UDK 630* 431 (001)

Izvorni znanstveni članci – Original scientific papers
Šumarski list, 11–12 (2015): 553–560

FUEL MODELLING AND POTENTIAL FIRE BEHAVIOR IN TURKEY

MODELIRANJE GORIVA I POTENCIJALNO PONAŠANJE POŽARA U TURSKOJ

Omer KUCUK[1,*], Ertugrul BILGILI[2], Paulo M. FERNANDES[3]

Summary

Description of fuel characteristics is an essential input to fire behavior models that can provide decision-support for fire management. Fuel models describe fuel characteristics for fire modeling systems based on Rothermel's fire spread model. In this study, fire behavior data collected in field experiments in different fuel complexes in Turkey is used in the process of fuel model development. Nine fuel models were built for low and tall maquis, Anatolian black pine (*P. nigra* J.F. Arnold *subsp. nigra var. caramanica* (Loudon) Rehder), litter, and slash variable in age and load. BehavePlus simulations of fire rate of spread, flame length and fireline intensity for typical summer weather conditions highlight the quite different fire potential between the studied fuel types. The difficulty in dealing with fuel complexes dominated by live fuels was evident from the simulations. On the contrary, the model correctly predicted the observed temporal decrease of fire behavior in slash. This study shows the crucial importance of experimental fire data to parameterize fuel models.

KEY WORDS: Fuel modeling, experimental fires, fire behavior, fire modeling systems, Turkey.

INTRODUCTION
UVOD

Fire has been a major force in shaping the landscapes of the world and consequently it has been the subject of a research effort of enormous proportions. An increasingly important requirement of forest and land management in fire-prone ecosystems is the ability to predict fire behavior.

Advances in fire behavior science have gradually resulted in the development of fuel and fire bihavior prediction model to support the decision-making process of land managers on a large array of fire management problems (Bilgili et al. 2006).

Fire behavior and fire danger are usually described in association with a fuel model or fuel type (Alexander et al. 1991; Hirsch, 1996). Strictly speaking, a fuel model is a set of a measurable fuel bed properties (Anderson, 1982), quantified for a distinctive vegetation community, to be used as an input to the mathematical fire spread model of Rothermel (1972). Fuel models support local fire behavior prediction, but also fire danger rating systems when a general assessment of potential fire behavior or fuel hazard is required in regional fire management planning (Anderson, 1982).

Differences in fire behavior, under similar meteorological and topographic conditions, are determined by fuel charac-

[1] Prof. Dr. Omer Kucuk, Kastamonu University, Faculty of Forestry, 37100 Kastamonu, Turkey, *Corresponding author: e-mail:kucuk61@yahoo.com

[2] Prof. Dr. Ertugrul Bilgili, Karadeniz Technical University, Faculty of Forestry, 61080 Trabzon, Turkey

[3] Assoc. Prof. Dr. Paulo M. Fernandes, Centro de Investigação e de Tecnologias Agro-Ambientaıs e Biológicas (CITAB), UTAD, Apartado 1013, 5001-801 Vila Real, Portugal

teristics (Anderson, 1982; Chandler et al. 1983; Pyne et al. 1996; Nelson, 2001; Bilgili & Saglam, 2003; Bilgili et al. 2006; Kucuk et al. 2012). A fuel model describes a complex of fuel elements through their average properties values (Burgan & Rothermel, 1984). Therefore, a fuel model is based on the physical rather than the floristic characteristics of a fuel complex and a single fuel model can be applied to various vegetation types whose fuel characteristics are similar to those represented by the model (Dimitrakopoulos, 2002).

The National Forest Fire Laboratory (NFFL) fire behavior fuel models (Anderson, 1982) provide a general framework to describe the surface fuel complex in temperate regions. The NFFL set of fuel models is often used in Europe, e.g. ICONA (1990). However, realistic estimates of fire characteristics for structurally different fuel types require specific fuel models. European examples include fuel models for Alpine (Allgöwer et al. 1998) and Mediterranean (Dimitrakopoulos, 2002; Cruz & Fernandes, 2008; Fernandes, 2009; Krivtsov et al. 2009) vegetation types. Although fuel models should be fine-tuned with observed fire behavior data in order to adequately reflect real-world fire characteristics (Burgan & Rothermel, 1984), such procedure is seldom followed (Cruz & Fernandes, 2008), which can have negative impacts on the conclusions reached by fire modeling exercises and application to fire management decisions.

Selecting, calibrating or developing fuel models and determining their fire behavior potential are of crucial importance in fire, forest, and land management in the Mediterranean region. In this study, fuel models calibrated with observed fire behavior characteristics were for the first time developed for important fuel types in Turkey and their potential fire behavior range then determined using the BehavePlus fire modeling system.

