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# Impact of deforestation on soil carbon stock and its spatial distribution in the Western Black Sea Region of Turkey

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ABSTRACT

Land use management is one of the most critical factors influencing soil carbon storage and the global carbon cycle. This study evaluates the impact of land use change on the soil carbon stock in the Karasu region of Turkey which in the last two decades has undergone substantial deforestation to expand hazelnut plantations. Analysis of seasonal soil data indicated that the carbon content decreased rapidly with depth for both land uses. Statistical analyses indicated that the difference between the surface carbon stock (defined over 0–5 cm depth) in agricultural and forested areas is statistically significant (Agricultural = 1.74 kg/m$^2$, Forested = 2.09 kg/m$^2$, $p = 0.014$). On the other hand, the average carbon stocks estimated over the 0–1 m depth were 12.36 and 12.12 kg/m$^2$ in forested and agricultural soils, respectively. The carbon stock (defined over 1 m depth) in the two land uses were not significantly different which is attributed in part to the negative correlation between carbon stock and bulk density (−0.353, $p < 0.01$). The soil carbon stock over the entire study area was mapped using a conditional kriging approach which jointly uses the collected soil carbon data and satellite-based land use images. Based on the kriging map, the spatially soil carbon stock (0–1 m dept) ranged about 2 kg/m$^2$ in highly developed areas to more than 23 kg/m$^2$ in intensively cultivated areas as well as the averaged soil carbon stock (0–1 m depth) was estimated as 10.4 kg/m$^2$.



## 1. Introduction

Soil organic carbon (SOC) is an important soil constituent influencing soil and water quality, farming practices and ultimately food production (Bruce et al., 1998; Phachomphon et al., 2010). The most significant component of terrestrial carbon are forests, which contain close to 77% of all carbon stored in vegetation and twice as much carbon as the atmosphere (Mantlana et al., 2009). It is estimated that destroying the world's forests, mainly for agricultural purposes, releases up to $2 \times 10^{15}$ g/yr of carbon to the atmosphere, much of which arises from cultivation which causes an accelerated decomposition of soil organic matter (Han et al., 2009).

Besides its significance to soil quality and food production, soil carbon pool plays an important role in the overall global carbon budget. In recent years significant efforts have been directed towards assessing the use of carbon sequestration in soils as a means to reduce carbon emissions and mitigate their ensuing adverse effects (Meersmans et al., 2008). However, the understanding of the dynamic exchanges between the soil carbon reservoir and the atmosphere and their potential impacts on the global climate remains somewhat limited. This is in part due to the insufficient data on historical and present SOC stocks and on the impact of soil characteristics, environmental conditions, and forest management and agricultural practices on this stock (Liebens and Van Molle, 2003; Smith, 2005).

Accurate estimation of SOC inventories is thus considered as an essential step for assessing the significance and impact of carbon sequestration (Meersmans et al., 2008; Phachomphon et al., 2010; Zhang et al., 2011). Efforts to estimate the SOC inventory range

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from the global or continental scales (e.g. Batjes, 1996; Jones et al., 2005) to the country scale (e.g. Bradley et al., 2005; Lettens et al., 2004) to regional scales (e.g. Mishra et al., 2010; Schulp and Verburg, 2009). Methods to estimate carbon stocks at the larger scales often rely on soil type and land use maps: a representative carbon stock value is computed for each land use and soil type combination and projected to all areas with the same soil type and land use. However, because of the spatial and temporal variability of environmental conditions and soil characteristics, and scarcity of soil carbon data, such an approach is associated with high levels of uncertainty (Lettens et al., 2004). To reduce this uncertainty, there is a need to conduct more local scale studies and to incorporate other related parameters such as climatic conditions, topography and land management practices (e.g. Schulp et al., 2008). Although significant progress has been achieved in developing robust methods for the analysis of spatio-temporal data, there is still no consensus within the research community on the most appropriate method for digital mapping of soil data (Bradley et al., 2005; Phachomphon et al., 2010).

Another important aspect influencing the soil carbon storage and the global carbon cycle is land use management practices (Batjes and Sombroek, 1997; Batlle-Bayer et al., 2010; Guo and Gifford, 2002; Luo and Zhou, 2006; Ogle et al., 2005; Post and Kwon, 2000; West and Post, 2002). Land use change is considered the second greatest cause of carbon emission after fuel consumption (Asan, 2002; Battle-Bayer et al., 2010; Quadrelli and Peterson, 2007; Watson et al., 2000). Soils have historically played the roles of both source and sink of carbon associated with changes in land management including forest management (Schlesinger, 1997). In most ecosystems worldwide, the conversion of land to agriculture will drastically change the natural internal nutrient cycling (Batjes and Sombroek, 1997; Lal, 2004; Watson et al., 2000).

