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Stable carbon isotope ratios in soil and vegetation shift with cultivation practices (Northern Laos)

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ABSTRACT

Stable carbon isotopes ($\delta^{13}C$) can serve as a natural tracer of how plants contribute to soil organic pools (SOM). The present study investigates whether a better knowledge of the vegetation could help to account more accurately for changes in SOM. Secondly it aims to identify environmental drivers for changes in the $\delta^{13}C$ of SOM. The study site was a small catchment where the initial forest had been cleared for agriculture in the 1960's. The $\delta^{13}C$ was determined in the surface vegetation and in SOM across 59 survey plots comprising fields and fallow land, 22 environmental and land use variables were also determined in the plots. Carbon isotope ratios in the C_3 pathway species (n = 209) ranged from −37.7 to −26.1‰, in the C_4 species (n = 29) from −15.2 to −10.3‰, in SOM from −28.1 to −22.6‰. Cultivation of C_4 crops did not affect the $\delta^{13}C$ of SOM suggesting that maize and Jobs' tears residues supplied little C_4 material to SOM. Plots covered by a mix of C_3 and C_4 weeds had significant higher $\delta^{13}C$ values in SOM than plots with only C_3 plants, suggesting that C_4 weeds more than C_4 crops contributed to SOM. Accounting only for the perennials in the plot population gave strongest associations between SOM and vegetation. Although C_4 annual crops and C_4 annual weeds often cover the soil extensively during cultivation years, their biomass contribution to SOM is therefore much less than perennial C_4 plants occupying the site for longer periods. Soil $\delta^{13}C$ increased significantly with short fallow periods in between cultivation years which can be explained by our finding that very short fallow periods were associated with the invasion of C_4 weeds. Competition with C_4 weeds in turn pushed the farmers to cultivate hardier crops like maize and Jobs tears, replacing rain fed rice.

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1. Introduction

Plant organic matter is supplied from the vegetation to the soil as litter and residues. To analyze the incorporation of plant material to soil a tracing method using natural abundances of stable carbon isotope ratios ($\delta^{13}C$) has been developed (Balesdent et al., 1987) and is widely used since. The $\delta^{13}C$ values of C_3 and C_4 photosynthetic pathway plants are diacritic different, those of C_3 plants averaging −27.1‰ (−21 to −35‰) and C_4 plants averaging −13.1‰ (−10 to −14‰) (Tietzen, 1991). Because this difference is much larger than the small isotopic changes which occur during C decay in the soil, soil organic carbon retains the signature of its source vegetation (Boutton, 1996). In sites where vegetation has changed from one photosynthetic pathway to the other, the isotopic composition of the soil organic carbon can therefore be used as a tracer of the source material. The ^{13}C labeling technique works best in ecosystems or agroecosystems that were initially under C_3 vegetation and then changed to C_4 vegetation, or vice versa. Stable carbon isotope ratios of soil organic matter (SOM) are used in two types of studies: paleo-environmental legacy studies and studies in SOM storage and turnover. Examples include shifts from C_3 tropical forests to savannas dominated by C_4 grasses, shifts from C_4 savannas to C_3 cropland, replacement of C_3 tropical forest with C_4 crops or pastures (Delègue et al., 2001; Heaton, 1999; McPherson et al., 1993; Desjardins et al., 2004; Queiroz Rossi et al., 2013; Wooller et al., 2005; Yoneyama et al., 2001), and cultivation of C_4 maize in temperate regions dominated by C_3 plants (Balesdent et al., 1998). It is then possible to calculate the proportion of C_3-derived carbon and C_4-derived carbon in soil using mass balance mixing equations (Balesdent and Mariotti, 1996; Yoneyama et al., 2001). Many studies on SOM turnover also use particle-size fractionation, because, commonly, the recent material is incorporated in the coarse material and the oldest in the fine fractions (Feller et al., 1991). Thus, if a change in C_3–C_4

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productivity has occurred, the δ^{13}C values of the new organic inputs should be most evident in sand fractions, whereas the δ^{13}C of the old plant communities should be most evident in the organic matter in the clay and silt size fractions (Boutton, 1996). It is important to note that new soil carbon can only be distinguished from old when one pool is principally originating from C_4 plants and the other from C_3 plants. However, the study of Balesdent and Mariotti, (1996) demonstrates that enriched values of δ^{13}C of SOM may occur without any historic occurrences of C_4 plants in the population. Their example, old forest of Fontainebleau, France, showed local variations of δ^{13}C in the surface vegetation corresponding to similar trends in SOM. Monitoring the fate of SOM in ecosystems could improve with a better knowledge of the input vegetation. For instance calculations on soil carbon changes in the agrosystem improved when weed biomass inputs to soil were taken into account (Diels et al., 2001; de Rouw et al., 2010), or when historic cultivation records were considered (Awiti et al., 2008). The question here addressed is: if we know more specifically the δ^{13}C of plants, can we use them more accurately to account for changes in SOM? For instance can we identify which plants are important contributors to SOM pools and which are not? And if so, can we identify agricultural practices that impact on the distribution of those plants?

