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# Effects of canopy on soil erosion and carbon sequestration in a Pedunculate Oak (*Quercus robur* L. *subsp. robur* L.) coppice stand during the conversion process into high forest

# Auswirkungen des Kronenschlussgrades auf Bodenerosion und Kohlenstoffspeicherung in einem Stieleiche (*Quercus robur* L. *subsp. robur* L.) Niederwald während der Umwandlung in Hochwald

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**Keywords:** *Canopy density, Soil Loss Predicting, Carbon storage, management, Coppice stand, High stand, Turkey*

**Schlüsselbegriffe:** *Kronenschlussgrad, Prognose des Bodenverlustes, Kohlenstoff-Sequestrierung, Management, Ausschlagwald, Türkei*

## Abstract

Many of the coppice stands in Turkey are in the process of conversion into high forest because of decreasing demand for fuel wood and negative effects of frequent clearcutting on soil, landscape and biodiversity. Most of these coppice stands are composed of pure and mixed oak stands. Main goal of this study is to determine the effects of canopy on soil erosion and carbon sequestration in a pure Pedunculate oak (*Quercus robur* L. subsp. *robur* L.) coppice stand during the conversion process into high forest. Obtained results showed that average soil loss amounts were 0.35, 0.70 and 0.93 t/ha/yr and total carbon stock amounts were 80.07, 77.86 and 64.2 tC/ha respectively under high, moderate and low canopy. In other words, decrease of canopy

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density increase soil losses and decreases carbon stocks ($p<0.05$) and in turn if the canopy get reduced during the conversion process, C stocks are at risk.

## Zusammenfassung

Viele der Niederwälder in der Türkei werden derzeit aufgrund der sinkenden Nachfrage nach Brennholz und der negativen Auswirkungen häufiger Nutzungen auf Boden, Landschaft und Biodiversität in Hochwald umgewandelt. Die meisten Niederwälder des Landes bestehen aus reinen und gemischten Eichenbeständen. Ziel dieser Studie ist es, die Auswirkungen des Kronenschluss auf die Bodenerosion und die Kohlenstoffspeicherung in einem reinen Stieleichenbestand (*Quercus robur* L. subsp. *robur* L.) während des Umwandlungsprozesses in Hochwald zu untersuchen. Unsere Ergebnisse zeigen einen durchschnittlichen Bodenverlust von 0.35, 0.70 und 0.93 t/ha/Jahr und die Kohlenstoffspeicherung 80.07, 77.86 und 64.2 tC/ha bei hohen, mittleren und niedrigen Kronenschluss. Mit anderen Worten, die Verringerung des Kronenschluss erhöht den Bodenverlust und verringert die Kohlenstoffvorräte ($p <0.05$) und wenn der Baldachin während des Umwandlungsprozesses reduziert wird, ist Kohlenstoffspeicherung gefährdet.

## Introduction

Turkey has a total of 22.3 million hectares of forests, including 19.6 million hectares of high forests and 2.7 million hectares of coppice. Forests cover 28.6% of the country's total area (OGM 2015). Main tree species of coppice stands are oaks. Pedunculate oak (*Quercus robur* L. subsp. *robur* L) is one of the most important tree species of coppice stands subjected to conversion into high forest in Turkey and it has a wide spreading area in Turkey as well. Pedunculate oak can be reach a size of up to 30-40 meters with a breast height diameter up to 2 m and live up to 1000 years (Örtel 2011). According to current data, the annual average harvested wood raw material from forests equals to 18.314.621 $m^3$/year (0.82 $m^3$/ha/year), which is 15.942.459 $m^3$/year (0.81 $m^3$/ha/year) from high forests and 2.372.162 $m^3$/year (0.87 $m^3$/ha/year) from coppice forests (OGM 2015). However, Boydak and Çalışkan (2015) reported that annual average wood raw material demand in Turkey is nearly 40 million $m^3$. Therefore, there is a significant wood raw material deficit in Turkey.

Due to the decreasing demand for fuel wood, interest on coppice management has been decreasing all over the world especially over the past two decades. Converting coppice stands into high forests with continuous cover has often been established during the last decades as a management goal in Turkey. Namely, approximately 3 million hectares of coppice forest were converted into high forest between 2006 and 2015 (OGM 2015). Today's societies appear to question and change the traditional forms of forest resource production due to concerns for deforestation and forest degradation (Asare et al. 2013). Gradual changing from intensive use of forest resources towards a more protective forest policy cause conversion of many coppice forests into high forests (Coppini and Hermanin 2007), allthough Donovan and Puri (2004) indicated that traditional knowledge on forest management is often well in line with current scientific knowledge. The process of converting coppice forests into high forests is based on the biological and economic principles of silviculture. So, decisions about the conversion process must be taken rationally considering both scientific and economic knowledge when allocating production or changing the mode of continuous production. A key objective of conversion of coppice into high forests is to be able to meet the future demand of forest products more efficiently. However, socio-economic dimensions of the conversion scales also has to be taken into consideration. Lafortezza et al. (2008) stated that over the past two decades especially in publicly-owned forests in Italy conversion of coppice forests into high forests have increased, but on privately-owned forests conversion is still limited, since the small-sized forest areas do not allow efficient high forest management. Yet, Ciancio et al. (2006) suggested that coppice forestry has some advantages for forest owners (e.g., simplicity of management, ease and rapidity of natural regeneration, fast growth of the new stand and, thus, shorter rotation and more frequent income than high forests).

