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Centralblatt <sup>für das gesamte</sup> Forstwesen

## Estimation of newly grown needle area in Norway spruce based on simple biometrical tree parameters

#### Abschätzung von neu zugewachsener Nadelfläche der Fichte mittels einfacher biometrischer Baumparameter

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- Keywords:shoot; needle projection area; shoot silhouette; tree crown; bio-<br/>mass; canopy; photosynthesis; allometry; Picea abies; assimila-<br/>tion; specific leaf area
- Schlüsselbegriffe: Trieb; Nadelprojektionsfläche; Silhouette des Triebes; Baumkrone; Biomasse; Kronendach; Photosynthese; Allometrie; Picea abies; Assimilation; spezifische Blattfläche

#### Abstract

Estimation of newly grown needle area, as the most active part of assimilation apparatus, is important for better understanding of biochemical processes of trees. This paper investigates the relationship between the projected area of newly grown needles and other biometric tree parameters (tree height  $H_{TREE}$ , diameter at breast height DBH, projected crown area and crown length) of Norway spruce trees. The total projected area of newly grown needles of seven sampled trees was estimated using a detailed inventory of the number and length of shoots. The relationship between this value and other readily measurable biometric tree characteristics was tested to find the best model for estimating total area of newly grown needles. The model using

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 $H_{TREE}$ \*DBH with a coefficient of determination of 0.96 had the best performance. The DBH and  $H_{TREE}$  inventory of all trees in the studied plot was used to estimate the total projected area of newly grown needles of the entire forest stand (4506.7 m<sup>2</sup> per hectare). We also investigated specific leaf area (SLA) of newly grown needles in vertical profile of tree crown. SLA increased constantly from the tree top (28.7 cm<sup>2</sup>.g<sup>2</sup>) to the crown base (80.3 cm<sup>2</sup>.g<sup>2</sup>).

#### Zusammenfassung

Die Ermittlung der jährlich neu gebildeten Nadelmasse als aktivster Teil der Assimilationsorgane eines Baumes ist sehr wichtig für ein besseres Verständnis der biochemischen Prozesse von Bäumen. Diese Studie beschreibt die Beziehung zwischen der Projektionsfläche von neu zugewachsenen Nadeln und der Baumhöhe (H<sub>TREE</sub>), des Stammdurchmesser in der Brusthöhe (DBH), der Projektionskronenfläche sowie der Kronenlänge der Gemeinen Fichte. Die gesamte Projektionsfläche von neu zugewachsenen Nadeln an sieben Probebäumen wurde mittels durch detaillierte Erfassung der Projektionsfläche von Nadeln und der Anzahl und Länge von neu zugewachsenen Trieben ermittelt. Das beste Modell erreichte mit dem Parameter H<sub>TREE</sub>\*DBH ein Bestimmtheitsmass von 0.96. Aus Messunge von DBH und H<sub>TREE</sub> aller Bäume konnte die gesamten Projektionsfläche der neu zugewachsenen Nadeln des gesamten untersuchten Bestandes ermittelt werden (4506.7 m<sup>2</sup> pro Hektar). Ausserdem, Es wurden auch die spezifische Blattfläche (SLA) für neu gebildete Nadeln im vertikalen Profil der Baumkrone untersucht. SLA nahm von dem Wipfel (28.7 cm<sup>2</sup>.g<sup>2</sup>) bis zur Kronenbasis (80.3 cm<sup>2</sup>.g<sup>2</sup>) stetig zu.

#### Introduction

Norway spruce (*Picea abies* (L.) Karst.) is one of the most important European coniferous tree species due its wide distribution, its economic importance and long tradition of cultivation (Caudullo et al. 2016). In the past, Norway spruce stands have often been favored because of their easy establishment, transparent management and high yield (Spiecker 2003).

Trees are growing in environment, where they constantly exchange matter and energy with atmosphere and soil. From the environment a plant must acquire resources that it can then save or spend in various ways to construct a product (Bloom 1985). The actual size of green leaf area is one of the key parameters influencing the total primary production of trees and the exchange of energy between trees and the atmosphere (Newman 1979). Solar energy is environmentally friendly and its conversion to energy of chemical substances is carried out only by photosynthesis – effective mechanism characteristic of plants (Tkemaladze and Makhashvili 2016). Tree crown architecture may be described by the vertical and horizontal distribution of plant organs, particularly focusing on the productive assimilation area (Echereme et al. 2015). The utilization of solar radiation (especially photosynthetically active radia-

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tion of wavelengths 400 – 700 nm) directly depends on tree crown architecture, its projected area and the forest stand structure (Mõttus et al. 2006; Pangle et al. 2009). The crown of Norway spruce is regularly conical and columnar, with whorled, short and stout branches, the upper level ascending and the lower drooping (Caudullo et al. 2016). The tree crown dimension is more easily measured by vertical crown length than by crown projection.

Forest stand production is closely connected with micro climatic conditions that are created within the forest stand. Incident solar radiation affects forest stand climate and is the exclusive source of energy for the production processes of the trees (Marková et al. 2011). Solar radiation is one of the most limiting factors in numerous processes of forest regeneration, stand development (Niinemets and Kull 1995) and radial growth (Beadle and Long 1985; Linder 1985; Monteith 1994). The size and distribution of the active assimilatory apparatus therefore plays a decisive and crucial role in forest growth and development.

The total leaf area of the plant can be obtained by either direct or indirect methods. Indirect, non-destructive methods are user friendly and provide robust leaf area estimates (Norman & Campbell, 1989). Another method would be removing and measuring all leaves of a plant. This direct method is destructive and can be used for model development. One of the most useful tools for assessment of total leaf area is specific leaf area (SLA). SLA uses relationship between the area of the representative mixed foliage sample with its dry weight (Kalácska et al. 2005; Nouvellon et al. 2010). SLA often serves as an indicator for potential growth rate and reacts very sensitively to changes of the availability of resources (Fellner et al. 2016).

The amount of needles growing on a tree influences photosynthesis, gas exchange, transpiration, the interception and utilization of inorganic and organic atmospheric pollutants and the leaching of substances from aerial plant surfaces (Riederer et al. 1988). Leaf area is therefore one of the most important structural characteristics of a tree or forest stand as it relates to its potential production or even health status (Pokorný and Stojnič 2012; Čater 2015). The amount of needles growing on a tree is adequately described using the projected area of needles. The young needles are photosynthetically highly active needles (Hom and Oechel 1983, Huttunen and Heikkilä 2001, Kayama et al. 2007) and net CO<sub>2</sub> assimilation rates decrease with needle aging in the conifer species (Freeland 1952; Warren 2005).

The main objective of the study was to determine the area of newly grown needles in the crown layer. Models for estimating the projected area of newly grown needles using some easily measurable biometric characteristics of shoots have been developed. Sufficiently accurate equations for calculating the projected newly grown needle area of trees using tree biometric characteristics have been developed.

#### **Material and Methods**

#### Site description

The amount of newly grown needles in a young spruce monoculture (*Picea abies* (L.) Karst.) was determined at the Rájec study site (the Drahanská vrchovina Highlands, the Czech Republic) after the 2014 growing season (Table 1). The experimental station Rájec was founded in 1975 and is included in the International Long Term Ecological Research Network (ILTER) and national infrastructure for carbon observation in the Czech Republic - CzeCOS.

The studied spruce monoculture was established through reforestation (5000 trees per ha) after a clearcut of a mature spruce stand in 1978 (Marková and Pokorný 2011). There were performed several thinnings in the experimental site, nevertheless none of them did not reduce amount of neighbors of studied trees at least ten years before investigation. Detailed analysis of the amount of newly grown needles was determined on seven selected trees growing in the forest stand, that are equipped with scaffolding that allowed for the taking of measurements in a vertical profile of tree crowns. Selected biometric characteristics of the studied spruce stand at the chosen experimental plot (four sampled plots with area 125 m<sup>2</sup>; 98 trees) are shown in Table 1.

Table 1: A description of the study site in 2014 (mean ± standard deviation)

Geographic coordinates	49°26'44" N; 16°41'49" E
Altitude (m.a.s.l.)	625
Geological subsoil	acid granodiorite
Soil type	modal oligotrophic Cambisol, moder form of humus
Mean annual air temperature (°C)	6.5
Mean annual total precipitation (mm)	717
Age (years)	36
Tree species composition	Norway spruce (100%)
Stand density (trees ha <sup>-1</sup> )	1960
Mean stand diameter at breast height (cm)	15.2 ± 5.1
Mean stand height (m)	15.2 ± 3.9
Mean stand living crown length (m)	7.6 ± 3.5
Mean stand crown projected area (m <sup>2</sup> )	7.1 ± 3.5
Stem volume (m <sup>3</sup> ha <sup>-1</sup> ) **	336.9
Total aboveground biomass (t ha <sup>-1</sup> ) **	183.3
Seasonal maximum of leaf area index (m <sup>2</sup> m <sup>-2</sup> )	7.5

Tabelle 1: Beschreibung den untersuchten Fläche im Jahre 2014 (Mittelwert ± Standardabweichung)

According to Marková and Pokorný (2011)

"According to Bellan et al. (2018)

The studied trees were selected according to the distribution of tree diameter at breast height (DBH) of the chosen experimental plot (Fig. 1). Two dominant trees, three co-dominant trees and two sub-dominant trees were chosen for the analysis.



Figure 1: Diameter at breast height (DBH) distribution at the study site in 2014. Black points represent the selected studied trees with their numbers used in this paper. Dashed line is a normal distribution of DBH.

