Research Article
Eur J Forest Eng 2018, 4(2): 33-42

Modelling Top Soil Erosion Depend on Stand Profile for Anatolian Black Pine (*Pinus nigra Arnold. subsp. pallasiana*) Plantation in a Semi-Arid Ecosystem in Turkey *

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Abstract

This paper researches top-soil loss depends on Anatolian black pine stands by different canopy density. The stand profile is playing an important role on the living and non-living environment in the ecosystem and it affects directly canopy density (CD), leaf area index and silvicultural treatments and indirectly affects the soil properties. Within the scope of the study, three different canopy densities (60%, 80%, 90%) were taken and the stand profiles were determined by an 20x20 meter sample plots representing the stand. All sample plots were selected under the same habitat conditions (Slope: 5%, Aspect: Northwest, Elevation: 1070 m) to estimate top soil loss model. As a result, the amount of top soil loss was determined as 0.052 t/ha/yr in 60% CD, 0.037 t/ha/yr in 80% CD and 0.017 t/ha/yr in 90% CD respectively. In addition, multiple regression model (Linear, R^2=0.96) was developed to estimate annual top soil loss depend on DBH (diameter of breast height), and tree height. On the other hand, simple regression model (Quadratic, R^2=0.98) using tree height variable was improved. Furthermore, more advanced models can be developed in the future by using the stand parameters in different ecological conditions and slope gradients.

Keywords: Soil loss, Canopy density, Anatolian Black Pine, Stand profile, ABAG

1. Introduction

Land use has changed over time and different effects have emerged. With the industrial revolution, a global-scale industrialization movement has begun, the world population has entered a period of rapid growth, and the vast majority of the population has evolved from agricultural society to industrial society (Agner, 2004; Grigg, 1987). Along with urbanization and the development of industry and technology, however, environmental problems have increased. One of the most important problems is the land degradation due to soil loss by erosion (IUCN, 2015). According to the land use in general, the least soil loss is seen in the unit area of forest ecosystems while the most in agriculture areas (Hacisalihoğlu et al., 2017; Offiong and Iwara, 2012; Cotler and Larrocea, 2006).

In addition, unsuitable land use and destruction of existing vegetation cause acceleration of erosion, unproductive soil and land degradation (Oldeman et al., 1990). Every year dozens of hectares of forest are converted into the agricultural area by cutting and burning activities in the Amazons (Inoue et al., 2010; Pascual, 2005; Same et al., 1997). Such areas, which are used intensively and cannot be improved naturally and artificially, quickly enter the degradation process (Maitima, 2009). After a certain period of time, those types of areas become unproductive and unusable.

Various methods have been developed to reduce the effect of land degradation and soil loss in terrestrial ecosystems (Rivas, 2006; Uslu, 1969) and it is aimed to prevent erosion and soil loss by developed methods. The destruction of nature by humans has started since the formation of the world and continues to increase day by day. The damage caused by the erosion has been realized very late by the people (Richter, 1998; Hacısalihoğlu, 2004). However, people have tried afforestation in degraded regions by ecologically suitable tree species to prevent land degradation resulted by soil erosion. An area that has been intensively used for agriculture or pastoral purposes for decades may be improved in terms of vegetative biodiversity and soil characteristics after being left to its natural state or restored (Aide et al., 1995; Benayas et al., 2007; Diez et al., 1997). Therefore, the afforestation efforts are vital for the lands prone to degradation. Reforestation efforts in Turkey have been carried out successfully in the dry and semi-dry regions prone to desertification such as Central Anatolia and South eastern Anatolia (Figure 1) (ÇEM, 2013).

* This work has been partially presented in IFES 2017 Symposium
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Received 06 Dec 2018; Accepted 13 Dec 2018

