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Land-use intensification and agroforestry in the Kenyan highland: Impacts on soil microbial community composition and functional capacity

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ABSTRACT

This study investigates microbial communities in soil from sites under different land use in Kenya. We sampled natural forest, forest plantations, agricultural fields of agroforestry farms, agricultural fields with traditional farming and eroded soil on the slopes of Mount Elgon, Kenya. We hypothesised that microbial decomposition capacity, biomass and diversity (1) decreases with intensified cultivation; and (2) can be restored by soil and land management in agroforestry. Functional capacity of soil microbial communities was estimated by degradation of 31 substrates on Biolog EcoPlates™. Microbial community composition and biomass were characterised by phospholipid fatty acid (PLFA) and microbial C and N analyses. All 31 substrates were metabolised in all studied soil types, i.e. functional diversity did not differ. However, both the substrate utilisation rates and the microbial biomass decreased with intensification of land use, and the biomass was positively correlated with organic matter content. Multivariate analysis of PLFA and Biolog EcoPlate™ data showed clear differences between land uses, also indicated by different relative abundance of PLFA markers for certain microorganism groups. In conclusion, our results show that vegetation and land use control the substrate utilisation capacity and microbial community composition and that functional capacity of depleted soils can be restored by active soil management, e.g. forest plantation. However, although 20–30 years of agroforestry farming practises did result in improved soil microbiological and chemical conditions of agricultural soil as compared to traditional agricultural fields, the change was not statistically significant.

1. Introduction

The high growth in human population in Sub-Saharan Africa has led to intensification of agriculture, deforestation and use of less suitable land for agriculture. The traditional techniques often leave the soil open to erosion by wind and rain, which result in depletion of soil organic matter and nutrients, in turn leading to lowered fertility.

In addition to decreased productivity, these conditions lead to loss of biodiversity both in flora and fauna (Matson et al., 1997; Tscharntke et al., 2012). The above-ground loss of biodiversity is well documented and of great concern, while the below-ground effects have been less studied. There is now, however, an increasing number of studies that have documented changes in soil microorganisms and fauna biodiversity of tropical soils in relation to intensified land use (e.g. Bossio et al., 2005; Huising and Okoth, 2011).

The traditional agricultural maize mono-cropping often results in removal of the above-ground biomass of stover after harvest. The consequences for soil fertility are reduced carbon and nutrient supplies (Mutuo et al., 2005). The tillage of crop fields also disturbs the habitats of soil organisms that in most cases show lower numbers and biomass in cultivated land than in undisturbed soil (Brady and Weil, 2002).

This study examines the structure and functional capacity of the microbial community in soil under different land uses on the slope of Mount Elgon in western Kenya, which is intensively used for agriculture. For more than 20 years, implementation of agroforestry in the region has been promoted with help of the NGO Vi

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Agroforestry Project (Vi AFP) and this type of land use is now wide spread. The aim is to conserve and restore soil fertility and to diversify agricultural production for improvement of farmers' economy and increase of wood production for fuel and construction. The agroforestry systems mainly include inter-cropping, trees scattered on farm, trees along conservation structures, hedgerow planting and woodlots (Dharani, 2002; Gachene and Kimaru, 2003; Maundu and Tengnäs, 2005). Mulching with leaves from the trees to the agricultural fields of agroforestry system farms is a recommended practice as well as other forms of returning crop residues to the soil. The beneficial effects of agroforestry on several ecosystem services and its capacity to restore soil structure and function have been assumed and have in many cases been supported by empirical studies (Jose, 2009; Sharma et al., 2009; Smith et al., 2012; Vincenti et al., 2013). However, not all studies have been able to demonstrate consistently significant effects on soil conditions and in particular not on soil microbial communities (e.g. Lacombe et al., 2009; Tornquist et al., 1999).

In this study the following hypotheses were tested: (1) Deforestation, agricultural cultivation and overuse of land resources lead to decrease of microbial biomass, change in community composition and decreasing functional capacity of soil microorganisms. (2) The microbial communities can be restored by active soil management, including implementation of agroforestry. The functional capacity of soil microorganisms was estimated by measuring the degradation of 31 different substrates on Biolog EcoPlates™. Microbial community composition and biomass were characterised by phospholipid fatty acid (PLFA) analysis and by determination of microbial C and N. The microbial community was also analysed in relation to chemical and physical soil conditions.

