Journal of Environmental Biology **January 2010,** 31, 185-188 (2010)

Long term effects of red deer (*Cervus elaphus*) grazing on soil in a breeding area

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(Received: March 15, 2009; Revised received: May 15, 2009; Accepted: September 18, 2009)

Abstract: *This paper examines the effects of red deer grazing on some properties of soil (sand, silt, clay, pH, electrical conductivity, organic carbon, bulk density, fine soil weight, compaction and saturation capacity), and litter (unit weight-mass, organic matter content (%) and organic matter mass) properties on a red deer breeding area by comparing an undisturbed area in Istanbul Belgrad Forest-Turkey. According to the results obtained in this study, the litter mass in the breeding area has been found considerably lower. There were some crucial changes in the characteristics of the soil which has been investigated in 0-5 cm depth. No important difference had been detected between the breeding area and the undisturbed area in terms of electrical conductivity. However, other investigated soil properties in 0-5 cm depth showed significant differences between the undisturbed area and the breeding area. Soil was significantly compacted by red deer grazing. The soil pH was 2.18 unit higher in undisturbed area. Moreover, organic carbon content (1.395%) in the breeding area was found quite lower. Depending on the compaction of the soil and lessen quantity of soil organic matter, the value of saturation capacity (28.83%) on the breeding area is considerably lower, bulk density and fine soil weights were significantly higher. Mean silt and clay proportions (25.4 and 33.7%, respectively) are quite higher and the mean sand proportion (40.9%) was lower in the breeding area than in the undisturbed area. Results indicated that long term red deer grazing in the breeding area adversely affected litter and soil properties.*

Key words: *Red deer, Breeding, Grazing, Soil, Compaction, Forest floor*
PDF of full length paper is available online
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Introduction

Grazing associated with animal activity is known to alter hydraulic and mechanical properties of soil. Trampling animals cause soil deformation by exerting high ground-contact pressures under their hooves (Yong-Zhong *et al.*, 2005; Zhao *et al.,* 2007). Besides soil compression, shear stresses further destroy soil structure due to kneading and homogenization, which cause a change in macroporosity and the connectivity of the pore system. Such changes depend not only on the magnitude of applied stresses, but also on aggregate stability at the time of trampling, which depends on soil moisture (Zhao *et al.,* 2007). Generally, grazing has been found to affect the physical condition of soil near the surface, because of hoof action and nutrient storage and cycling potential through grazing intensity and urine and dung deposition (Liebig *et al.*, 2006). The correlations among soil properties are very complex, especially on the plot or regional scale. These characteristics make it very hard to interpret the various studies and to predict the relevant processes and mechanisms that influence soil properties (Zhao *et al.*, 2007).

Overgrazing causes a decline in soil physical, chemical and biological properties, resulting in dramatic changes in vegetation. Moreover, modifications in nutrient cycling led to permanent degradation of land productivity and destruction of the ecosystem (Pei *et al.,* 2008). Higher bulk densities and lower elemental concentrations in heavily grazed areas may also be caused by erosion. Increased bulk densities and decreased organic carbon concentrations in grazed areas are due to the combined effect of loss of organic matter following animal trampling, and lower above and below-ground organic matter input as a consequence of grazing (Smit and Kooijman, 2001; Steffens *et al.*, 2008). Overgrazing has led to significant changes in plant cover and in some places to the complete absence of vegetation cover. The degradation of the vegetation exposes the soil surface directly to wind and water erosion, leading to loss of the fertile top soil and its content of nutrients and seeds. The soil becomes compacted by animals trampling, thereby affecting the water infiltration and impairing plant germination, regeneration and growth (Xie and Wittig, 2004). These processes may cause low water storage capacity and loss of soil fertility (Zhao *et al.,* 2007).

Most studies of grazing impacts on nutrient cycling have been conducted in grasslands or pastures. However, in forest areas, the situation is more complicated, because the grazed vegetation is overgrown by trees, which are not directly affected by large herbivores. Browsing may be important in forests. The trees may alter the effect of grazing in different ways (Smit and Kooijman, 2001). The effects of deer grazing on soils may be important on long term determination of ecosystem sustainability (Binkley *et al.,* 2003).

Deer populations have been increasing in Europe, Russia and North America during the last 100-200 years (Gill, 1990). On the other hand, deer populations in Turkey have been decreasing during the same period because of uncontrolled hunting. To increase the deer population, Turkish General Directorate of Forestry decided to create deer breeding areas by the end of the 1950s. Istanbul

Special Issue - **Forest, Forestry and Environment in Turkey**
Guest Editor - **Professor Dr. Munir Ozturk**

Belgrad Forest Red Deer Breeding Area was founded in 1959 by importing 6 red deer, covering 103.5 ha area. Today, the number of deers has reached 200. The goal of this study is to evaluate changes in some litter and soil properties in a red deer breeding area, as compared with an adjacent undisturbed area of oak-dominated forest in Istanbul Belgrad Forest.

