the main agricultural land use system practiced by subsistence farmers in the humid tropics. To avoid deforestation and reduction in the extent of natural areas, increasing agricultural

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production should depend chiefly on improved soil productivity rather than on expansion of areas under cultivation (Rasheed, 1996; Lynam et al., 1998). This calls for a development of methods and strategies for maintaining soil fertility, based on a good understanding of soil behaviour under each land use practice, with quantified rates of changes in soil properties (Tulaphitak et al., 1985; Sanchez et al., 2003).

In shifting cultivation systems, the complexity of temporal and spatial changes of the soil characteristics makes it difficult to obtain such complete datasets for large areas. Consequently, quantitative predictions on medium and long-term soil fertility development or prediction of changes in crop growth become almost impossible. Therefore, quantitative indicators, rather than actual predictions, are used to assess soil productivity status and potential (Bouma, 1998). For similar reasons but a different application, Larson and Pierce (1991) proposed the concept of a Minimum Data Set (MDS) for evaluating soil quality. They stressed that a MDS, in combination with pedotransfer functions, should be designed in such a way that quantitative attributes can be measured quickly for more responsive land use or management decisions. Some soil properties are more sensitive to change in management than others. These may serve as early signals of soil change, and thus may be included in the MDS. In addition, some properties may be highly correlated, so that a few may substitute for many.

Minimum datasets for assessing soil quality from plot to regional scales have been developed by many authors (Glover et al., 2000; Liebig et al., 2001; Andrews et al., 2002). However, due to the spatial diversity of soil types and land use systems, these MDS suffer from two constraints: first, they are often site-specific and therefore difficult to extrapolate to other, even adjacent areas; second, the development of MDS has relied primarily on expert opinion for the selection of MDS components (Karlen et al., 1997). While the resulting MDS is not necessarily wrong, it makes extrapolation of MDS systems difficult and subject to discussion.

Andrews and Carroll (2001) attempted to create a transferable framework or general approach for choosing a MDS through the use of multivariate statistical techniques to minimize disciplinary bias. They applied principal components analysis (PCA) to the set of all soil variables that might be included in an MDS. They then selected all principal components (PC) that explained at least 5% of the total variance. For each of the selected PCs, the variable with the largest eigenvector was chosen for the MDS. They concluded however, that the MDS indicators and scoring functions may still need to change with differing management, climate, soil type or time. Using the eigenvector of a variable for one PC does not provide information about the magnitude (norm) of the resulting vector of the variable in a multi-dimensional space, either of PCs or original variables. Therefore, this approach may leave out some important indicators just because they were not highly weighted in any of the selected PCs considered individually.

This paper describes an objective methodology for identifying and quantifying selection criteria to create an MDS based on critical soil characteristics that are the most affected by land use practices, in the first instance in shifting cultivation systems in southern Cameroon, but with potentially wide applicability. Moreover, the methodology also incorporates the cost of data acquisition. We evaluate the success of the method in our test area by: (i) its interpretability in terms of what is known about soil processes in these systems; and (ii) its robustness to subsetting of the observations.

2. Conceptual framework of the MDS development

The concept of MDS as used in this study differs somewhat from that used in soil quality assessment (Karlen et al., 1997; Herrick, 2000; Andrews et al., 2002). Rather than being a subset of variables to be combined in one index such as soil quality indices, the MDS here should just be considered as the smallest set of soil properties that can best represent human-induced change in the area. These can be used either individually or in combination, as in a soil quality index, to assess this effect on soil condition.

We agree with Gregorich et al. (1994) that the soil properties to be included in a MDS must be sensitive to changes in soil management, soil perturbations, and inputs into the soil system. Each selected property must also be easily and reproducibly measurable. Following these principles and building on the work of Andrews and Carroll (2001), we propose here a multi-criteria quantitative procedure for MDS selection including: (i) the development of selectors based on