METHODS
METODE

Fuel characteristics and fire behavior experiments – *Karakteristike govora i eksperimenti ponašanja požara*

In this study we considered four fuel types, respectively slash of Anatolian black pine (*P. nigra* J.F. Arnold *subsp. nigra var. caramanica* (Loudon) Rehder), black pine litter, low maquis, and tall maquis. Taken together, these fuel types represent nearly half of Turkey's wildland area, 19.8 % corresponding to black pine and 27% to maquis (OGM, 2006).

Kastamonu was the study area for Anatolian black pine slash. Slash of three different ages (3, 12, 24 month) at two fresh fuel loading levels (8 kg m^{-2} and 16 kg m^{-2}) was used. Fuels in the burning plots (3x1 m) were made up of foliage and branches. A series of 30 burning plots were established on level terrain occupied by newly cut black pine slash fuels. Fuel was uniformly distributed to the greatest extent possible. The plots were laid out in parallel, in the direction of the prevailing wind. Fuel material within one 0.09 m^2 (30x30 cm) sampling frame was removed from each plot down to the mineral soil, and then sorted into needles and branches, later subdivided by size class. Fuel depth was measured as the vertical distance from the litter layer bottom to the slash top, at three points in each plot with a ruler. During the experimental burns, 2-m open wind speed, air temperature and relative humidity were recorded at 15-second intervals using an automatic weather station set up at the site edge. The wind measurements were averaged over the fire spread period. Plots were burned over two years under varying temperature, relative humidity, moisture and wind speed conditions (Küçük et al. 2008).

Fuel modeling for the black pine litter fuel bed was conducted in a 45 year-old stand with an average diameter at breast height (dbh) of 30 cm, average live crown base height of 6 m, and an average height of 18 m, averaging 700 stem ha^{-1}. No living plants were present in the understorey and living trees made up 100% of the overstorey. Surface fuels consisted primarily of needle litter along with some branches and cones. Surface fuel loading measurements were based on three fuel samples randomly taken immediately adjacent to each burning plot. Surface fuel material within a 30x30 cm sampling frame was removed down to mineral soil, and then sorted into litter (needles, branches) and duff. Burn plots in black pine litter (*n*=28) were established on flat terrain and measured 3x1 m (3 m long and 1 m wide) and were laid out, in parallel, in the direction of the prevailing wind for subsequent line ignition. The plots were surrounded by cleared fire lines (0.5 m width) so that each plot would burn free from the influence of other fires (Kucuk et al. 2007).

Fuel models were also built for low (< 1-m tall) and tall maquis (> 1-m tall). Shrub fuels are most common in the southwestern of Turkey. The study areas were located in Antalya and Keşan. The dominant plant species were *Quercus coccifera* L. for low maquis and *Arbutus andrachne* L. and *Pistacia lentiscus* L. for tall maquis. A detailed description is included in Saglam et al (2008a, 2008b). A series of 18 burning plots were established at the experimental burning sites. The size of each plot was 0.06 ha (20 × 30 m), delimited by a 5-m wide fire-break bulldozed to mineral soil to enable easy access and facilitate fire control. A complete fire weather station was established on the site 10 days prior to the burnings. Air temperature, relative humidity, 2-m open wind speed and precipitation were recorded at 13:00 local standard time.

The shrub fuel parameters measured for fuel modeling were height, fuel loading by size class and condition (dead or alive), and the moisture contents of dead fine fuel and live fine fuel. Fuel heights of litter and shrubs were measured as the vertical distances from the bottom of each layer to the apparent average top of the layer.

Dead fuel components were separated by size classes defined by their diameter, respectively 0 to 0.6 cm (fine fuels), 0.6 to 2.5 cm (medium branches) and 2.5 to 7.5 cm (coarse branches), corresponding to the 1h, 10h, and 100h timelags (Rothermel, 1972; Deeming et al. 1972). Fuel moisture contents were determined by sampling dead and woody fine fuels immediately before each fire. Samples were weighed, taken to the laboratory and oven-dried to a constant weight at 105 °C for at least 24 h. Moisture contents were calculated on a dry weight percentage basis.

All experimental fires were conducted from late July through early September; the fire season generally lasts from late June until mid October. Weather conditions and fuel moisture contents are thus of crucial importance for wildfires at this period in the study areas.

Except for low maquis, all fires were carried out in flat areas. The preferred time of ignition was mid-afternoon to coincide with daily peak burning conditions. All fires were ignited with a drip torch to rapidly establish a fire line along the windward edge of the plot. Fires were allowed to propagate with wind down the length of the plot in order to simulate a free burning fire. In all experimental fires, the 2-m open wind speed was recorded at 15 second intervals by an automatic weather station set up on the site. The wind measurements were averaged over the period of fire spread.