Some research results indicate that coppice management is contrary to forestry approach suitable to nature (e.g., frequent clearcutting over large areas causes soil erosion on steep slopes, short rotation period, skidding harvested trees while logging remove the humus horizon, maintaining monolayer stands, low levels of dead biomass and etc.) and that yield is lower when compared to high forest management (Ciancio et al. 2006; Picchio et al. 2009). On the other hand, coppice management done in accordance with the scientific principles can have an important role in forests providing bioenergy (Šrámek et al. 2015) and has positive ecological characteristics in terms of soil, water yield, forest structure variety and soil flora (Harmer 1995; Geray 2007; Çağlar 2007; Vacik et al. 2009). However, Šrámek et al. (2015) recognized that coppicing may have negative effects on soil and site. Relatively high consumption of soil nutrients in coppice managements compared with high forests and statistically significant relations between biomass production and nutrient content of the coppice stands were reported depending on the intensive or extensive management strategies and tree species (Ranger and Bonneau1986; Ranger and Nys 1996).

The main regeneration type in a coppice forest is vegetative propagation. With vegetative propagation, there is little renewal of the genetic structure of the forest population, since mutation (rarely happening in trees in nature) and natural regeneration (ignorable in many coppice stands) are not take into consideration (Çalıkaoğlu and Kavgacı 2001). Some researchers discovered that coppice management has a decreasing effect on biodiversity (Ciancio et al. 2006; Chatziphilippidis and Spyroglou 2004). Sjölund and Jump (2015), on the other hand, stated that there were no statistically significant differences in genetic diversity between coppice and high forest stands. Valbuena-Carabaňa et al. (2008) suggested that intense thinning practices are unadvisable in the conversion of *Q. pyrenaica* coppice into high forest due to the significant losses of genetic diversity by removing unique genotypes.

Consequently, the process of converting coppice forests into high forests is complex considering its technical, administrative, social, economic, and ecological dimensions. In turn, it is necessary to investigate the ecological, economic and social dimensions across scales and to make decisions according to the scientific evidence during the process of converting coppice forest into high forest (Bekiroğlu et al. 2013; Carvellini 2014; Mairota et al. 2016). Coppice stands being converted into high forests should be constructed in a way, that keeps productivity continuously high both in terms of quality and quantity, and have a stand structure that is resistant to forest pests and fires (Niemela et al., 1996; Joys et al. 2004; Piegai et al. 2004; Andreatta 2006; Coppini and Hermanin 2007; Geray 2007; Çağlar 2007; Atmış and Günşen 2009; Yeşildağ and Tolunay 2012).

It is well known that, forest thinning directly and indirectly affects soil carbon © stocks and dynamics (Ma et al. 2004; Tian et al. 2010; Olajuyigbe et al. 2012; Baena et al. 2013; Cheng et al. 2015). Zhang et al. (2018) indicated that thinning significantly increased soil respiration in both broadleaved and mixed forests but not in coniferous forest due to the difference of litter fall quality. Zheng (2006) emphasized that vegetation is one of the key factors affecting soil erosion. Coppice management limited forest stand fertility and C storage capacity in the coppiced forest ecosystems (Noormets et al. 2015; Vacca et al. 2017; Lee et al. 2018). Drake et al (2013) emphasized that total respiratory C losses in coppice were much lower than in uncut control plots and this fact was mainly due to the lower biomass accumulated in the coppice treatments. Yücesan et al (2013) indicated that according to the surface stoniness, soil depth and the slope gradient, thinning intensity should be regulated as moderate and low intensity for controlling the site factors more efficiently in artificial beech stands. Hartanto et al (2003) stated that canopy density, sapling density, litter depth and woody debris appeared to be important ecological factors that determine the magnitude of soil loss.

The silvicultural tool usually adopted for converting coppices is the gradual thinning of sprouts by releasing of the best shoot on each stump during the long time required to complete the conversion. The main goal of this study is to investigate the change in the amount of soil loss and carbon sequestration depending on the gradual thinning effect on canopy density. We also analyse the ecological losses due thinning intensity in the process of converting coppice forest into high forest.

## Material and methods

### Material

The study area is placed in the Northwestern Region of Turkey in the Güngörmez village Saray/Tekirdağ (41° 29′ 20.79 ″ **N** 27° 59′ 31.38″ **E**) (Fig. 1). Study area is approximately 70 km far away from centre of the Tekirdağ province. The terrain of study area has straight topography with low slope gradient. In recent years, many wind turbines have been built on this region because of the high wind potential. According to the climate data of the last 75 years, the average annual temperature is 14.0 °C and the annual total rainfall is approximately 580.8 mm. Most of rainfall occurs in winter and autumn season and according to Walter (1974) climate diagram (Figure 2); there is a water shortage in this region from June to September throughout to year and there is a water gap in June, July and August. So, evapotranspiration can be said to be relatively high in this dry period. In addition, the study area is classified as "steppe" according to DeMartonne and "C1, semi dry, less humid" for Thornthwaite method (MGM 2017).

