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Glucose decomposition and its incorporation into soil microbial biomass depending on land use in Mt. Kilimanjaro ecosystems

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ABSTRACT

Land use change can affect terrestrial C stocks, resulting in increased CO_2 flux from soil to the atmosphere. In Africa, conversion of natural ecosystems to agricultural lands is the most common land use change. This study investigated the effects of six land use types occurring in Mt. Kilimanjaro ecosystems i.e. (1) lower montane forest (2) grassland and (3) savannah (natural ecosystems) (4) Chagga homegardens (semi-natural ecosystem) and (5) maize fields and (6) coffee plantation (agroecosystems) on microbial biomass carbon (MBC) and dynamics of ^{14}C labelled glucose added into soil. Decomposition of ^{14}C labelled glucose and its incorporation into microbial biomass in surface soils (0–10 and 10–20 cm) were determined. MBC decreased significantly with increased intensity of land use. Mineralization of the ^{14}C labelled glucose occurred in two phases with contrasting rates: 0–10 days (6–18% of $^{14}C\ d^{-1}$) and 15–65 days (<0.1% of $^{14}C\ d^{-1}$). Land use intensification in agroecosystems led to an average increase of glucose decomposition of 14%. The decay rates of the labile C pool in intensively used agricultural lands were up to three times higher compared to natural ecosystems. The incorporation of ^{14}C glucose into microorganisms ranged between 1 and 7% of ^{14}C input in all soils, and was highest in savannah. Agricultural intensification decreased C content in soil through increased mineralization of organic substances and negatively impacted the upper soil layer more compared to the lower one. Based on these results we conclude that semi-natural ecosystems (e.g. Chagga homegardens) are more sustainable in Mt. Kilimanjaro ecosystems compared to intensive agroecosystems.

1. Introduction

Terrestrial ecosystems play an important role in the global carbon (C) cycle. Soil-vegetation systems can act as a sink or source of atmospheric CO_2 depending on the mineralization and formation of soil organic carbon (SOC) [66]. Terrestrial biosphere-atmosphere exchanges are affected by both anthropogenic disturbances, e.g. clearing of land for crop production and conversion of forest to pasture, as well as natural disturbances, e.g. wild fires. Such land use changes affect C stocks in soil [44] and atmospheric greenhouse-gas emissions [64]. Generally, losses of up to 50% of SOC have been reported after 30–50 years of crop production [52]. Conversion of natural ecosystems to agricultural land in Africa has led to a decrease in C stocks [41,48]. Whereas the trend of organic matter (OM) loss due to land use change is well known, the effect of land use changes on specific ecosystems functions, e.g. C and N cycles, decomposition and nutrient mineralization, microbial biomass content, are less known [45], especially in the terrestrial tropical and sub-tropical ecosystems.

Tropical ecosystems are known to influence global climate and biogeochemical cycles, especially C turnover and sequestration [56]. At the same time they are very sensitive to the changes because the cycles of C and nutrients in tropics are much faster compared to temperate ecosystems [71]. Nevertheless, C stocks dynamics in differing land use types in tropical Africa remain widely unknown [42,50]. Expansion of land area for crop production is widely regarded as one of the most important human alterations of the global environment [45]. The conversion of natural ecosystems to intensively used agricultural lands causes a significant decrease in terrestrial C stocks, resulting in changes in CO_2 fluxes [56].

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Carbon emissions from deforestation and forest degradation have been estimated to account for about 20% of global anthropogenic CO_2 emissions [64]. These emissions have generally increased in tropical and sub-tropical ecosystems since the 1950s [56]. There is still a large uncertainty as to C stocks and CO_2 fluxes following deforestation, so making accurate estimates of greenhouse gas emissions from deforestation in the tropics remains difficult. Therefore, adaptive management of terrestrial ecosystems and soil C sequestration is a new challenge in the context of climate change mitigation [23].

Tropical and subtropical ecosystems are very sensitive to land use changes, because much higher temperature lead to decomposition rates of organic substrates that are much higher compared to temperate ecosystems [27]. Therefore, there is considerable concern that land-use change from natural ecosystems to agricultural land lead to a depletion of soil C and subsequent increases in CO_2 levels in the atmosphere [48]. Conversion of natural ecosystems to intensive agricultural used ecosystems (among others: maize and coffee) is common in East Africa. However, the Chagga homegardens in Tanzania well exemplify a traditional sustainable land use system with many ecosystem services [61]. The Chagga homegardens are characterised by an integration of numerous trees (e.g. *Grevillea robusta*, *Cordia abyssinica* and *Albizia schimperiana*), coffee shrubs, and food crops (e.g. banana, maize, beans, potato, sweet potato and tomato) on the same agroecosystem [18,61]. The shading effect of the crown layer of the trees, higher precipitation and cooler annual average temperature of about 19 °C provides cooler micro-climate which supports the thriving of a larger microbial population than entirely agroecosystems located at a lower elevation.

