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Full Length Research Paper

Fire behavior in Mediterranean shrub species (Maquis)

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The prediction of fire behavior in fire prone ecosystems is of vital importance in all phases of fire management including fire prevention, presuppression, suppression and fire use. This paper deals with an experimental burning exercise conducted in the Mediterranean region in Turkey. A series of 18 experimental fires were carried out in tall maquis fuels in Asar District, Antalya, southwestern Turkey. The site was selected for its structural homogeneity. But, there was an apparent variation in the fuel loadings in different plots. Weather conditions were within reasonable ranges during the burns. Wind speed ranged from 4.8 to 14.4 km h^{-1}, relative humidity from 16 to 76% and air temperature from 23.7 to 36°C. Of the fire behavior characteristics, rate of spread ranged from 0.38 to 7.35 m min^{-1}, fuel consumption from 1.57 to 3.05 kg m^{-2}, and fire intensity from 188.72 to 5906.48 kW m^{-1}. Rate of spread was related to wind speed, relative humidity, moisture content of live fuels and vegetation cover. Fuel consumption was related to fuel loading and wind speed, and fire intensity was related to wind speed, moisture contents of live fuels and mean vegetation height and vegetation cover. Results obtained in this study should be invaluable in fire management planning.

Key words: Fire behavior, fuel biomass, Maquis, shrubland, Turkey.

INTRODUCTION

Fire is a major determining factor of the alteration and the structure of fire-prone ecosystems. In the Mediterranean region, shrub fuels are known for their flammability and tendency to sustain high intensity fire even at moderate fire danger situations (McCaw, 1995; Fogarty, 1996; Plucinski and Catchpole, 2002). The shrub fuels, known as maquis, grow extensively at low elevations adjacent to open forests of oak and pine and as an understorey in these forest types in the Mediterranean and Aegean Regions in Turkey. Maquis occupies about 6 million hectares (OGM, 2006), an area representing 30% of the country's forested lands. Maquis is found in fire prone areas and is highly adapted to frequent forest fires (Neyişçi, 1987). Thus, the prediction of fire behavior has a vital importance for the ecology of maquis in the face of fire and for the assessment of fire danger and implementation of fire management planning.

Maquis vegetation type is composed of several species such as *Arbutus andrachne* L., *Pistacia lentiscus* L., *Quercus coccifera* L., *Phillyrea latifolia* L., and *Cistus creticus* L. The abundance of different species in the composition results in a great variance in the structure and composition of the fuel complex. Burning characteristics differ greatly among different species (Neyişçi, 1987; Santoni et al., 2006; Morandini et al., 2006), thus rendering the fire danger potential and fire behavior characteristics highly variable. Although a series of fire behavior studies are available for the Mediterranean shrub fuels (De Luis et al., 2004; Morandini et al., 2006; Santoni et al., 2006), fire behavior in maquis fuels are not well understood and there is a lack of fire behavior data in maquis fuels (Bilgili and Saglam, 2003) in Turkey. The objective of this paper is to determine fire behavior characteristics based on varying weather conditions in tall shrub species (maquis) in the Mediterranean region. The results generated from this study should be invaluable in all phases of fire management planning and decision making processes.

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MATERIAL AND METHODS

Description of the study area

The area is situated in Asar District of Antalya State Forest Enterprise (36° 56' N; 30° 36' E), and has an elevation of 270 m above sea level. The area is mainly level with a maximum slope of 3°. The climate of the study area is Mediterranean climate with long hot summer and mild short winters. Annual average max and min temperatures are 34.4°C in July and·5.6°C in January, respectively. An average precipitation is 805 mm. Soils in the area are shallow and loam and sandy loam of limestone origin. The vegetation is open shrubland with an average height of 1.7 m. The understory is composed of annual and perennial herbs and grasses. The dominant plant species of the area were *A. andrachne* L., *P. lentiscus* L., *Q. coccifera* L., *P. latifolia* L., *C. creticus* L. and, to a lesser extent (less than 10%), *Ceratonia siliqua* L., *Crataegus monogyna* Jacq., *Rhamnus ssp.* and *Daphne sericea* Vahl.