Fire behavior was monitored during each fire, starting from the time the ignition line was lit. Head fire rates of spread were determined by timing when the fire front arrived preplaced poles. In addition, the progress of the fires was video-recorded from two sides and photographic records were taken for later evaluation. Frontal fireline intensity was calculated for each plot as per Byram (1959):

$$I = H \times W \times R$$

where I is the fireline intensity (kW m^{-1}), H is the heat yield of the fuel (kJ kg^{-1}), W is the weight of fuel consumed per unit area in the active flaming zone (kg m^{-2}), and R is the rate of spread (m s^{-1}).

Development of custom fuel models – *Izrada uobičajenih modela goriva*

The Behave Fire Behavior Prediction and Fuel Modeling System was among the early computer systems developed for wildland fire management. It has been updated and expanded and is now called the BehavePlus Fire Modeling System to reflect its expanded scope. BehavePlus provides a means of modeling fire behavior characteristics (such as rate of spread and flame length), fire effects (such as scorch height and tree mortality), and the fire environment (such as fuel moisture and wind adjustment factor) (Andrews et al. 2005). We used BehavePlus 4.0 software for both developing the custom fuel models and estimating potential fire behavior.

For each fuel complex, an initial fuel model was developed in BehavePlus by entering the average measured fuel characteristics. The variables surface area to volume ratio and heat content of the particles, as well as dead fuel moisture of extinction, are also required to run the surface fire spread model of Rothermel (1972). Representative values were taken from the literature (Dimitrakapoulos, 2001; Cohen et al. 2003; Fernandes, 2009). The resulting fuel model was then parameterized to match the experimental fire behavior characteristics, especially through the adjustment of fuel depth. The measured 2-m wind speed was assumed to equate the midflame height wind speed required by BehavePlus.

RESULTS AND DISCUSSION
REZULTATI I RASPRAVA

Table 1 contains the parameters for the fuel models developed in this study. Fuel loads are isimilar between low and tall maquis indicating that tall maquis is a more aerated fuel complex. This should be an outcome of the different dominant species – *Quercus coccifera* L. in low maquis, *Arbutus andrachne* L. and *Pistacia lentiscus* L. in tall maquis – and because biomass increase in tall shrubs is largely caused by increases in larger live branches that do not necessarily contribute to fire behavior. Also, low maquis is richer in fine dead fuels, because the species dominating tall maquis do not carry dead fuels in the canopy, and because litter fuels were incipient in tall maquis.

The descriptive statistics of the fuel and fire behavior characteristics are given in Table 2. Oven-dry fuel biomass (1h, 10h, 100h) ranged from 2.30 to 49 t ha^{-1}, 0 to 19.50 t ha^{-1}, and 0 to 0.60 t ha^{-1}. Dead fine fuel moisture (*Md*) content ranged from 7%–25%. Average *Md* was 12,6%. Fuel depth changed from 2.3 cm to 300 cm. In this study, all experimental fires were done under the mid wind conditions. Mean wind speed was 8.8 km h^{-1}. Rate of fire spread and fire line intensity are important fire behavior characteristics. In this study, Rate of fire spread ranged from 0.30 m min^{-1} to 6.10 m min^{-1}, and fire line intensity ranged from 22 kW m^{-1} to 4241 kW m^{-1}.

Table 3 displays the observed and predicted fire behavior characteristics for the developed fuel models. The main criteria to adjust the fuel models was rate of fire spread, and it was not always possible to predict adequately both rate of spread and energy release (Burgan & Rothermel, 1984). Consequently, a stronger agreement exists between observed and predicted rate of spread than between observed and predicted flame length or fireline intensity. A one order of

Table 1. Fuel parameters for the 9 custom fuel models.
Tablica 1. Parametri goriva za 9 uobičajenih modela goriva.

No (Br)	Fuel model (Model goriva)	Dead fuel load (Teret mrtvog goriva) (t ha^{-1})				SVR (m^{-1})		Fuel depth (Dubina goriva) (m)	Mx (%)	HC (kJ kg^{-1})
		1h	10h	100h	Live finefuel (Živo fino gorivo)	1h	live			
1	Low maquis (Niska makija) *Q. coccifera*	6.5	1.26	0.66	12.8	3900	3900	0.8	25	20500
2	Tall maquis (Visoka makija) (*A. andrache, P. lentiscus*)	3.5	0	0	14.2	3600	3600	2.3	25	21500
3	*Pinus nigra* litter (stelja)	4.5	1.9	0	0	4640	–	0.055	30	20500
4	*P. nigra* slash (otpad) 12M 8kg	11.5	11	0	0	500	–	0.21	35	20500
5	*P. nigra* slash (otpad) 12M 16kg	23	18.5	0	0	400	–	0.36	35	20500
6	*P. nigra* slash (otpad) 3M 8kg	28	15	0	0	1500	–	0.22	35	20500
7	*P. nigra* slash (otpad) 3M 16kg	49	19.5	0	0	800	–	0.38	35	20500
8	*P. nigra* slash (otpad) 24M 8kg	6.5	9.5	0	0	400	–	0.12	25	20500
9	*P. nigra* slash (otpad) 24M 16kg	13.5	18	0	0	400	–	0.28	25	20500

M: month (mjesec); 1h, 10h and 100h respect to dead fuel timelag size classes respectively < 0.6 cm, 0.6–2.5 cm, and > 2.5 cm (1h, 10h i 100h u odnosu na mrtvo gorivo, kašnjenje, veličinu odnosno klase < 0.6 cm, 0.6–2.5 cm, te > 2.5 cm); SVR: surface area to volume ratio (površina prema omjeru obujma); Mx: dead fuel moisture of extinction (količina vlage kod koje prestaje gorenje mrtvog goriva); HC: heat content (količina topline).

