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Crown Fuel Load for Young Calabrian Pine (*Pinus brutia* Ten.) Trees

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ABSTRACT

In this paper, crown fuel load was calculated for young calabrian pine. Equations were developed for predicting needle, branch, available fuel and total fuel. Equations were based on the data from 35 destructively sampled young calabrian pine trees. The relationships between needle and branch fuel load and tree properties were determined as linear regression. Results indicated that needle, branch and total fuel load could be accurately predicted using the regression equations calculated. The consequent equations were able to account for 50%-81% ($p < 0.05$) of the observed variation in the total fuel load.

Keywords: Fuel load, Crown fuel, Forest fire, Calabrian pine

Genç Kızılçam (*Pinus brutia* Ten.) Ağaçlarında Tepe Yanıcı Madde Miktarı

ÖZET

Bu çalışmada, genç kızılçam meşcereleri için tepe yanıcı madde miktarı hesaplanmıştır. İbre, dal, tüketilebilir (ulaşılabilir) ve toplam yanıcı madde tahmini için modeller geliştirilmiştir. Eşitliklerde rasgele seçilmiş 35 adet genç kızılçam ağacından elde edilen veriler esas alınmıştır. İbre ve dal yanıcı miktarı ile ağaç özellikleri arasındaki ilişkiler doğrusal regresyonla belirlenmiştir. Sonuçlar, ibre dal ve toplam yanıcı madde miktarının regresyon eşitlikleri kullanılarak doğru bir şekilde hesaplanabileceğini göstermiştir. Sonuçta, toplam yanıcı madde miktarındaki değişikliğin %50-81 (p<0.05'ini açıklayan modeller olmuştur.

Anahtar Kelimeler: Yanıcı madde miktarı, Tepe yanıcı madde, Orman yangını, Kızılçam

1. INTRODUCTION

Fire behavior is a result of the interaction of fire weather, topography and fuel properties. Fuel load is one of the most important fuel characteristics. Knowledge of fuel load of forests is useful as it provides a more complete inventory in a stand and quantifies combustible materials to help predict fire intensity and fire behavior in specific forest cover types (CRUZ ve ark. 2003; GRAY / REINHARDT 2003) and relates to the potential fire hazard reflected in different magnitudes over the stages of stand development. At the same time, accumulation of fuel biomass in forest stands is an important determination of fire frequency and severity (SAH ve ark. 2004), and ultimately their ecological effects (ROTHERMEL 1972; KAUFFMAN ve ark. 1994; PAATALO 1998). For this reason, many researchers have developed allometric equations to predict biomass. Allometric equations are commonly used to predict biomass on the basis of easily measured tree properties such as crown length, crown width, diameter at breast height (dbh) and total height (KILL 1967; BROWN 1978; STOCKS 1980; JOHNSON ve ark. 1990; SCOTT / REINHARDT 2002).

Although many biomass studies involving tree species have been conducted in many countries, most growth and yield studies provide biomass values for individuals having diameters (dbh) greater than 8 cm. While previous studies can be considered sufficient for typical growth and yield purposes, it has little value in areas where detailed fuel properties are of great concern, i.e., fire behavior prediction. According to the authors, only a few studies exist in Turkey that could serve that purpose (KUCUK 2004; KUCUK ve ark. 2007; KUCUK ve ark. 2008).

The primary objective of this study is to develop regression models (equations) to determine crown fuel load of young calabrian pine for fire behavior prediction purposes based on readily measurable fuel characteristics such as height, crown width, crown length, diameter at breast height. The results of this study will not only contribute to the prediction of fire behavior but surely be of invaluable use in other forestry disciplines.

2. MATERIAL and METHODS

2.1. Study Area

Calabrian pine is the most widely distributed coniferous species in Turkey covering a land area of 4.2 million ha. Pure stands of calabrian pine are mostly found in fire prone areas and are usually originated from high-intensity, stand-replacing fires

(TURNA / BILGILI 2006). The trees were taken from an average 30 year-old stand with an average diameter (dbh) of 16 cm, and an average height of 10 m. Density and composition of the crown layer in each plot were relatively homogeneous.