Preburn fuel sampling

Fuel sampling was carried out throughout the study area on twenty four 3 × 3 m randomly located sample plots. Average height and vegetation cover were determined before all the plants were cut in each plot. The height was determined by taking the average of eight readings made at 1 m intervals from the soil surface to the tip of the branches along the two opposite sides of each plot. Shrub vegetation cover was estimated by running two transects along the two opposite sides of each plot and adding the distances the transect runs over shrub crowns, and expressing these as a fraction of the total transect length (Martin et al., 1981). The relationship to calculate the percent shrub vegetation cover was of the form:

Shrub vegetation cover percent = (Shrub cover length / total transect length) x 100

Following the measurements, all shrubs were cut at groundline in each plot. Each plant was divided into components of leaf and branches. Dead and live woody parts were separated. All woody parts were further separated into size classes by diameter: fine branches (0 - 0.5 cm), medium branches (0.6 - 2.5 cm), thick branches (> 2.5 cm in diameter), and available fuel (leaf + fine branches (less than 0.6 cm in diameter) (Roussopoulos and Loomis, 1979; Martin et al., 1981; Sağlam et al., 2008). The biomass size classes are useful in calculating fire intensity and fuel consumption. All dead and live fuel samples by size classes were weighed to the nearest 0.1 g and subsamples were taken from each class and weighed to the nearest 0.1 g in the study area. Subsamples were then taken to the laboratory for further analyses. All fuel samples transferred to the laboratory was oven dried to a constant weight for 24 h at 100°C, and weighed to the nearest 0.1 g. Final leaf and branch biomass determinations were made on the basis of oven dry measurements. Fuel loadings of the experimental plots were estimated using the equations generated from these measurements.

Statistical analysis

Correlation and regression analyses were performed to relate fire behavior characteristics to fuel properties and weather conditions. Regression analyses considered fuels and weather conditions as the independent variables, and fire behavior characteristics as the dependent variables. Before the analyses, the variables were tested for normality and as a result, no transformation was deemed necessary as all the variables satisfied the homoscedasticity - homogeneity of the variance over the range of the data - and the linearity assumption for the variables to be used in the analyses. Then, using linear regression models, equations were generated for predicting fire behavior. All selected equations were significant at the 95% significance level. Statistical analyses were performed using SPSS 11.0 for Windows (SPSS, 2001).

Height and vegetation cover

Average height and vegetation cover were determined in each experimental plot before the burnings. The procedure for the measurements was the same as that explained in the preburn fuel sampling section above, with a difference that measurements were made on only one side of the plot.

Fuel moisture contents

Moisture content of live and dead fuels was obtained from clipped samples immediately before each burning. As the moisture content levels may vary greatly among different species, samples were taken from different plant species on a relative basis such that each plant was represented according to its relative coverage in the burning plot. Samples were weighed, taken to the lab and oven-dried at 105°C for 24 h. Fuel moisture was expressed as a percentage of dry weight.

Environmental variables and fire behavior

A series of 18 burning plots were established at the experimental burning site. Each plot was more or less 0.06 ha (20 × 30 m), and was 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.

Wind speed, relative humidity, and air temperature were recorded at 15 s intervals during each fire. Plots were burned over under varying temperature, relative humidity, fuel moisture and wind speed conditions. Fires were started with a drip torch to rapidly establish a fire line along the windward edge of each plot. Fire intensity was calculated using Byram's equation (1959):

$I = Hwr$

Where, I is the fire line intensity (kW m^{-1}), H is heat yield of the fuel (kJ kg^{-1}), w is the dry weight of the fuels consumed by the fire (kg m^{-2}) and r is the rate of spread of the flaming front (m s^{-1}). In this study, an energy content of 19000 kJ kg^{-1} was used based on the relevant information (Brown and Davis, 1973; Alexander, 1982; Bilgili and Saglam, 2003).