The study site is a small cultivated catchment, object of ecological studies since 1998 (Observatory of Multiscale Environmental Change, MSEC3). It is a representative site of forest conversion to agriculture in tropical Asia, a region where deforestation is spreading at an unprecedented scale. In order to address the two questions mentioned above we sought relationships between the δ^{13}C of the topsoil, the δ^{13}C of the surface vegetation, and a large number of measured environmental and land use variables in 59 survey plots.

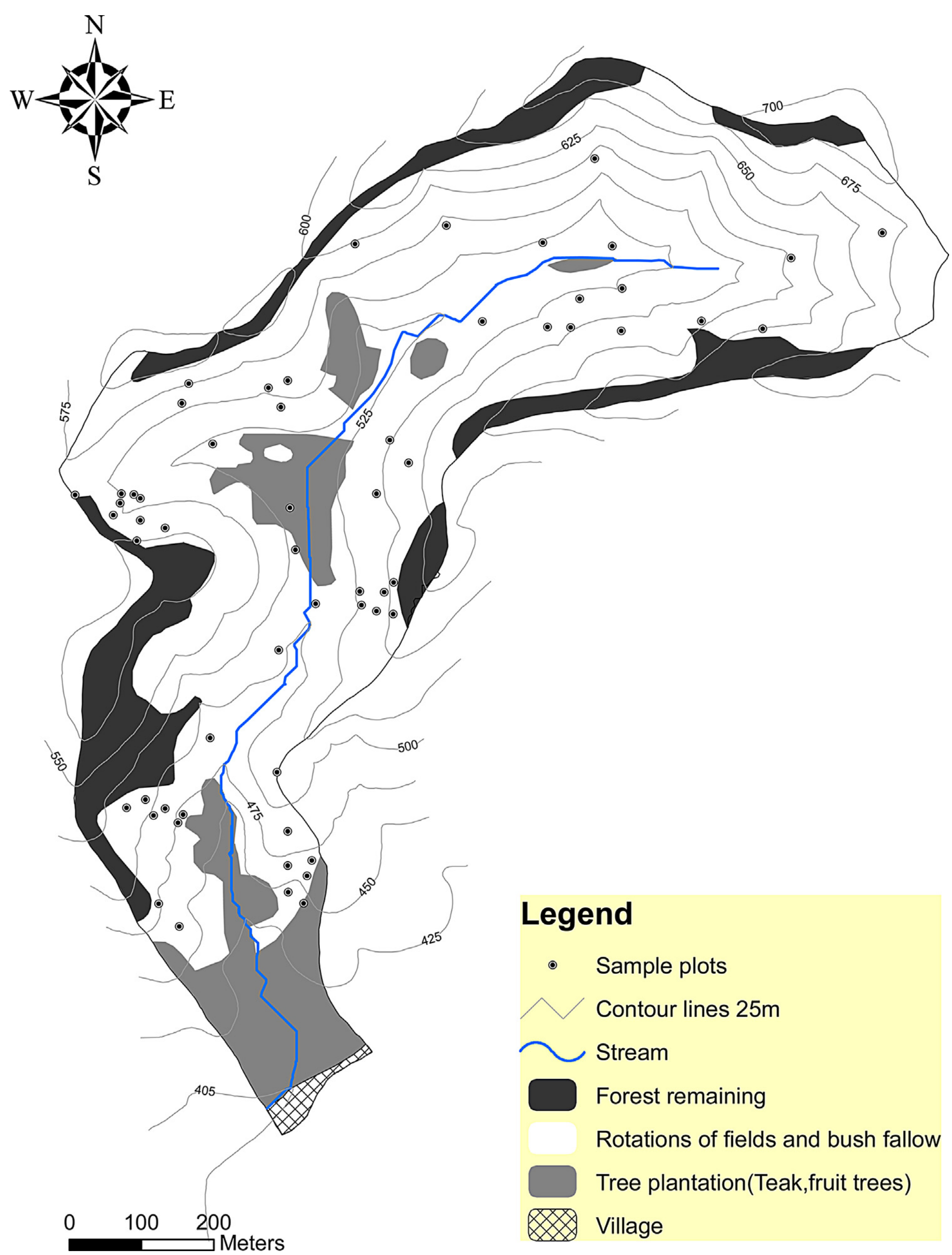

Fig. 1. Topographic map of study area Houay Pano catchment with land use and sample locations.

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