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Estimation of Crown Fuel Load of Suppressed Trees in Non-treated Young Calabrian Pine (*Pinus brutia* Ten.) Plantation Areas

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Abstract

Aim of study: *Pinus brutia* is the most widespread conifer forest tree species in Turkey. It is mainly distributed in fire sensitive regions of the country. The economic importance in wood production and the deterministic role in forest fires fighting activities make this forest tree more valuable and important. This study describes crown fuel load of suppressed trees in non-treated young Calabrian pine stands.

Area of study: The study area is located in the Western Black Sea region of Turkey. Sampling plots were located in Hacımahmut Forest Planning Unit.

Material and methods: Trees were selected from non-treated young Calabrian pine plantation stands and used to obtain live crown fuel load and characteristics. For this purpose, 30 young suppressed trees were cut and sampled.

Main results: In sampled trees, oven dried total live needle biomass ranged between 0.54 kg and 3.19 kg and total live crown fuel load chanced between 1.96 kg and 12.73 kg. Regression models to estimate crown fuel load were developed according to some tree characteristics. Models developed explained 0.79 to 0.89% of the observed variation.

Highlights: Regression analysis indicated that the total live crown fuel load was strongly correlated with both diameters at breast height (*DBH*) and crown base height (*CBH*).

Keywords: Forest Fires, Live Crown Fuel Load, Biomass, *Pinus brutia*, Turkey

Müdahale Görmemiş Genç Kızılçam (*Pinus brutia* Ten.) Ağaçlandırma Alanlarındaki Mağlup Ağaçlarda Tepe Yanıcı Madde Miktarının Tahmini

Öz

Çalışmanın amacı: Kızılçam Türkiye'deki en yaygın ibreli orman ağacı türüdür. Çoğunlukla ülkenin yangına hassas bölgelerinde yayılmaktadır. Odun üretimindeki ekonomik önemi ve orman yangınları ile mücadele çalışmalarındaki belirleyici rolü bu orman ağacını değerli ve önemli kılmaktadır. Bu çalışma, ağaçlandırma alanlarındaki mağlup kızılçam ağaçlarındaki tepe yanıcı madde miktarını açıklamaktadır.

Çalışma alanı: Çalışma alanı Batı Karadeniz Bölgesi'nde yer almaktadır. Örnekleme alanları Hacımahmut Orman İşletme Şefliği sınırları içinde yer almaktadır.

Materyal ve yöntem: Ağaçlar hiç müdahale görmemiş genç kızılçam ağaçlandırma alanlarından seçilmiştir. Ağaçlar tepe yanıcı madde miktarları ve özelliklerinin elde edilmesinde kullanılmıştır. Bu amaçla 30 adet mağlup gövde genç kızılçam ağacı kesilmiş ve örneklenmiştir.

Sonuçlar: Örneklenen ağaçlarda fırın kurusu toplam canlı ibre miktarı 0.54 kg – 3.19 kg ve toplam canlı tepe yanıcı madde miktarı 1.96 kg – 12.37 kg arasında değişmektedir. Çalışmada, bazı ağaç özellikleri dikkate alınarak tepe yanıcı madde miktarını tahmin eden regresyon modelleri geliştirilmiştir. Geliştirilen bu modellerin R^2 değerleri 0.79 ile 0.89 arasındadır.

Önemli vurgular: Regresyon analizi sonuçlarına göre toplam canlı tepe yanıcı madde miktarının göğüs yüksekliğindeki çap (*DBH*) ve tepe altı yüksekliğiyle (*CBH*) kuvvetli ilişkili olduğunu göstermiştir.

