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The Effect of Coniferous Forest Age on Some Soil Organic Carbon Fractions in a Semiarid Ecosystem

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ABSTRACT: Soil organic C content in forested areas creates a greater attention for carbon sequestration and removal of atmospheric CO_2 back into soil. The aim of this study was to evaluate the effect of different age of pine forest (*Pinus nigra*) plantation on soil organic C content and some biological carbon fractions in a semiarid ecosystem of northern Turkey. Soil samples were taken from 0 – 5, 5 – 15, and 15 – 30 cm depths of different age (7, 14, and 40 years) of adjacent forested area with three replications. Soil organic C content significantly increased in 14yr forested area compared to 7 and 40yrs forested areas ($p<0.05$). Similarly, mineralize C content was greater in 14yr forest up to 15 cm depth. Microbial biomass carbon (MBC) varied depending on forest age and the greatest MBC was observed in 7yr forest at 0 – 5 cm and 15 – 30 cm depths. The greater soil organic C in 14yr forest could be the effect of both pine forest and arable plants compared to 40yr forest where the high intensity of tree covers inhibits arable plant growth. Most of the organic materials in pine forest stay as litter debris on the soil surface and the lower amount of organic C could be transferred in mineral soils.

Keywords: *Organic carbon, Carbon management, Pine forest, Biological carbon fractions, Forest age*

1. Introduction

Soil management has been considered as crucial for carbon sequestration. One of the most important ecosystem in terrestrial is forest, plays a significant role in global C cycle by converting atmospheric C into biomass, and emitting it back into atmosphere or sequestering it into stable soil organic matter pools (Post and Know 2000). The amount of C pool in a forest depends on soil properties, climate, and anthropogenic activities. Many factors such as environmental factors (e.g. climate, parent material, landscape position) and human-induced factors (e.g. land use type, management intensity) may vary soil C stocks (Mau *et al.*, 2005; von Lützow, 2006). The capacity of soil to sequester soil organic C depends on soil structure which is the key element in soil C dynamics (Six *et al.*, 2002). Pedology is also a describing factor of soil organic carbon stability, more than individual soil physico-chemical properties (Soucémarianadin et al. 2018).

Atmospheric CO_2 can be lowered either by reducing emissions or increasing CO_2 storage in terrestrial ecosystems. Most of the carbon enters the terrestrial ecosystem through the process of photosynthesis. Therefore, soil organic C concentrated in the upper level of soil can be significantly affected by land use and soil management practices (Tian *et al.*, 2002). The amount of soil C can be determined by the difference between the rate of organic C input through leaf and root biomass and its mineralization (Golchin *et al.*, 1994; Gregorich and Janzen, 1996). The estimation of soil organic C pools in soil is difficult due to the greater variability of C stocks due to complexity of physical, chemical, and biological processes that affect C cycling in the soil (Trumbore *et al.,* 1995). The large C sink in forest ecosystem is mainly the result of high biomass, which can be associated with less intensive harvesting regimes. Schils *et al.* (2008) indicated that managed forest land can sequester C between the ranges of 0.01 to 0.8 Mg ha^{-1} yr^{-1}.

Forests have been considered a significant resource for carbon storage putting on the one side of the earth's surface, where soil carbon is double or triple the amount in the above ground biomass as being available into the atmosphere (Kumur *et al.,* 2013). The different tree species in forests have a different effect on the carbon storage of ecosystem, for example coniferous species tend to accumulate soil organic matter in the forest floor, but are low in the mineral soil, compared with deciduous trees (Jandl *et al.,* 2007). The trees with high wood density such as deciduous tree species can accumulate more carbon than trees with light wood like coniferous tree species (i.e. pines) (*Fissore et al.,* 2008). Boreal forests store carbon in woody biomass as well as litter, coarse woody debris and peat (Karbanov, 2000). Soil organic C pool under most alpine scrub was 32.72 percent higher as compared to Himalayan temperate forests, 53.88 percent higher than Himalayan dry temperate forest, 60.41 percent more than sub-alpine forest and 103.28 percent higher as compared to tropical deciduous forest (Palpanwar and Gupta, 2013). It is possible to mitigate climate change with protecting existing forest, expanding carbon sink, using wood products for fossil fuels and reducing emission from deforestation and degradation (Kaul *et al.,* 2009). Forestation of sloppy and shallow soils in terrestrial ecosystem can sequester more carbon and protect soil and carbon transportation through runoff. The quantity and quality of soil organic carbon sequestration in forests can vary after the year of plantation. The objective of this study was to determine the amount of soil organic carbon at the different ages of pine-plantation in a semiarid ecosystem of northern Turkey.