Abbildung 1: Verteilung der Brusthöhendurchmesser (DBH) der untersuchten Fläche im Jahre 2014. Schwarze Punkte repräsentieren die ausgewählten untersuchten Bäume und die in dieser Studie verwendete Nummerierung. Die gestrichelte Linie markiert eine Normalverteilung von DBH.

#### Needle level

The area of newly grown needles was observed on the seven selected trees (Fig. 1) throughout the whole tree crown profile at the end of the 2014 growing season. Newly grown shoots (16 per tree) were removed from three additional trees of different social status (dominant, co-dominant and subdominant; Fig. 2). These 48 shoots were selected following the shoot length distribution within the tree crown.



Figure 2: Methodology of sampling and analysis. L<sub>SHOOT</sub>- length of shoot in cm, A<sub>SHOOT</sub>- projected area of shoot in cm<sup>2</sup>, NN<sub>SHOOT</sub>- number of needles per shoot, NA<sub>SHOOT</sub>- projected area of needles in cm<sup>2</sup>/shoot, SLA – specific leaf area (cm<sup>2</sup>.g<sup>-1</sup>).

Abbildung 2: Methodik der Probenahme und Analyse. L<sub>SHOOT</sub> - Länge des Triebes in cm, A<sub>SHOOT</sub> - projizierte Fläche des Triebes in cm<sup>2</sup>, NN<sub>SHOOT</sub> - Anzahl der Nadeln per Trieb, NA<sub>SHOOT</sub> - projizierte Fläche der Nadeln in cm<sup>2</sup>/Trieb, SLA - Spezifische Blattfläche (cm<sup>2</sup>.g<sup>-1</sup>).

The length of the removed newly grown shoots ( $L_{SHOOT}$ ) was measured from the beginning of growth in the current year to the bottom of the new terminal bud and the area of removed newly grown needles ( $NA_{SHOOT}$ ) was measured using image analysis. Images of the removed newly grown shoots were taken with a Nikon D5100 digital SLR camera (Nikon Corp., Japan) and a Tamron 17-50/F2.8 AF (Tamron Corp., Japan) lens set at 35-mm focal length for better optical quality. Images were captured in high resolution on a background marked with millimeter gridlines. The projected area of the removed shoot ( $A_{SHOOT}$ ) was captured on one side by the camera at a 90° angle loosely laid on a flat table (Fig. 3). Needles were separated from the shoot and scanned by an image scanner (Perfection V500, EPSON) (Fig. 3). NA<sub>SHOOT</sub>,  $A_{SHOOT}$  and number of needles ( $NN_{SHOOT}$ ) was determined from images by ImageJ (National Institutes of Health, USA). The parameters of the removed newly grown shoots ( $L_{SHOOT}$ ,  $NN_{SHOOT}$  and  $NA_{SHOOT}$ ) were further analyzed to assess the correlations between the projected area of needles and shoot characteristics.

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Figure 3: Newly grown shoot projection (A) and the projected area of needles separated from this shoot (B).

Abbildung 3: Neu gewachsener Trieb (A) und die projizierte Fläche, der von diesem Trieb abgetrennten Nadeln (B).

The silhouette area to projected needle area ratio (SPAR) of a shoot is defined by Stenberg et al. (1995) as:

SPAR 
$$(\alpha, \beta) = \frac{A_{SHOOT}(\alpha, \beta)}{NA_{SHOOT}}$$
 Eq. (1),

where  $A_{SHOOTI}(\alpha,\beta)$  is the projected area of shoot for inclination ( $\alpha$ ), rotation angle ( $\beta$ ), and NA<sub>SHOOTI</sub> is the projected needle area. SPAR was calculated only at  $\alpha = 90^{\circ}$  and  $\beta = 0^{\circ}$  (i.e. the shoot projection area was determined only for a loosely laid shoot on flat table) and this parameter was described as SPAR<sub>max</sub>.

The shoot area to total needle area ratio (STAR<sub>cal</sub>) was calculated after converting the projected needle area ( $NA_{SHOOT}$ ) to total needle area ( $TNA_{SHOOT}$ ) using the equation for one-year-old needles published by Homolová et al. (2013):

$$TNA_{SHOOT} = NA_{SHOOT} * 3.13$$
 Eq. (2).

Specific leaf area (SLA, ratio between projected needle area and needle dry mass) was determined on ten trees growing in the studied forest stand (including the seven trees used in detailed analyses; Fig. 2). One sample branch was taken from each third

of tree crown. Afterward three subsamples (consisting of approximately 50 needles each) were collected from each sample branch. Needle subsamples were scanned, oven-dried (at 80°C for 48 h) and weighed (precision  $\pm 0.001$  g). Needle area of subsamples was determined by ImageJ (National Institutes of Health, USA).

#### Shoot level

The detailed analysis of newly grown shoots was performed on the seven selected studied trees throughout the whole tree crown at the end of the 2014 growing season (Fig. 2). The height of all living branches in whorls was measured during the shoot sampling period. The number of newly grown shoots was counted on every living branch in the whorl and in the inter-whorl. L<sub>SHOOT</sub> was measured on living branches in whorls along the whole vertical profile of the tree crown.

#### Tree and stand level

The position, height ( $H_{TREE}$ ), vertical length of the living crown ( $L_{CROWN}$ ) and projected crown area ( $PA_{CROWN}$ ) of the selected studied trees and finally of all trees on the experimental plot were determined using the FieldMap measuring system (IFER, Czech Republic). The top of the highest tree and the lowest living whorl in the stand defines the height of the stand crown layer. The base of the living crown was considered the whorl closest to the ground surface that had a minimum of two living branches. DBH of the selected studied trees was calculated from the stem circumference measured with tape at a height of 1.3 m above the ground.

Tree crown dimension, as the potential base for budding, is directly related to the amount of newly grown shoots. Chosen tree and crown biometric characteristics are provided in Table 2. For the seven selected Norway spruce trees, the average DBH was 15.3 cm  $\pm$  4.0, and the average tree height was 15.5 m  $\pm$  3.3.

Table 2: Chosen biometric characteristics of the seven studied trees. Trees were divided into three categories according to their social status within the forest stand.

Tabelle 2: Ausgewählte biometrische Merkmale von sieben untersuchten Bäumen. Die Bäume wurden nach ihrem sozialen Status innerhalb des Bestandes in drei Kategorien unterteilt.

Social status of the tree	Tree (No.)	Tree height (m)	Diameter at breast height (cm)	Projected area of tree crown (m²)	Length of living crown (m)
dominant	7	19.3	19.2	9.2	10.2
uommant	6	17.4	21.3	10.8	11.4
	5	16.7	15.8	8.4	7.8
co-dominant	4	16.4	14.7	6.1	6.5
	3	16.8	15.9	4.1	7.3
sub-dominant	2	13.3	11.6	5.1	5.7
	1	8.6	8.6	4.0	3.6

#### **Statistical analysis**

To determine the relationship between NA<sub>SHOOT</sub> and an easily measurable shoot parameter, a list of measured newly grown shoot characteristics was established and the best model was estimated using QCExpert 3.3 (TriloByte Statistical Software Ltd 2013). Linear, exponential, polynomic, logarithmic and power models were tested and the quality of the models was evaluated based on (i) mean quadratic error of prediction (MEP), (ii) Akaike information criterion (AIC) and (iii) coefficient of determination (R<sup>2</sup>). MEP and AIC values are decreasing with increasing model quality, and higher R<sup>2</sup> values indicate higher suitability of the model. MEP was the decisive factor in selecting the best model.

A list of the biometric characteristics of the seven studied trees ( $H_{TREE}$ , DBH, PA<sub>CROWN</sub>,  $L_{CROWN}$ ) was made to find the most appropriate and most suitable model to describe the total projected area of newly grown needles on a tree. The dependence of newly grown needles area on each of tree characteristic parameter was estimated in QCExpert 3.3 and SigmaPlot 11.0 (Systat Software, Inc.).

#### Results

#### Needles

The length of the 48 shoots removed from the subset of three trees (sub-dominant, co-dominant and dominant) ranged from 21.8 to 113.3 mm. The mean values of the biometric measurements performed on these 48 shoots, obtained through image analysis, are provided in Table 3. SPAR<sub>max</sub> varied from 0.299 to 0.662 with a mean value of 0.514. Shoot area to total needles area ratio (STAR<sub>cal</sub>) (calculated with the conversion factor published by Homolová et al. 2013) ranged from 0.096 - 0.211 with a mean value of 0.164.

Table 3: Selected biometric characteristics of the 48 removed newly grown shoots.

	Mark	Mean	Std. Dev.	Min	Мах
Shoot length (mm)	L <sub>SHOOT</sub>	60.6	23.7	21.8	113.3
Number of needles per shoot	<b>NN</b> SHOOT	145.7	68.1	49.0	315.0
Needle density on the shoot (needle.cm $^{-1}$ )	<b>ND</b> <sub>SHOOT</sub>	23.6	3.2	17.7	30.7
Projected needle area (mm <sup>2</sup> )	NA <sub>SHOOT</sub>	13.0	3.0	7.7	19.6
Specific leaf area (cm <sup>2</sup> .g <sup>-1</sup> )	SLA	43.9	13.1	28.7	80.3

Tabelle 3: Ausgewählte biometrische Merkmale von 48 neu gewachsenen Trieben.