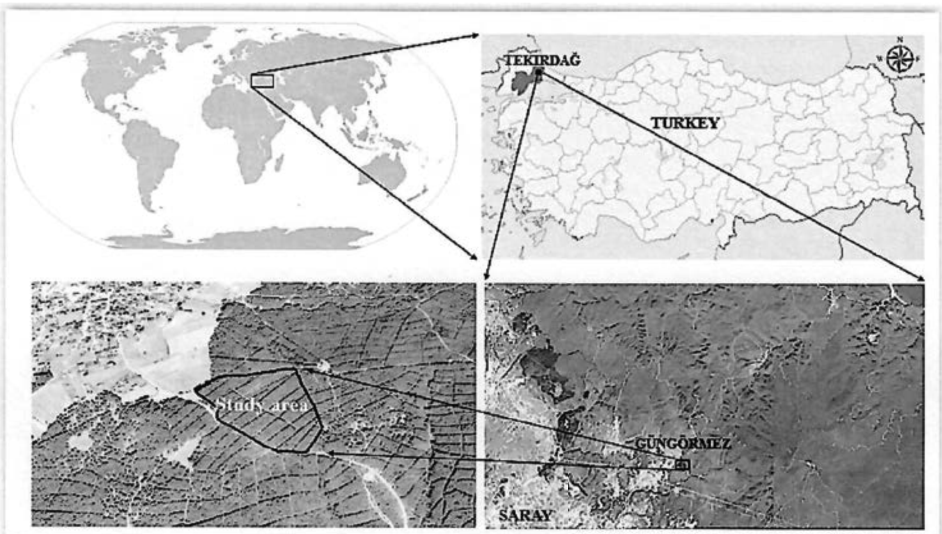


*Figure 1: The location of the study area*

Abbildung 1: Das Untersuchungsgebiet

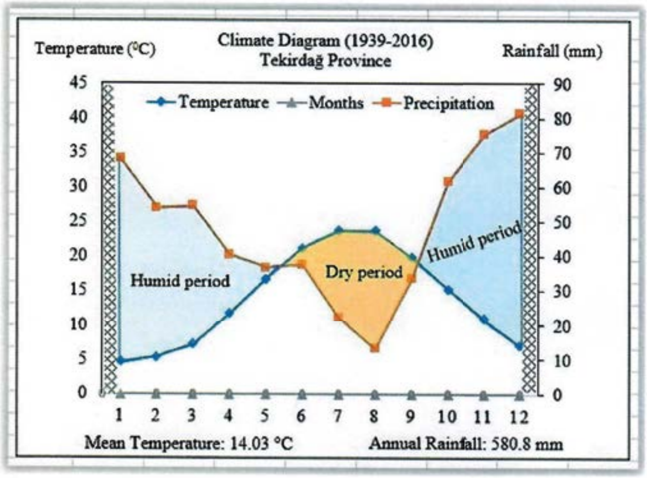


*Figure 2: Walter climate diagram of the study area*

Abbildung 2: Walter Klima Diagramm des Untersuchungsgebiets

The study area has been managed as a coppice stand in the last ten years before conversion into high forest (Figure 3) and the converting process was started in 2006. Total area of the stand is 8.53 ha. Average slope in study area is 10%, average elevation is 240 m.a.s.l. and the main aspect is southwest. The main rock is neritic limestone. There is an impermeable clay layer above the main rock. Soil texture is clay and average surface stoniness is 3%.

*Figure 3: Picture of* Quercus robur *L. subsp.* robur *L. coppice stand (Stand profile 1, Canopy density is 75%)*

Abbildung 3: Aufnahme des *Quercus robur* L. subsp. *robur* L. Niederwaldes (Bestand 1, Kronenschlussgrad 75%)

## Methods

As part of the conversion process gradual thinning of sprouts by releasing the best shoots of each stump were applied in the study area by local directorate of forest enterprise in 2006 and by varying the thinning intensity the forest stand now has three area with different canopy density (25%, 55% and 75%, Figure 4). Average canopy density degree was 75% in 6 of 18 parcels, 55% in 6 of 18 parcels and 25% in 6 of 18 parcels in the study area.

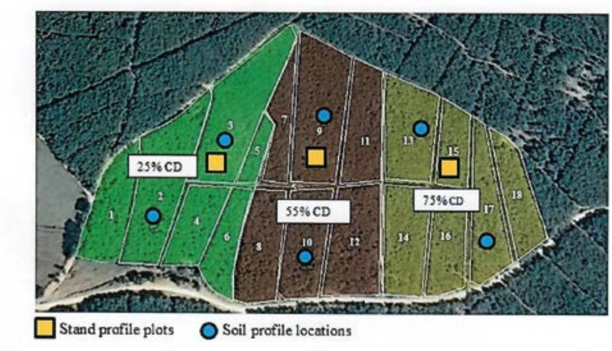


*Figure 4: Location of stand profile plots and soil profile locations at the three canopy densities (CD)*

Abbildung 4: Lage der Bestandesprofile und Bodenproben bei den drei unterschiedlichen Kronenschlussgraden (CD)

To explore the relations between thinning intensity depending on the canopy density and stand structure (single or two-storied structure) three stand profiles were determined for 20 by 20 m (400 m²) area for each of the three different canopy density degree in 2017 (Figures 5 to 7). In each stand profile slope gradient, aspects were determined. All living trees in the stand profiles were measured for their coordinates, diameter at breast height 1.3m (DBH), diameter at 0.3 m height (D03), tree height, crown width and living crown height to quantify stand characteristics and canopy density. Both height characteristics were measured with Vertex Forester device. All trees in the stand profile were classified as either dominant trees (height > 2/3 of the height of the tallest trees in the overstory), as intermediate (height between 1/3–2/3 of the tallest tree height) or as suppressed trees (height smaller 1/3 of the dominant tree height as understory), by using the IUFRO classification (Ucler et al. 2001; Genc et al. 2012; Oktan 2015; Yücesan et al., 2015). Three stand profiles (each one represent a different canopy density) were drawn with the "*ARGUS Forstplanung*" simulation program (Staupendahl 2003).