2. Materials and Methods

This study was conducted in the north site of Turkey, where is on the passing zone between humid and arid regions. The average precipitation and temperature of the area are around 434 mm and 12.5 ^{o}C, respectively. The coldest and warmest month's average temperatures are 1.8 ^{o}C in January and 22.3 ^{o}C in July and August, respectively. Soil samples were taken from three different ages (5, 14, and 40 years) of pine forest (*Pinus nigra*) plantation area. The forest ages were slected based on same location. The three different ages of plantation areas are adjacent and cover about 10 ha area. Three different sampling locations were chosen randomly in each planting area and soil samples were collected from 0–5, 5–15, and 15–30 cm depths with three replications in November. Soil samples were stored at 4 ^{o}C until analysis. Some soil physical, chemical, and biological analyses were performed on soil samples.

Soil particle distribution was determined by Bouyocous hydrometer procedure (Bouyocous, 1951). Soil pH was also determined based on 1:2.5 (w:v) dilution method (Richard, 1954). Soil bulk density was measured by inserting 5 cm diameter cylinder (Tüzüner, 1990). Soil carbonates were determined by the calcimeter method (Nelson, 1982). Soil organic C content was measured by Walkey-Black wet oxidation procedure (Nelson and Sommer, 1982). Mineralizable C contents was determined in the soil samples after adjusting moisture content to 60% of water holding capacity at 25 ^{o}C for 28 days incubation. The CO_2-C produced during incubation was trapped in 5 mL of 1 M sodium hydroxide (NaOH) solution, and the extra OH^- was titrated using 0.05 N HCl solutions. Microbial biomass C (MBC) was determined using fumigation-incubation method (Horwath and Paul, 1994). Analysis of variance was performed to test the effects of forest age on different soil parameters. The significant differences between means were indicated at probability of 0.05 using SPSS program. Duncan test was used to compare means in same soil depths.

3. Results and Discussion

Some soil physical and chemical properties have been significantly affected with plantation time of *Pinus nigra* in semiarid ecosystem (Table 1). Soil clay content was slightly greeter in 40yr (40 year) forested area compared to 7yr and 14yr forests ($p<0.05$). However, clay content was similar in 7yr and 14yr forests. Soil bulk density significantly increased in 14yr forested area due to compaction of grazing animals in the study area. Generally, soil bulk density increased with the increases of soil depth. Soil pH was similar in the different age of forested areas and soil pH ranged from 7.7 to 7.9.

Table 1: The some soil physical and chemical properties of different age of forested areas.

Forest age	**Depth**	**Clay**	**Bulk density**	**pH**
year	**cm**	**%**	**g cm^{-3}**	
7	0-5	33.33 (5.21) a	1.32 (0.03) a	7.76 (0.03) a
	5-15	37.33 (5.93) ac	1.48 (0.12) ab	7.76 (0.02) a
	15-30	34.67 (3.72) a	1.62 (0.03) c	7.88 (0.01) a
14	0-5	32.00 (5.78) a	1.50 (0.03) b	7.73 (0.05) a
	5-15	25.33 (1.77) b	1.60 (0.07) c	7.81 (0.04) a
	15-30	35.33 (1.77) a	1.63 (0.04) c	7.82 (0.06) a
40	0-5	45.33 (1.33) c	1.30 (0.04) a	7.71 (0.07) a
	5-15	50.67 (2.41) d	1.40 (0.05) a	7.85 (0.00) a
	15-30	43.33 (0.67) c	1.40 (0.02) a	7.84 (0.10) a
			p value	
Forest age		0.03	0.05	ns
Depth		ns	0.04	ns
Forest age*Depth		ns	ns	ns

Not: Parenthesis indicates standard error (n=3). Different letters in same colon shows significant difference.