Anahtar Kelimeler: Orman Yangınları, Tepe Yanıcı Madde Miktarı, Biyokütle, *Pinus brutia*, Türkiye

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Introduction

There are many biotic and abiotic disturbances (Attiwill, 1994) limiting the utilization of forest resources in forest ecosystems (Gadow, 2000). One of the most important one is undoubtedly forest fires (Bowman et al., 2009). The ability to control forest fires and the successful prediction of fire behavior are mostly associated with fuel (Alexander, Cruz, Vaillant & Peterson, 2013) and its characteristics (Bilgili, 2003; Fernandes, 2009). Fuels are indispensable and essential component of fire events (Byram, 1959) and fire management (Agee et al., 2000). Therefore, fuel classification (Gould, McCaw, Cheney, Ellis & Matthews, 2008; Gould and Cruz, 2012) and crown fuel load determination (Kucuk, Bilgili & Saglam, 2008a) are of great importance in fire prevention and fire suppression activities.

Some types of forests support only surface fires (Weaver, 1943; Weaver, 1967) while some support crown fires (Van Wagner, 1978; Veblen, 2000). Conifer forests are generally liable to support crown fires (Turner and Romme, 1994). Especially young conifer forests are subject to very intense crown fires. In a crown fire, by the uninterrupted aid of surface fuel consumption, most of the consumed materials are derived from aerial fuels. The crown fuel term is applied to describe aerial fuels at the tree level and the canopy fuel term is applied to describe stand level (Cruz, Alexander & Wakimoto, 2003).

In forests, some trees develop well and placed as a dominant or co-dominant trees in upper part of the canopy while some are less develop as suppressed trees in lower part of the canopy. Especially in dense stands, these suppressed trees are mainly subject to silvicultural interventions (Smith, Larson, Kelty & Ashton, 1996). Physical interventions to these trees or self-competition of trees with each other result in the removal of trees from the canopy to the surface, resulting in an increase of surface fuel loads. This increases the intensity of surface fires while decreasing canopy bulk density hence mitigating the behavior of crown fires (Agee & Skinner, 2005).

Canopy fuels, composed of different structures and statutes of tree crowns, are mainly responsible for the behavior of crown fires, such as intensity and spread of fire (Alexander and Cruz, 2016). Therefore, most of studies were conducted to obtain for tree crown fuel loads based on some trees (Stocks, 1980; Ter-Mikaelian and Korzukhin, 1997; Stocks, et al., 2004; Mitsopoulos and Dimitrakopoulos, 2007) and canopy fuel characteristic on flammable stands around the world (Cruz et al., 2003; Cruz and Fernandes, 2008).

In Turkey, especially for the establishment of Turkey Fire Danger Rating System (Kucuk, Bilgili, Saglam, Dinc Durmaz & Baysal, 2007b), some crown fuel load determination studies were conducted in fire sensitive region of the different parts of the country. Together with these studies, fuel types of fire sensitive region of the Turkey have been revealed (Kucuk, Bilgili & Fernandes, 2015). In addition, the amounts and properties of the crown fuel component characteristics have been determined (Kucuk, Saglam & Bilgili, 2007c; Kucuk and Bilgili, 2008b). Calabrian pine (*Pinus brutia* Ten.) has the largest distribution covering nearly 5.6 million ha of forest lands in Turkey (GDF, 2018), was mainly studied tree species (Kucuk & Bilgili, 2007a; Kucuk et al., 2008a; Bilgili and Kucuk, 2009). But, in most of these studies, there is no information for planted and non-treated forests of Calabrian pine crown fuel load in suppressed trees.

There are also several biomass studies conducted for the same tree species from Turkey (Sun, Uğurlu & Özer, 1980; Durkaya, Durkaya & Unsal, 2009; Sonmez, Kahriman, Sahin & Yavuz, 2016; Eker, Poudel & Ozcelik, 2017; Sakici, Kucuk & Asrafh, 2018) and from different countries (Zianis et al., 2011; de-Miguel, Pukkala, Assaf, & Shater, 2014). However, these studies do not deal with and explain fuel components of tree crowns especially according to status of tree crowns in forest canopies. In these studies, some informations about the tree crown characteristics were mostly not reported.