Table 2. Descriptive statistics for fuel and fire behavior characteristics.
Tablica 2. Opisna statistika za gorive karakteristike ponašanja požara.

Parameters	Minimum	Maximum	Mean	Std. Error	Std. Deviation
1h	2.30	49.00	14.5809	4.26514	14.14588
10h	.00	19.50	8.8100	2.41088	7.99599
100h	.00	.60	.1073	.07197	.23871
Md (%)	7.40	25.00	12.6909	1.60909	5.33675
Ml (%)	.00	227.30	49.9364	23.12048	76.68197
Fuel depth (cm)	2.33	300.00	58.7330	28.96258	91.58771
W (km h^{-1})	3.60	11.50	8.8212	.82029	2.72059
ROS (m min^{-1})	.30	6.10	2.3516	.64873	2.15159
FLI (kW m^{-1})	22.00	4241.22	1479.6566	443.96996	1472.48178
Slope (°)	.00	10.00	.9091	.90909	3.01511

Table 3. Fuel models, mean experimental fire environment characteristics and corresponding predicted (P) and observed (O) fire behavior characteristics.
Tablica 3. Modeli goriva, srednje karakteristike okoliša eksperimentalnog požara te odgovarajuće predviđene (P) i opažene (O) karakteristike ponašanja požara.

No (Br)	Fuel model (Model goriva)	Md (%)	Ml (%)	W (km h^{-1})	Slope (Nagib) (°)	ROS (m min^{-1})		FLI (kW m^{-1})		FL (m)	
						O	P	O	P	O	P
1	Low maquis (Niska makija) *Q. coccifera*	11.8	88	11	10	3.4	5.4	1361	1230	–	2
2	Tall maquis (Visoka makija) (*A. andrache, P. Lentiscus*)	12.3	106	10.5	0	3.6	5.5	2476	376	–	1.2
3	*Pinus nigra* litter (stelja)	9	–	3.6	0	0.5	0.5	289	56	–	0.5
4	*P. nigra* slash (otpad) 12M 8kg	8.5	–	5.2	0	0.6	0.6	170	246	0.6	1
5	*P. nigra* slash (otpad) 12M 16kg	8.1	–	6.1	0	0.8	0.8	371	476	1	1.3
6	*P. nigra* slash (otpad) 3M 8kg	15.3	–	11.5	0	1.8	1.8	1250	2389	1.5	2.8
7	*P. nigra* slash (otpad) 3M 16kg	16.2	–	11	0	2.2	2.2	2830	5983	2	4.3
8	*P. nigra* slash (otpad) 24M 8kg	9.7	–	9.2	0	0.3	0.3	22	55	0.2	0.5
9	*P. nigra* slash (otpad) 24M 16kg	7.4	–	8.2	0	0.6	0.6	110	176	0.7	0.8

Md: moisture content of dead fine (Sadržaj vlage mrtvog finog); (1 h) fuel (goriva); Ml: moisture content of live fine woody fuel (sadržaj vlage živog finog drvenog goriva); W: midflame wind speed (brzina vjetra srednjeg plamena); ROS: rate of spread (brzina širenja); FLI: fire line intensity (intenzitet požarne fronte); FL: flame length (duljina plamena); O: observed (opaženo); P: predicted (predviđeno).

magnitude difference between observed and estimated fireline intensity was found for tall maquis, which is due to the very low amount of dead fuel in relation to live fuel. The reason for this disagreement is the fact that Rothermel's model was developed using only dead fuels and it was mathematically extended to live fuels, where the live fuel component burns only when the complex contains enough dead fuel to sustain live fuel combustion (Catchpole & Catchpole 1991). For both low and tall maquis, fire spread rate is overpredicted by more than 50%, which is also consistent with the importance of live fuels in these vegetation types.

Comparatively, the predictions for the remaining fuel complexes, which are entirely composed of dead fuels, are in closer agreement with observed fire characteristics. Slash fuel fire behavior exhibits a clear and marked temporal trend, with important decreases with slash age. As time passes and foliage retention decreases, the fuel bed packing ratio decreases up to a point where the available fuel does not optimize combustion.