New needle production estimated by the model was at an average of 188 453 needles per tree (according to relationship on Fig. 4 and model in Table 4). We detected a strong relationship (i) in shoot length versus the number of needles ( $R^2 = 0.93$ )(Fig. 4), (ii) shoot length versus the projected area of newly grown needles ( $R^2 = 0.91$ ) (Fig. 5), and (iii) the projected area of shoot versus the projected area of newly grown needles ( $R^2 = 0.93$ ) (Fig. 5).



Figure 4: Relationship between number of needles and shoot length. See Table 4 for the model description.

Abbildung 4: Beziehung zwischen Anzahl der Nadeln und Trieblänge. Die Tabelle 4 stellt die Beschreibung der Modelle dar.



Figure 5: Relationships between projected area of newly grown needles and selected shoot parameters. See Table 4 for the description of the models.

Abbildung 5: Beziehungen zwischen der projizierten Fläche von neu gewachsenen Nadeln und ausgewählter Triebparametern. Tabelle 4 zeigt die Modellparameter.

Specific leaf area (SLA) of needles increased from 28.7 cm<sup>2</sup>.g<sup>-1</sup> on the top of tree to 80.3 cm<sup>2</sup>.g<sup>-1</sup> at the base of crown. Important change occurs in height, with the branches in the lower layers of the canopy being more affected by competition for light than in the upper canopy. In particular, the increase in SLA occurred at a higher rate from 14 m height (62% of stand crown layer) down to 6 m. Furthermore, SLA showed greater variability in the lower parts of the crown than in the upper parts (Fig. 6).



Figure 6: Specific leaf area in different height. Horizontal bars represent standard deviation. See Table 4 for the model description.

Abbildung 6: Spezifische Blattfläche in unterschiedlicher Baumhöhe. Horizontale Fehlerbalken repräsentieren die Standardabweichung. Tabelle 4 zeigt die Modellparameter.

The best correlation was found in the relationship between the projected area of needles ( $NA_{SHOOT}$ ) and the number of needles ( $NN_{SHOOT}$ ) ( $R^2=0.96$ ). Nevertheless, the estimation of the projected area of newly grown needles was calculated from the shoot length ( $L_{SHOOT}$ ) because this parameter is more easily measurable (coefficient of determination  $R^2=0.91$ ) – Fig. 5, Table 4.

Table 4: Models for relationships displayed in Fig. 4, Fig. 5 and Fig 6.  $R^3$  - coefficient of determination, MEP - mean quadratic error of prediction, AIC - Akaike information criterion,  $NA_{SHOON}$ - projected area of needles in cm<sup>2</sup>/shoot,  $L_{SHOON}$ - length of shoot in cm,  $NN_{SHOON}$ - number of needles per shoot,  $A_{SHOON}$ - projected area of shoot in cm<sup>2</sup>,  $H_{BRANCH}$  – height of branch in m.

Tabelle 4: Beschreibung der Modelle, die in Abb. 4, Abb. 5 und Abb. 6 verwendet wurden. R<sup>2</sup> - Bestimmtheitsmaß, MEP - mittlerer quadratischer Fehler der Vorhersage, AlC - Akaike Informationskriterium, NA<sub>SHOOT</sub> - projizierte Fläche der Nadeln in cm<sup>2</sup>/Trieb, L<sub>SHOOT</sub> - Länge des Triebes in cm, NN<sub>SHOOT</sub> - Anzahl der Nadeln per Trieb, A<sub>SHOOT</sub> - projizierte Fläche des Triebes in cm<sup>2</sup>, H<sub>BRANCH</sub> – Höhe der Verzweigung in Metern.

Model structure	R <sup>2</sup>	MEP	AIC
$NA_{SHOOT} = 0.991691 * L_{SHOOT} = 1.640337$	0.91	19.85	136.09
$NA_{SHOOT} = 0.082885 * NN_{SHOOT} + 3.27E-04 * NN_{SHOOT}^{2}$	0.96	8.89	101.70
NA <sub>SHOOT</sub> = 2.030590 * A <sub>SHOOT</sub> - 0.424537	0.93	14.61	123.59
NN <sub>SHOOT</sub> = 17.740414 * L <sub>SHOOT</sub> <sup>1.161459</sup>	0.93	364.08	276.18
SLA = 338.787991 * H <sub>BRANCH</sub> <sup>-0.816197</sup>	0.88	42.12	113.17

The total projected area of newly grown needles on the tree level was calculated from the set of shoot lengths measured on each of the seven studied trees using the parametrized model (Table 4). The projected area of newly grown needles growing between whorls ( $NA_{TREE_BW}$ ) corresponds to roughly one-fifth of the projected area of newly grown needles in whorls ( $NA_{TREE_BW}$ ) for sub-dominant trees and to roughly one-third for dominant trees. The total surface area of newly grown needles of the seven selected trees (Table 5) reached 51 m<sup>2</sup>.

Table 5: The projected area of newly grown needles displayed separately for branches in whorls, branches between whorls and for all branches for the whole living crown.

Tabelle 5: Die Projektionsfläche der neu gewachsenen Nadeln getrennt für Äste in den Quirlen, Ästen zwischen den Quirlen und für alle Äste der lebenden Krone.

		The projec	ted area of ne	wly grown	
Social status	Tree	needles on trees (m <sup>2</sup> )			
of the tree	(No.)	Branches	Branches	All	
		bet in whorls		branches	
			wnoris		
dominant	7	2.2478	0.9451	3.1929	
donnant	6	2.3035	0.9661	3.2696	
	5	1.9441	0.7578	2.7019	
co-dominant	4	2.0800	0.5407	2.6207	
	3	1.8291	0.6245	2.4536	
sub-dominant	2	1.0687	0.2377	1.3064	
	1	0.6197	0.1283	0.7479	

#### Shoots

The inventory of each living branch in whorls and between whorls (Table 6) allowed us to describe the crown architecture of the seven studied trees. The mean  $L_{SHOOT}$  was 4.8 cm and the average number of newly grown shoots per tree was 1707.

Table 6: Selected biometric characteristics of the branches and newly grown shoots of the seven studied trees.

Tabelle 6: Ausgewählte biometrische Merkmale der Zweige und neu gewachsenen Triebe der sieben untersuchten Bäume.

Social status of the tree	Tree (No.)	Number of living whorls	Number of living branches in whorls	Mean length of the whorl branch (cm)	Number of newly grown shoots on the whorl branches	Mean length of newly grown shoots on the whorl branches (cm)	Number of newly grown shoots between whorl branches	Mean length of newly grown shoots between whorl branches (cm)
dominant	7	20	72	114 ± 33.4	1688	$4.9 \pm 1.8$	684	5.0 ± 1.9
uommanit	6	17	65	115 ± 35.8	1605	$5.1 \pm 1.5$	638	5.3 ± 1.6
	5	16	57	103 ± 38.9	1439	4.9 ± 1.3	516	5.2 ± 1.8
cu- dominant	4	15	53	103 ± 29.2	1360	5.3 ± 1.3	422	4.8 ± 1.6
dominant	3	16	59	108 ± 36.4	1233	5.2 ± 1.4	424	5.2 ± 1.4
sub-	2	13	40	98 ± 31.2	914	4.5 ± 1.7	224	4.3 ± 1.5
dominant	1	15	42	57 ± 27.9	506	4.7 ± 1.5	185	3.3 ± 1.5

For each of the seven studied trees, the tree crown was subdivided into five horizontal layers of equal thickness: 0-20%, 21-40%, 41-60%, 61-80% and 81-100% of the vertical tree crown length, starting from the whorl closest to the ground surface that had a minimum of two living branches, and ending with the top of the tree. The mean shoot length was then calculated for each tree crown section. The highest mean length of shoots was observed in the upper sections from 61 to 100% of relative tree crown length in all tree social status groups (Fig. 7.). The highest mean length of shoots was observed in whorls on the top of the crowns (81 – 100% of tree crown length) in co-dominant and sub-dominant trees and the second highest fifth (61 – 80% of tree crown length) in dominant trees. Sub-dominant trees, in contrast with dominant and co-dominant trees, did not produce any new shoots in the lowest living whorls (0 – 20% of tree crown length). There is also noticeable change in slope of newly grown shoot length trend in height 15 m (70 % of stand crown layer). New shoots growing under this height are shorter and the length of shoots decreases faster with decreasing height (Fig. 7).



Figure 7: Mean length of newly grown shoots in whorls located at different heights along the tree stem (left). Mean length of newly grown shoots according to the social status of the trees and grouped by relative crown position (right). Horizontal bars represent standard deviation.

Abbildung 7: Die mittlere Länge der neu gewachsenen Triebe in Quirlen entlang der Baumhöhe (links) und die mittlere Länge der neu gewachsenen Triebe gruppiert nach sozialem Status des Baumes und relativer Kronenposition (rechts). Horizontale Fehlerbalken repräsentieren die Standardabweichung.

#### Tree and stand level

Different models were established using tree height ( $H_{TREE}$ ), diameter at breast height (DBH), projected area of crown ( $PA_{CROWN}$ ) and crown length ( $L_{CROWN}$ ) as independent variables to estimate the projected area of newly grown needles ( $NA_{TREE}$ ) of trees (Table 7). These equations were examined separately for branches in whorls, for branches in inter-whorls and for all branches. The best correlations were found in the relationships of  $NA_{TREE}$  with  $H_{TREE}$  ( $R^2 = 0.92$ ), of  $NA_{TREE}$  with DBH ( $R^2 = 0.90$ ), of  $NA_{TREE}$  with  $L_{CROWN}$  ( $R^2 = 0.90$ ), of  $NA_{TREE}$  with  $H_{TREE}$  and DBH ( $R^2 = 0.96$ ), of  $NA_{TREE}$  with  $PA_{CROWN}$  and  $L_{CROWN}$  ( $R^2 = 0.82$ ). The relationship between NATREE and PACROWN ( $R^2 = 0.63$ ) demonstrated the lowest correlation. The model with DBH and HTREE (Fig. 8) was chosen to estimate the projected area of newly grown needles on the trees due to its highest accuracy and because these parameters are commonly measured.