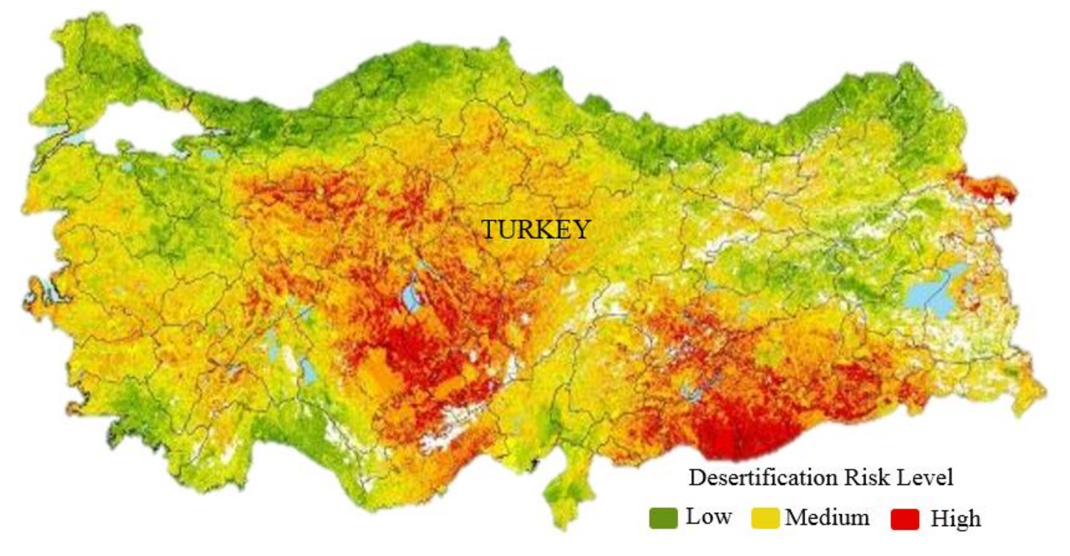


Figure 1. Turkey desertification risk map (Modified from ÇEM, 2018)

Anatolian black pine (*Pinus nigra* Arnold. subsp. *pallasiana*) is a species that has been adapted to drought and extreme climatic conditions thanks to the deep root system. It is often used in semi-arid barren regions such as the Central Anatolian, and enriching the ecosystem in terms of ecologically (Güner, 2011; Ertekin, 2010; Polat, 2014). In this study, the relationships between the stand structure and the soil erosion were investigated in an Anatolian black pine afforestation area determined within the boundaries of Ankara province, Gölbaşı district in Turkey. The main purpose of this research is to determine the effects of the stand profile components on topsoil loss amounts.

2. Material and Methods

2.1. Study Area

The study area is located in the Central Anatolia Region of Turkey in Gölbaşı/Ankara province (39°50’23” N - 32°48’28” E and Elevation: 1070 m asl) (Figure 2). The main aspect of the area is the Northwest (NW) and average terrain slope is 5%.

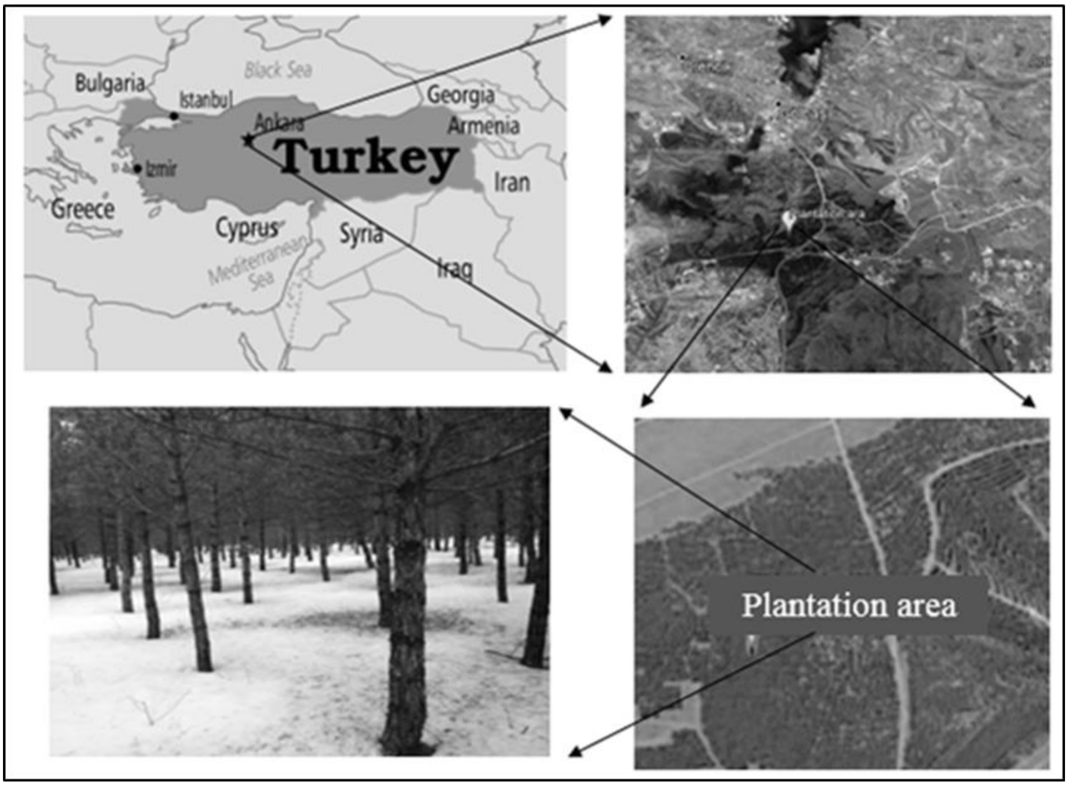


Figure 2. Study area location and sample points (please use original colored images)