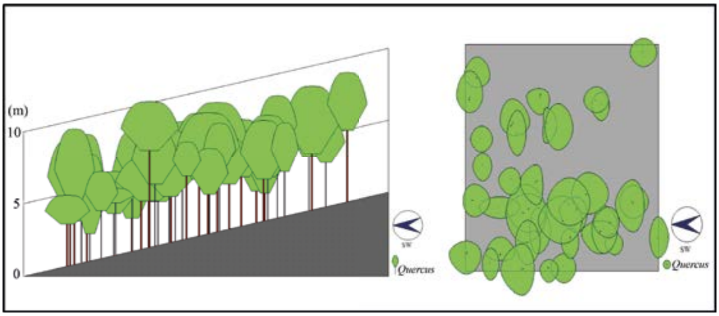


*Figure 5: Stand profiles of sample plot 1*

Abbildung 5: Bestandesprofil der Probefläche 1.

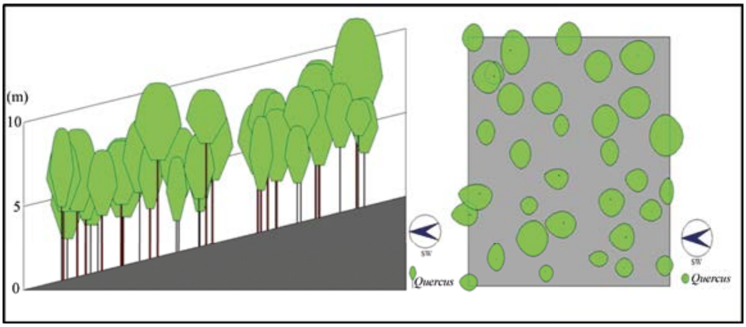


*Figure 6: Stand profiles of sample plot 2*

Abbildung 6: Bestandesprofil der Probefläche 2

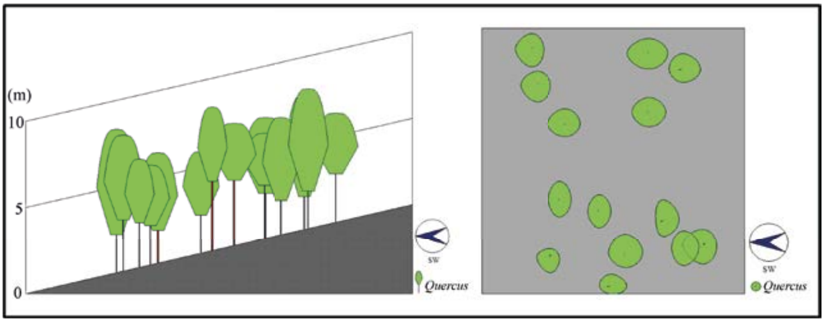


*Figure 7: Stand profiles of sample plot 3*

Abbildung 7: Bestandesprofil der Probefläche 3

Study area with different canopy density degrees were split into six separate homogenous parcels with no differences in slope gradient and slope length. In total, 18 sample parcels have been established. Random sampling was used to select six soil sample locations (each canopy density represented by two soil profiles) for analysing soil properties (Figure 4). Soil sampling locations have been chosen to averagely represent the study area with different canopy density. Soil profiles were established in 2017 down to 60 cm depth. Disturbed soil samples (approximately 2 kg) were taken from soil profiles at 0-20 cm depth level (top soil). In soil analysis, air dried and sieved (< 2.0mm) soil particles were used to determine soil particle size distribution such as sand (%), silt (%) and clay (%) ratio depend on Bouyoucos hydrometer method (Bouyoucos 1962). Soil pH was determined by using digital pH meter (Hach Company USA) and the organic matter content by the Walkley-Black, wet oxidation method (Allison 1965) in laboratory condition. Permeability class and the other hydro-physical soil properties such as field capacity (%) wilting point (%), saturation (%), saturated hydraulic conductivity (cm/hr) and bulk density are described according to Saxton's Hydraulic Properties Calculator (Saxton et al. 1986). Surface stoniness (%), slope gradient (%), aggregate class etc. are determined separately (B.K. 1994) in each soil sample locations.

In this study, to estimation of soil loss, Allgemeine Boden Abtrags Gleichung (ABAG), which was developed out of the Universal Soil Loss Equation (USLE) with the units converted to the metric system and adapted to the European conditions (Schwertmann et al. 1990). We use this model to determine soil loss by erosion (Eq. 1).

$$A = K \; x \; R \; x \; LS \; x \; C \; x \; P \qquad (1)$$

Where A is the average annual soil loss (t/ha/year), K the soil erodibility factor, R the rainfall erosivity factor, LS slope and slope length factor (L: slope length, S: slope gradient), C the cover management factor and P is the supporting practice factor. K, LS, C and P factors have been estimated using equations and values from the literature (Schwertmann et al. 1990). R value was taken from Dogan and Gücer's study (Dogan and Gucer 1976). In the calculation of soil loss, R (75.0) and P (1.0) values were taken as fixed values for all sample parcels The K value was also taken as a fixed value estimated from mean soil properties of 6 soil sample locations ($K_{topsoil}$= 0.1644) assuming the soil properties do not change at short distances. Plant cover factor (C) values were estimated according to equations made by Schwertmann et al (1990). Thereby, C value was taken as 0.01 for the sample parcels with 75%, 0.02 for 55%and 0.03 for 25% canopy density respectively. LS values were calculated separately for three sample parcels due to differences in slope gradient (S) and slope lengths (L).