Fires in young and middle-aged Calabrian pine forests, especially in afforested areas, are usually occurred in the form of active crown fires. Crown fires are the most challenging types of fires for firefighting studies (Viegas, 2012). Therefore, the studies to determine the crown fuel characteristic and load, especially in non-treated pine planted stands are critically important for the determination of crown fire initiation and spread (Van Wagner, 1977; Alexander, 1998; Cruz, Butler, Alexander, Forthofer & Wakimoto, 2006), crown fire intensity calculation (Rothermel, 1991; Scott and Reinhardt, 2002; Reinhardt, Scott, Gray & Keane, 2006) and forest firefighting activities (Taylor, Pike & Alexander, 1997; Werth et al. 2011).

Determination of crown fuel load and its characteristics also provides some important contributions for forest fire researcher in crown fire modeling studies (Van Wagner, 1977; Finney, 1998; Scott, 1999) and for forest managers in fuel management prioritization and evaluation (Hessburg, Reynolds, Keane, James & Salter, 2007; Cruz, Alexander & Dam, 2014). The aim of this study was to investigate crown fuel load of suppressed trees in non-treated Calabrian pine plantation stands.

Material and Method

Study Area

The study area is located at 40^0 24' latitude and 30^0 38' longitude (Figure 1). Soils in the area are shallow and composed of crumbs and carbonates of the cretaceous period. Soil types are of brown forest soil and lime brown forest soil. The continental climate prevails in the study area characterized by cold winters, mild and rainy spring and autumn, hot and dry summers. According to 28-year measurement data (1990-2017), average temperature is 10.9 $^{\circ}$C and total annual precipitation is 564.4 mm (GDM, 2018). The altitude varies between 650 m and 690 m with an average slope 0-15 %.

Sampling plots were selected randomly taking into consideration crown closure and the stages of stand development. Selected sampling plots were located in compartments 160, 179 and 181 under the responsibilities of Hacımahmut Forest Planning Unit under the responsibilities of Göynük State Forest Enterprise in Bolu Regional Directorate of Forestry.

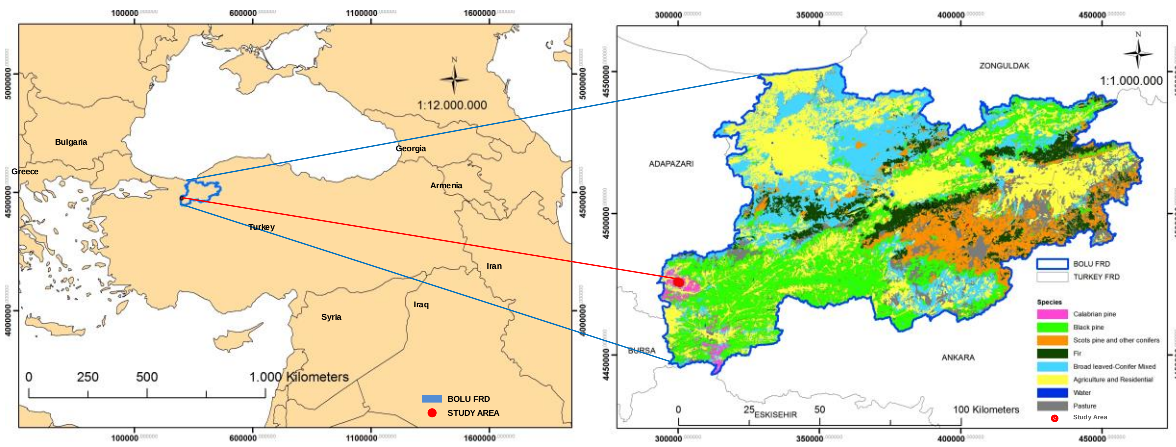

Figure 1. Study area

Hacımahmut Forest Planning Unit area covers 20949.9 ha of land area, of which 15686.0 ha is forested. Approximately 26% of this forested area consists of Calabrian pine. These stands were established by afforestation at the beginning of 1990s. From the establishment date to 2016, no silvicultural practices were performed. In this respect, the study area provides a unique opportunity for investigation and assessment of crown fuel load from a non-treated and planted Calabrian pine stands.