The study area is located in northwest part of Turkey (latitude 40º 47′, longitude 26º 40′. The study area was of predominantly pure and uniform calabrian pine overstory. The altitude is about 350 m. The area is characterized by typical Marmara climate with long hot summers and mild short winters. Mean annual rainfall on the site is 650 mm with precipitation being mainly from December to May. Soil type is brown forest soil.

2.2. Measurements and Data Collection

A total 35 young calabrian pine individuals were selected for the study. Selection was made such that samples represented a range of crown dimensions. Some measurements were taken before the trees were cut. These measurements included tree height (h), crown width (cw), crown length (cl), diameter at breast height and age.

Sample trees were felled carefully so as to avoid breaking branches. Following the felling, trees were destructively sampled. Partial sampling was accomplished by dividing the crown into 21 sections and removing all branches originating in sections 1, 6, 11, 16, and 21 (ROBICHAUD / METHVEN 1992). The resulting sample weight was then multiplied by a factor of 4.2 to represent the full crown. The study involved a wide range of crown size (Table 1).

Table 1. Descriptive statistics for calabrian pine sampled trees

	Height (m)	DBH (cm)	Crown length (m)	Crown width (m)	Height to live crown base (m)	Age (years)
n	35	35	35	35	35	35
Minimum	9	13	4	2.6	3	25
Maximum	12	19	7	5.3	6	38
Mean	10.25	15.91	5.75	3.74	4.5	30
Range	3	6	3	2.8	3	13
Standard error	0.15	0.32	0.14	0.11	0.17	0.47
Standard deviation	0.87	1.87	0.81	0.68	0.98	2.78

Samples were then separated based on predetermined, standard fuel size classes (BROWN 1978; SCOTT / REINHARDT 2002). The biomass categories recognized were: needles, branches <0.6 cm, 0.6-1 cm, 1-2.5 cm and 2.5> cm in diameter. Boles and cones were not included in the analyses. Available fuel for consumption (SCOTT / REINHARDT 2002) composed of needle plus fine branches less than 0.6 cm roundwood diameter was also analyzed as a separate category.

Samples were then separated based on predetermined size classes. Each branch sample was separately labeled and transferred to the laboratory for detailed needle analyses. All needles were removed from each branch sample and subsequently fresh weight of branch and of all needles were measured. Then, the needle and branch samples were dried to a constant weight for 24 h at 100^{o}C, and weighed to the nearest 0.01 gram. Final needle and branch biomass determinations were made on the basis of oven dry measurements.

2.3. Statistical Analysis

The most commonly used statistical method of examining crown weights is the regression analysis (BROWN 1978) Correlation and regression analyses were performed to determine the relationship between needle, branch fuel and tree properties. Regression analyses considered tree properties as the independent variables and needle and branch biomass as the dependent variables. The independent variables used were h, cl, cw, dbh. Before the analyses, the variables were tested for normality and as a result a logarithmic transformation was deemed necessary for all variables. To analyze the relationships between fuel load and tree properties, a stepwise function and logarithmic linear regression models were used. The equations were of the form: $ln(Y) = a + b_i ln(x_i) + \varepsilon$ where, Y is the dependent variable (needle, branch or total fuel), ln is the natural logarithm, x_i are the independent variables, a is the constant, b_i are the regression coefficients, and ε is the error term. Statistical analyses were performed using SPSS 10.0 for Windows (SPSS 1999).

3. RESULTS

The summary of crown fuel characteristics and tree properties are given in Table 2.

Correlation and regression analyses were undertaken to investigate the relationships between tree properties and associated tree components. As a result of correlation analysis, crown fuel biomass components were closely related to some tree characteristics. Needle, available and total fuel were closely related to DBH, crown length and crown width respectively ($r = 0.752, 0.787, 0.707$; $p < 0.01$). Similarly, available and total fuel were closely related to DBH, crown length and crown width. In this study, it was estimated needle, fine and total crown fuel for young calabrian pine trees. Larger crown fuel was not estimated. In general, all of needle and branches less than 0.6 cm in diameter were consumed during the crown fires (CALL / ALBINI 1997; STOCKS ve ark. 2004). Fuels greater than 1.0 cm in diameter little consume.