Table 7: Models for estimating the projected area of newly grown needles of trees ( $NA_{TREE}$ ) based on chosen biometric characteristics of selected studied trees.  $NA_{TREE,IM}$  - estimated projected area of newly grown needles of the branches in whorls,  $NA_{TREE,BM}$  - estimated projected area of newly grown needles of the branches between whorls.  $H_{TREB}$  - tree height (m), DBH - stem diameter at breast height (cm),  $PA_{CROWN}$  - crown projection area ( $m^2$ ),  $L_{CROWN}$  - crown length (m),  $R^3$  - coefficient of determination, MEP - mean quadratic error of prediction, AIC - Akaike information criterion. The domains of functions are for  $H_{TREB}$  = (4.6;21.0), DBH = (4.4;24.5),  $PA_{CROWN}$  = (2.0;19.6),  $L_{CROWN}$  = (3.1;11.9)

Tabelle 7: Modelle zur Ermittlung der Projektionsfläche von neu gewachsenen Baumnadeln (NA<sub>TREE</sub>) basierend auf ausgewählten biometrischen Merkmalen der untersuchten Bäume. NA<sub>TREE\_IW</sub> - geschätzte Projektionsfläche von neu zugewachsenen Nadeln der Zweige in Quirlen, NA<sub>TREE\_BW</sub> - geschätzte Projektionsfläche von neu zugewachsenen Nadeln der Zweige zwischen Quirlen. H<sub>TREE</sub> - Baumhöhe (m), DBH - Stammdurchmesser in der Brusthöhe (cm), PA<sub>CROWN</sub> - Kronenprojektionsfläche (m<sup>2</sup>), R<sup>2</sup> - Bestimmtheitsmaß, MEP - mittlerer quadratischer Fehler der Vorhersage, AIC - Akaike Informationskriterium. Der Anwendungsbereiche der Modelle ist für H<sub>TREE</sub> 4.6 bis 21.0 m, DBH 4.4 bis 24.5 cm, PA<sub>CROWN</sub> 2.0 bis 19.6 m2 und L<sub>CROWN</sub> 3.1 bis 11.9m.

Model structure	R <sup>2</sup>	MEP	AIC
NA <sub>TREE</sub> = (-0.003981) * H <sub>TREE</sub> + 0.009524 * $H_{TREE}^2$	0.92	0.13	-15.17
NA <sub>TREE</sub> = 0.06173* (DBH) <sup>1.32763</sup>	0.90	0.20	-13.59
$NA_{TREE} = 0.42044 * PA_{CROWN} - 0.010116 * PA_{CROWN}^2$	0.63	0.48	-4.76
NA <sub>TREE</sub> = 2.34564 * Ln(L <sub>CROWN</sub> ) - 2.26024	0.90	0.12	-13.66
NA <sub>TREE</sub> = 1.148093 * Ln(PA <sub>CROWN</sub> * L <sub>CROWN</sub> ) - 2.042118	0.82	0.25	-9.94
$NA_{TREE} = 0.013617 * (H_{TREE}^2 * DBH)^{0.622032}$	0.96	0.07	-19,87
NA <sub>TREE</sub> = 0.029973 * (H <sub>TREE</sub> * DBH <sup>2</sup> ) <sup>0.528578</sup>	0.94	0.09	-17,48
$NA_{TREE} = 0.011363 * H_{TREE} * DBH - 6.76439-06 * (H_{TREE} * DBH)^2$	0.96	0.06	-20.60
NA <sub>TREE_IW</sub> = 0.009669 * H <sub>TREE</sub> * DBH - 9.30293-06 * (H <sub>TREE</sub> * DBH) <sup>2</sup>	0.94	0.04	-23.41
$NA_{TREE_BW} = 0.001694 * H_{TREE} * DBH - 2.53855-06 * (H_{TREE} * DBH)^2$	0.96	0.01	-35.02



Figure 8: Relationship between the projected area of newly grown needles (NA) and parameter Tree height x DBH (upper) and model residuals (lower).

Abbildung 8: Die Beziehung zwischen der projizierten Fläche der neu gewachsenen Nadeln (NA) und Parameter der Baumhöhe x DBH (oben) und Modellreste (unten).

The DBH and H<sub>TREE</sub> inventory of all trees in the studied plot was used to estimate the total projected area of newly grown needles of a young spruce stand at the Rájec study site (Fig. 9, Table 7). The total projected area of newly grown needles in 98 trees growing in four sampled plots (à 125 m<sup>2</sup>) was 4506.7 ± 516 m<sup>2</sup> per ha.



Figure 9: Projected area of newly grown needles of all trees in the experimental plot in 2014 estimated by the model using parameter  $H_{\text{TREE}} \times DBH$  (Table 7).

Abbildung 9: Die projizierte Fläche der neugewachsenen Nadeln der Bäume auf der untersuchten Fläche im Jahre 2014 geschätzt vom Modell mit Parameter von H<sub>TREE</sub> x DBH (Tabelle 7).

#### Discussion

This study provides functions for estimation of area of newly grown needles based on simple biometrics parameters of the tree and vertical variability of shoot and needle parameters in the tree crown. The information about newly grown area of needles is valuable, because the area of new needles or new needle biomass is closely associated with production of forest and carbon sequestration.

#### Needle level

New needle production was at an average of 188 453 needles per tree and strong relationships between the shoot length and the number of needles and between the shoot length and the projected area of newly grown needles were found. Similar results were observed by Sander and Eckstein (2001) for mature Norway spruce. Annual needle production is controlled by genetic and/or ecological factors (Sander and

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Eckstein 2001). Light availability, as an ecological factor, decreased with the social status of the trees (Kučera et al. 2002). The number of needles per cm of shoot length ranged from 18 to 31, which corresponded with the range of 6 – 63 needles per cm of shoot length presented by Sander and Eckstein (2001) and 13 – 23 needles per cm of shoot length presented by Stenberg et al. (1999). The shoot silhouette to total needle area ratio (STAR<sub>max</sub>) reported by Palmroth et al. (2002) ranged from 0.116 to 0.251, which compared well with the 0.096 – 0.211 range of STAR<sub>cal</sub> presented in this paper.

Significant changes have been found for SLA and shoot length at relative stand crown layer height 62 % and 70 % respectively. Reich et al. (1998) found out SLA changes in case of light competition which resulted in higher SLA in low light condition and lower SLA in higher light condition. At the lower vertical level of the crown the value of SLA is affected by forest density (i.e. by the shading of neighboring individuals). Equally, the SLA changes are affected by the cumulative leaf area index (LAI) of individuals (Fellner et al. 2016; Konôpka et al. 2016) and by changing light due to various light transmission through the crown layer (Ellsworth and Reich 1993). According to Ellsworth and Reich (1993), the intersection of the curve of cumulative LAI and the light transmission is at 60 % of the crown height. This is consistent with our findings.

#### Shoot level

The number of newly grown shoots varied between 691 - 2372 (from sub-dominant trees to dominant trees). Norway spruce is able to compensate for a loss of lower crown needle mass by branch and foliage growth in the upper crown (Gilmore and Seymour 1997, Kantola and Mäkelä 2006). The reduction of new shoots and leaf mass is evident in the lower parts in our stand, where no development of newly grown shoots was observed at the base of the crown in sub-dominant trees. This will result in crown shortening and the accumulation of leaf biomass in the upper part of the tree. The greatest length of newly grown shoots was observed in the upper part of tree crown, especially in dominant trees (the greatest length of shoots was achieved at the 61% to 100% relative crown position). The reason for this trend is that trees in the understorey often invest in height growth to avoid shade (Oliver and Larson 1996, Pretzsch 2010). The length of newly grown shoot depends on the position in the canopy and competing environment, which increases the variability in length of newly grown shoots. The highest variability was found at the lower part of crown, where the variability in light intensity and competition are at the highest level. Stand properties such as stand structure, length and size of the branches play a significant role in the development and growth of tree crowns (Deleuze et al. 1996; Lindström 1996) and the thinning regime also has a significant effect on tree crown formation (Pape 1999). Shape and crown development is greatly affected by stand density. If the stand density decreases to the extent that the trees can achieve their maximum crown projection area, the shape of the crown will start to be different (Pretzsch 2010).