Within the wind range adopted for simulation (0–20 km h^{-1}), the response of rate of fire spread to wind was relatively linear, in accordance with most empirical models of fire spread in shrubland (Vega et al. 1998; Fernandes, 2001; Bilgili & Saglam, 2003; Saglam et al. 2008b; Anderson et al. 2015). From Figure 1, it is quite apparent that the difference is marked in potential fire spread between maquis, especially low maquis, and the horizontally-dominated fuel beds. Rate of spread is predicted to be similar between black pine litter and fresh slash particularly at higher wind speeds.

Similarly to wind speed, shrub fuels were more responsive to variation in dead fuel moisture content, indicating that dramatic changes in fire behavior can occur as weather conditions change (Figure 2). Rates of spread in black pine slash and litter varied only within a narrow range of 1–4 m min^{-1} in response to the comparatively large moisture content range of 4–20%, implying that wind variation would be much more important than moisture content variation in these fuel complexes, in accordance with other studies in pine fuel types (e.g. Küçük et al. 2007; Tanskanen et al. 2007; Küçük et al. 2008; Fernandes et al. 2009).

Figure 3 illustrates the effect of slash age on potential fire spread rate. Initially (month 3) the difference between 8 kg m^{-2} and 16 kg m^{-2} treatments is more evident (3.2 versus 2.4 m min^{-1}), but rate of spread decays quite fast and after 9 months it decreases to one third of month 3 values. From the point of view of fire hazard, the changes occu-

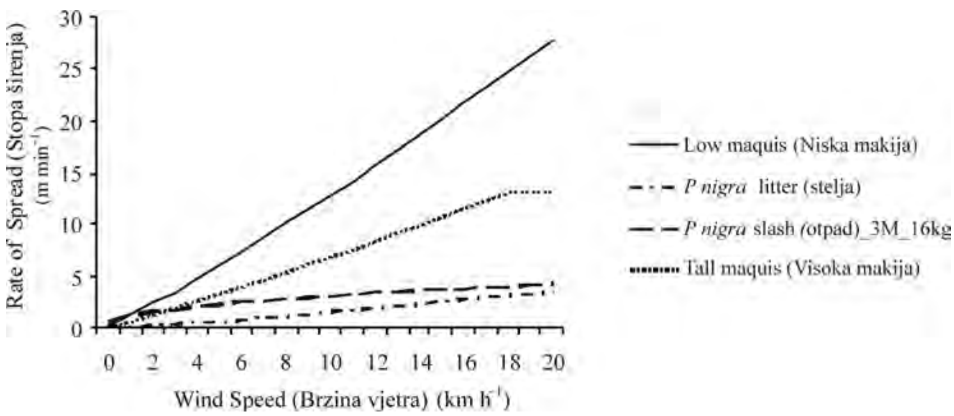

Figure 1. Relationships between rate of spread and wind speed for each fuel model developed.
Slika 1. Odnos između stope širenja i brzine vjetra za svaki razvijeni model goriva.

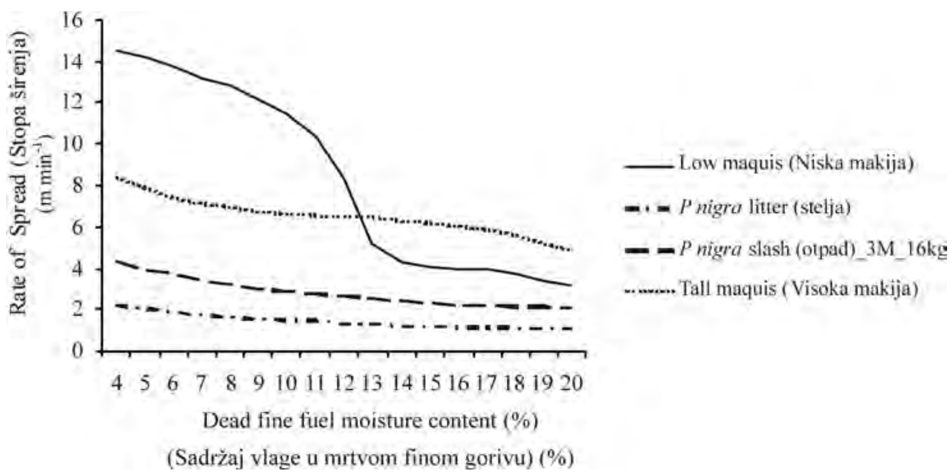

Figure 2. Relationships between rate of spread and dead fine fuel moisture content.
Slika 2. Odnos između brzine širenja i sadržaja vlage u mrtvom finom gorivu.