Table 2. Tree properties associated with the oven dry biomass of tree components

Tree properties						Fuel load (kg/tree)					
No	tree height (m)	crown length (m)	crown width (m)	age	dbh (cm)	needle	fine branch (<0.6 cm)	medium branch (0.6-1 cm)	thick branch (1-2.5 cm)	coarse branch (>2.5 cm)	total fuel
1	11.0	6.0	3.6	33	15	2.08	2.33	1.8	3.65	2.49	12.35
2	11.1	6.0	3.75	32	16	2.31	2.58	1.72	4.87	2.95	14.44
3	11.5	6.0	4.25	35	18	5.64	3.04	4.55	2.33	5.06	20.61
4	10.6	4.2	3.35	38	15	1.35	1.86	1.93	1.94	1.98	9.06
5	11.5	6.5	3.25	33	16	2.67	2.67	2.13	2.14	4.38	13.99
6	12.0	6.0	4.0	32	18	4.36	3.07	3.44	3.83	5.44	20.13
7	10.0	4.8	3.30	31	13	1.66	1.96	2.03	2.02	1.94	9.62
8	10.0	4.0	2.55	32	13	1.86	1.09	1.65	2.15	1.46	8.22
9	10.8	5.0	3.60	32	15	2.15	2.17	3.06	3.21	3.26	13.86
10	10.0	5.5	3.45	26	14	2.02	2.22	2.82	3.24	3.45	13.74
11	8.6	5.0	2.65	28	16	1.93	2.25	2.12	2.48	3.34	12.12
12	9.7	5.5	3.15	29	16	2.60	2.03	2.28	2.95	4.12	13.99
13	9.7	6.5	3.90	31	19	4.19	3.15	3.58	3.71	6.54	21.18
14	11.5	6.0	3.50	29	17	2.36	2.80	3.17	3.27	5.14	16.74
15	10.8	5.8	4.15	28	16	4.14	2.19	3.22	3.44	4.71	17.70
16	11.0	5.5	3.60	27	15	2.82	2.13	2.96	3.15	3.32	14.38
17	10.2	7.2	3.95	30	19	4.55	2.55	3.10	3.13	8.76	22.09
18	10.1	6.5	4.20	30	18	4.38	3.27	4.98	7.26	6.85	26.75
19	10.0	6.4	3.0	28	13	3.59	1.89	3.70	4.69	5.81	19.68
20	10.0	5.5	5.25	26	18	4.14	3.26	4.50	4.73	6.58	23.22
21	11.0	6.5	3.50	30	16	4.14	2.89	3.17	3.82	5.68	19.71
22	11.0	5.6	3.10	31	15	2.18	1.39	3.16	2.59	4.76	14.07
23	10.5	6.4	4.80	27	18	4.66	3.75	4.05	4.79	6.36	23.61
24	8.6	4.2	3.00	27	14	1.66	1.98	2.05	1.94	2.47	10.08
25	8.6	4.6	3.75	25	14	2.05	1.85	2.14	1.72	2.91	10.67
26	9.2	5.4	4.40	28	14	2.60	2.41	1.84	2.74	3.20	12.78
27	9.7	6.5	5.10	31	18	4.58	3.16	3.11	3.52	5.98	20.34
28	10.0	6.5	5.30	32	18	4.29	4.47	3.86	3.72	7.15	23.50
29	9.6	5.4	3.25	28	13	2.37	2.17	2.02	2.51	3.94	13.02
30	10.1	7.0	4.20	30	17	5.24	3.14	3.15	3.89	6.17	21.59
31	8.7	5.8	3.45	28	14	3.22	2.20	2.89	3.16	3.77	15.25
32	10.0	5.0	3.30	31	16	2.11	2.15	1.93	3.07	3.59	12.85
33	10.1	7.0	4.60	34	19	5.0	2.33	3.30	5.05	6.91	22.59
34	10.5	5.5	3.10	29	15	2.71	3.33	2.90	4.27	3.52	16.72
35	11.0	5.8	3.80	32	16	3.16	2.79	2.30	5.95	4.75	18.94

