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Effects of afforestation on soil organic carbon and other soil properties

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ABSTRACT

Soil organic carbon (SOC) makes up a significant portion of the worlds terrestrial carbon stocks, and changes in land-use and land cover are changing soil carbon stocks. This study investigated the effects on soil organic carbon and some other soil properties of afforestation efforts using 15-year-old *Pinus nigra* Arn. Subsp. *nigra* (Black Pine) and *Cedrus libani* A. Rich (Lebanon cedar) on bare land in the semi-arid Nigde Akkaya dam watershed for erosion control and green belt creation. Soil samples were collected from three land use types (Black Pine planted, Lebanon cedar planted area and bare land) at two soil depths (0–10 cm and 10–20 cm) and replicated three times. Among the soil properties substantially affected by the change in land cover are soil organic carbon, bulk density, particle density, water holding capacity and total porosity. Generally, soil organic carbon was observed to increase after afforestation. Soil organic carbon (SOC) values were 1.09% and 1.13% in Black Pine and the Cedar area, respectively. These values were significantly higher than the values for the bare land soils (0.54%). For all types of land use, the amount of SOC in the soils decreased with depth. The amount of carbon sequestrated in Black Pine, Cedar and bare land sites at depths of 0–10 cm and 10–20 cm were 18.20 t/ha and 16.33 t/ha, 23.54 t/ha and 12.38 t/ha and 11.2 t/ha and 7.22 t/ha, respectively. The bulk density values obtained from the 0–10 cm layer soils in the afforested lands (1.53 g/cm^3 for Black Pine and 1.58 g/cm^3 for Cedar) were different from and lower than those in bare land (1.75 g/cm^3). Afforestation efforts led to an increase in water holding capacity (WHC) of the soil. Total porosity (TP) of the 0–10 cm layer soils increased after afforestation. This study indicated that on degraded land in a semiarid region, afforestation increased soil carbon sequestration, improved some soil properties and reduced erosion over a 15-year period.

1. Introduction

Global warming is one of the major environmental problems affecting Turkey and the whole world. One of the most common ways of combating global warming is endeavoring to mitigate its effects by, for example, reducing the greenhouse gas emissions that cause global warming and improving areas that sequester carbon. The primary areas that sequester carbon are soils and forests. The changes in the amount of carbon sequestered by vegetation and soils are closely related to the increase or decrease in the amount of CO_2 accumulation in the atmosphere. Thus, it becomes more and more important to determine the changes in the amount of carbon sequestrated in forest ecosystems (Tolunay and Çomez, 2008). Soils are major terrestrial ecosystems that have the capacity to store a significant amount of organic carbon. The Kyoto Protocol regarded this property of soils as a significant way to manage and reduce greenhouse gas emissions (Ruiz-Sinoga et. al, 2012). However, changes in land use affect carbon sequestration by soils (Feller and Bernoux, 2008; Jobbágy and Jackson, 2000; Mendham et al., 2003; Mondini and Sequi, 2008; Ogle et al., 2005). It is estimated that the amount of global soil organic carbon (SOC) sequestration exceeds the atmospheric pool threefold, and it is four times greater than the biotic C pool (Lal, 2001). An increase in CO_2 emissions to the atmosphere across the globe may decrease as a result of local changes in land use and land cover, particularly grassland and agricultural and forestry practices (Wali et al., 1999). The loss of approximately 1.7 and 0.1 PgCyr-1 to the atmosphere is caused by deforestation and erosion, respectively (Bruce et al., 1999). One of the reasons for the reduction in the amount of SOC is that native vegetation is removed for agricultural production purposes (Davidson and Ackerman, 1993; Mann, 1986). However, if management practices change (Lal, 2001) or reforestation efforts are conducted (Post and Kwon, 2000), the amount of SOC may potentially and substantially rise.