#### Tree and stand level

Many studies indicate that DBH may be an appropriate parameter for estimating total leaf biomass, but there are no published predictions of area of newly grown needles. Marklund (1987), Mund et al. (2002) and Wirth et al. (2004) published allometric relationships between DBH and leaf biomass with significant coefficients of determination ( $R^2 = 0.81$ ,  $R^2 = 0.87$  and  $R^2 = 0.90$ , respectively). The presented study confirms that a model using DBH as predictor produces good results ( $R^2 = 0.90$ ) when estimating the projected area of newly grown needles in trees (NATRFF). The most common measured variable is DBH, while the measured  $H_{TRFF}$  and other tree variables such as  $L_{CROWN}$ and PACROWN are less frequent (Cienciala et al. 2008). The parameters HTRFF, LCROWN and PA<sub>CROWN</sub> individually explained 92 %, 90 % and 63 % of the variability in the observed NATREE, respectively. Modelling NATREE using two independent variables as predictors (DBH and H<sub>TRFF</sub>) increased the coefficient of determination from 0.90 (for DBH) and 0.92 (for  $H_{TRFF}$ ) to 0.96 and decreased MEP from 0.64 to 0.57. The importance of additional independent variables was also presented by Černý (1990), Wirth et al. (2004) and Cienciala et al. (2008). L<sub>CROWN</sub> (as a factor reflecting tree dimension) was found to be a better parameter for estimating area of newly grown needles increment than PA<sub>CROWN</sub>. This was also shown by Krejza et al. (2015), who found similar dependences when they investigated relationships between basal area growth and crown dimension.

#### Conclusion

The area of newly grown needles is closely connected with basic biometric parameters of the tree. The models have been developed for the prediction of newly grown needles on the basis of a detailed inventory of the newly grown shoots and shoots biometric characteristic of young Norway spruce trees. Values that are relatively easily obtained (DBH, H<sub>TREE</sub>, L<sub>CROWN</sub> and PA<sub>CROWN</sub>) were used as input parameters for the model. The created models may be used to calculate the amount of newly grown needles area within the crown layer on the basis of knowledge of the tree height and tree diameter at breast height. Developed models brought the tool for determination of positive component of annual dynamic of leaf area index. The results can be easily combined with specific leaf area and produced valuable information about increment of new needle biomass, which is described as the most productive part of needle biomass.

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#### Author's contribution statement

Michal Bellan did the majority of the fieldwork, prepared the application for data analysis, went through the entire mathematical process and prepared the majority of the manuscript. Jan Krejza went through the entire mathematical process, partially helped with fieldwork and contributed to creating the text of the manuscript. Irena Marková contributed to creating the text of the manuscript; all authors contributed substantially to discussions and revisions.

#### **Conflict of interest**

The authors declare no conflicts of interest.

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## Effects of stand density on soil organic carbon storage in the top and deep soil layers of *Fraxinus mandshurica* plantations

#### Auswirkungen der Bestandesdichte auf die Kohlenstoffspeicherung in oberen und tiefen Bodenschichten von *Fraxinus mandshurica* Aufforstungen

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- Keywords:Manchurian Ash; Afforestation; Litter input; Carbon sequestra-<br/>tion; Refractory; Respiration; Dissolved organic carbon; Fine root<br/>biomass
- **Schlüsselbegriffe:** Mandschurische Esche; Streufall; Kohlenstoff Sequestrierung; Atmung, Gelöster organischer Kohlenstoff; Feinwurzelbiomasse

#### Abstract

Forests stand density has been reported to influence soil organic carbon (SOC) storage, yet this effect is often inconsistent. Especially for SOC in deep soil layers few studies examined its changes with stand density. In this study we investigated the effects of stand density on SOC storage by collecting soil samples from a *Fraxinus manshurica* plantation at three different stand densities. We took samples at two soil depths from 0-10 cm (top layer) and 40-60 cm (deep layer), fractionated the soil material with a 0.4 mm mesh to remove the labile fraction and then used the sieved material for laboratory incubation. Soil properties in different stand densities were examined before the incubation. After the incubation, soil respiration and the final

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carbon balance were determined. Our results indicate that the SOC storage increased with increasing stand density in both top and deep layers. The fractionation lowered the carbon concentration in both layers with the reduction in the top layer being highest at the low stand density site, while in deep layer it was highest at middle stand density. At the end of the incubation, total respiration in the top layer decreased with increasing stand density, whereas it remained invariable in the deep layer. The specific respiration decreased with increasing stand density in both layers. Addition of leaf litter after incubation resulted in an increase of the carbon content in top soil samples with the scale of accumulation increasing with increasing stand density. We concluded that the increasing SOC storage with stand density is due to its resistance versus microorganisms in top soil layer and not related to deep soil layer.

#### Zusammenfassung

Die Bestandsdichte eines Waldes soll einen entscheidenden Einfluss auf die Speicherung von organischen Kohlenstoff im Boden haben, allerdings ist dieser nicht immer eindeutig. Insbesondere für den organischen Kohlenstoff in tieferen Bodenschichten gibt es nur wenige Studien, die den Effekt der Bestandesdichte untersucht haben. Diese Studie erforscht die Auswirkungen der Bestandsdichte auf die Lagerung des organischen Kohlenstoffs mittels Bodenproben aus drei verschiedenen Bestandsdichten und aus zwei Bodenschichten in 0-10 cm (oberste Schicht) und 40-60 cm (tiefe Schicht) für eine Fraxinus manshurica Aufforstung. Die Proben wurden mit einem 0.4 mm Sieb getrennt, die labilen Komponenten entfernt und dann für die Inkubation im Labor verwendet. Vor der Inkubation wurden die Bodeneigenschaften in verschiedenen Bestandsdichten ermittelt. Nach der Inkubation wurde die Bodenatmung und die gesamte Kohlenstoffbilanz gemessen. Unsere Ergebnisse zeigten, dass die organische Kohlenstoffspeicherung mit zunehmender Bestandsdichte sowohl in oberen wie auch in unteren Bodenschichten zunahm. Die Fraktionierung reduzierte die Kohlenstoffkonzentration in beiden Schichten, wobei die Abnahme in den oberen Bodenschichten am größten bei niedriger Bestandsdichte war, während die Abnahme in den tieferen Bodenschichten am höchsten bei mittlerer Dichte war. Am Ende der Inkubation nahm die Gesamtrespiration im Oberboden mit zunehmender Bestandsdichte ab, während sie in in den tieferen Bodenschichten unverändert blieb. Die spezifische Respiration nahm in beiden Schichten mit zunehmender Bestandsdichte ab. Nach der Inkubation führte die Zugabe von Laubstreu zu einer Erhöhung des Kohlenstoffgehalts in oberen Bodenproben, wobei das Ausmaß der Akkumulation mit zunehmender Bestandsdichte zunahm. Wir schlussfolgeren, dass die zunehmende organische Kohlenstoffspeicherung mit der Bestandsdichte eher auf die Widerstandsfähigkeit gegen Mikroorganismen in der obersten Bodenschicht als auf die tiefen Bodenschichten zurückzuführen ist.

#### 1. Introduction

Soil is the largest carbon pool in terrestrial ecosystems and exceeds the amount of carbon in atmosphere and biomass (Post et al. 1982; Jobbágy 2000). Thus even a small change of soil organic carbon (SOC) sinks affects not only soil properties and microorganism activity (Bonner et al. 2018), but may have a substantial effect on the carbon balance, potentially leading to global climate change (Schlesinger and Andrews 1990; Davidson and Janssens 2006).

Studies suggested that the forest soil plays an important role in carbon sink (Brown et al. 1993; Peng et al. 2008). A number of variables have been reported to affect SOC storage in forests, such as tree species composition (Langenbruch et al.2012; Vesterdal et al. 2013), management practices (Frouz et al. 2009; Klumpp et al. 2009; Shahzad et al. 2012), climate conditions (Razanamalala et al. 2017), etc. As one of the management practices, stand density of afforestation has been reported to influence SOC storage (Jandl et al. 2007; González et al. 2012; Zhou et al. 2013), yet its effects are somewhat inconsistent, as SOC storage both increased (Fernández-Núñez et al. 2010; Sitters et al. 2013) and decreased (Noh et al. 2013) with increasing stand density. The variation of stand density will likely lead to the differences in the carbon input and output of soils (Litton et al. 2003; Fang et al. 2007; Noh et al. 2010), which may cause the change of recalcitrance of SOC, which in turn affects SOC storage. However, the effect of variation of stand density on SOC recalcitrance is poorly explored, which may explain our ambiguous understanding discrepant of stand density effects on SOC storage. We conclude that the evaluation of the size and recalcitrance of soil carbon sink by stand density is an important task.

Kirkby et al. (2014) suggest that SOC fractions can be separated into coarse and fine fractions according to the size and density of the particles. The coarse fraction, which is mainly composed of the residuals of plants and animals, has a high microbial activity, while the fine fraction, which is mainly composed by refractory humus, has a slow turnover time (Falloon and Smith 2000). The fine fraction in soil usually represent a larger share of the entire SOC pool compared to the coarse fraction (Kirkby et al. 2011).

Many studies have examined the properties of SOC (Cui et al. 2014; Liang et al. 2017). The surface soils received more attention than the subsoils, although the latter also store large amounts of carbon as well (Batjes 1996; Jobbágy 2000; Fontaine et al. 2007). The surface SOC sink is mainly regulated by the input of fresh organic carbon, unlike in subsoils the carbon sink is affected by physical disturbance (Salomé et al. 2010). Therefore, surface soils and subsoils should be both considered when studying SOC storage, which could lead to a better understanding of the mechanism of SOC storage change.

Manchurian ash (Fraxinus mandshurica) is a commonly used species for afforestation

in northeast China, which helps to upscale the findings of this study on SOC in ash forests for understanding the regional soil carbon sink and provide advice for future afforestation. We investigate the effects of variation of stand density on SOC recalcitrance and subsequently on SOC storage in different layers by sampling both top and deep soil layers from 18-year-old ash plantations at three different stand densities. The objective of this study is to reveal the mechanisms of how stand density regulates SOC storage. We hypothesized that the SOC storage in different stand density sites is affected by the recalcitrance of SOC.

