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Soil carbon dynamics in the humid tropical forest zone

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Abstract

Conversion of natural forests to agriculture in the humid tropics leads to a reduction in ecosystem carbon storage due to the immediate removal of aboveground biomass and a gradual subsequent reduction in soil organic carbon. A considerable part of soil carbon is protected from microbial attack by a range of physical and chemical mechanisms and is not sensitive to landuse change. We analyzed the soils data base for Sumatra (Indonesia) developed by the Center for Soil and Agroclimate Research (CSAR) to estimate effects of landuse on soil C content. Sumatra has a considerable diversity of soils ranging from those of recent origin in the highlands, to older sedimentary and heavily leached soils in the pedimont peneplain and large areas of wetland soils along the coast. Peat soils (Histosols) and other wetland soils (Aquic and Fluvic suborders) contain the greatest soil C reserves, followed by young volcanic soils (Andisols). Agricultural use of these soils can have a disproportionately large effect on C release to the atmosphere. On the major part of the upland soils the difference in (top) soil C content between natural forest and agricultural land is in the range 0.5–1.0% C, equivalent to a change in total C stock of 10–20 Mg ha^{-1}. These results agree with data collected in S. Sumatra in the 1930s. C_{org} of forest soils is related to soil pH, and is lowest in the pH range 5.0–6.0. Wetland conditions, lower pH, higher altititude (lower temperature) and higher clay and silt content all contributed to higher soil C contents in a multiple regression analysis of the whole data set. Existing models and data sets are insufficient to predict changes in soil C contents under various landuse practices. Carbon isotope studies, and especially the $\delta^{13}C$ method may be used to study the effects of landuse change, especially when the vegetation was changed from one dominated by C3 plants (most forest

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species) to one dominated by grasses and crops with a C4 photosynthetic pathway. Results from Brazil documented a gradual decline of organic matter originating from the forest system and its partial replacement by organic matter derived from inputs of sugarcane during the first fifty years of cultivation. Forest conversion to well managed grasslands may lead to an increased soil C storage, after an initial decline. The consequences of erosion on losses of soil C depend on the scale at which these losses are considered, because of sedimentation processes. When net erosion losses are not expressed per unit area, but per length scale to the power 1.6, erosion losses appear to be largely independent of scale. The 'fractal dimension of erosion' (on average around 1.6) probably is a landscape characteristic and estimates of its value are needed for extrapolation. Better understanding of soil C deposition sites is needed to evaluate overall erosion effects and test whether or not erosion can contribute to net C sequestration.

Keywords: carbon sequestration; erosion; land use change; soil organic matter; Sumatra; stable isotopes

1. Introduction

Soil organic matter (SOM) plays a key role in crop production under the low external input conditions prominent in the humid tropics. Recently, the role of soil C storage for the global C budget has come to be considered a topic of equal importance. In this paper we will try to relate these two aspects in reviewing the dynamics of soil C in the humid tropical forest zone.

1.1. Soil organic matter fractions and function for crop production

Soil organic matter plays a number of roles in cropping systems (Fig. 1) and its dynamics merit special interest from those who seek to improve the sustainability of cropping systems, especially in the humid forest zone (Sanchez et al., 1989). For all the roles of soil organic matter, technical alternatives exist. Today's hydroponic horticultural systems show that it is not only possible, but even economically attractive under certain conditions, to grow crops without any soil organic matter, or even without soil. Yet, for the vast majority of tropical farmers these technical substitutions are not feasible and soil organic matter still fulfills all functions. A 'shadow price' of soil organic matter (Izac, 1997) might be based on the price of the technical substitutes which are not (or less) necessary if soil organic matter levels are maintained. Fig. 1 tentatively indicates 'labile' and 'stable' soil organic matter pools associated with the organic matter functions, but this needs further specification. A considerable part of current agricultural productivity in the tropics is based on the nutrients mineralized from labile soil organic matter pools accumulated under natural vegetation. Many of the positive effects of agricultural practices such as ploughing, drainage and liming on crop yields result from accelerated breakdown of soil organic matter. A conflict thus exists between the role of organic matter as source of nutrients and its other roles. Soil organic matter reduction, in part, requires slash-and-burn