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Effect of land use, time since deforestation and management on organic C and N in soil textural fractions

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ABSTRACT

Deforestation and subsequent cultivation practices often result in loss of soil organic matter, in a degree depending on time since deforestation and soil and crop management. A land in North Greece was studied in order to check the influence of land use and management on soil organic C (SOC) and N. Cultivated soils with three dates since deforestation (25, 34 and 72 years) were compared to adjacent undisturbed forest soils. Two management systems were used in the cultivated soils: not irrigated wheat with superficial ploughing and irrigated cotton crop with deeper ploughing alternated with wheat every two years. Soil samples were separated in textural size fractions and organic C and N were analysed. In terms of land use, the most distinctive differences between agricultural and forest plots were found in coarse particulate organic matter (2.8 g kg^{-1} soil in agricultural land vs 14.8 g kg^{-1} soil in forest sites), and in the fine sand fraction SOC (8.6 g kg^{-1} soil in agricultural land vs 40.6 g kg^{-1} soil in forest sites), and N (1 g kg^{-1} soil in agricultural land vs 2.4 g kg^{-1} soil in forest sites), with minimal differences in the clay fraction (15.5 g kg^{-1} soil in agricultural land vs 21.2 g kg^{-1} soil in forest sites for SOC, and 2.2 g kg^{-1} soil in agricultural land vs 2.4 g kg^{-1} soil in forest sites for N). Time as a factor was significant for all the studied properties regarding the first years following deforestation. Management practices had an effect on SOC and, more pronounced, on N, with the wheat plots showing higher contents. Clay particles present the most stable behavior in terms of SOC (especially regarding time and management as factors) and N (especially regarding land use and time as factors) protection and maintenance.

1. Introduction

Deforestation is a practice adopted worldwide, aiming to obtain new land for agricultural purposes, increasing CO_2 release from soil to atmosphere (Eleftheriadis and Turrión, 2014; Kucuker et al., 2015; Gómez-Acata et al., 2016; de Oliveira Marques et al., 2017) and often leads to a depletion of the soil organic carbon (SOC) and N stocks when followed by intense agricultural practices (Ashagrie et al., 2007; Caravaca et al., 2004; Ratnayake et al., 2011), due to reduced input of biomass and enhanced decomposition after physical disturbance (Poeplau and Don, 2013). Yang et al. (2004) reported that land use changes, especially conversion of forest to cropland, can alter C and N pools and N availability for plant uptake. Hajabbasi et al. (1997) reported in their study that deforestation and subsequently tillage practices resulted to a 50% decrease in SOC and total N and a decrease in aggregate size, overall resulting to a decrease in soil quality and productivity of natural soils. Losses between 24 and 52% have been reviewed by Smith et al. (2016). Sigstad et al. (2002) found that soil C after 15 years since deforestation with continuous cultivation is almost completely worn out.

Soil tillage involves disturbance of the upper soil layers resulting to the breakdown of soil aggregates, thus influencing C stability in the soil (Paustian et al., 2000). This depletion in SOC content is primarily due to accelerated decomposition rates caused by soil tillage, which enhances aeration and physical contact to decomposer organisms (Zinn et al., 2002). Grasslands and generally uncultivated soils have often higher C and N contents than cultivated arable soils, due to the higher incorporation of SOC, the absence of soil tillage and reduced exposure to erosion (Hassink, 1997). Changes in management practices are reflected by the SOC and N status (von Lutzow et al., 2002). The buildup of SOC and N is determined by the amount and quality of the input of organic residues and their decomposition rate (Hassink, 1994). Wright and Hons (2004) concluded that soil management strategies play significant roles in SOC and N sequestration. Tillage systems that minimize

Abbreviations: SOC, soil organic C; cPOM, coarse particulate organic matter

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soil disturbance (minimum tillage and reduced tillage) generally increase the storage of SOC compared to conventional tillage, mainly due to the increased stability of soil macroaggregates (Jacobs et al., 2010).

In arable soils most of the SOC can be found in the clay and silt fractions, whereas in forest and grassland soils the contribution of sand size SOC to total organic matter is greater (Caravaca et al., 1999). With cultivation, the decline of SOC is most pronounced for the labile fractions (primarily particulate organic matter – POM), which provides an earlier indication of the consequences of different soil managements (Guggenberger and Zech, 1999; Six et al., 2002). POM is assumed to be associated with the sand fraction (Glaser et al., 2000). Clay contents are positively correlated with SOC concentrations (Serrano et al., 2016), when other factors such as vegetation, climate and hydrology, are similar (Schmidt and Kögel-Knabner, 2002). Carbon stored in the clay fraction contributes more to the long term stability of SOC than C in the sand and the silt fraction (Ratnayake et al., 2011; Serrano et al., 2016). The protection of SOC and the stabilization of N by silt and clay particles are well established (Six et al., 2002; Romanyà and Rovira, 2011). Due to structural stability of silt and clay fractions, more time is required to observe any effect of land-use changes (Saha et al., 2010).