A large proportion of Turkey's soils are exposed to erosion at different levels. Millions of tons of fertile top soils are lost through erosion each year. One of the most common methods adopted for combating erosion in Turkey is afforestation. Afforestation efforts have generally been carried out for wood production, erosion and flood control, green belt creation and recreational purposes. Afforestation, rehabilitation, erosion control and bare land rehabilitation were conducted on 2.420.000 ha as part of the "Action Plan for National Afforestation Mobilization" in 2008–2012 (url 1). So far, afforestation efforts have been conducted in Turkey with the purpose of combating erosion and protecting soils, but they have taken on new meaning in terms of

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comprehending the positive impacts of forests in the struggle against the effects of global warming. However, due to the positive impacts of woodlands, which serve as carbon sinks, these lands have attracted the attention of scientists interested in biomass production and the amount of carbon sequestrated in soils. Various articles have been published on carbon sequestration in soils in humid and tropical regions, yet studies on carbon sequestration need to be conducted in Turkey as it is largely covered by semi-arid regions with widespread soil degradation that are under the influence of extreme ecological conditions and susceptible to the negative impacts of climate change. Taking the ecological constraints of semi-arid regions into consideration, revealing the ecological outcomes, such as changes in soil properties, from covering degraded lands with vegetation is of great importance (Paniagua et al., 1999). Understanding this process contributes to the determination of the amount of carbon sequestrated by degraded lands following the afforestation process and plays a significant role in the success of management plans. Studies should especially be conducted on lands exposed to erosion in arid and semi-arid regions. The literature is generally composed of studies of the effects of vegetation on soil properties; however, additional studies of which vegetation types are affected at which level are also needed (An et al., 2009; Fu et al., 2003; Stolte et al., 2003). It has been found out that the type of vegetation can lead to changes in some soil hydrological properties, such as infiltration capacity, hydraulic conductivity and water retention (Gutierrez et al., 1995). Afforestation, which is a way of preventing the soil on the degraded land from eroding, contributes to the reduction in soil erosion (Oscar, 2001) and increases the organic matter in the soil (Thapa, 2003). According to Silver et al. (2000), the changes in SOC are susceptible to the effects of vegetation cover for a short period of time. Gol et al. (2010) indicated that different soil properties, including soil organic matter and bulk density, were affected by afforestation efforts that lasted 46 years.

Following preliminary work conducted by the Intergovernmental Panel on Climate Change, the research area for this study is located on the upper part of the Seyhan Watershed situated within the Mediterranean Region, the region most vulnerable to global warming (IPCC, 2007). The aim of this study is to evaluate the effects of afforestation efforts using different species of trees on semi-arid degraded land as measured by soil organic carbon and selected soil properties. To this end, two sites with similar lithology, slope and exposure but afforested with different tree species and an adjacent, degraded area subject to erosion were compared.

2. Material and methods

2.1. Site description

Nigde Province is located in the southeast of the Central Anatolia Region where the Bolkar and Aladag Mountains twist towards the north within the Central Taurus Mountains. The province lies at approximately a 1211 meter altitude. The afforestation site is located in the Hidirlik district within the provincial borders of Nigde (Fig. 1, Table 1). According to data obtained from the weather station in Nigde, the average annual temperature is 11.0 °C, average annual rainfall is 337.5 mm and average annual moisture content is 59.5% (Anonymous, 2009). According to the Thornthwaite classification, this is a type of continental climate that may be referred to as DB'_1,db'_2 and defined as semi-arid; heat is at the mesothermal level, and the water surplus is insignificant (Anonymous, 2013). The lithology in the research area consists of marble belonging to the Nigde massive (Goncuoglu, 1986), and brown soils are widespread (Anonymous, 1993). Salinization was not observed in the soils, and the texture in the research area is generally sandy loam. The topography of the research area and adjacent sites is characterized by mountains, but the afforestation site is located on the subslope. The general characteristics of the afforestation site are stated in Table 1. Typical vegetation around the research area includes *Picea orientalis* (L.) Link, *Robinia pseudoacacia* L., *C. libani* A. Rich., *Cerasus vulgaris* Miller, *P. nigra* Arn. subsp. *nigra. Caramanica*, *Fraxinus ornus* L. subsp. *cilicica* (Lingelsh) Yalt., *Cupressus sempervirens* L., *Pyracantha coccinea* Roemer, *Berberis vulgaris* L., *Ligustrum vulgare* L., *Ailanthus altissima* (Miller) Swingle, *Morus alba* L., *Acer platanoides* L., *Acer negundo* L., *Platanus orientalis* L., *Vitis viniferea* L., *Betula pendula* Roth and *Rhus coriaria* L., *Juglans regia* L. Herbaceous vegetation consists of such species as *Capsella bursa-pastoris* (L.), *Ranunculus cuneilaminatus* Greuter and Burdet, *Tamarix parviflora* DC., *Astragalus hamosus* L., *Trifolium retusum* L., *Hordeum murinum* L. subsp. *glaucum* (Steudel.) Tzvelev, *Euphorbia microsphaera* Boiss., *Poa bulbosa* L., *Agropyron cristatum* (L.) Gaertner. subsp. *pectinatum* (Bieb.) Tzvelev var. *pectinatum*, *Stipa lessingiana* Trin and Ruper (Baskose et al., 2012).