#### 2. Materials and methods

#### 2.1 Study area

This study area is located in Maoershan Experimental Station of Northeast Forestry University, Heilongjiang Province, China (127°36′47″ E, 45°18′13″ N) with an average altitude of 300 m. The climate type of this region is temperate continental monsoon climate with a mean annual temperature of 2.8 °C and mean annual precipitation of 700 mm (Zhou 1994). The forests in this region are mainly composed of *Fraxinus mandshurica*, *Larix gmelini*, *Betula platylhylla*, *Acer mono*, *Phellodendron amurense* and *Populus davidiana*.

The studied ash plantations were planted in 1998 with 2-year-old seedlings with three different afforestation densities (2200, 4400 and 10000 trees per hectare). The plantations were planted on a north-facing slope with an inclination of less than 10° and the soil type is an Alfisol. Those plantations were not artificially thinned. Due to natural thinning the stand density was lower than when the stands were planted. The dead trees were removed in every winter, as local residents collected fuel wood usually in October and November. The stand structure of the plantations are shown in Table 1.

Table 1: Stand structure of ash plantations with different original stand density, current stand density, average tree height and average diameter at breast height are presented as means  $\pm$  standard error (n = 3).

Tabelle 1: Merkmale von Eschenaufforstungen mit unterschiedlicher Bestandsdichte. Für aktuelle Bestandesdichte, durchschnittliche Höhe und durchschnittlichen Durchmessers bei Brusthöhe zeigen wir Mittelwert  $\pm$  Standardfehler (n = 3).

	Original density (trees · ha <sup>-1</sup> )	Current density (trees · ha <sup>-1</sup> )	Average height (m)	Average diameter at breast height (cm)
Low density	2200	$1407 \pm 87$	$10.3\pm0.5$	$9.0 \pm 0.3$
Middle density	4400	$2943 \pm 137$	$9.7 \pm 0.7$	$7.5 \pm 0.5$
High density	10000	$4011 \pm 182$	$9.4 \pm 0.7$	$6.4 \pm 0.3$

#### 2.2 Methods

#### 2.2.1 Sampling

Three sampling sites with a size of 20 m by 20 m were established under each stand density (9 sampling sites in total) in early September 2015. The density plantations were separated by a 20 m buffer, and the three replicate sites were also separated by a 20 m buffer. For sampling roots, six plots from each site were randomly chosen located at 50 to 70 cm distance from trees. A soil core with inner diameter of 60 mm was used for 0-10 cm layer (top soil) and for 40-60 cm layer (deep soil) to measure the fine root biomass with a diameter of less than 2 mm (Eissenstat et al. 2000). For sampling soils three profiles were dug in each site from 0-10 cm and 40-60 cm. Soil samples from the three profiles of each site were homogeneously and equally mixed, and passed through a 2 mm mesh to remove stones and plants debris, before the soil properties were measured. The properties of soil samples were described in Table 2. As suggested by Kirkby et al. (2011), a fractionation was used to obtain the refractory SOC fraction, which was subsequently used for incubation by using a 0.4 mm mesh. Besides, we collected the annual fresh leaf litter of ash trees from the forest floor to use as a substrate subsequently in the incubation. The leaf litter was grounded into pieces with 1 to 2 mm size and dried before application.

#### 2.2.2 Incubation setup

A weight of 60 g air dried soil sample from each density site of top layer and deep layer was put into a 500 ml jar with the water content of 40 % water holding capacity (WHC). All the samples were put into an incubator in the dark at 25 °C for 8 days of pre-incubation. To simulate field conditions, all the topsoils were amended with annual litter as the substrate. The deep soil samples did not get additional litter input, as the deep soil layer receive little litter carbon input. After the pre-incubation, 6.44 mg C g<sup>-1</sup> grounded air-dried annual ash litter (carbon concentration 454.97 mg g<sup>-1</sup>; nitrogen concentration 20.04 mg g<sup>-1</sup>; phosphorus concentration 0.88 mg g<sup>-1</sup>) was added into the topsoils from all the density sites, while deepsoil samples did not receive additional substrate. Subsequently, the water content was adjusted to 65 % WHC with the soil and added litter getting mixed. A 25 ml beaker filled with 10 ml 1 mol L-1 NaOH solution was suspended up inside the jar for trapping CO<sub>2</sub> released from soil (Aye et al., 2018). All the jars were sealed airtight at 25 °C for the incubation of 121 days. There were three replicate sites for each stand density with three top layer and deep layer replicate soil samples for each site, which was 54 jars to be incubated (3 densities \* 3 sites \* 2 layers \* 3 replicates). At the day 2, 4, 7, 11, 18, 29, 36, 45, 61, 79, 100 and 121, CO<sub>2</sub> trapped in NaOH solution was measured with titration. When the incubation ended, samples from topsoils were fractionated to separate the refractory fraction and not fully decomposed litter by using "dry sieving and winnowing" method mentioned by Kirkby et al. (2011). Using this method, soil particles that were not able to pass through the 2 mm mesh, were taken as the light fraction and considered as the not fully decomposed litter in this experiment. The particles that passed through 0.4 mm mesh were taken as the heavy fraction, known as the refractory fraction of SOC. The particles that passed 2 mm mesh but not passed the 0.4 mm mesh compounded both fractions, which were separated with blowing wind as only the light fraction rather than the heavy fraction can be blown away. The weight and carbon content of the refractory fraction and the not fully decomposed litter before and after incubation were measured to determine the carbon balance.

#### 2.2.3 Analysis

The carbon and nitrogen concentration was measured with Vario MACRO Elementor Co., Germany. The mineral nitrogen concentration was the sum of ammonium concentration and nitrate concentration, which was extracted with 2 mol L<sup>-1</sup> KCl and measured ammonium and nitrate respectively by Auto Analyzer 3. Microbial biomass was determined with the chloroform fumigation method (Vance et al. 1987). Carbon was extracted with 0.5 mol L<sup>-1</sup> K<sub>2</sub>SO<sub>4</sub> and subsequently measured by Liqui TOCII. Microbial biomass carbon was estimated as the difference between the fumigated soil sample and unfumigated sample. DOC was extracted with deionized water and measured by Liqui TOCII.

#### 2.2.4 Statistic

All the data were presented as the average value of the three replicate sites of each stand density. Means were compared with the ANOVA method using the LSD criterion. The SOC storage and fine root biomass in top layer were calculated as the total amount per unit area within the 10 cm while in deep layer were calculated within the 20 cm. Correlations between indexes were calculated as Pearson Correlation Coefficient. The total respiration is presented as the amount of accumulative CO<sub>2</sub> released during the incubation period normalized to the sample weight, while the specific respiration is presented as the amount of accumulative CO<sub>2</sub> released during incubation period normalized to the sample. All the data were statistically analyzed with SPSS 19.0.

#### 3. Results

## 3.1 SOC storage and other soil properties in top and deep soil in different stand density

In field condition, the SOC storage was found higher in high stand density site in both top layer and deep layer, with 15.52 % and 10.90 % higher in topsoils and 31.81 % and 9.99 % higher in deepsoils compared to the low stand density site and middle stand density site, respectively. The microbial biomass carbon and dissolved organic carbon were both found higher in low stand density site and lowest in high stand
Table 2: Soil properties and fine root biomass in top layer and deep layer at three different stand densities. We present mean  $\pm$  standard error (n = 3). The different capital letters represented the significant difference of samples among stand densities in the same layer, and the different lowercase letters represented the significant difference of samples between two layers in the same stand density (P<0.05).

Tabelle 2: Bodeneigenschaften und Feinwurzelbiomasse in der oberen und tiefen Bodenschicht unter drei unterschiedlichen Bestandesdichte. Wir zeigen Mittelwert  $\pm$  Standardfehler (n = 3). Die unterschiedlichen Großbuchstaben repräsentierten signifikante Unterschiede hinsichtlich Bestandesdichte in derselben Schicht und die unterschiedlichen Kleinbuchstaben repräsentierten signifikante Unterschiede zwischen den zwei Schichten in derselben Bestandesdichte (P<0.05).