This study examines the effects of deforestation and land use change to hazelnut plantation in the Karasu region, located within the provincial borders of Sakarya, Turkey, on soil carbon content and carbon stock. The study area was chosen because it had the highest rate of deforestation in Turkey, as reported by Forest Service of Turkey (Forest Service, 2007). The specific objectives of this study are (i) to assess the relationship between the soil carbon content and soil parameters in both forested and agricultural (hazelnut) lands; (ii) to evaluate the impact of the land use pattern in the study area on the SOC stock; and (iii) to present a modified kriging approach that combines soil carbon data at selected locations and satellite-based land use type images for the mapping and estimation of SOC stocks.

## 2. Materials and methods

### 2.1. Study area

The selected study area is located in the Karasu District of Sakarya, Turkey (Fig. 1). The Karasu region has an area of about 450 km$^2$. Forest clearance between 1994 and 2003 was 26,343 ha, which is almost two times greater than the forest area 13,784 ha remaining in 2004 (Forest Service, 2003). Cleared forest lands in the area had primarily been converted to hazelnut plantations, which may have resulted in disturbances on the ecosystem carbon balance (Oral et al., 2013).

The high financial income for planting hazelnut agriculture accelerated the land conversion in the region from forest to agriculture from 1980 to 1995 (Bayar, 1996). Most of the hazelnut orchard places have been generally converted from natural forest land in Black Sea region (Gol, 2009). Turkey, has twenty percent of the country's hazelnut production (Reis and Yomralioglu, 2006), about 77% of world hazelnut production and 75% of world hazelnut trade (TUIK, 2009). The average annual precipitation is 805.7 mm (Bayar, 1996). The mean annual temperature along the Black Sea coastal belt is 14–15 °C, dropping to 8–10 °C at an elevation of 1000 m above sea level. Deciduous broad leaf forests are common on the coastal Black Sea belt while coniferous forests are found on the upper part of the mountains.

### 2.2. Soil sampling and analysis of soil parameters

The data examined in this study were collected in April (Spring) and November (Fall) of 2009. In total 360 soil samples were collected and analyzed in the laboratory for soil elemental carbon, gravimetric soil moisture, soil texture, pH, and electrical conductivity. The data were collected from 45 locations distributed over the entire study area: 21 points classified as forest areas while the remaining 24 points are located within hazelnut plantations that were forest about 2 decades ago (Fig. 1). At each location, undisturbed soil samples were taken from four different depths, 0–5,

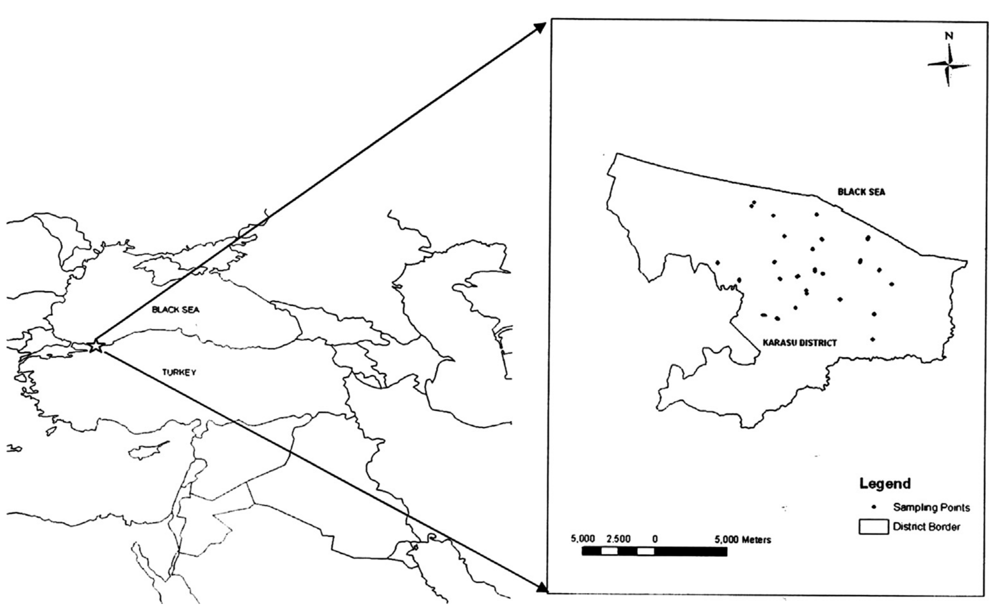


**Fig. 1.** Study area and soil sampling locations.