Postburn fuel sampling

Postburn fuel loading was estimated after each fire to determine fuel consumption. Remaining fuel in each plot was estimated by clipping, oven drying and weighing all material form randomly selected three 3 × 3 m sample plots. Fuel consumption was calculated based on the difference between pre- and post-burn fuel loadings.

Table 1. Pre-burn fuel characteristics associated with the experimental fires.

Fire no	VC	H (m)	Moisture Contents (%)		Fuel loadings (kg m^{-2})[a]			
			Live fuels	Dead fuels	FL_{lf}	FL_{lm}	FL_a	FL_t
1	0.70	2. 50	60.30	13.30	1.58	1.05	1.68	3.38
2	0.95	3.00	78.00	50.00	2.17	1.63	2.37	5.13
3	0.75	2.00	88.50	21.90	1.27	0.84	1.52	2.81
4	0.75	2.60	90.00	25.00	1.68	1.15	1.80	3.69
5	0.90	2.00	72.10	27.60	1.34	0.93	1.71	3.15
6	0.70	2.50	78.60	24.20	1.58	1.05	1.68	3.38
7	0.80	2.30	82.10	23.50	1.50	1.04	1.73	3.40
8	0.90	1.80	78.60	33.30	1.21	0.80	1.59	2.80
9	0.90	2.00	95.30	52.40	1.34	0.93	1.71	3.15
10	0.85	2.20	118.80	22.50	1.45	1.02	1.75	3.37
11	0.90	1.75	164.00	67.60	1.18	0.77	1.56	2.71
12	0.60	2.00	130.10	37.30	1.19	0.74	1.33	2.47
13	0.95	2.50	133.20	38.10	1.74	1.30	2.07	4.20
14	0.85	2.75	126.80	33.00	1.87	1.35	2.05	4.29
15	0.80	2.75	125.60	28.50	1.84	1.29	1.96	4.10
16	0.60	2.00	125.60	28.50	1.19	0.74	1.33	2.47
17	0.80	2.50	125.60	28.50	1.64	1.15	1.83	3.71
18	0.90	2.75	142.50	34.90	1.91	1.40	2.13	4.48
Max	0.95	3.00	164.00	67.60	2.17	1.63	2.37	5.13
Min	0.60	1.75	60.30	13.30	1.18	0.74	1.33	2.47
Mean	0.81	2.33	106.43	32.78	1.54	1.07	1.77	3.48
SD	0.11	0.37	29.24	12.95	0.29	0.25	0.27	0.73
SE	0.03	0.09	6.89	3.05	0.07	0.06	0.06	0.17
N	18	18	18	18	18	18	18	18

[a] Estimated (see text for explanation).

RESULTS

Pre-burn fuel characteristics for each plot are presented in Table 1. Although the site was selected for its structural homogeneity, there was an apparent variation in the fuel loadings in different plots. Live fine fuel biomass ranged from 1.18 to 2.17 kg m^{-2}, live medium fuel biomass from 0.74 to 1.63 kg m^{-2}, available fuel biomass from 1.33 to 2.37 kg m^{-2} and total fuel biomass from 2.47 to 5.13 kg m^{-2}.

Table 2 displays the observed variations in fire behavior values and fire weather conditions recorded on site during each experimental fire. Experimental burnings were conducted under relatively wide range of weather conditions. Wind speed ranged from 4.8 to 14.4 km h^{-1}, relative humidity from 16 to 76% and air temperature from 23.7 to 36°C. Variability in weather and fuel conditions was reflected in the associated fire behavior parameters. Rate of spread ranged from 0.38 to 7.35 m min^{-1}, fuel consumption from 1.57 to 3.05 kg m^{-2}, and fire intensity from 188.72 to 5906.48 kW m^{-1}.

Correlation and regression analyses were undertaken to investigate the relationships between fire behavior characteristics and associated fuel properties and weather conditions. Table 3 displays the correlation coefficients showing trends and relationships among the independent and dependent variables. The relationships that have the best fits to the predicted variables are given in Table 4. Equations are presented with up to five independent variables as the additional independent variables increased the percent variability explained by the equation.