2.2. Climate

According to the climate data of the last 89 years, the average annual temperature is 11.9 ºC and the annual total rainfall is 387.2 mm. According to Walter (1975) climate diagram, study area is included in semi-arid regions (Figure 3). There is water shortage in the environment and a dry period occurs from June to October throughout the year. In addition, the study area is classified as "arid" according to Aydeniz climate classification, "Among step and humid" according to DeMartonne and "B1, semi dry" according to Thornthwaite method (MGM, 2018).

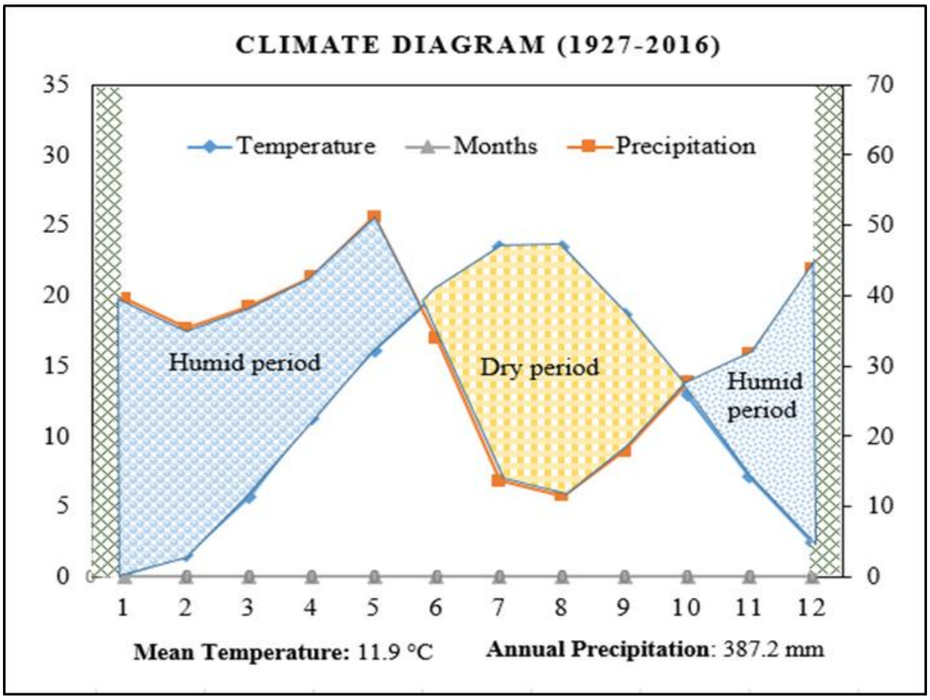


Figure 3. Walter climate diagram of research area

2.3. Forest Stand Structure

The study area had been used until 1980s for pastural purposes and later was planted (afforested) by Anatolian black pine (*Pinus nigra* Arn. subsp. *pallasiana* (Lamb.) Holmboe). The geological structure is from the upper paleocene period and parent material is Lime and lime stone. Soil is textured generally clay in both land use types (forested and barren area). The canopy closure of the forested area is over 50%. Forest stand intensity is 775 tree/ha, mean DBH is 19.5 cm, and mean height is 10.1 m. Stand age is approximately 40 yrs in the study area (Figure 4).

Figure 4. Forest stand structure of study area (please use original colored image)

2.4. Analysis of Stand Profile

In a forest ecosystem, stand structures are mostly affected by DBH, diameter at 0.30 height, tree height, crown shape (four cardinal directions), crown width, height to crown base, and tree distribution parameters. Many stand profile software using these parameters have been developed so far such as Forest and tree designer software (SVS) and Forest stand designer software (ARGUS Forstplanung) (Figure 5 and 6) (Hann, 1997; Latham, 1998; Hyyppa, 2001; Mashall, 2003).