Field Studies

Field studies were carried out in the summer of 2016. To obtain general properties of suppressed trees, 3 sampling plots were selected from non-treated pure young and middle-aged Calabrian pine stands. Plots were on a relatively level terrain. Crown closure in plots ranged between 80 and 95%. Suppressed trees larger than 5 cm diameter at breast height (*DBH*) in plots were determined according to Kraft tree class system (Kraft, 1884). Suppressed trees in plots were evaluated and measured on the 0.1 ha plot (radius 17.80 m), and trees larger than 5 cm diameter at breast height were measured in the core area of the plot (radius 8.90 m). All measured trees were numbered and diameter at breast height (*DBH*), tree height (*H*), tree age (*AGE)*, crown base height (*CBH)*, and crown width *(CW)* measurements were made by two perpendicular directions of furthest living branches length, bark thickness (*BT*) (0.30 cm above the surface), and tree status (live or dead) were measured. Tree characteristics of each sampled plots are given in Table 1.

Table 1. Sampled plots average values

Plot no	1	2	3
Av. *DBH* (cm)	15.29	12.62	16.15
Av. *H*	12.78	8.09	12.23
Av. *CBH*	7.11	2.99	5.82
Av. *CL*	6.36	5.10	5.54
Stems (ha^{-1})	2000	1550	1200
Site Index	Good	Medium	Good
Av. BA (m^2 ha^{-1})	38.95	22.43	25.13

Av:Average; DBH: Diameter at Breast Height; H: Tree Height; CBH: Crown Base Height; CL: Crown length; BA: Basal Area

Tree Measurement and Data Collection

A total of 30 trees were selected from the sampled plots to obtain live crown fuel load. Trees were cut and felled carefully and live branches pruned from the trunk. Dead materials were separated from all living branches. Needless on the branches were removed carefully and weighted in the field. In addition, all live branches were classified in 5 section classes as a 0-0.3 cm (very thin), 0.3-0.6 cm (thin), 0.6-1.0 cm (medium), >1.0 cm (thick) (Kucuk et al., 2008a) except for cones and boles of trees. The weight of needless and branches were weighed by a precision scale (0.1 g sensitivity) in the field and some samples were taken for the determination of oven dried fuel weight. Samples were placed in paper bags, labeled, and transported to the laboratory. Samples were waited in the laboratory conditions to get room dried properties. Then samples were placed in oven and waited 24 hours at 105 ^{0}C for oven drying process. Oven-dried fuel weight of samples was measured at 0.01g sensitivity scale. Some descriptive statistics of tree characteristics and crown fuel components for the sampled trees are given in Table 2.

Table 2. Descriptive statistics of sampled Calabrian pine trees

	N	Min.	Max.	Av.	S.E.E.	S.D.
AGE (year)	30	22.00	26.00	23.73	0.18	0.98
RCD (cm)	30	12.20	24.00	18.85	0.64	3.51
DBH (cm)	30	8.10	18.30	13.00	0.54	2.94
H (cm)	30	7.90	12.70	10.80	0.19	1.02
CBH (cm)	30	3.60	7.70	6.19	0.17	0.92
CL (cm)	30	3.10	7.80	4.61	0.20	1.08
CW (cm)	30	1.70	4.05	2.85	0.12	0.66
BT (cm)	30	1.70	3.30	2.59	0.07	0.37
N (kg)	30	0.54	3.19	1.80	0.14	0.77
VTB (kg)	30	0.13	0.89	0.47	0.04	0.21
TB (kg)	30	0.39	2.24	1.14	0.09	0.51
MB (kg)	30	0.28	1.54	0.78	0.07	0.36
TB (kg)	30	0.45	5.39	2.47	0.29	1.57
TCF (kg)	30	1.96	12.73	6.65	0.60	3.29

N: Number; MIN.: Minimum; MAX. Maximum; AV: Average; S.E.E.: Standard error of estimate; S.D.: Standard Deviation; RCD: Root Collar Diameter, DBH: Diameter at Breast Height, H: Height, CBH: Crown Base Height, CL: Crown Length, CW: Crown Width, N: Needle, VTB: Very Thin Branches, TNB: Thin Branches, MB: Medium Branches, TKB: Thick Branches, TCF: Total Crown Fuel.