The biomass relationships of the different tree parts as well as total fuel biomass were separately compared and selected based on their R^2 values. A linear model with DBH as predictor provided the best fit for the biomass of many pine species was existed in literature (SAH ve ark. 2004). In this study, the allometric relationships between biomass and DBH, crown length, crown width was chosen as the best fitted equations to the predicted needle, branch and total fuel load. As biomass relationships for crown fuel size classes have not been reported for calabrian pine trees in Turkey. Therefore, this regression models can be used for similar calabrian pine stand structure.

DBH alone explained 50% of observed variation in the needle. Crown length and crown width together explained 74% observed variation in the needle (Figure 1). Similarly, DBH, crown length and crown width were the most significant determinant of available fuel. DBH alone explained 60% of observed variation and crown length and crown width together explained 81% observed variation in the needle (Figure 2). While DBH alone explained 58% of observed variation ($P < 0.05$) crown length and crown width together explained 80% observed variation ($P < 0.05$) in total fuel (Figure 3).

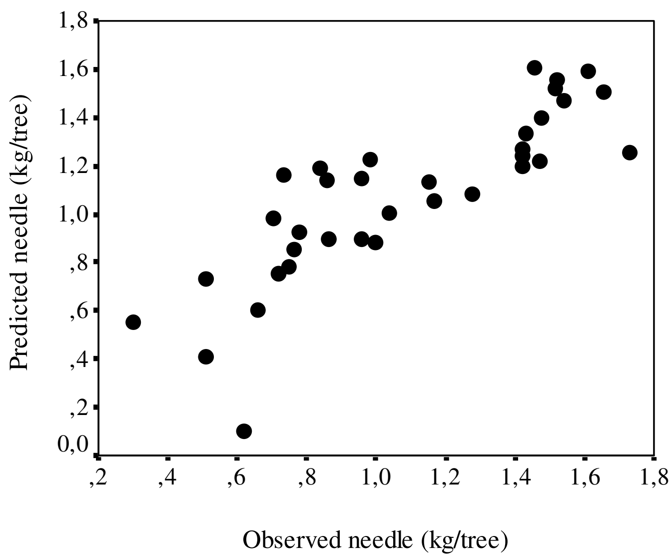

Figure 1. Logarithmic relationships between predicted and observed needle fuel

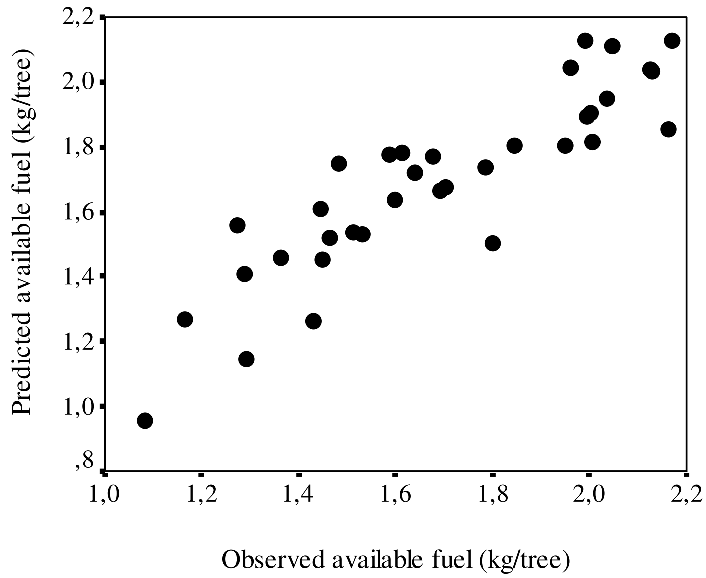

Figure 2. Logarithmic relationships between predicted and observed available fuel