Materials and Methods

The research area was located in Belgrad Forest (41° N, 28° E) in Istanbul province, in the Marmara geographical region of Turkey. According to the long-term data from Bahçeköy Meteorology Station (the closest to the research area), average annual precipitation is 1074.4 mm, annual mean temperature is 12.8°C, mean range 9-17.8°C. The climate of Istanbul Belgrad Forest is close to sea (ocean) climate with a medium water deficit in summer. The vegetation period lasts for 7.5 months (230 days) on average.

We aimed to investigate the impacts of red deer grazing on the litter and surface soil layer (0-5 cm depth) in the breeding area, which has been used for a long time, in comparison with an adjacent undisturbed area. The disturbed and undisturbed areas were chosen for their proximity to ensure the most similar site factors possible. The altitude of the research area is 143 m, slope is 12% and the sites are exposed to the south. Main tree species in the areas are oak (*Quercus frainetto*), hornbeam (*Carpinus betulus*), beech (*Fagus orientalis*) and chestnut (*Castanea sativa*). The breeding area was sampled at 20 different points at 10 m intervals; 20 samples were taken from each of litter and 0-5 cm soil point. As a control, soil and litter samples from 20 different points were taken again at 10 m intervals (20 samples from each of the litter and 0-5 cm soil) in the undisturbed area situated at least 50 m away from the breeding area to reduce edge effect. The samples of the litter were taken from a 20x20 cm area by collecting litter layer of the forest floor. Soil compaction was measured 50 different soil points using a pocket penetrometer in both the breeding and undisturbed areas. Soil samples were taken from 0-5 cm with the aid 100 cm^3 steel soil cores. A total of 300 cm^3 soil samples was taken for each of the sampling points. All samples were collected in January 2008. Samples were put in polyethylene bags, labeled, and brought to the laboratory. The mass of oven dried samples was calculated from the difference between the values of wet and oven dried samples, after litter and soil samples were place in an oven under 105°C for 24 hr. All reported masses are oven dried values. Organic matter content of the litter samples was measured with the loss on ignition method, after grinding and burning at 550°C. Soil bulk density was determined by the core method. Soil samples were sieved with a 2 mm screen after plant materials and other debris were removed, and thus represent fine soil weights. Sand, silt and clay proportions of soil samples in the laboratory were determined with the Bouyoucos hydrometer method. Organic carbon content was determined with the Walkey and Black dichromate oxidation procedure. All samples were free of carbonate so that the total carbon concentration was equal to the organic carbon concentration. Saturation capacity, pH and electrical conductivity values were also measured in the laboratory as described by Karaöz (1989 a,b, 1992).

The values found for the undisturbed area and the breeding area were compared statistically at $p<0.05$ significance level by using independent sample t-test statistical analysis. Mean values for all properties are shown in relevant tables.

Results and Discussion

Litter properties: In the undisturbed area, litter mass (1095.35 kg ha^{-1}) was significantly higher than that of the breeding area (501.55 kg ha^{-1}) (Table 1). Moreover, lower litter in breeding area showed that elk grazing and trampling decreased the litter. In addition, there was no herbaceous cover on the elk area, and the leaves of small shrubs were possibly eaten by deers. We inferred that the amount of litter fall was also decreasing based on the lack of herbaceous cover in the breeding area and the removal of leaves of small shrubs by red deers. Organic matter content (56.75%) of litter in the breeding area was significantly lower than that in the undisturbed area (79.07%) (Table 1). Due to effects of deer trampling and long term grazing effects of deers, sticking and mixing of litter with mineral soil layers led to lower organic matter contents in the litter. In addition, changed soil properties because of long term deer grazing should have negative effects on decreases in biological activities, such as decomposition and mineralization of litter in the breeding area. Depending on the considerable difference in the litter mass, organic matter amounts (kg ha^{-1}) in unit area also showed important differences, and organic matter amounts in undisturbed area (865.75 kg ha^{-1}) were very much higher than those in the breeding area (282.13 kg ha^{-1}) (Table 1).