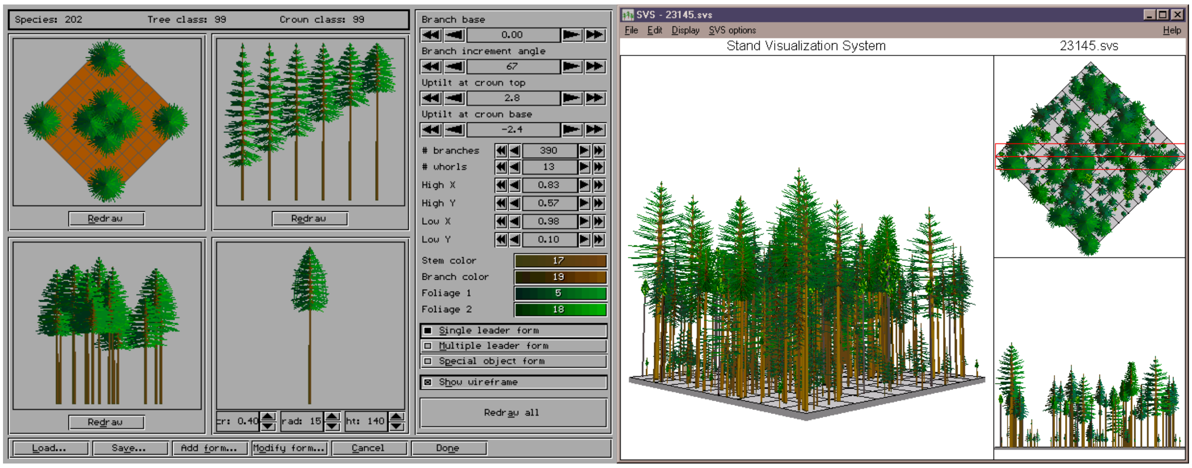


Figure 5. Forest and tree designer software (SVS)

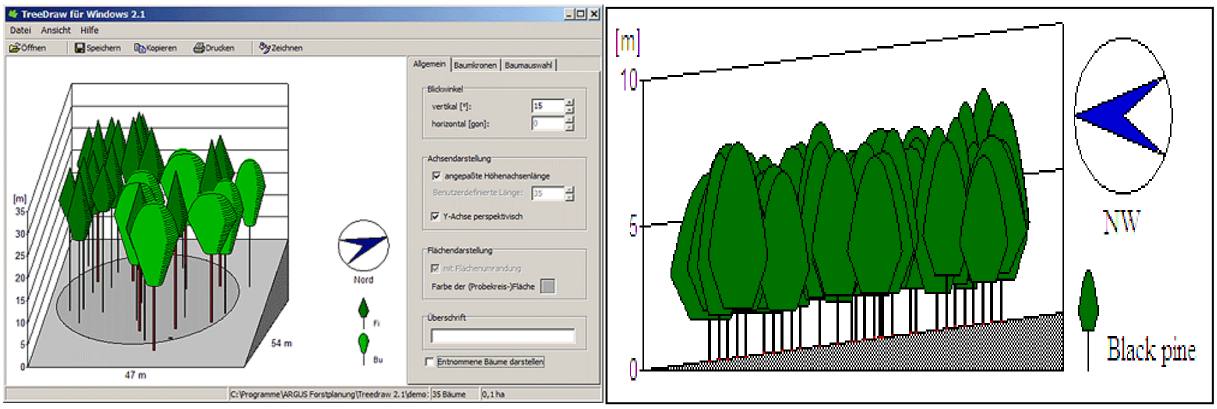


Figure 6. Forest stand designer software (ARGUS Forstplanung)

In this study, totally three stand profile plots were taken from forested area and painted by using the “ARGUS Forstplanung” simulation program (Staupendahl, 2003). Vertical stand profiles were used to determine the canopy closure in each sample plot (20 m x 20 m) (Figure 7). Slope, aspect, distribution of trees in the coordinate axis (x, y), DBH, diameter at0.30 height, tree height, crown shape (four cardinal directions), height to crown base parameters in all living trees were determined for sampling plots to quantify canopy closure and stand profile (Figure 8). Tree height features were measured with Vertex Forester device. All trees were classified as either dominant or suppressed trees using the classification of IUFRO (Yücesan et al., 2015).

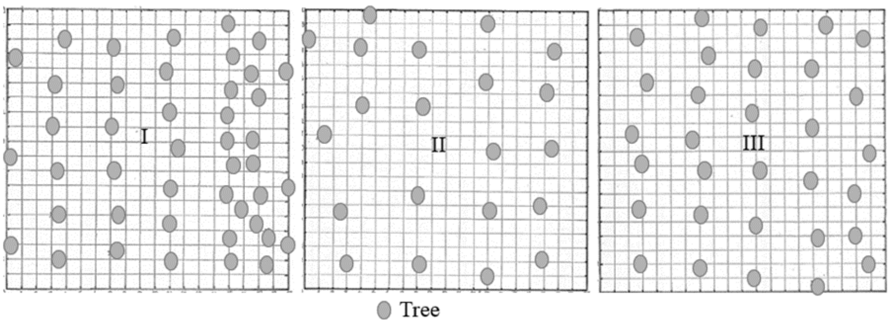


Figure 7. Tree distributions in the stand profiles (400 m^2)