Statistical Analysis

The correlation analysis was used to investigate the relationships between crown fuel components and measured properties of trees. The linear regression analysis (Brown, 1978; Stocks, 1980) was used to investigate the relationships between crown fuel load of trees as dependent variables (needle (kg), branches (kg) and total crown fuel load (kg)) and trees measured characteristics values (diameter (cm), height (m), age (year), crown base height (m), crown width (m), crown length (m)) as independent variables. All statistical analyses were performed in SPSS 21.0 for windows.

Results and Discussion

Results of correlation analysis between crown fuel components and measured properties of sampled trees are given in Table 3. According to the results of correlation analysis, needle, very thin branches, thin branches, medium and thick branches with total crown fuel were positively and closely correlated with root collar diameter, diameter at breast height, crown length and crown width (p<0.01). Crown length, crown width, needle, thick branches and total crown fuel amount were closely correlated with height (p<0.01). Very thin, thin and medium branches were positively correlated with H (p<0.05). Very thin, thin, medium branches with crown length were negatively correlated with CBH (p<0.05).

Table 3. Correlation matrix

	RCD	*DBH*	*H*	*CBH*	*CL*	*CW*	*N*	*VTB*	*TNB*	*M*	*TKB*	*TCF*
CD	1											
DBH	0.862**	1										
H	0.564**	0.665**	1									
CBH	-0.056	-0.147	0.391*	1								
CL	0.539**	0.712**	0.617**	-0.452*	1							
CW	0.696**	0.764**	0.619**	-0.189	0.748**	1						
N	0.780**	0.895**	0.602**	-0.131	0.629**	0.750**	1					
VTB	0.671**	0.811**	0.389*	-0.428*	0.698**	0.659**	0.783**	1				
TNB	0.805**	0.898**	0.422*	-0.456*	0.738**	0.725**	0.859**	0.938**	1			
M	0.758**	0.900**	0.427*	-0.434*	0.729**	0.686**	0.842**	0.927**	0.964**	1		
TKB	0.739**	0.900**	0.530**	-0.326	0.707**	0.741**	0.913**	0.881**	0.923**	0.915**	1	
TCF	0.784**	0.926**	0.529**	-0.330	0.721**	0.757**	0.943**	0.912**	0.959**	0.949**	0.988**	1

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).
RCD: Root Collar Diameter, DBH: Diameter at Breast Height, H: Height, CBH: Crown Base Height, CL: Crown Length, CW: Crown Width, N: Needle, VTB: Very Thin Branches, TNB: Thin Branches, MB: Medium Branches, TKB: Thick Branches, TCF: Total Crown Fuel

Crown Fuel Models

Live crown fuels of the sampled trees were mainly composed of thick branches (34.1%) followed by needles (28.3%). Very thin (7.4%) and thin branches (17.9%) with medium branches (12.3%) represented 37.6% of the total crown fuel load. In a previous study, the proportion of needle value was reported as 26% (Kucuk et al. 2008a) which is very close to our finding in the current study. The active crown fuel load (i.e., needles and very thin and thin branches 0-0.6 cm) that are usually consumed during crown fires (Stocks et al., 2004) represented 53.6% of total crown fuel load of sampled trees. This finding was also very similar to the results of previous study (56%) carried out by Kucuk et al. (Kucuk et al. 2008a) who worked on young Calabrian pine trees.