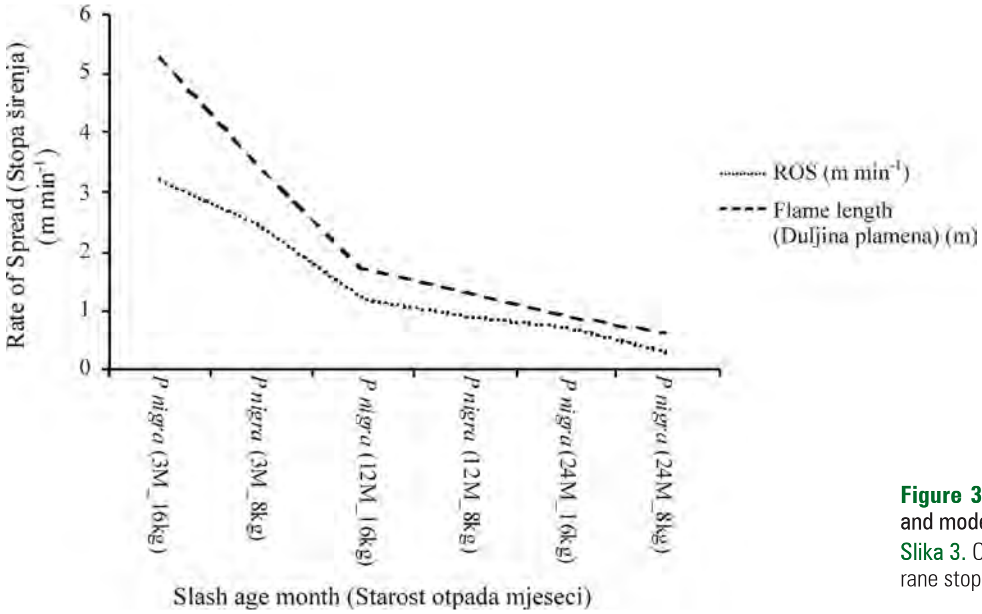

Figure 3. Relationships between slash age and modeled rate of spread and flame length.
Slika 3. Odnos između starosti otpada i modelirane stope širenja te duljine plamena.

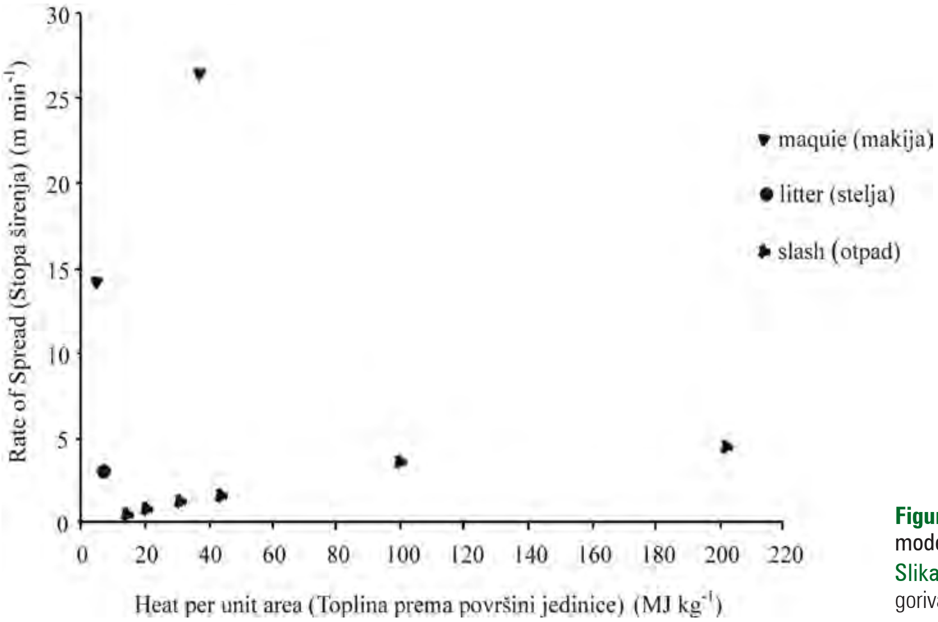

Figure 4. Fire characteristics chart for the fuel models developed in this study.
Slika 4. Karta karakteristika vatre za modele goriva izrađene u ovoj studiji.

rring after one year are not meaningful because changes in available fine fuel are minor.

The fire characteristics chart (Figure 4) emphasizes the previous findings on the differences between fuel complexes. Low maquis is characterized by relatively fast spread rate and high heat release per unit area, whereas tall maquis is lower in spread rate and energy release, due to the factors previously discussed. Two more distinct situations arise, respectively (i) fresh slash fuels, with low spread potential but high energy release rate, and (ii) slash fuels lacking needles and pine litter, with both low spread and low heat per unit area.

CONCLUSION
ZAKLJUČAK

In this study we have developed custom fuel models for important fuel types in Turkey by combining measured and literature-collected fuel characteristics with fire behavior observed in experimental fires. Fire behavior simulations based on the fuel models developed for low and tall maquis, Anatolian black pine litter and different slash ages and loads were quite effective in showing the distinct fire potentials associated with these fuel types. Fire spread and intensity predictions for horizontally-dominated fuels closely matched the observed fire behavior characteristics. However, higher discrepancies were found for the elevated fuel complexes dominated by live fuels, especially for tall maquis, due to known deficiencies in Rothermel's fire spread model. A larger and more robust experimental database will be needed before representative fuel models for maquis vegetation can be built. On the other hand, BehavePlus was quite effective at describing the temporal dynamics of fire hazard decrease in slash.