The aims of this paper were to determine the changes in terms of SOC and N distribution in particle-size fractions that resulted from a) land use change from forest to agriculture, b) the amount of time from deforestation (25, 34 and 72 years) and c) the type of crop established with different management types (wheat fields vs cotton-wheat rotation fields) in an area of Northern Greece. The three stages of deforestation (1933, 1971, 1980) and the big amount of time elapsed since the first one, along with the differences between the remaining undisturbed forest and the different land management types, offered an interesting opportunity of studying these changes.

2. Materials and methods

2.1. Study area

The study area is located in Filyria, county of Central Macedonia, North Greece (40°54′11.69″ N to 40°53′41.9″ N, and 22°28′47.97″E to 22°29′37.10″E). The altitude ranges from 145 to 195 m and the climate is temperate Mediterranean with a mean annual temperature of 15.0 °C, (absolute maximum 40.4 °C, absolute minimum −17.4 °C) and mean annual precipitation of 506 mm. The soils of the area have developed from limestone, and are classified as Xeralfs. Soil A horizons have mainly clay loam textures, (mean percentages of sand, silt and clay: 30, 36, and 34%, respectively for the forest topsoil mineral horizon, and: 26, 38, and 36%, respectively for the Ap horizon at agricultural land). Mean pH was between 7.73 and 8.02 and concentrations of $CaCO_3$ were 1–7% at the forest sites compared to 1–14% at the cultivated plots. There are no differences between the different plots of the study area in terms of basic soil attributes. The dominant forest species is *Quercus pubescens*. The area was deforested at 3 stages (1933, 1971, 1980) leaving only 80 ha of natural forest undisturbed. These fields (2–9 ha mean extension) are cultivated mainly with wheat and cotton, and in several plots cherry trees are established. The mean slope of the area is 2–2.2%.

2.2. Management practices

The agricultural plots selected are cultivated with wheat and with cotton-wheat rotation. In the cotton-wheat rotation fields the cotton crop is alternated with wheat every two years (two consecutive years of cotton crop, one year of wheat), whereas the wheat fields are cultivated solely with wheat. For wheat, the management practices include ploughing up to 20–30 cm, fertilization with 20-10-0 fertilizer (applying 300–400 kg ha^{-1}), and NH_4NO_3 (100–150 kg ha^{-1}), and no irrigation is applied. Cotton management includes deep ploughing up to 30–40 cm in September, followed by surface ploughing in March, fertilization with 11-15-15 or 12-12-17 + micronutrients (250–300 kg ha^{-1}) is applied once per period and NH_4NO_3 (100 kg ha^{-1}) twice per period, and irrigation is applied by sprinklers every 10–15 days at summer, with an amount 300–400 m^3 of water per hectare. Management practices are similar since 1933. History data were collected from the Greek Forestry Service, the National Agricultural Service and from interviews with all the farmers of the selected plots.

Practice of irrigation and tillage intensity are the main differences between the two crop types. The division to wheat and crop plots relates to reduced tillage practices for the wheat plots (no deep ploughing) that are not irrigated, and conventional tillage practices for the cotton plots that are irrigated.

2.3. Experimental design and sampling

Three sampling categories referring to each deforestation stage (1933, 1971, and 1980) in the cultivated fields and one category referring to the natural remaining forest were considered. For each deforestation year category, two management subcategories were considered (wheat and cotton-wheat rotation), and for each management subcategory, 4 plots were sampled (24 cultivated plots). In adjacent areas to these agricultural soils, a total of eight plots of remaining undisturbed forest (*Quercus pubescens*) were selected. A composite sample was taken in each plot, which was obtained by mixing fifteen random subsamples from the 0–15 cm mineral layer. The selection of this superficial soil layer was made due to the need of comparison between agricultural soil layers and forest soil layers where the microbiological populations are mainly active in the first 15 cm (Eleftheriadis and Turrión, 2014). Soil sampling took place at the end of November 2005, after harvest. The sampling areas were chosen depending on homogeneity and similarity between them, no erosion was evident, no different slopes and orientations.

2.4. Particle-size fractionation

Soil samples were fractionated following a procedure that consisted of four steps:

1) Sonication with an energy of 60 J ml^{-1} to disrupt aggregates into single particles (sonifer Branson 450, t = 3 min 40 s)
2) Manual wet sieving in two substeps to separate particles coarser than 0.2 mm (coarse sand) and between 0.2 mm and 0.05 mm (fine sand).
3) Sonication with an energy of 300 J ml^{-1} to disrupt microaggregates (sonifer Branson 450, t = 60 min)
4) Centrifugation to separate silt from clay particles.

At the end, the fractions obtained were: coarse sand, fine sand, silt and clay. Coarse particulate organic matter (cPOM) has been defined as particulate organic matter associated with coarse sand (Buyanovsky et al., 1994) and was separated from coarse sand through flotation-decantation in water.

2.5. C and N analyses

Soil organic C and total N in the whole soil samples as well as in each sample of the separated fractions (fine sand, silt and clay) were determined by dry combustion using a LECO-CHN2000 analyzer. Soil organic carbon was calculated from the amount of total carbon subtracting C from carbonates. Soil total carbonates were determined by elimination using acid previously titrated with 0.5 M NaOH (FAO, 2007). The ratio between SOC and total N was then calculated.