Other studies have reported results similar to our findings, for instance the fact that over grazing reduced input from litter-fall (Smit and Kooijman, 2001; Xie and Wittig, 2004; Yong-Zhong *et al.,* 2005; Huang *et al.,* 2007; Steffens *et al.,* 2008) due to plant cover reduction (Smit and Kooijman, 2001; Yong-Zhong *et al.,* 2005; Huang *et al.,* 2007) and litter consumption (Xie and Wittig, 2004). With year-long continuous grazing, the height, cover and dry weight of grass and shrub cover can be greatly reduced (Pei *et al.,* 2008). Higher grazing intensity leads to a reduction in the number of plants, plant basal area, and the amount of deposited dead plant material that acts as protective mulch for the soil (da Silva *et al.,* 2003). In addition, animal trampling has a severe effect on soil compaction (Hamza and Anderson, 2005), and at the same time may stimulate organic matter decomposition, due to the destruction of soil aggregates by mechanical stress (Steffens *et al.,* 2008) and poor living conditions for soil organisms (Xie and Wittig, 2004). However, qualitative changes in litter input in overgrazing areas under forest cover may have be more important than the quantitative changes (Smit and Kooijman, 2001).

Soil properties: All soil properties of the breeding area were significantly different from the undisturbed area, except for electrical conductivity (Table 2). Similarly, Yong-Zhong *et al.,* (2005) found that electrical conductivity was similar under three grazing treatments, and Liebig *et al.,* (2006) reported that electrical conductivity did not differ between grazing treatments. However, other investigated soil

Table - 1: Litter properties under breeding and undisturbed area

Characteristics	Breeding area[a]	Undisturbed[a]	*P*[b]
Litter mass (kg ha^{-1})	501.55	1095.35	0.000*
Organic matter (%)	56.75	79.07	0.000*
Organic matter mass (kg ha^{-1})	282.13	865.75	0.000*

[a] = Values are mean, [b] = Data were analyzed using independent sample t-test at p < 0.05 significance level, * = p<0.0001

Table - 2: Investigated soil characteristics in 0-5 cm soil depth

Characteristics	Breeding area[a]	Undisturbed[a]	*P*[b]
Compaction (kg cm^{-2})	2.26	0.38	0,000*
Bulk density (g cm^{-3})	1.478	0.850	0,000*
Fine soil (<2mm) weight (g cm^{-3})	1.439	0.790	0,000*
Sand (%)	40.9	66.5	0,000*
Silt (%)	25.4	14.9	0,000*
Clay (%)	33.7	18.6	0,000*
Organic carbon (%)	1.395	7.691	0,000*
pH	4.48	6.66	0,000*
Electrical conductivity (μS cm^{-1})	270.30	353.11	0,059[NS]
Saturation capacity (%)	28.83	71.47	0,000*

[a] = Values are mean, [b] = Data were analyzed using independent sample t-test at p < 0.05 significance level, * = p<0.0001, ns = Non significant effect

properties such as sand, silt and clay proportions, fine soil (<2mm) weight, organic carbon, pH, saturation capacity, compaction and bulk density showed significant differences between undisturbed area and breeding area.