Natural ecosystems are continually being converted to agricultural land. Therefore, there is an urgent need to improve the management of organic inputs and soil organic matter (SOM) dynamics in tropical land-use systems [40]. Input of organic substances such as crop residues and litter, play a critical role in the tropical and sub-tropical ecosystems because they provide both a short-term supply of nutrients and substrate for synthesis of SOM in the long-term [17]. Although decomposition of plant litter and its physical and chemical processes remain a major determinant of nutrient cycles of most terrestrial ecosystems, there is still little understanding for the management of organic C inputs in tropical ecosystems.

In order to understand and quantify C-dynamics in tropical soils depending on land use, decomposition of ^{14}C-labelled glucose and its incorporation into microbial biomass was investigated in an incubation experiment with soils from different land use systems. Glucose is the most common easily available substrate because it represents simple monosaccharaides [12] that will be produced during decomposition of e.g. cellulose, present in plant residue and will be released as root exudates [13,15].

The objectives of this study were to (1) evaluate the effect of land use change on mineralization of easily available substrates and (2) assess glucose stabilization in soil by incorporation into microbial biomass. This study focused on two hypotheses: (1) increased agricultural intensification will increase mineralization of easily available substrates; and (2) increased agricultural intensification will decrease the contents of MBC as well as the incorporation of simple organic substrates into MB.

2. Materials and methods

2.1. Study area

This study was conducted using soils from the southern slopes of Mt. Kilimanjaro, Tanzania (3°4′33″S 37°21′12″E). The diverse climatic differences at Mt. Kilimanjaro create a high diversity of ecosystems [34] and vegetational zonation [24,70]. The vegetation in Mt. Kilimanjaro is described in detail by Ref. [24]. Rainfall pattern is seasonal and varies with altitude. The long rains extend from March to June and the short rains between November and December. The southern slopes at 700 m a.s.l. receive an annual rainfall of 800–900 mm and slopes at 1500 m a.s.l. receive 1500–2000 mm. The forest belt lies between 2000 and 2300 m a.s.l [26]. The mean annual temperature varies between 10 and 21 °C and Zech (2006) described the soils from Mt. Kilimanjaro as Andosols.

2.2. Description of study sites and soil sampling

Soils were sampled at 0–10 cm and 10–20 cm depths from six ecosystems i.e., lower montane forest, grassland and savannah (natural), homegardens (semi-natural), and coffee plantations and maize fields (agroecosystems). Two sites representing each land use type were sampled. These ecosystems are located at different elevations (Fig. 1). A brief description of the study sites is given in Table 1.

The natural ecosystems have been altered through collection of firewood and occasional mowing. Due to the high demand of building material, firewood and farmland, lower montane forests have also been converted to grassland, which subsequently could be converted to coffee plantations. Moreover, the continued demand and expansion of agricultural land has resulted to the clearing of savannah woodlands characterized by *Acacia* trees for maize cultivation [50]. Intensively used agricultural ecosystems i.e. maize fields and coffee plantations are characterized by considerable disturbances through mechanization, use of pesticides and relatively frequent fertilization. The Chagga homegardens can be classified as agrisilvicultural system [25] and have been developed through anthropogenic influence on the lower montane forest [25,50]. The Chagga farming system has often been described as a model sustainable land use system and has evolved over more than five centuries [61]. However, the farming system has not changed much over the last decades compared to land uses in lower elevations [25]. After removing visible plant debris and roots, soil was sieved through a 2.0 mm mesh screen and stored under moist field conditions at 5 °C until analysis.

2.3. Incubation and ^{14}C glucose labelling

The incubation was conducted in closed vessels, in the dark at room temperature for 65 days. Four replicates, for each ecosystem

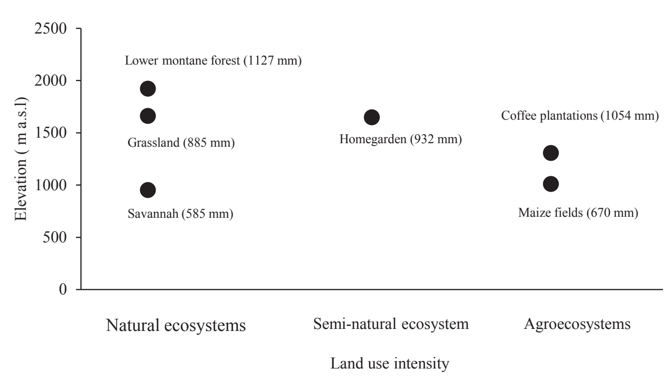

Fig. 1. Elevation (m a.s.l), annual rainfall (mm yr^{-1}) and land use intensities categories of the investigated ecosystems of Mt. Kilimanjaro.