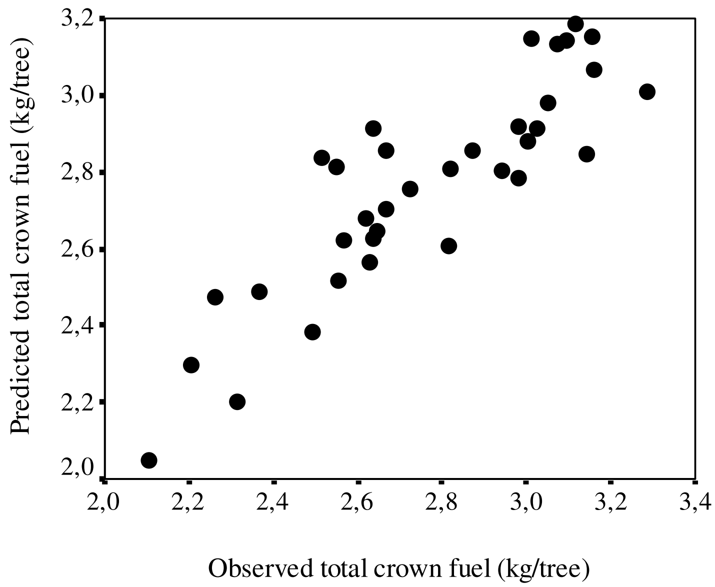

Figure 3. Logarithmic relationships between predicted and observed total fuel

Table 3 lists the summary regression equations for predicting needle, available and total crown fuel in young calabrian pine based on the data obtained in this study.

Table 3. Regression equations for predicting needle available and total fuel load in calabrian pine

Crown fuel components	Model form	Constant	Coefficients		R^2_{adj}	SEE
		a (SE)	b (SE)	c (SE)		
Needle	*ln*Y=a+b(*ln*DBH)	-5.475 (1.101)**	2.375 (0.398)**		0.504	0.274
	*ln*Y=a+b(*ln*cl)+c(*ln*cw)	-2.780 (0.405)**	1.634 (0.279)**	0.781 (0.229)**	0.740	0.198
Available fuel	*ln*Y=a+b(*ln*DBH)	-3.938 (0.791)**	2.040 (0.286)**		0.597	0.197
	*ln*Y=a+b(*ln*cl)+c(*ln*cw)	-1.423 (0.278)**	1.217 (0.191)**	0.767 (0.157)**	0.806	0.136
Total	*ln*Y=a+b(*ln*DBH)	-2.774 (0.794)**	2.006 (0.288)**		0.584	0.198
	*ln*Y=a+b(*ln*cl)+c(*ln*cw)	-0.426 (0.281)**	1.419 (0.193)**	0.554 (0.159)**	0.799	0.137

SE: standard error, SEE: standard error of estimate, ** $p < 0.001$

4. CONCLUSIONS

Regression equations were calculated to predict needle and branch fuel load of calabrian pine using the data for 35 trees. Equations were based on the relationships between tree properties (crown length, crown width and DBH) and fuel (needle, branch and total). Regression models were quite satisfactory in predicting crown fuel. Results showed that the relationships were able to explain 74 percent of the variation in needle, 81% in available fuel and 80% in total fuel load. In terms of the percent variability explained, the results agree well with the available studies on other species (SAH ve ark. 2004; XIAO / CEULEMANS 2004).

Accurate and timely information on fuel properties is of crucial importance in fuel management and fire control activities. The relationships developed in this study use tree properties that can easily be measured and/or predicted. Nowadays, tree dimensions and dbh can be predicted easily with remote sensing, aerial photos and satellite images (OSWALD ve ark. 2000; SCOTT ve ark. 2002) making the prediction of fuel biomass possible for large areas at low costs.

Given the range of the data on which the relationships were based, the study makes an invaluable contribution to biomass research in general and fire behavior in particular. However, it should be kept in mind that the range of fuel properties on which the relationships were based represents the range conditions under which it is possible to use the relationships generated from this study.

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