The average compaction value was 2.26 kg cm^{-2} on the breeding area and 0.38 kg cm^{-2} in the undisturbed area (Table 2). We found very low soil penetration resistance values in the undisturbed area when compared to former studies at similar research sites (Demir *et al.,* 2007a,b) possibly due to wet soil at the sampling time. These compaction values showed that 0-5 cm soil depth of the breeding area was substantially compacted in comparison to the undisturbed area. Soil bulk density (1.478 g cm^{-3}) and fine soil weight (1.439 g cm^{-3}) on the breeding area are quite higher than those in the undisturbed area. Similarly, Binkley *et al.* (2003) found that elk grazing and hoof action compacted soils in Rocky Mountain National Park. In addition, they found that the bulk density of the 0-15 cm depth mineral soil was higher in grazed units (0.94 kg l^{-1}) than in ungrazed units (0.87 kg l^{-1}), and the major soil effects of high elk populations in their study sites appeared to be an increase in soil bulk density with grazing (Binkley *et al.,* 2003). Most studies of grazing effects have found that grazing and over grazing compacted soil and increased soil bulk density as a consequence of increased animal trampling (Hiernaux *et al.,* 1999; Xie and Wittig, 2004; Liebig *et al.,* 2006; Huang *et al.,* 2007; Zhao *et al.,* 2007; Pei *et al.,* 2008; Steffens *et al.,* 2008), except for studies of elk impacts on soil (Frank and Groffman, 1998). Organic carbon content (1.395%) on the breeding area has been found quite lower than the content in the undisturbed area (7.691%) (Table 2). The literature reports contrasting results on the effect of grazing on C concentrations (Steffens *et al.,* 2008). With increasing grazing intensities, decreasing C stocks (Hiernaux *et al.,* 1999; Xie and Wittig, 2004; Huang *et al.,* 2007; Pei *et al.,* 2008), as well as unchanged (Binkley, 2003) and increasing stocks have been found (Steffens *et al.,* 2008). Although soil organic matter accounted for a proportionally low amount of the soil, numerous other physical and chemical properties depended on the quantity of organic matter present in the soil. Firstly, organic matter plays an important role in the structure and stability of the soil and thus influences plant growth. Secondly the nutrient supply present in the soil and its availability to plants has a direct correlation to the condition of the soil organic matter. The decrease in soil organic matter which accompanies frequent grazing is a result of a decrease in the amount of plant litter on the one hand and an increase in soil compaction on the other hand, which creates unfavorable living conditions for organisms vital for the incorporation of the humus into the soil (Xie and Wittig, 2004). Depending on the compaction of the soil and amount of decrease in soil organic matter (organic carbon), considerable differences were found between the undisturbed area and the breeding area in terms of saturation capacity. Saturation capacity in the breeding area (28.83%) was considerably lower in the undisturbed area (71.47%) (Table 2). Parallel to this result, Pei *et al.,* (2008) found that surface soil water content in the non-grazed area was 27–31% higher than the grazed area. Zhao *et al.* (2007) concluded that heavy grazing resulted in a more homogenous spatial distribution of soil properties by soil compaction and soil homogenization accompanied by a reduced input of organic matter and a reduced soil water storage capacity. Moreover, some researchers reported that changes in soil texture and loss of fine soil fractions after grazing might have major influences on water-holding capacity (Yong-Zhong *et al.,* 2005; Pei *et al.,* 2008). Mean silt and clay proportions (25.4 and 33.7% respectively) were quite higher and the mean sand proportion (40.9%) was lower on the breeding area than that in the undisturbed area. The reasons for the important differences in the sand, silt and clay proportions might be the changes in the natural structure, mixing of different soil horizons and soil compaction along with possible surface flow and erosion effects. Many researches have found grazing effects on soil particle size distribution. Pei *et al.* (2008) ascertained that particle size distribution showed more silt, clay and very fine sand and less fine and coarse sand in the top 20 cm of soils in a non-grazed area compared with soils in a grazed area. Soil coarse sand fraction (>0.25 mm) in the grazed area was 16–26% higher than that in the exclosures (Pei *et al.,* 2008). In an another study, the particle size distribution showed more silt and clay and less sand in the top 15 cm of soils under the non-grazed sites compared with soils under the continuously grazed site (Yong-Zhong *et al.,* 2005). Results of Huang *et al.* (2007) indicated that fine silt (0.01–0.001mm) removal and medium sand (0.5–0.25mm) increase occurred resulting in coarser surface soil. They inferred that soil erosion by wind was the main cause for changes in soil particle composition, and that trampling by animals led to the loss of top soil by wind erosion (Huang *et al.,* 2007).

The soil pH was significantly 2.18 units higher in undisturbed area (6.66 pH) than that in the breeding area (4.48 pH) (Table 2). The breeding area was significantly more acidic than the undisturbed area, possibly due to the changes in the other soil properties, decreasing litter and absence of herbaceous cover in the breeding area, because changes in the properties of the decomposing organic matter can influence soil acidity. Deer urine and feces might also have a negative impact on the pH, however, we did not assess the direct cause of the lower pH on breeding area. Many researches have also found different effects on soil pH due to grazing. Binkley *et al.* (2003) found no overall effect of elk grazing on pH in the Rocky Mountains. Xie and Wittig (2004) indicated the pH value of the soil solution was not significantly affected by grazing. Some researchers described that grazing tended to increase acidity at the soil surface, and the pH was strikingly higher in the ungrazed control (Hiernaux *et al.,* 1999; Yong-Zhong *et al.,* 2005; Pei *et al.,* 2008). The difference in soil pH was probably related to plant cover, root systems and soil organic carbon because extensive secretion of organic acids from the roots and amounts of CO_2 released from roots and microorganisms could lead to a decrease in pH. The decline in pH value could possibly be related to greater secretion of organic acids by presumably more root biomass and more active microorganism metabolism in the rhizosphere (Pei *et al.,* 2008).

In conclusion, we aimed to quantify the long-term impacts of deer grazing on the topsoil and litter properties in a breeding area in an oak-dominated forest. Deer grazing caused significant decreases in the litter, in saturation capacity, and increases in fine soil weight, in bulk density due to the soil compaction by animal trampling in breeding area. It is obvious that changes because of soil compaction cause negative impacts on the water and air capacities of soils. Adequate management strategies should be implemented in order to mitigate such negative impacts. One of them can be setting shorter time periods of utilization of breeding areas. Another strategy can be rehabilitation or rotation in breeding areas to protect the ecosystem sustainability.

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