In this study, *DBH*, *CBH* and *AGE* were found to be significant predictors for the estimation of crown fuel loading of Calabrian pine trees from non-treated planted forest. Developed regression models for the estimation of crown fuel loads in sampled Calabrian pine characteristics were given in Table 4. Analyses indicated that *DBH*, *AGE* and *CBH* were significant predictors for the estimation of crown fuel loading. Crown fuel estimation studies from Turkey, *DBH* and *CBH* were mostly found a main predictor (Kucuk et al., 2008a; Kucuk and Bilgili, 2008b; Bilgili and Kucuk, 2009). According to biomass determination studies of Calabrian pine trees; DBH was also found a good predictor from Turkey (Durkaya et al., 2009; Sonmez et al., 2016) and Greece (de-Miguel et al., 2014). In Turkey, for the determination of crown fuel load of Anatolian black pine (*Pinus nigra* J.F Arnold subsp. *nigra* var. *caramanica* (Loudon) trees, *DBH* was found to be the main predictor for the estimation of total live crown fuel load (Kucuk et al., 2007c).

In most fuel determination studies, *DBH* was found a good parameter for the estimation of total biomass and its components of trees (Stocks, 1980; Johnson, Woodard, & Titus, 1990). As a result, tree diameter at breast height could be used as a basic integration parameter for crown fuel determination studies (Mitsopoulos and Dimitrakopoulos, 2007). But using only diameter at breast height is not sufficient for the estimation of total fuel load and its components at stand and forest level. To obtain reliable parameters for the determination of flammable materials of a stand and forest canopy, extra parameters such as *CW*, *CBH*, and *CL* are especially needed.

According to developed allometric equations for the estimation of different fuel components of tree crown, predicted and observed needle biomass for model 1*b* (Figure 2a), predicted and observed active fuel load for model 2*c* (Figure 2b), predicted and observed all branches biomass for model 3*b* (Figure 2c), and predicted and observed total crown fuel amounts for model 4*b* (Figure 2d) are given in Figure 2.

Table 4. Developed regression models for the estimation of crown fuel loads of Calabrian pine trees

No	Models	R^2	*S.E.E.*[a]	*p*
1*a*	$TCFL_{needle}$= -1.239 + (0.234 x *DBH*)	0.795	± 0.3495	0.000
1*b*	$TCFL_{needle}$= 3.280 + (0.254 x *DBH*) + (-0.201 x *AGE*)	0.849	± 0.2994	0.002
2*a*	$TCFL_{activefuel}$= -2.392 + (0.448 x *DBH*)	0.851	± 0.5499	0.000
2*b*	$TCFL_{activefuel}$= -0.707 + (0.437 x *DBH*) + (-0.249 x *CBH*)	0.874	± 0.5057	0.020
2*c*	$TCFL_{activefuel}$= 4.725 + (0.458 x *DBH*) + (-0.285 x *CBH*) + (-0.231 x *AGE*)	0.895	± 0.4632	0.020
3*a*	$TCFL_{allbranches}$= -5.525 + (0.799 x *DBH*)	0.830	± 1.059	0.000
3*b*	$TCFL_{allbranches}$= -0.838 + (0.767 x *DBH*) + (-0.693 x *CBH*)	0.892	± 0.8464	0.000
4*a*	$TCFL_{all}$= -6.757 + (1.034 x *DBH*)	0.852	± 1.2635	0.000
4*b*	$TCFL_{all}$= -2.078 + (1.001 x *DBH*) + (-0.692 x *CBH*)	0.888	± 1.0996	0.004