2. Materials and methods

2.1. Study area

The study took place on the slopes of Mt Elgon, west of Kitale in Rift Valley province, Kenya (coordinates of area centre: 1°04′N, 34°04′E). The areas surrounding Mt Elgon National Park have been almost completely deforested due to agriculture and fuel wood collection, but to a great extent, trees have now been reintroduced in agroforestry systems and in forest plantations and wood lots. The climate is highland equatorial with a mean annual temperature of 18 °C (Kitale town, 1900 m a.s.l.) and average annual precipitation of around 1300 mm, most falling during April–July (long rains) and October–November (short rains). The soils on the mountain slopes are reddish sandy clay loams developed from basalt and ashes and rich in organic matter. By the foot of the mountain the soils are dark brown andosols and nitosols. Maize and sunflowers are the most favoured crops, while *Acacia* spp., *Grevillea robusta*, *Sesbania sesban*, *Calliandra calothyrsus*, *Passiflora edulis*, *Cordia africana*, *Markhamia lutea* and *Persea americana* are the most commonly planted tree species. Mt Elgon National Park covers the area of the mountain above ca 2200 m and upto the summit at 4321 m a.s.l. The vegetation is composed of a zonation of mountain forest and afro-alpine vegetation above the tree line.

2.2. Sampling

Soil samples were taken in four different habitat types representing increasing land-use intensity: planted forest or woodlots consisting of many different species of trees (FO); agroforestry fields (AF); agricultural fields (AG = harvested and not replanted maize fields); and eroded land (ER = bare, uncultivated land often used as pathways). Together with staff from Vi AFP, farms on the chosen altitudes and cultivation systems were selected. There were nine replicates of each land use; five replicates were situated on altitudes between 1900 and 2000 m, and four replicates on altitudes between 2000 and 2200 m. All sampling sites were on small-scale farms, except one that was situated on Olof Palme Agroforestry Centre (OPAC, 1900 m a.s.l.). AF soil samples were collected in small agricultural fields surrounded by planted trees. For comparison, soil sampling (four replicates) was also performed in indigenous forest of Mt Elgon National Park (EL, 2200–2400 m a.s.l.). Dominating trees in the EL sites were *Okotea usambarensis*, *Olea africana* and *Juniperus procera*. In total, this added upto 40 sampling locations spread over an area of more than 100 km^2.

Samples for soil physical and chemical analyses were collected on all 40 locations during February–March 2007. Five soil cores from 0–25 cm depth were randomly collected with an auger from a ca. 25 m × 25 m area. The cores were bulked into one soil sample, put in plastic bags and tagged and then carefully mixed. The bags were left open to air-dry for a minimum of five days before transport to the lab at Moi University in Eldoret where soil physical and chemical analyses were done.

Samples for soil microbial analyses were taken at the same 40 locations as for physical and chemical analyses and by the same sampling technique, but at a later date during March 2007. These samples were transported in cool boxes and with minimal disturbance within 46 h to the Tropical Soil Biology and Fertility Programme of International Centre for Tropical Agriculture/World Agroforestry Centre laboratory in Nairobi (TSBF-CIAT/ICRAF) where total microbial C and N and Biolog EcoPlate™ analysis were done on the fresh soil. Thereafter the remaining soil was stored in freezer at −20 °C for later transport to SLU in Uppsala, Sweden, where the PLFA analysis was done.

2.3. Physical and chemical analyses

All physical and chemical analyses were performed according to Anderson and Ingram (1993). Briefly, soil particle size analysis was performed using the hydrometer method. Sand, silt and clay content of the soil was measured as percentage of weight of oven-dry and organic matter-free soil. Extractable nitrate was determined by a colorimetric method. Soil samples were extracted with potassium sulphate after which salicylic acid and sodium hydroxide were added and then analysed by the molybdenum blue method. After colour development, absorbance was read at 419 nm. Plant available P was analysed by the Olsen method. Air-dried soil was extracted with sodium bicarbonate at pH 8.5. The solution was filtered and the absorbance was measured at 880 nm. The organic carbon content was determined by complete oxidation by heating after addition of sulphuric acid and aqueous potassium dichromate mixture. The remaining potassium chromate that was titrated against ferrous ammonium sulphate gave the measure of organic carbon content. For total nitrogen, samples were completely oxidised by treating with hydrogen peroxide, selenium and sulphuric acid. After the acid digestion, sodium reagents were added and the absorbance was measured at 650 nm.

2.4. Microbial analyses

Microbial C (MBC) and N (MBN) was analysed by chloroform fumigation-extraction. Fumigated and non-fumigated soil was extracted with potassium sulphate and the difference in concentration gave the amount of microbial biomass C and N in soil (Anderson and Ingram, 1993).

Microbial metabolic activity was measured using 96 well Biolog EcoPlates™ where soil microbes are cultured in different substrates. The assay is based on the capacity of microorganisms