Soil organic C content was significantly affected by forest age in the study area (Fig. 1). Soil organic C content was generally greater in 14yr forested soil compared to 7yr and 40yr. However, mineral soil organic C content was similar through the soil depth in 14yr and 40yr forests. The highest soil organic C content in 14yr forest could be the result of high density of grasses between the trees, but the soil surface in 40yr forest was cover by larger trees without any grasses. Therefore, the combined effect of tree and grasses in 14yr forest created a larger soil organic C in mineral soil. This result also indicated that most of the soil organic C in old pine forest accumulates at the surface soil as litter debris. Prietzel *et al.* (2006) reported that the organic layer displayed an increase of 0.4 Mg C ha^{-1} yr^{-1} in a long-term experiment under Scots pine. The significant difference in soil organic C between the different age of forested area occurred up to 15 cm depth. The similar soil organic C content in 7yr and 40yr in mineral soils may relate to the disturbance effect of soil during forest plantation and lower C input through pine roots. Nielsen *et al.* (2012) identified the forested mineral soils of Denmark as a C pool sequestering 0.08 Mg C ha^{-1} yr^{-1}. However, repeated sampling in England and Wales indicated losses of C (Bellamy *et al.*, 2005), in spite of the evidence of supporting C accumulation (Gruneberg *et al.*, 2014). Soil organic C pool of organic layer is largely depending on tree species and parent material, and the C pool of the mineral soil varies among soil groups (Gruneberg *et al.*, 2014). In addition, the influence of environmental factors (depth, soil, vegetation and climate) with the degree of significance on soil organic C stability varies among the soil organic C pools (Soucémarianadin et al. 2018). We identified lower amount of soil organic C in mineral soil of 40yr forest, where most of the organic C was stored at the surface as organic layer. This result indicates that soil organic C in coniferous forest is largely stored on organic layer than mixed and deciduous forests as indicated by other researchers (Oostra *et al.,* 2006; Schulp *et al.,* 2008; Wiesmeier *et al.,* 2013).

Mineralize soil organic C content was significantly affected by forest age ($p<0.05$) (Fig. 2). Mineralize soil organic C content showed an increasing trend from surface to deeper depth. Mineralize C content was generally greater in 14yr forest as similar as soil organic C. The greater mineralize C content was measured in 14yr forest up to 15 cm depth and the greatest mineralize C was observed in 7yr and 14yr forests at 15 -30 cm depth. The greater mineralize C content at 15-30 cm depth could be attributed to higher soil bulk density and disturbance of soil during incubation. The differences in mineralizable C content could be the both effect of soil organic C content and the quality of organic materials which manage microbial activity and decomposition of organic material. Generally, woody plant residues have lower decomposition rate than other plant residues. Soil organic C content is high in grassland which contains an intensive root system that creates an ideal environment for soil microbial activity (Conant *et al.,* 2001).