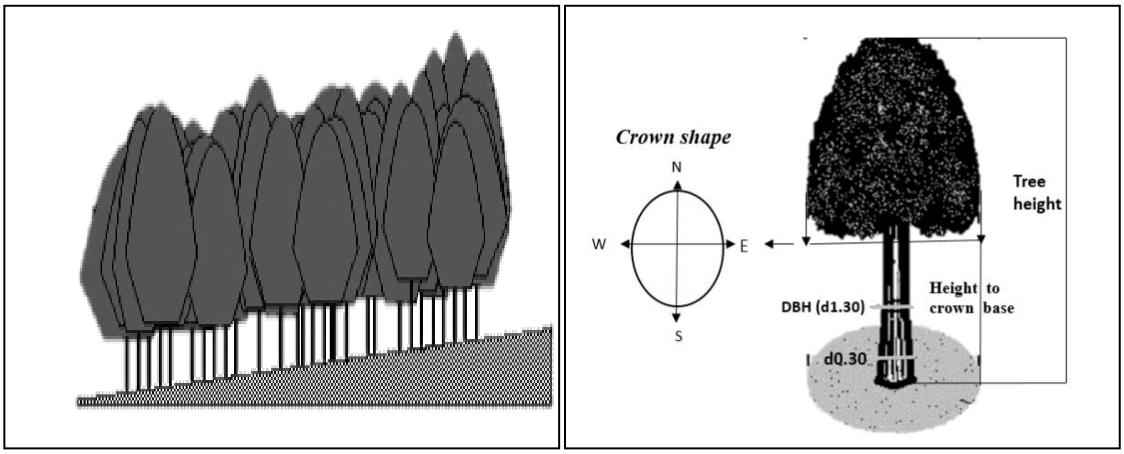


Figure 8. Determined tree properties in stand profiles (please use original colored image)

2.5. Soil Sampling and Analysis

Three forested plots (50 m x 50 m) were selected in the study area. Totally 18 soil samples in the topsoil level (0-20cm) were collected from in different canopy density (CD) classes (60% CD, 80% CD, and 90% CD) to perform soil analysis and calculate soil loss amounts (Figure 9).

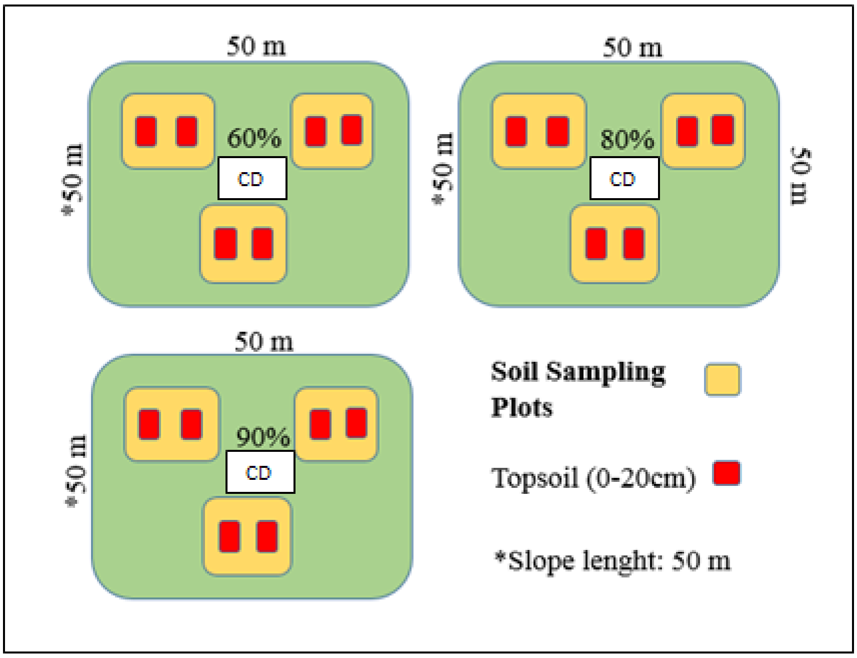


Figure 9. Soil sampling pattern of the study area

Surface stoniness (%), slope (%), aggregate classes etc. were assessed in each study site respectively (Kartieranleitung, 1994). In soil analysis, sieved (<2.0 mm) soil particles were used. Permeability class was determined according to Saxton et al. (1986). Soil texture was determined according to bouyoucos (1962) hydrometer method. The organic matter content by the Walkley-Black, wet oxidation method (Allison, 1965).