[a]Standart error of estimate

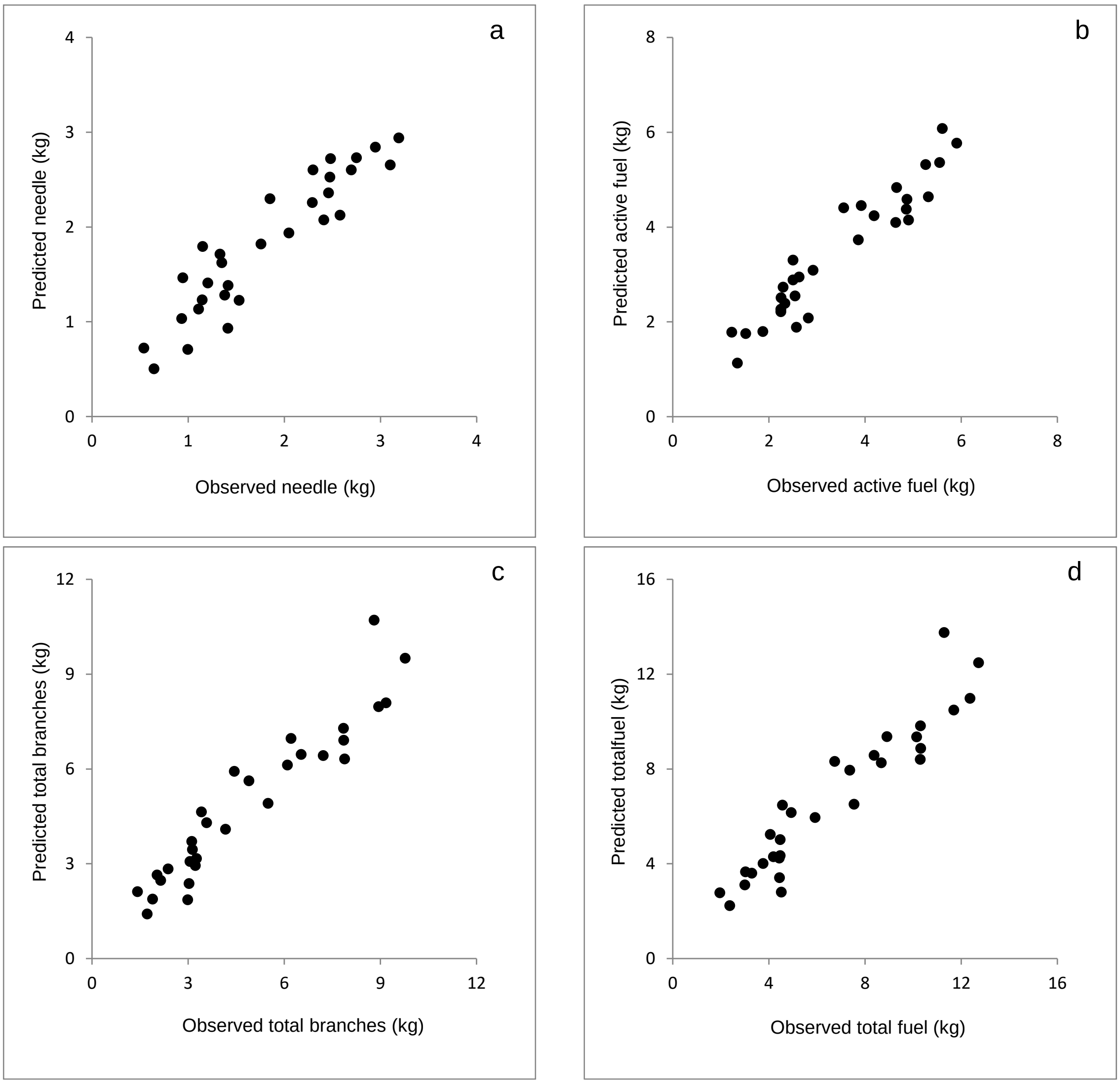

Figure 2. Relationship between predicted and observed needle (a), active fuel (b), all branches (c), and total crown fuel (d)

Conclusion

In this study, some allometric equations were developed to estimate total crown fuel load of Calabrian pine trees from non-treated planted stands. Models derived from this study can be useful for the calculation of slash fuels deposited on the forest floor after silvicultural interventions. In addition, by using these developed models, it will be possible for the estimation of dry crown biomass for determination of carbon stock (Sakici et al., 2018), assessment of carbon emission released due to crown fires (Kucuk and Bilgili, 2010) for climate change projection, and development of decision support system for the establishment of fire danger rating system (Bilgili, Dinc Durmaz, Saglam, Kucuk & Baysal, 2006). Such models can enhance the understanding of tree growth and increment in forestry science. Also, for fire managers and researchers, investigation of non-treated afforestation fuel types and development of fuel models will allow enhancing the behavior of surface and crown fires in fire sensitive Calabrian pine forests.

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