Rate of spread was highly correlated with wind speed (r = 0.771; $P<0.01$), relative humidity (r = -0.683; $P<0.01$) and air temperature (r = 0.586; $P = 0.05$). Wind speed alone explained 57% of observed variation ($P<0.01$) in the rate of fire spread. Squaring wind speed had a positive effect and the addition of vegetation cover as the second independent variable highly improved the percent variability explained ($R^2 = 0.737$; $P<0.01$). Relative humidity as the third independent variable improved the rate of spread prediction significantly ($R^2 = 0.821$; $P<0.01$). Similarly, the addition of the moisture content of live fuels as the third independent variable also, somewhat improved the percent variability explained in the rate of fire spread ($R^2 = 0.832$; $P<0.01$). The relationship between

Table 2. Fire behavior values and fire weather conditions associated with the experimental fires.

Fire No.	RH (%)	T (°C)	W (km h^{-1})	Rate of spread (m min^{-1})		Fuel consumption (kg m^{-2})		Fire intensity (kW m^{-1})	
				Observed	Predicted	Observed	Predicted	Observed	Predicted
1	66	25.4	10.6	1.76	1.45	2.09	2.07	1124.12	903.02
2	52	26.6	9.2	3.82	2.93	3.05	3.01	3561.35	3294.62
3	40	27.5	11.3	3.33	3.38	1.57	1.80	1601.28	1779.63
4	65	26.9	8.6	0.89	0.71	2.20	2.19	597.86	955.12
5	76	23.7	8.2	0.80	1.46	1.75	1.90	433.67	1205.78
6	28	33.5	11.6	2.10	3.93	2.03	2.12	1307.81	1947.84
7	28	32.6	10.3	2.06	3.67	2.08	2.08	1311.33	1814.18
8	28	30.5	10.3	4.28	4.33	1.92	1.72	2533.57	1569.58
9	31	30.0	12.4	5.92	5.66	2.18	1.98	4014.61	3455.41
10	31	29.6	9.1	4.05	2.91	2.02	2.03	2499.44	1852.87
11	60	26.4	4.8	0.38	0.46	1.58	1.56	188.72	1905.63
12	24	33.6	14.4	6.25	4.84	1.69	1.71	3237.43	3600.20
13	25	32.0	12.5	5.57	6.66	2.73	2.58	4655.53	5551.46
14	19	34.0	8.7	4.43	2.94	2.60	2.53	3561.15	2227.55
15	17	35.0	9.9	2.85	3.88	2.41	2.47	2108.67	2710.14
16	16	36.0	10.6	3.22	2.34	1.57	1.56	1539.39	545.10
17	17	34.0	13.2	6.06	6.18	2.37	2.35	4396.25	4374.84
18	22	36.0	13.1	7.35	6.45	2.64	2.84	5906.48	5712.45
Max	76	36.0	14.4	7.35	6.66	3.05	3.01	5906.48	5712.45
Min	16	23.7	4.8	0.38	0.46	1.57	1.56	188.72	545.10
Mean	35.8	30.7	10.5	3.62	3.57	2.14	2.14	2476.59	2522.52
SD	19.3	3.9	2.3	2.06	1.89	0.43	0.42	1622.79	1521.91
SE	4.5	0.9	0.5	0.49	0.45	0.10	0.10	382.50	358.72
N	18	18	18	18	18	18	18	18	18

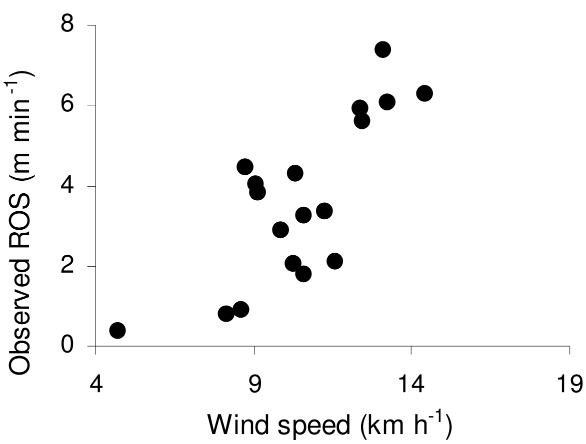

Figure 1. Relationship between wind speed and observed rates of spread.