2.6. Soil Loss Estimation by ABAG

In this study, ABAG (Allgemeine Boden Abtrags Gleichung) (Schwertmann et al. 1990) simulation model modified from USLE-Universal Soil Loss Equation (Wischmeier and Smith, 1978) was used in calculating soil loss (Equation 1).

$$A = K \times R \times LS \times C \times P \quad (1)$$

Where A is the average annual soil loss (t/ha per year), K is the soil erodibility factor, R is the rainfall erosivity factor, LS is slope and slope length factor, C is the cover management factor and P is the supporting practice factor. Climate erosivity, represented by R, can be estimated from the rainfall intensity and R value was calculated based on erosion index map (Dogan and Gücer, 1976) and K, LS, C, and P values were calculated according to ABAG (Schwertmann et al., 1990).

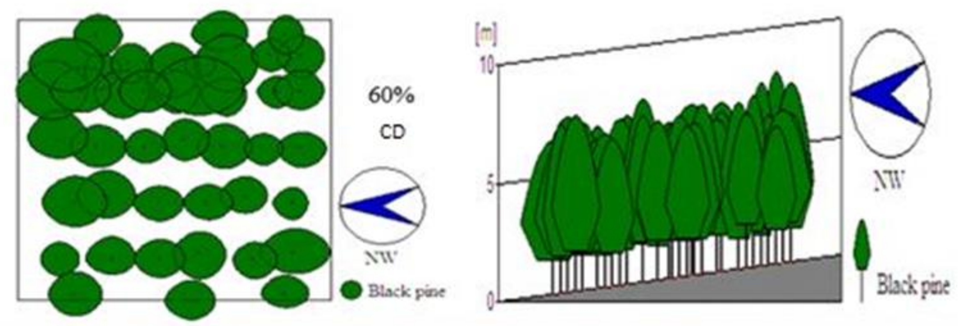
In soil loss equation in this study, the values of the specified factors were generally fixed (R : 25.0, P:1.0, L: 50 meters, S: 5%, LS: 0.624) at all plots. However, C factor had different value depending on land use and crown closures (60% CD: 0.03, 80% CD: 0.02, 90% CD: 0.01), and K factor was calculated based on soil properties in each sample plots.

2.7. Statistical Analysis

Statistical analyses were performed with SPSS version 23.0 software package (SPSS Institute Inc., Chicago, IL, USA, 2016). Differences between groups were established by One Way Anova and Correlations were tested by Pearson's correlation coefficient. Multiple regression model (Linear, R2=0.96) was developed to estimate annual top soil loss depend on DBH, and tree height. On the other hand, simple regression model (Quadratic, R2=0.98) using tree height variable was improved. Results are expressed as means ± SE (Standard error). Statistical significance was defined as P was <0.01 and <0.001.

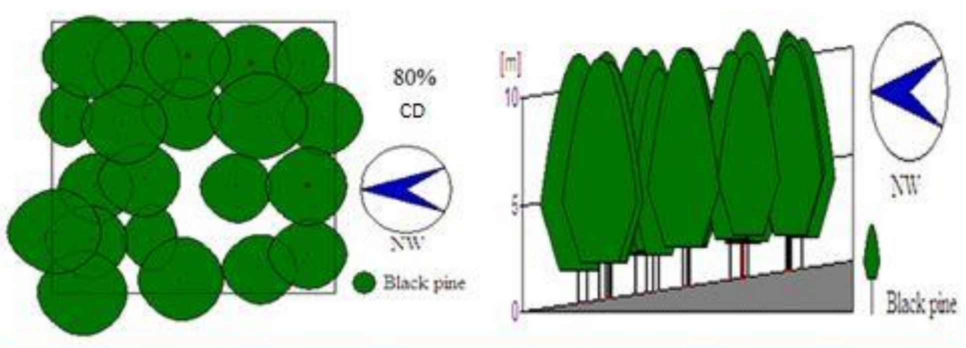
3. Results and Discussion

In the research area, 42 trees (mean DBH: 15.60 cm, mean height: 6.78 m) in 60% CD plot, 21 trees (mean DBH: 24.52 cm, mean height: 11.02 m) in 80% CD plot, and 30 trees (mean BHD: 21.40 cm, mean height: 14.02 m) in 90% CD plot were determined (Figure 10, 11, 12). As a result, soil loss amount was significantly (p<0.01) affected by canopy density (CD), and CD and soil loss were highly correlated (p<0.01) with DBH, d0.30, tree height, crown shape, and height to crown base parameters (Table 2).