Paramatara	Top layer (0-10 cm)			Deep layer (40-60 cm)			
Farameters	Low density Middle density High de		High density	Low density	Middle density	High density	
SOC storage (t · ha-1)	36.21±1.99 Ba	37.72±3.94)Ba	41.83±2.78 Aa	15.78±1.00 Bb	18.91±0.71 Ab	20.80±1.49 Ab	
Microbial biomass carbon (mg · kg <sup>-1</sup> )	1453.80±116.18 Aa	1288.51±106.32 Ba	1244.15±115.59 Ba	339.46±45.79 Bb	326.78±42.88 Bb	534.16±45.55 Ab	
Dissolved organic carbon (mg $\cdot$ kg <sup>-1</sup> )	35.82±1.94 Aa	34.81±2.24 Aa	29.71±2.05 Ba	34.50±2.25 Aa	36.31±2.59 Aa	28.68±1.46 Ba	
Available nitrogen (mg · kg <sup>-1</sup> )	15.83±1.36 Aa	16.60±1.59 Aa	17.07±1.98 Aa	1.41±0.35 Bb	1.28±0.16 Bb	1.87±0.10 Ab	
pH (1M KCl, 1:2.5)	$5.03 \pm 0.04  Aa$	$5.04 \pm 0.08$ Aa	$5.08 \pm 0.03 \ Aa$	$4.09 \!\pm\! 0.11  Ab$	$4.15\!\pm\!0.03Ab$	$4.02\!\pm\!0.06Ab$	
Clay (%)	$42.63\!\pm\!3.42Aa$	44.18±4.12 Aa	43.77±2.88 Aa	38.52±4.12 Ba	36.82±2.39 B a	38.71±2.79 Ba	
Silt (%)	$33.63\!\pm\!2.61Ba$	$31.59 \!\pm\! 3.04  Ba$	32.69±3.70 Ba	39.66±4.50 Aa	$41.06\!\pm\!2.58Aa$	41.62±5.26 Aa	
Sand (%)	23.74±3.16 Aa	24.23±3.86 Aa	23.54±3.09 Aa	21.82±3.96 Ba	$22.12\!\pm\!2.68Ba$	19.67±4.45 Ba	
Fine root biomass (g · m <sup>-2</sup> )	408.63±26.32 Aa	341.78±29.91 Ba	241.16±14.90 Ca	13.12±2.89 Cb	34.19±5.62 Bb	47.16±6.30 Ab	

density site in topsoils. In deepsoils, however, the microbial biomass carbon was found the lowest in high stand density site, which is opposite to the trend of dissolved organic carbon. The pH was 5.03 to 5.08 in topsoils and 4.02 to 4.15 in deepsoils, which remained unchanged with stand density. There was no difference of particle distribution with stand density in both topsoils and deepsoils. For the fine root biomass, it was found increasing with stand density in topsoils but decreasing with stand density in deepsoils (Tab. 2).



Figure 1: The total carbon concentration of soil samples in top layer (T) and deep layer (D) from low density (LD), middle density (MD) and high density (HD) with and without fractionation. The different capital letters represented the significant difference of unfractionated samples among stand densities in the same layer, and the different lowercase letters represented the significant difference of fractionated samples among stand densities in the same layer. The asterisks represented the significant effects of fractionation on carbon concentration (n = 3; P < 0.05).

Abbildung 1: Die Kohlenstoffkonzentration der Bodenproben in der oberen (T) und der tieferen Bodenschicht (D) mit niedriger (LD), mittlerer (MD) und hoher Bestandesdichte (HD) mit und ohne Fraktionierung. Die verschiedenen Großbuchstaben zeigen signifikanten Unterschiede der unfraktionierten Proben zwischen den Bestandesdichten in derselben Schicht, und die unterschiedlichen Kleinbuchstaben repräsentierten den signifikanten Unterschied der fraktionierten Proben zwischen den Bestandesdichten in derselben Schicht. Die Sterne repräsentieren die signifikanten Auswirkungen der Fraktionierungauf die Kohlenstoffkonzentration (n = 3; P<0.05).

# 3.2 Carbon concentration in top and deep soil in different stand density changed by fractionation

There was not any significant variation of soil carbon concentration with changing stand density before fractionation. After fractionation, the soil carbon concentration in topsoils was found highest in middle density site with 4.42 % and 6.79 % higher than in high density site and low density site, respectively. In deepsoils, it was found highest in high density site with 16.73 % and 7.48 % higher than in middle density site and low density site, respectively. Furthermore, the carbon concentration of each soil sample decreased with the application of fractionation. In topsoils, the decre-

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ments are getting slighter with increasing stand density while in deepsoils the scale of decrements presents the highest in middle density site and lowest in low density site (Fig.1).



Figure 2: The accumulated total respiration of samples in top layer (a, left) and deep layer (b, right) for low, middle and stand density with simulating litter accessibility expected in the field.

Abbildung 2: Die kumulierte Gesamtrespiration der Proben in der oberen Bodenschicht (a, links) und tiefen Bodenschicht (b, rechts) für niedrige, mittlere und hohe Bestandesdichte, unter simulierten Streuinput.

# 3.3 Respiration of topsoils and deepsoils from different density sites

Total respiration in topsoils is significantly higher than in deepsoils, but its change patterns with different stand density are distinct in top layer and deep layer. Total respiration was found significantly higher in topsoils than in deepsoils and decreased in topsoils with stand density while it remained unchanged in deepsoils (Fig.2). The specific respiration in deepsoils was higher than in topsoils, which in both layers presenting the highest in low density site (Fig. 3).

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Figure 3: The accumulated specific respiration of samples in top layer (a, left) and deep layer (b, right) at low, middle and stand density while simulating litter accessibility expected in the field.

Abbildung 3: Die kumulierte spezifische Respiration von Proben in der oberen Bodenschicht (a, links) und tiefe Bodenschicht (b, rechts) für niedrige, mittlere und hohe Bestandesdichte, unter simulierten Streuinput.

# 3.4 Carbon balance in topsoils from different density sites

During the incubation, the content of refractory fraction of organic carbon increased by 4.64 % to 9.08 % compared to the samples before incubation. The scale of increment increased significantly with stand density. After the incubation, only 29.66 % to 31.68 % of added litter remained. The amount of litter decomposition in the duration of incubation did not vary with stand density (Tab. 3).

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Table 3: Changes of refractory SOC content and substrate carbon content of the 121 days of incubation in top layer at low, middle and high stand density ( $g \cdot kg^{-1}$ ). We present means  $\pm$  standard error (n = 3). The different lowercase letters represented the significant difference among stand density (P<0.05).

Tabelle 3: Veränderungen des organischen Kohlenstoffgehalts und des Kohlenstoffgehalts des Substrats während der 121-tägigen Inkubation in der obersten Bodenschicht bei niedriger, mittlerer und hoher Bestandesdichte (g  $\cdot$  kg<sup>-1</sup>). Wir zeigen Mittelwert  $\pm$  Standardfehler (n = 3). Die unterschiedlichen Kleinbuchstaben repräsentieren signifikante Unterschiede zwischen der Bestandesdichte (P<0.05).

	Refra	ctory SOC fraction		Carbon from substrate			
	Before incubation	After incubation	Increment	Before incubation	After incubation	Decrement	
Low density	(54.15±0.93) b	(56.66±3.28) a	(2.51±0.45) c	6.44	(2.04±0.32) a	(4.40±0.32) a	
Middle density	(57.82±1.86) a	(62.43±0.82) a	(4.60±0.79) b	6.44	(1.99±0.59) a	(4.45±0.59) a	
High density	(55.37±2.91) ab	(60.41±4.30) a	(5.03±0.53) a	6.44	(1.91±0.20) a	(4.53±0.20) a	

# 3.5 Correlations of SOC indicators with changing stand density in top and deep soil.

In top soil layer, the SOC storage was found positively correlated to SOC increment and negatively correlated to available nitrogen. The dissolved organic carbon was found negatively correlated to both substrate carbon decrement and SOC increment, and positively correlated to fine root biomass. There was also a negative correlation between SOC increment and fine root biomass (Tab. 4).

In deep soil layer, the SOC storage was found positively correlated to available nitrogen and negatively correlated to specific respiration. The available nitrogen was found negatively correlated to both total respiration and specific respiration. Obviously, the positive correlation was found between total respiration and specific respiration (Tab. 5).

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Table 4: The Pearson correlations among SOC storage, Litter decomposition amount, SOC increment, Dissolved organic carbon, Available nitrogen and Fine root biomass in top soil layers (n=9). The asterisk represented the significant correlation between the two indexes.

Tabelle 4: Die Pearson-Korrelationen zwischen der organischen Kohlenstoffspeicherung, Streudekomposition, organischem Kohlenstofzuwachs, gelöstem organischen Kohlenstoff, verfügbarem Stickstoff und Feinwurzelbiomasse im Oberboden (n = 9). Der Stern zeigt die signifikante Korrelation zwischen den beiden Indices.

	SOC storage	Litter decomposition amount	SOC increment	Dissolved organic carbon	Available nitrogen	Fine root biomass
SOC storage	1					
Litter decomposition	0.60	1				
SOC increment	0.81 *	0.42	1			
Dissolved organic	-0.06	-0.68 *	-0.74 *	1		
Available nitrogen	-0.66 *	-0.35	0.13	0.16	1	
Fine root biomass	-0.60	-0.14	-0.82 *	0.72 *	-0.06	1

Table 5: The Pearson correlations among SOC storage, Total respiration, Specific respiration, Dissolved organic carbon, Available nitrogen and Fine root biomass in deep soil layers (n=9). The asterisk represented the significant correlation between the two indexes.

Tabelle 5: Die Pearson-Korrelationen zwischen der organischen Kohlenstoffspeicherung, Gesamtrespiration, spezifischer Respiration, gelöster organischer Kohlenstoff, verfügbarem Stickstoff und Feinwurzelbiomasse in tieferen Bodenschichten (n = 9). Der Stern repräsentiert signifikante Korrelation zwischen den beiden Indices.

	SOC storage	Total respiration	Specific respiration	Dissolved organic carbon	Available nitrogen	Fine root biomass
SOC storage	1					
Total respiration	-0.30	1				
Specific respiration	-0.69 *	0.88 *	1			
Dissolved organic	-0.22	-0.16	-0.10	1		
Available nitrogen	0.61	-0.68 *	-0.66 *	-0.39	1	
Fine root biomass	0.63 *	-0.06	-0.33	-0.40	0.46	1

#### 4. Discussion

#### 4.1 The effects of stand density on carbon storage in topsoils

In the ash plantations, the SOC storage in topsoils increased with the magnitude of stand density (Tab.2), possibly due to the increase of the refractory SOC pool as we hypothesized. After fractionation, the light fraction, known to be microbial active with a high carbon concentration, has been removed by the 0.4 mm sieving. The retained heavy fraction is known to be refractory with relatively low carbon concentration. That could be the explanations of the generally lower carbon concentration after sieving (Magid and Kjaergaard 2001; Kirkby et al. 2011; Fig. 1). Only for the low stand density site we discovered a significant decrease in carbon concentration after sieving (Fig. 1), indicating the larger amount of easily degradable carbon contained in topsoil at a low stand density. Thus, at the high stand density site, higher percentage of refractory fraction in topsoils may lead to potentially higher recalcitrance of SOC. We considered the recalcitrance as one possible reason for the higher SOC storage in high stand density site compared to low stand density site.