In each canopy density class, carbon sequestration was estimated using the three stand profile areas (20 x 20 m=400 $m^2$) and two smaller quadrats (1 x 1 m) were taken randomly located within the stand profiles. Species type, diameter at breast height

(DBH) and tree height of living trees were recorded (DBH ≥ 8 cm, height ≥ 1.3 m). There were no standing dead trees in the stand profiles. In each quadrat (1 x 1 m), all plants including seedlings (DBH<8 cm, height < 1.3 m), saplings, shrubs, herbs and woody species were destructively harvested. In destructive sampling, the vegetation in each area was cut and weighed (fresh weight) in the field and subsamples of the vegetation were taken, weighed fresh in the field, and weighed again after oven-drying to determine the dry-weight. Biomass of each ground vegetation component was oven-dried during 72 hours at 65 °C to calculate dry biomass on an area basis (t/ha).

In each of three sample stand profile, four samples of litter, consisting of leaves, fruits, buds, barks, branches and twigs (diameter < 1 cm) was sampled using 25 cm x 25 cm metal quadrats. The four quadrats were systematically distributed in each 400 $m^2$ plot. All material of litter was collected inside the quadrats. To minimize contamination with mineral soil, the samples were soaked and washed in water. All components of litter were oven-dried at 65°C and weighed.

To estimate belowground biomass and carbon stock, we used the roots directly measured in the field using our four soil profile plots. The roots were separated from the soil by soaking in water and then gently washing them over a series of sieves with mesh sizes of 2 and 5 mm. We then sort the roots into three groups, fine (< 2 mm), small (2-5 mm) and coarse (>5 mm) roots. The roots from each sizes category were oven-dried at 65 °C for 24 h, weighed and analysed for carbon content.

The carbon stocks (tC/ha) was estimated as the sum of living trees, soil, weed and litter in the stand profiles for different canopy classes The living tree biomass C stock was obtained directly using algorithmic carbon equation for *Quercus robur* L. (Makineci et al. 2015) and shown in Eq. 2.

$$LTC = (0.0466\ x\ DBH^{2.574})\ x\ 1.053 \qquad (2)$$

LTC is living tree carbon stock and DBH is diameter at breast height of living trees (cm).

Soil carbon stock in tC $ha^{-1}$ were calculated for the soil depth intervals 0–10 cm, 10–30 cm, 30-60 cm, 60-90 cm and 90–120 cm. Soil organic carbon stock (SOCS) was computed as the product of three variables, BD, soil sampling depth (cm) and carbon concentration (C%) calculated as a function of OM (%). SOCS (t $ha^{-1}$) was estimated according to Eq. 3 and 4.

$$C\ \% = 0.58\ x\ OM \qquad (3)$$

$$SOCS = BD\ x\ C\ \%\ x\ D \qquad (4)$$

In the equation OM is organic matter, BD is soil bulk density (g $cm^{-3}$), and D is soil sampling depth (cm) (Guo and Gifford 2002). Carbon stocks for litter and weed were estimated from the tables for Pedunculate oak species in Turkey developed by Makineci et al. (2015).

Test of normality was used to test whether obtained soil loss and carbon sequestration under different canopy density have normal distribution. Thus, it was decided that the parametric or non-parametric test should be used. The Mann-Whitney U test was used to compare differences between two independent groups if the distribution was not normal. ANOVA was used to compare the means of three independent groups in order to determine whether there was statistical confirmation that the mean soil loss and carbon sequestration amounts were significantly different if the distribution was normal. Obtained results were expressed as means ± standard error. Pearson's correlation coefficients were used to examine the relation between normally distributed data. Spearman's correlation coefficient was used for non-normal distributed data. Statistical significance was defined as $p<0.05$ and $p<0.01$ level. Analysed soil properties and soil loss amounts were analyzed using the SPSS program (version 23.0 software package, Institute Inc., Chicago, IL, USA, 2016).

## 3. Results

Two storied stand structure (74% of trees were overstory trees) was identified in sample plot 1 (canopy density 75%) (Figure 5). Single storied structures were identified in sample plot 2 (canopy density 55%) and in sample plot 3 (canopy density 25%) (Figure 6-7). The stand profile components were summarized in Table 1.

*Table 1: Summary of stand characteristics according to canopy density*

Tabelle 1: Zusammenfassung des Bestandesmerkmale hinsichtlich der Kronenschlussgrad

| Sample Plots | Stem number ($ha^{-1}$) | Mean DBH (cm) | Mean D03 (cm) | Mean tree height (m) | Mean total crown shape (m) | Mean height to crown (m) | Basal area ($m^2$ $ha^{-1}$) |
|---|---|---|---|---|---|---|---|
| 3 | 350 | 8.4 | 10.71 | 7.01 | 4.46 | 2.61 | 1.97 |
| 2 | 825 | 9.3 | 11.46 | 7.78 | 4.38 | 3.65 | 5.58 |
| 1 | 950 | 9.3 | 11.37 | 7.33 | 5.82 | 3.60 | 6.62 |
| Mean ± SD | 708 ± 317 | 9.0 ± 1.3 | 11.2 ± 1.7 | 7.37 ± 1.28 | 4.89 ± 0.81 | 3.29 ± 1.01 | 4.72 ± 2.44 |