U.S. fire modeling systems can be powerful tools to use in fire research and management applications but are based in laboratory experimental conditions and have been poorly tested. Consequently, their use should rest on sound experimental data. This study is the first to attempt to develop fuel models in Turkey, and one of the first in the Mediterranean Basin that resorts to experimental fire data to do so. Future studies will be dedicated to gather additional fire behavior data for a range of vegetation types and weather conditions in Turkey.

ACKNOWLEDGEMENTS
ZAHVALE

This study was conducted with the cooperation and efforts of many people. This study was partially supported by EFIMED and The Scientific and Technological Research Council of Turkey, Project No: TOVAG-108 O 327.

REFERENCES
LITERATURA

- Alexander M.E., B.J. Stocks, B.D. Lawson, 1991: Fire behavior in black spruce-lichen woodland: the Porter Lake Project. Forest Canada. Northern Forestry Centre, Information Report NOR-X-310. (Edmonton, Alberta) pp. 44.
- Allgöwer B., S. Harvey, M. Rüegsegger, 1998: Fuel models for Switzerland: description, spatial pattern, index for torching and crowning, In: Viegas D.X. (ed.), Proc. 3rd International Conference on Forest Fire Research & 14th Fire and Forest Meteorology Conference, ADAI, Coimbra, pp. 2605–2620.
- Anderson, H.E, 1982: Aids to determining fuel models for estimating fire behavior, USDA Forest Service, Ogden, 22p,
- Anderson, W.R., M.G. Cruz., P.M. Fernandes, L.Mccaw, J.A. Vega, R. Bradstock, L. Fogarty, J. Gould, G. Mccarthy, J.B. Marsden-Smedley, S. Matthews, G. Mattıngly, G. Pearce, B. Van Wılgen, 2015: A generic, empirical-based model for predicting rate of fire spread in shrublands, *Int J Wildland Fire* 24(4): 443–460.
- Andrews, P.L., C.D. Bevins, R.C. Seli, 2005: BehavePlus fire modeling system, version 4.0: User's Guide, Gen. Tech. Rep. RMRS-GTR-106WWW Revised. Ogden, UT: Department of Agriculture, Forest Service, Rocky Mountain Research Station. 132 pp.
- Bilgili, E., B.D. Durmaz, B. Saglam, O. Kucuk, İ. Baysal, 2006: Fire behavior in immature calabrian pine plantations, *Forest Ecol Manag* 234S: S77–S112.
- Bilgili E., B. Saglam, 2003: Fire behaviour in maquis in Turkey, *Forest Ecol Manag* 184: 201–207.
- Burgan R., R. Rothermel, 1984: BEHAVE: fire behaviour prediction and fuel modeling system – FUEL subsystem, USDA Forest Service, Ogden, pp 137.
- BYram, G.M, 1959: Combustion of forest fuels, In: Davis, K.P. (Ed.), Forest fire control and use, McGraw-Hill, New York, pp. 90–123.
- Catchpole, E.A., W.R. Cathcpole, 1991: Modeling moisture damping for fire spread in a mixture of live and dead fuel, *Intl J Wildland Fire* 1(2): 101–106.
- Chandler, C., P. Cheney, P. Thomas, L. Trabaud, D. Williams, 1983: Fire in forestry. Vol. 1: Forest fire behavior and effects, Krieger Publishing, Florida, pp. 450.
- Cohen, M., P. Cuiñas, C. Diez, P. Fernandes, M. Guijarro, C. Moro, 2003: Wildland fuel particles characterization database content. Deliverable D6-03-A1, Fire Star: a decision support system for fuel management and fire hazard reduction in Mediterranean wildland-urban interfaces, Contract No. EVG1-CT-2001-00041.
- Cruz, M.G., P.M. Fernandes, 2008: Development of fuel models for fire behaviour prediction in maritime pine (*Pinus pinaster* Ait.) stands, *Int J Wildland Fire* 17: 194–204.
- Deeming, J.E., J.W. Lancester, M.A. Fosberg, R.W. Furman, M.J. Schroeder, 1972: The National Fire-Danger Rating System. USDA Forest Service, Research Paper, RM-84, pp.165
- Dimitrakopoulos, A.P., 2001: A statistical classification of Mediterranean species based on their flammability components, *Int J Wildland Fire* 10(2): 113–118.
- Dimitrakopoulos, A.P., 2002: Mediterranean fuel models and potential fire behaviour in Greece, *Int J Wildland Fire* 11: 127–130.
- Fernandes, P.M., 2001: Fire spread prediction in shrub fuels in Portugal, *Forest Ecol Manag* 144: 67–74.
- Fernandes, P.M., 2009: Combining forest structure data and fuel modeling to classify fire hazard in Portugal, *Ann Forest Sci* 66: 415.
- Fernandes, P.M., *H.S. Botelho, F.C. Rego, C. Loureiro, 2009:* Empirical modelling of surface fire behaviour in maritime pine stands, *Int J Wildland Fire* 18: 697–710.
- Hirsch, K.G.,1996: Canadian Forest Fire Behavior Prediction System User Guide, Nat. Res. Can. For. Serv., Nor. For. Cent. Special Rep., Edmonton, Alta.
- ICONA, 1990: Clave fotografica para la indenditicación de modelos de combustible, Defensa contra incendios forestales, MAPA, Madrid.
- Krivtsov, V., O. Vigy, C. Legg, E.Rigolot, et al., 2009: Fuel modelling in terrestrial ecosystems: An overwiev in the context of the development of an object-orientated database for wild fire analysis, *Ecol Model* 220(21): 2915–2926.
- Küçük, Ö., E. Bilgili, İ. Baysal, 2007: Fire development from a point source in surface fuels of a mature Anatolian black pine stand, *Turk J Agric For* 31(4): 263–273.
- Küçük, Ö., E. Bilgili, B. Sağlam, Ş. Başkaya, B. Durmaz, 2008: Fire behavior in Anatolian black pine (*Pinus nigra* Arnold) slash, *Turk J Agric For* 32(2): 121–129.
- Küçük, Ö., E. Bilgili, S. Bulut, M. Fernandes, 2012: Rates of surface fire spread in a young calabrian pine (*Pinus brutia* Ten.) plantation, *Environ Eng Manag J* 11(8): 1475–1480.