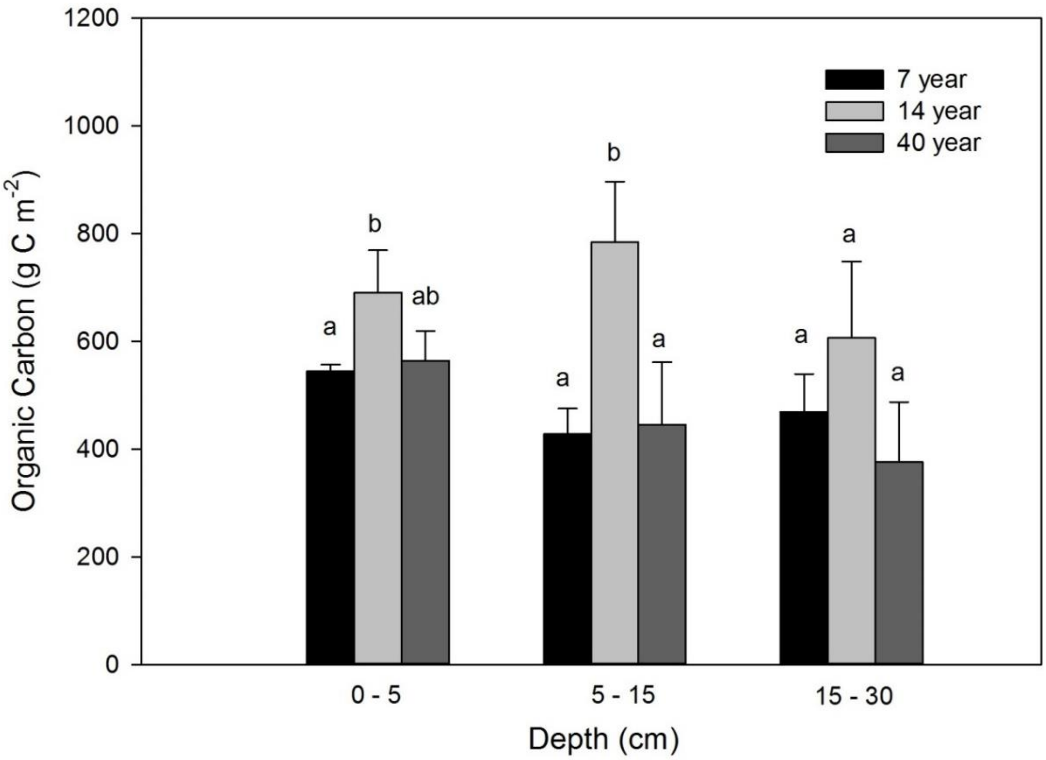

Fig. 1. The effect of different age of forest on soil organic C content in a semiarid ecosystem. Different letters indicate significant difference in same depth.

Microbial biomass C (MBC) content varied depending on forest age (Fig. 3). The greater MBC was measured in 7yr forest at 0 – 5 cm and 15 – 30 cm depths ($p<0.05$). Microbial biomass C was similar at 5 – 15 cm depth while the differences occurred at surface and deeper depth. The variation in MBC under different age of forested area may associated with nutrient availability and quality of soil organic C which enhance microbial biomass and microbial activity. In addition, the high MBC content is an indication of soil quality and nutrient status of soil. The increasing age of forest increases nutrient uptake and shifts in soil organic C to more resistant and polymerized woody materials.

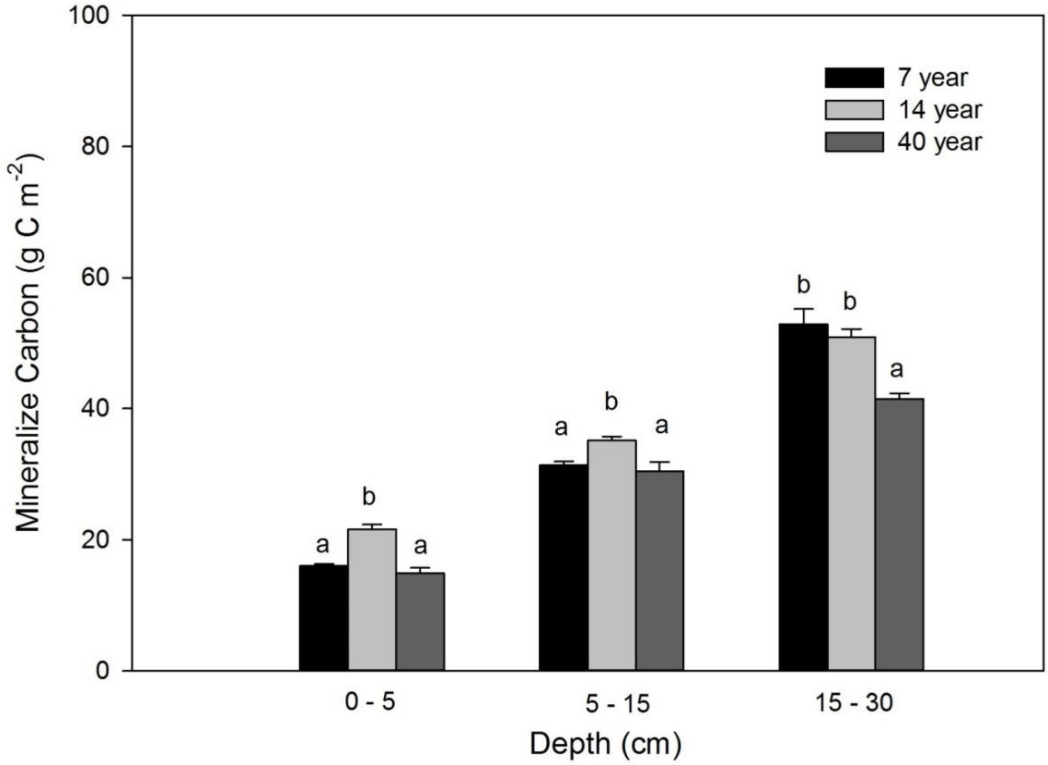

Fig. 2. The effects of different age of forest on mineralize carbon content in a semiarid ecosystem. Different letters indicate significant difference in same depth.