Canopy structure was more heterogeneous in sample plot 1. However, despite their lower canopy densities, canopy structures were more homogenous in the sample plot 2 (canopy density is 55%) and sample plot 3 (canopy density is 25%). Mean basal area was 6.62 m²/ha in sample plot 1, 5.68 m²/ha in sample plot 2 and 1.97 m²/ha in sample plot 3. Mean DBH (diameter at breast height) values were 9.32 cm in sample plot 1, 9.27 cm in sample plot 2 and 8.43 cm in sample plot 3. Both trees in sample stands were of >8 cm DBH. So sample stands had entered to pole stage with DBH values ranging from 8.0 to 19.9 cm and subjected to moderate thinning in accordance with the silvicultural perspective. Mean height values were 7.33 m in sample plot 1, 7.78 m in sample plot 2 and 7.01 m in sample plot 3.

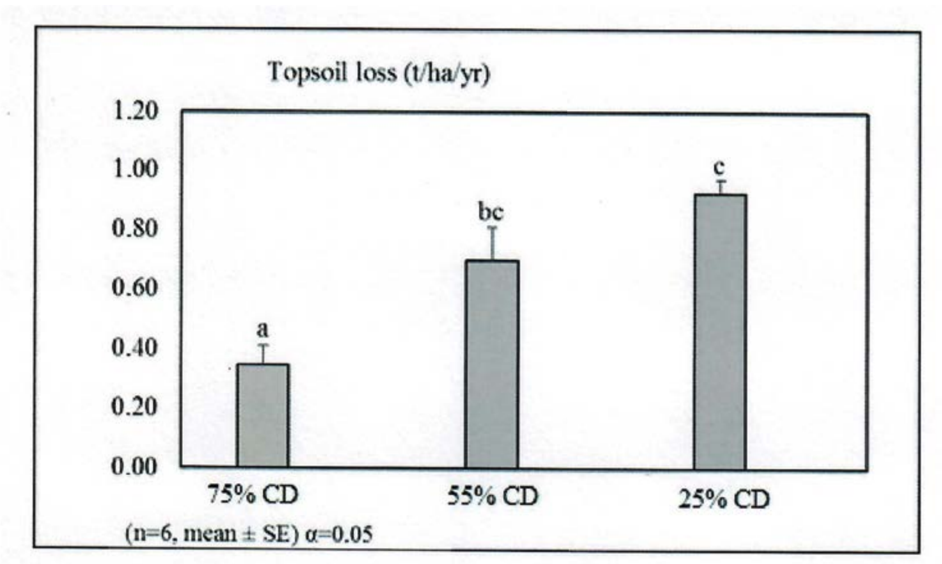


*Figure 8: Top soil loss versus canopy density (CD)*

Abbildung 8: Oberboden Verluste gegenüber der Kronenschlussgrad (CD)

*Table 2: The soil properties and K factor (Mean ± SD, n=6)*

Tabelle 2: Die Bodeneigenschaften und der K-Faktor (Mittelwert ± SD, n=6)

| **Parameters** | **Topsoil** | **Subsoil** |
|---|---|---|
| **Texture** | Clay | Clay |
| **Sand (%)** | 42.72 ± 2.06 | 27.91 ± 1.69 |
| **Fine sand (%)** | 7.94 ± 0.97 | 5.93 ± 0.11 |
| **Silt (%)** | 16.29 ± 6.06 | 17.41 ± 4.27 |
| **Clay (%)** | 40.98 ± 6.69 | 54.68 ± 3.53 |
| **Organic matter (%)** | 4.20 ± 1.68 | 0.85 ± 0.24 |
| **pH** | 5.15 ± 0.17 | 5.27 ± 0.31 |
| **Field capacity (%)** | 36.17 ± 1.65 | 44.63 ± 1.64 |
| **Wilting point (%)** | 23.72 ± 1.75 | 32.42 ± 1.93 |
| **Saturation (%)** | 47.82 ± 1.13 | 49.67 ± 0.83 |
| **AWHC (cm/cm)** | 1.24 ± 0.01 | 1.22 ± 0.03 |
| **Sat. Hyd. Cond. (cm/h)** | 4.38 ± 1.13 | 0.63 ± 0.17 |
| **Bulk density (g/cm$^3$)** | 1.40 ± 0.03 | 1.35± 0.02 |
| **K factor** | 0.1644 | 0.1635 |

Lowest predicted soil loss amount obtained as 0.35 t/ha/year in the top soil (0-20 cm depth) in stand profile 1 (canopy density is 75%). On the other hand, predicted top soil loss amounts obtained as 0.70 t/ha/year in the stand profile 2 (canopy density is 55%) and 0.93 t/ha/year in the stand profile 3 (canopy density is 25%) (Figure 8). Obtained results showed that only canopy density has significant ($p<0.05$) effect on the amount of top soil loss. So it is possible to say that there was a linear correlation between soil loss amount and canopy ($Y = 77.372 \times X + 103.858$ ($R^2 = 0.93$). The amount of soil loss per unit area increases as the canopy cover decreases (Figure 8). However, only the amount of soil loss at 75% canopy density was found to be significantly lower ($p < 0.05$) than the other stand profiles. The amount of soil loss in the stand profile with 25% canopy density has not been significantly increased compared to the stand profile where the canopy density was 55% ($p>0.05$).