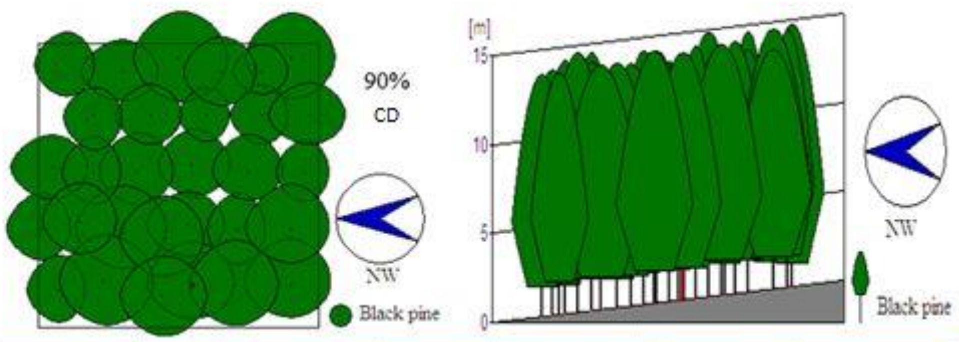
Number of tree	Mean DBH (cm)	Diameter of d0.30 (cm)	Mean height (m)	Mean Total Crown shape (m)	Height to crown base (cm)	Basal area (m2/ha)
42	15.60	19.74	6.78	6.15	1.56	20.46

Figure 10. Stand profile I with 60% CD



Number of tree	Mean DBH (cm)	Diameter of d0.30 (cm)	Mean height (m)	Mean Total Crown shape (m)	Height to crown base (cm)	Basal area (m2/ha)
21	24.52	28.24	11.02	11.07	1.74	25.10

Figure 11. Stand profile II with 80% CD



Number of tree	Mean DBH (cm)	Diameter of d0.30 (cm)	Mean height (m)	Mean Total Crown shape (m)	Height to crown base (cm)	Basal area (m2/ha)
30	21.40	25.30	14.02	10.06	1.82	27.39

Figure 12. Stand profile III with 90% CD

The amount of top soil loss was determined as 0.052 t/ha/yr in 60% CD, 0.037 t/ha/yr in 80% CD, and 0.017 t/ha/yr in 90% CD (Figure 13). In addition, multiple regression model (Linear, R2=0.96) was developed to estimate annual top soil loss depend on DBH, and tree height. Besides, in the study area, low slope, limited annual precipitation and more vegetation cover made the less soil loss in a unit area. On the other hand, simple and multiple regression models using tree height and DBH (cm) variables were improved (Figure 14, Table 1).