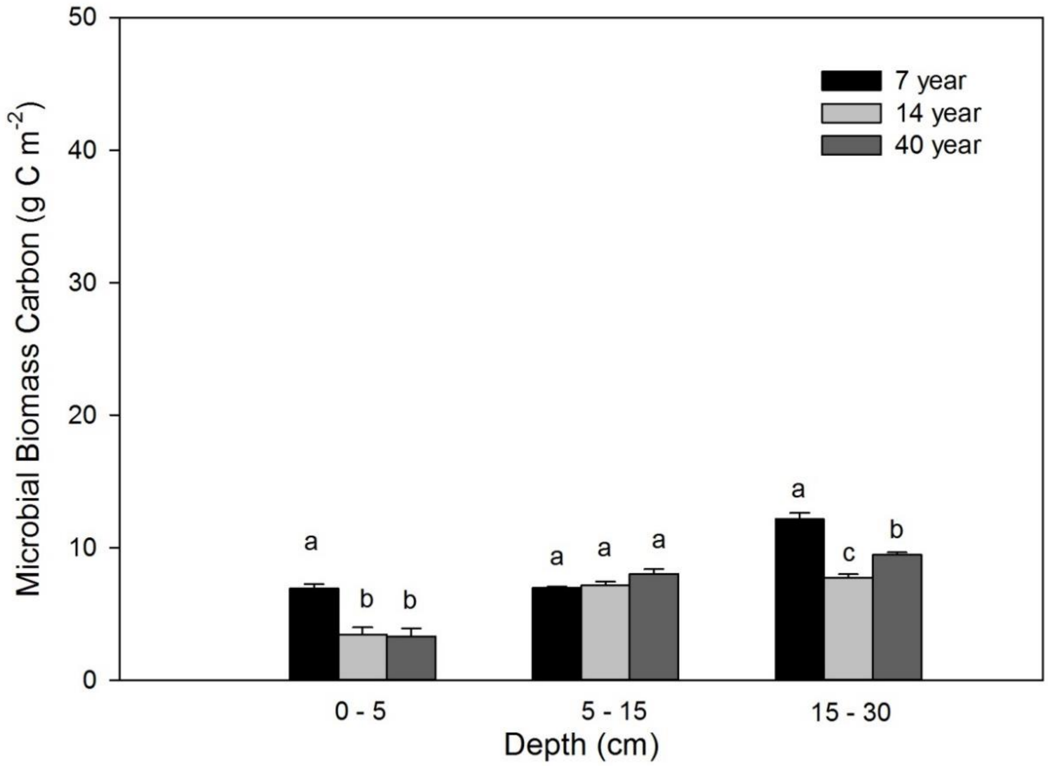

Fig. 3. The effects of different age of forest on microbial biomass carbon content in a semiarid ecosystem. Different letters indicate significant difference in same depth.

4. Conclusions

Conversion of arable lands to pine forest can change soil organic C and some biological C fractions. Soil organic C content varies depending pine forest plantation age. The greater mineral soil organic C content was observed in 14yr forested area compared to 7yr and 40yr forests. The higher soil organic C content could be the effect of both arable plants and pine forest. However, soil organic C level was lower in 40yr forest due to high intensity of forest which shaded soil surface and inhibited arable plant growth. Moreover, pine forest has limited organic C addition in mineral soil and most of the organic materials stay on the surface as needle plant litter. Mineralize C fraction has been significantly affected by forest age. Similarly, mineralize C content was greater in 14yr than 7yr and 40yr forests up to 15 cm depth while mineralize C was equal in 7yr and 14yr at 15 – 30 cm depth. The greater MBC was obtained in the youngest forest at 0 – 5 and 15 – 30 cm depths. The changes in MBC are an indication of quality of soil organic matter and nutrient status of soils. As consequences, pine forest (*Pinus nigra*) has lower organic C input in mineral soil and most of the organic materials stay at the surface as litter debris. The combine effect of forest and arable plants creates an increase in soil organic C, mineralize C, and MBC in 14yr forest.

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