The soil loss in the study was assessed with different slope and length conditions under the same climatic and soil conditions, in 3 sample stand profiles with different canopy density. LS factor, which is a component of slope length and slope, has not changed significantly ($p>0.05$) between sample parcels (Figure 9). However, there was a significant correlation ($p<0.01$) between soil loss and canopy density (Table 4). For this reason, the most important factor that affected the soil loss was "C" factor which is the only component of canopy density.

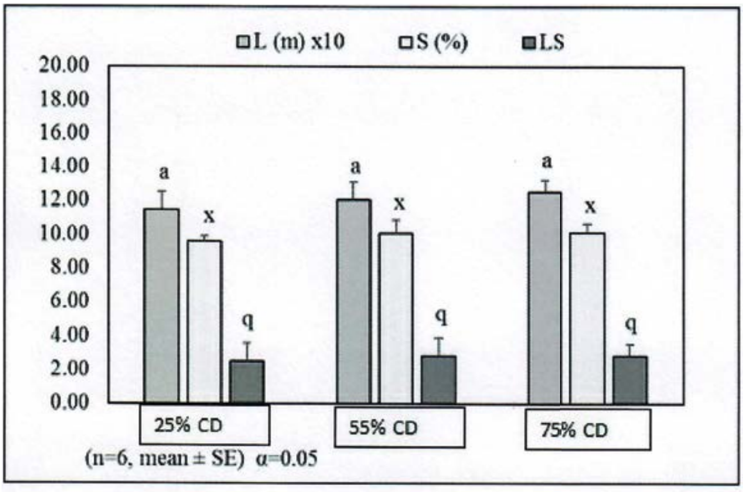


*Figure 9: L, S and LS factors grouped by canopy density (CD)*

Abbildung 9: L, S und LS Faktor gruppiert nach Kronenschlussgrad (CD)

*Table 3: Carbon sequestration of a Pedunculate oak coppice forest in the study area*

Tabelle 3: Kohlenstoffspeicherung eines Stieleichen-Niederwalds im Untersuchungsgebiet

| Sample Plot | Carbon sequestration (t/ha) | | | | |
|---|---|---|---|---|---|
| | Tree | Litter | Weed | Soil | Total |
| 1 | 14.983 | 2.703 | 0.133 | 62.25 | 80.07 |
| 2 | 12.773 | 2.703 | 0.133 | 62.25 | 77.86 |
| 3 | 4.158 | 2.168 | 0.199 | 62.25 | 68.77 |
| Mean ± SD | 10.64 ± 0.15 | 2.53 ± 0.31 | 0.155 ± 0.04 | 62.25 | 75.57 ± 5.99 |

Total carbon stock was obtained as 80.07 t/ha in sample plot 1, 77.86 t/ha in sample plot 2, 68.77 t/ha in sample plot 3 (Table 3). So, there was also a linear correlation between total carbon stock and canopy density. Low C stocks in low canopy density is mostly due to low tree biomass. Because of the OM (organic matter), BD (soil bulk density) and D (soil sampling depth) did not differ between the three stand profile plots the estimated soil carbon stocks were the same. Weed and litter types were largely similar in the three plots at different canopy densities. Estimated carbon stocks values for litter are highest for plot 1 and 2 (canopy density 75% and 55%), while weed carbon mass was highest in plot 3 (canopy density 25%, Table 3). Finally, we show in Table 4 the results of our correlation between soil loss and stand structure using Pearson's correlation coefficient.

*Table 4: Correlations between the soil loss and stand structure components. We show Peasonn correlation coefficients and significance level. Number of observations was always 85.*

Tabelle 4: Korrelationen zwischen den Komponenten Bodenverlust und Bestandesstruktur. Wir zeigen die Pearson Korrelationkoeffizienten und Signifikanzniveaus. Die Anzahl der Beoabachtugnen betrug immer 85.

| | Canopy density | X location (m) | Y location (m) | d.1.30 (cm) | d 0.30 (cm) | Tree height (m) | Height to crown (m) | Basal area ($m^2$) | Soil loss (t/h/y) |
|---|---|---|---|---|---|---|---|---|---|
| Canopy density<br>Pearson Corr. | 1 | | | * | | | ** | * | ** |
| X location (m)<br>Pearson Corr.<br>Sig. (2-tailed) | -0.149<br>0.174 | 1 | | | | | | | |
| Y location (m)<br>Pearson Corr.<br>Sig. (2-tailed) | 0.095<br>0.388 | 0.082<br>0.455 | 1 | | | | | | |
| d.1.30 (cm)<br>Pearson Corr.<br>Sig. (2-tailed) | 0.217*<br>0.046 | 0.034<br>0.760 | 0.038<br>0.733 | 1 | ** | ** | ** | ** | |
| d 0.30 (cm)<br>Pearson Corr.<br>Sig. (2-tailed) | 0.147<br>0.180 | -0.032<br>0.768 | 0.041<br>0.708 | 0.927**<br>0.000 | 1 | ** | ** | ** | |
| Tree height (m)<br>Pearson Corr.<br>Sig. (2-tailed) | 0.049<br>0.657 | 0.134<br>0.222 | -0.049<br>0.655 | 0.515**<br>0.000 | 0.424**<br>0.000 | 1 | ** | ** | |
| Height to crown (m)<br>Pearson Corr.<br>Sig. (2-tailed) | 0.309**<br>0.004 | -0.181<br>0.098 | -0.047<br>0.667 | 0.375**<br>0.000 | 0.295**<br>0.006 | 0.670**<br>0.000 | 1 | ** | * |
| Basal area ($m^2$)<br>Pearson Corr.<br>Sig. (2-tailed) | 0.217*<br>0.046 | 0.033<br>0.761 | 0.037<br>0.738 | 0.998**<br>0.000 | 0.925**<br>0.000 | 0.528**<br>0.000 | 0.387**<br>0.000 | 1 | |
| Soil loss (t/ha/yr)<br>Pearson Corr.<br>Sig. (2-tailed) | -<br>0.964**<br>0.000 | 0.184<br>0.091 | -0.100<br>0.365 | -.0.179<br>0.101 | -0.109<br>0.320 | 0.011<br>0.920 | -0.242*<br>0.025 | -0.180<br>0.098 | 1 |