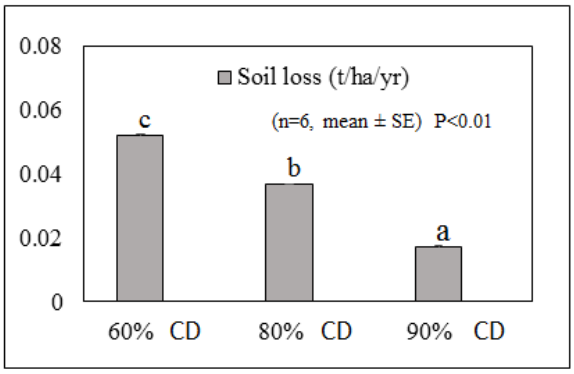


Figure 13. Soil loss amounts according to canopy density

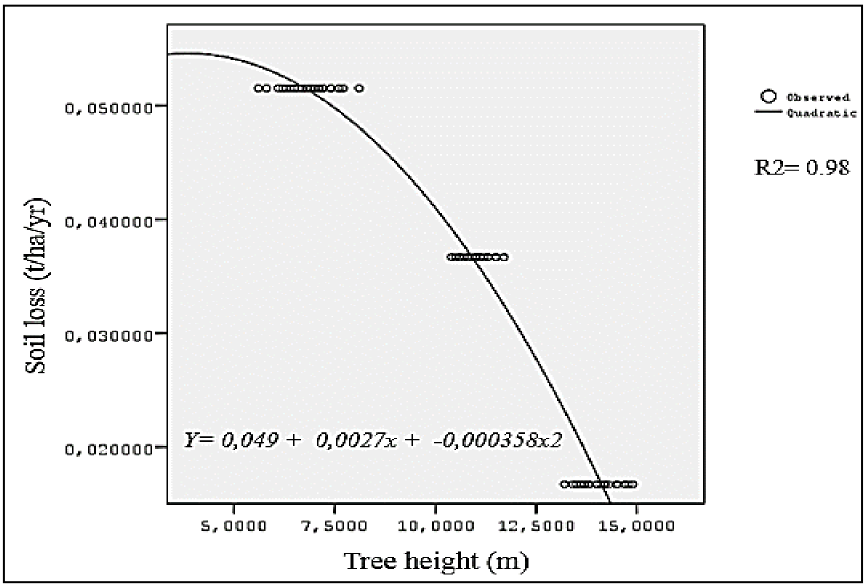


Figure 14. Simple regression model estimating soil loss amounts

Table 1. Multiple regression model estimating soil loss amounts

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std.Er.	Standardized Coefficients Beta	t	Sig.	95%Confidence Interval for B Lower Bound	95%Confidence Interval for B Upper Bound	Correlations Zero-order	Correlations Partial	Correlations Part	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1 (Constant)	.083	.001		75.925	.000	.081	.085					
Tree_Height_m	-.005	.000	-.978	-44.328	.000	-.005	-.004	-.978	-.978	-.978	1.000	1.000
2 (Constant)	.079	.001		58.213	.000	.076	.082					
Tree_Height_m	-.005	.000	-1.054	-39.924	.000	-.005	-.005	-.978	-.973	-.801	.577	1.732
D1.30_cm	.000	.000	.118	4.465	.000	.000	.001	-.567	.426	.090	.577	1.732

Y=0.07907809059586 + -0.004952243863731a** + 0.0003976574499382b**** R^2= 0.96 Y*= Soil loss, a**=Tree height (m), b***=DBH (cm)

Vegetation cover, the density of planted seedlings, litter thickness and woody materials are important ecological factors for estimation of the soil loss degree (Özhan, 2005). Besides, there is a close relation between soil loss and stand profile parameters (Table 2). The degree of canopy density determines the size of the rain drops and the power of the erosion (Thornes, 1990; Kosmas et al., 1997).

Table 2. Correlations between canopy density (CD) and stand profile parameters

Correlations

	CD	d1.30_cm	d0.30_cm	Tree_Height_m	North_Shape_m	South_Shape_m	West_Shape_m	HCB_cm	Crown_Shape_m	X_value_m	Y_value_m
CD- Person corr.	1	.689*	.628**	.986**	.764**	.815**	.619**	.708**	.762**	-.063	.045
Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000	.000	-.552	.668
N	93	93	93	93	93	93	93	93	93	93	93

**SCD* was highly correlated (p<0.01) by DBH, d0.30, tree height, crown shape and height to crown base parameters.

The seedlings litter and dead woody residues protect the soil surface, thus preventing soil decomposition and reducing the particle movement of the soil at the slope by providing surface roughness. However, the role of these ecological factors is less important than precipitation when determining the amount of rainfall (Wainwright and Thornes, 2004; Walling, 1982). Among the factors explaining the degree of soil erosion, vegetation and land use are considered to be the most important factors that exceed the effect of rainfall intensity and slope change (Thornes, 1990; Kosmas et al. 1997; Wainwright and Thornes, 2004). Hacısalihoğlu et al. (2017) emphasized that soil loss by erosion, soil carbon stock and total carbon stock in a unit area are significantly affected by vegetation cover depending on land use change. Yücesan et al. (2013) stated that different release cutting intensities effect soil loss significantly in oriental beech stands. So, it is necessary to determine the proper stand structure during the silvicultural treatments in order to prevent the soil loss amount. Stand structure plays an important role on biotic and abiotic factors. Stand profile directly affects crown closure, leaf area and forest tending while affects the soil loss indirectly. However, canopy density is one of the silvicultural parameters that affect soil loss (Hyink, 1983; Falge, 1997; Binkley, 2002; Yao, 2010).

4. Conclusions

In this study, it is concluded that DBH, tree height, number of trees in the sample unit and the homogeneous distribution of trees in the unit area have an effect on canopy density. Soil loss amount was decreased by increasing canopy density. Tree height has a great affect in the soil loss amounts. Created models should be used for Anatolian Black pine ecosystem which show similar ecological conditions (in case of >50% CD and 5% slope, in plantation area). Furthermore, more advanced models can be developed in the future by using the stand parameters in different ecological conditions. On the other hand, mechanization level for forestry operations, suitable logging techniques and harvesting methods deal with the related stand structures should be determined according to decrease top soil loss amounts in stands.

Acknowledgement

A part of this paper has been presented at the International Forestry and Environment Symposium on “Climate Change and Tree Migration": November 07-10, 2017. Authors would like to thank undergraduate student Yusuf Kürşat Kaya.

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