- Nelson, R.M., 2001: Water relations in forest fuels. In: Johnson, E.A., Miyanishi, K. (eds.). Forest fires: behavior and ecological effects, Academic Press, San Francisco, CA. pp. 79–143.
- OGM, 2006: Forest and forestry in Turkey. General Directorate of Forestry report, Ankara Turkey, pp,160.
- Pyne, S.J., P.L. Andrews, R.D. Laven, 1996: Introduction to wildland fire science. 2nd edn, John Wiley, New York, pp, 769.
- Rothermel, R.C., 1972: A mathematical model for predicting fire spread in wildland fuels, Ogden, USDA Forest Service, Res. Pap. INT-115, Ogden, pp, 40.
- Sağlam, B., Ö. Küçük, E. Bilgili, B. Dinç Durmaz, İ. Baysal, 2008a: Estimating fuel biomass of some shrub (Maquis) species in Turkey, *Turk J Agric For* 32(4): 349–356.
- Sağlam, B., E. Bilgili, Ö. Küçük, B. Dinç Durmaz, 2008b: Fire behavior in Mediterranean shrub species (Maquis), *Afr J Biotechnol* 7(22): 4122–4129.
- Tanskanen, H., A. Granström, M. Larjavaara, P. Puttonen, 2007: Experimental fire behaviour in managed *Pinus sylvestris* and *Picea abies* stands of Finland, *Int J Wildland Fire* 16(4): 414–425.
- Vega, J.A., P. Cuiñas, T. Fontúrbel, P. Pérez-Gorostiga, C. Fernéndez, 1998: Predicting fire behaviour in Galician (NW Spain) shrubland fuel complex, III. International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology Vol. I, pp. 713–728.

Sažetak

Opis karakteristika goriva je nužan podatak za modele ponašanja požara koji mogu dati podršku odlukama za požarno upravljanje. Modeli goriva opisuju karakteristike goriva za sustave modeliranja požara koji se temelje na Rothermelovom modelu širenja požara. U ovoj studiji, podaci o ponašanju požara prikupljeni u terenskim eksperimentima u različitim kompleksima goriva u Turskoj korišteni su u procesu razvoja modela goriva. Napravljeno je devet modela goriva za nisku i visoku makiju, anatolski crni bor (P. nigra J.F. Arnold subsp. nigra var. caramanica (Loudon) Rehder), stelju te otpad, varijable u starosti i težini. BehavePlus simulacije stope širenja požara, duljine plamena i intenziteta požarne fronte za tipične ljetne vremenske uvjete naglašavaju potpuno drukčiji potencijal požara između izučavanih tipova goriva. Iz simulacija su očite teškoće u bavljenju kompleksom goriva kojima dominira živo gorivo. Nasuprot tomu, model je točno predvidio privremeno smanjenje ponašanja požara u otpadu. Ova studija pokazuje ključnu važnost eksperimentalnih podataka o požaru, kako bi se izvršila parametrizacija modela goriva.

KLJUČNE RIJEČI: Modeliranje goriva, eksperimentalni požari, ponašanje požara, sustavi modeliranja požara, Turska.