*: Correlation is significant at the 0.05 level (2-tailed).
**: Correlation is significant at the 0.01 level (2-tailed).

## 4. Discussion

During the process of converting coppice pedunculate oak stand into high forest, high intensity of release cutting/tending decreases the plant coverage and canopy density. At the same time higher thinning intensity caused to a change in the storied structure and generally single storied structure was dominant where high thinning intensity were applied. Obtained results showed that there was a linear correlation between thinning intensity and soil erosion. Increasing rate of thinning intensity, which affected the storied structure as well causes higher soil erosion. Thus, soil erosion was also considered as a variable of determining land use change (Bakker et al. 2005). In this study the amount of soil loss in the topsoil tend to increase as the canopy decreased (Figure 7, Table 4). This effect is caused by the increase of the "C" factor. So, change of the canopy density can be seen as the main driver for increasing the annual soil loss per unit area. Already many studies reported that the "C" factor has a significant effect on the soil loss (Zhao et al. 2012; Kuok et al. 2013; Karamage et al. 2016). The energy for moving soil by water under a forest cover is linked to the energy of falling raindrops. Brandt (1988) stated that the energy change by the multiple canopies varied between 0.03 and 0.66 times that of the rainfall. Yücesan et al. (2013) found negative correlation between soil loss amount, soil loss tolerance and canopy density also for Oriental beech.

The general soil properties of the study area have clay texture. The amount of sand and organic matter in the topsoil was found to be higher than the subsoil (Table 2). The presence of an impermeable clay layer in the lower soil ensured that the amount of clay in this layer was high. This has caused the soil's hydro-physical properties such as field capacity, wilting point, saturation, AWHC, SHC to behave differently in the subsoil It has been reported that the hydro-physical properties of the soil are significantly affected by changing the proportion of soil, particle size density (Luce and Black 1999).

Obtained results showed a linear correlation between canopy density and total carbon sequestration. Decreasing rate of thinning intensity during the conversion process increased the carbon sequestration amount. Zhang et al (2018) stated that forest thinning is widely used in forest management activities and has complex effects on underground carbon processes. It is known that soils represent the most important long-term organic carbon (OC) reservoir which mostly based on the organic matter (Schimel, 1995; Tarnocai et al. 2009). Carbon stock potential of the soils has an important effect on environmental problems such as climate change (Plante and Conant 2014). It is also an important parameter in reducing the soil loss (Wei et al. 2007). Lee et al. (2018) emphasized both continuing and abandoning coppice management caused an increase in the C stocks, but in long-term larger differences in the C sequestration between continuing and abandoning coppice management should be possible. The thinning from below intensity (extraction of 30% of basal area at the most) applied in the beech coppices to be converted into high forest showed a positive effect on volume growth rate and diameter increment and led to stands with fewer but larger trees (Ciancio et al. 2006). Ciancio et al. (2006) also emphasized that the decrease of stocking did not affect height growth of released trees, thus the higher mean stem volume was due to the crown enlargement, which allowed a higher diameter growth. However, Cañellas et al. (1998 and 2004) and Ducrey (1992) reported different response of height compared to DBH in thinned oak coppices due to the growth of epicormic branches as a consequence of higher light intensity. Though oriental beech forms a wide crown, 3 years after heavy thinning canopy density cannot reach to high levels (Yücesan et al. 2015). Yet, Pedunculate oak has higher crown growth ability than oriental beech. When the trees tend to expand the crown closure, the trend of stabile growth may decline as the increase in diameter will decrease (Yücesan et al. 2015). In coppice stands branches and tops can represent 10-30% of the total mass (Baldini et al. 2008), and their release into the stand improves dead fuel accumulation and increase the risk of the occurrence of wildfires, which represent a serious hazard for woodland, infrastructure and people (Marchi et al. 2007).

## 5. Conclusion

The growth and site conditions are very important for good stand developement. Soil and organic matter loss affect growth environment negatively. Canopy density has positive effects on both reduction of soil loss and carbon sequestration. When soil loss and total carbon stocks are considered, the stand canopy density should be kept at high levels (70-100%) as far as possible during the process of conversion coppice forest into high forest. Tending or release cutting operations at moderate intensity seem better suited for oak coppices during the conversion process. On the other hand, the completion of the crown development of the trees at 70-100% canopy density may also positively affect the seed tree features. Increasing quality and quantity of seed trees will in turn affect the success of natural regeneration and conversion process of coppice stands into high forest positively. Yet we require in-situ observations of soil loss to verify the findings of our study.

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