After incubation, the carbon content of all the topsoils increased compared to those before incubation (Tab. 3), indicating that under natural conditions (with litter input) the refractory fraction of SOC will be continuously accumulated. This was consisting with the results of studies of SOC storage in chronosequence forests (Sharma et al. 2009; Uri et al. 2014). Meanwhile, after incubation, the accumulation amount increased with increasing stand density (Tab.3), indicating higher stand density of ash will not only increase the percentage of refractory fraction of SOC in topsoils, but also benefit for its accumulation. This is also confirmed by the positive correlation between SOC storage and the increment after incubation (Tab. 4).

With the incubation of 121 days, no differences of soil samples receiving carbon from substrate were found in different stand density sites, but the increment of carbon content of the topsoils increased significantly when stand density gets higher (Tab. 3), indicating less SOC derived carbon emission stimulated by litter input with increasing stand density. As the addition of fresh carbon will stimulate the mineralization of SOC, which is known as the priming effect (Kuzyakov et al. 2000; Fontaine et al. 2004; Blagodatskaya et al. 2011), we inferred that the priming effect of the refractory fraction of SOC will be restricted with increasing stand density in topsoils (Fig. 2). Creamer et al. (2015) reported that the chemical similarity of SOC and added substrates would alter the intensity of priming effect due to the "co-metabolism". The more chemically similar they are, the stronger potential priming effect of SOC will be, as the promoted microorganism by the addition of substrate better equipped to decompose SOC. In our experiment, all the substrates are annual litter. As Pascault et al. (2013) mentioned the positive relationship between priming effect intensity and substrate degradability, we considered that with increasing stand density, it is the SOC microbial availability decreases. Also, our results of decreased microbial biomass with increasing stand density supported this point (Tab. 2). Thus, the decreasing microbial availability of refractory fraction of SOC with increasing stand density is also considered to be an explanation of higher SOC storage in higher density site.

# 4.2 The effects of stand density on carbon storage in deepsoils

Similar to the topsoils, SOC storage in deepsoils also increases with increasing stand density (Tab. 2). The scale of decrement of soil carbon concentration with fractionation presented the highest in middle density site (Fig. 1), indicating the largest percentage of easily decomposed SOC in the deep layer from middle density site. This result, however, is not considered as the contribution to the change of SOC storage in deepsoils as Salomé et al. (2010) pointed out that the recalcitrance of SOC in deepsoils from microbe is mainly caused by the incapability of the microbes to contact the substrate it can use, which is known as the spatial isolation. The high amount of easily decomposed SOC in deepsoil of middle density site might be potentially not available to the microorganism because of the isolation, subsequently affects SOC storage barely.

It has been reported that the intensity of specific respiration could express the recalcitrance of SOC (Lv et al. 2005). Therefore, the negative correlation between specific respiration and SOC storage in our results (Tab. 5) probably indicated that the increasing SOC storage with increasing stand density is due to the higher recalcitrance of SOC. As some studies pointed out that DOC is one kind of labile carbon for microorganism in soil which is also allowed to move freely in soil solution (Neff and Asner 2001; Qiu et al. 2016), we expected DOC could somehow explain the variation of SOC recalcitrance, in turns the SOC storage with stand density changing. However, no significant correlations were found between DOC and specific respiration or SOC storage (Tab. 5). Thus, the recalcitrance of SOC in deepsoils might not be considered as the reasons for SOC storage variation with stand density. Moreover, the specific respiration is a key path for soil carbon pool output (Guenet et al. 2012; Heitkötter et al. 2017). The weaker output of carbon with increasing stand density could partly explain the accumulated SOC storage with increasing stand density.

Guo et al. (2005) reported the crucial effects of fine root on SOC storage. In our results, a positive correlation was found between fine root biomass and SOC storage in deepsoils (Tab. 5), implying the impact of fine root biomass on SOC storage. Normally, soil in deep layer is not able to contact the forest floor to receive the carbon feedback, which makes the fine root in deep layer one of the few paths for carbon input (Hu et al. 2016). Thus, we speculated the SOC storage increasing with increasing stand density could also be explained by the higher input level, as more root exudates and litter will be when more fine root biomass exists (lversen et al. 2008).

# 5. Conclusion

In conclusion, the SOC storage of ash plantations increased with increasing stand density in both top soil layer and deep soil layer. In topsoils, as we hypothesized, the increasing SOC storage is due to the recalcitrance of SOC that increased with increasing stand density. With stand density increasing, higher percentage of refractory fraction exists, with this fraction being also more recalcitrant for microorganism. In deep soils, however, the recalcitrance of SOC might not be taken as the reason for SOC variation with stand density as we hypothesized. It is the higher input and lower output of carbon with increasing stand density that resulted in the higher SOC storage.

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Centralblatt <sup>für das gesamte</sup> Forstwesen

# 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, mai ment, Coppice stand, High stand, Turkey							
Schlüsselbegriffe:	Kronenschlussgrad,	Prognose	des	Bodenverlustes,	Kohlen-			
	stoff-Seauestrieruna.	Managem	ent, A	Jusschlagwald, Tü	rkei			

#### 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 roburl* L. subsp. *roburl* 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<sup>3</sup>/year (0.82 m<sup>3</sup>/ha/year), which is 15.942.459 m<sup>3</sup>/year (0.81 m<sup>3</sup>/ha/year) from high forests and 2.372.162 m<sup>3</sup>/year (0.87 m<sup>3</sup>/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<sup>3</sup>. 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 signifi-

#### cant 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 (C) 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

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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 m<sup>2</sup>) 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).

$$A = K x R x LS x C x P \tag{1}$$

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<sub>topsoil</sub>= 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 ( $20 \times 20 \text{ m}=400 \text{ m}^2$ ) and two smaller quadrats ( $1 \times 1 \text{ m}$ ) were taken randomly located within the stand profiles. Species type, diameter at breast height

(DBH) and tree height of living trees were recorded (DBH  $\ge$  8 cm, height  $\ge$  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<sup>2</sup> 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 roburl* L. (Makineci et al. 2015) and shown in Eq. 2.

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

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

Soil carbon stock in tC ha<sup>-1</sup> 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<sup>-1</sup>) was estimated according to Eq. 3 and 4.

$C \% = 0.58 \ x \ OM$ (3)	3	)
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 $SOCS = BD \ x \ C \ \% \ x \ D \tag{4}$ 

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In the equation OM is organic matter, BD is soil bulk density (g cm<sup>-3</sup>), 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  $\pm$  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

Sample Plots	Stem number (ha <sup>-1</sup> )	Mean DBH (cm)	Mean D03 (cm)	Mean tree height (m)	Mean total crown shape (m)	Mean height to crown (m)	Basal area (m² 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 ±	$708 \pm$	$9.0 \pm$	$11.2 \pm$	$7.37 \pm$	$4.89\pm 0.81$	$3.29 \pm$	$4.72\pm2.44$
SD	317	1.3	1.7	1.28		1.01	

Tabelle 1: Zusammenfassung des Bestandesmerkmale hinsichtlich der Kronenschlussgrad

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

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area was 6.62 m<sup>2</sup>/ha in sample plot 1, 5.68 m<sup>2</sup>/ha in sample plot 2 and 1.97 m<sup>2</sup>/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 $\pm$ SD, n=6)

Parameters	Topsoil	Subsoil
Texture	Clay	Clay
Sand (%)	$42.72\pm2.06$	$27.91 \pm 1.69$
Fine sand (%)	$7.94\pm 0.97$	$5.93\pm0.11$
Silt (%)	$16.29\pm 6.06$	$17.41\pm4.27$
Clay (%)	$40.98 \pm 6.69$	$54.68\pm3.53$
Organic matter (%)	$\textbf{4.20} \pm \textbf{1.68}$	$0.85\pm0.24$
рН	$5.15\pm0.17$	$5.27\pm0.31$
Field capacity (%)	$36.17 \pm 1.65$	$44.63 \pm 1.64$
Wilting point (%)	$23.72\pm1.75$	$32.42 \pm 1.93$
Saturation (%)	$47.82 \pm 1.13$	$49.67\pm0.83$
AWHC (cm/cm)	$1.24\pm0.01$	$1.22\pm0.03$
Sat. Hyd. Cond. (cm/h)	$4.38 \pm 1.13$	$0.63\pm0.17$
Bulk density (g/cm <sup>3</sup> )	$1.40\pm0.03$	$1.35{\pm}~0.02$
K factor	0.1644	0.1635

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

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 × X + 103.858 (R<sup>2</sup>= 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: Kohlenstoffsp	eicherung eines	s Stieleichen-Niederwald	s im Untersuchungsgebiet
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Sample	Carbon sequestration (t/ha)								
Plot	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	$10.64\pm0.15$	$2.53\pm0.31$	$0.155\pm0.04$	62.25	$75.57\pm5.99$				

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

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