This study was conducted in May, 2012, in Cedar and Black Pine afforestation sites planted in 1998 by the General Directorate of Afforestation on significantly degraded land located within the Nigde Akkaya dam watershed to form a greenbelt and combat erosion. Soil sampling in the afforestation area was applied with tree crown projection. The surface of the soil was covered with a thin litter layer (1.5 cm). Saplings were planted in 3 × 3 m spaces (Fig. 1). Afforestation efforts and preparation of the land for research was performed utilizing machines and equipment. Cedar and Black Pine plantations in the research area stretch to 650 ha and 20 ha, respectively (Anonymous, 2010). The bare land specified as the control area was considerably degraded grassland exposed to erosion and was not subject to any fertilization.

2.2. Experimental design and sampling

Soil samples were collected in a factorial combination of three land use types × two soil depths. For each afforestation site (Black Pine and Cedar) and the bare land site used as a control, three 30 × 30 m sampling plots were selected. The three land uses were divided into three replicates at two different depths. Soil samples were collected from two different depths (0–10 cm and 10–20 cm) in three randomly selected subplots of each sampling plots (3 × 3 × 3 × 2). In total, 108 soil samples were collected including 18 to be disturbed and 18 to be core samples from each type of land use. Core samples were taken with the help of 100 cm^3 steel cylinders. Furthermore, the diameter and height of 10 randomly selected saplings from each sampling area were measured.

2.3. Laboratory analysis

The soil samples were air-dried and passed through 2 mm sieves in the laboratory. A 1:5 soil to water ratio mixture was used to determine the pH value and electrical conductivity (EC) of the soil, and the test was conducted with a multiparameter WTW. The soil samples to be analyzed for soil bulk density were collected with a 100 cm^3 volume steel cylinder. Both the diameter and the height of the cylinder were 5 cm. The methods adopted for the determination of bulk density (BD), particle size distribution and soil organic carbon (SOC) were the core method (Blake and Hartge, 1986), the hydrometer method (Gee and Bauder, 1986) and the Walkey Black method (Schnitzer, 1982), respectively. Particle density (PD) was determined using the picknometer method. The formula for calculating total porosity (TP) was ((PD − BD) / PD ∗ 100) where PD stands for particle density and BD for bulk density of the soils. Water holding capacity (WHC) was calculated for soil core samples as the difference between oven-dry and saturated weights (Gulcur, 1974; Ozyuvaci, 1976). The dispersion ratio (DR), which shows the degree of erodibility of the soils, was calculated following Middleton (Balci, 1996). The carbon sequestrations potential of the soils was calculated for each depth and land use with the following equation (url 2):

$$\mathrm{SOC} = \mathrm{SOC} \times \mathrm{soil\,depth} \times \mathrm{bulk\,density} \times 10.000 \quad (1)$$