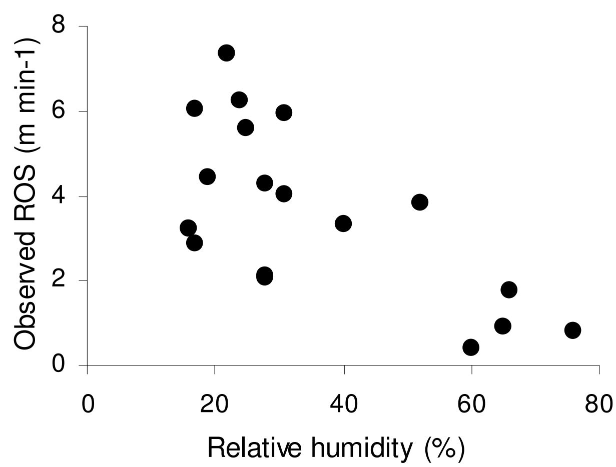

Figure 2. Relationship between relative humidity and observed rate of spread.

wind speed and observed rate of spread is shown in Figure 1. The relationship between relative humidity and observed rate of spread is shown in Figure 2.

Fuel consumption was significantly related to fuel biomass and wind speed. Live fine, live moderate, available and total fuel biomass individually explained 86, 89, 91 and 92% of the observed variation in fuel consumption,

Table 3. Correlation matrix between the variables used in the analyses.

	RH	T	MC_l	MC_d	VC	H	H^2	H×VC	ROS	W	F_{lf}	F_{lm}	F_a	F_t	FC	FI	W^2
RH	1																
T	-.933**	1															
MC_l	-.448	.496*	1														
MC_d	.058	-.098	.482*	1													
VC	.166	-.284	.073	.489*	1												
H	-.123	.227	-.050	-.197	.155	1											
H^2	-.109	.211	-.041	-.148	.184	.998**	1										
H×VC	-.019	.025	.027	.155	.677**	.828**	.844**	1									
ROS	-.683**	.586*	.363	.131	.128	.169	.166	.237	1								
W	-.574*	.551*	-.009	-.275	-.310	.131	.100	-.055	.771**	1							
F_{lf}	-.080	.150	-.019	-.040	.375	.972**	.980**	.934**	.199	.048	1						
F_{lm}	-.079	.125	.004	.016	.473*	.938**	.948**	.969**	.238	.039	.992**	1					
F_a	-.018	.024	.019	.149	.673**	.831**	.847**	1.00**	.235	-.052	.936**	.970**	1				
F_t	-.064	.100	.011	.056	.532*	.914**	.926**	.983**	.241	.014	.982**	.998**	.984**	1			
FC	-.191	.194	.031	.114	.530*	.863**	.873**	.948**	.406	.169	.934**	.955**	.948**	.960**	1		
FI	-.598**	.530*	.363	.198	.345	.397	.399	.523*	.946**	.648**	.461	.508*	.522*	.517*	.655**	1	
W^2	-.560*	.548*	.099	-.166	-.306	.072	.044	-.095	.786**	.986**	-.004	-.011	-.093	-.033	.125	.656**	1

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).
RH, relative humidity (%); T, air temperature (℃); MC_l, moisture contents of live fuels (%); MC_d, moisture contents of dead fuels (%);VC, vegetation cover; H, mean vegetation height (cm); H^2, mean vegetation height × mean vegetation height; H×VC, (mean vegetation height × vegetation cover); W, wind speed (kph); ROS, rate of spread (m min^{-1}); F_{lf}, live fine fuel loading (<0.6 cm; kg m^{-2}); F_{lm}, live medium fuel loading (0.6 - 2.5 cm; kg m^{-2}); F_a: total available fuel (<0.6 cm; kg m^{-2}); F_t, total fuel loading (kg m^{-2}); FI, fire intensity (kW m^{-1}); FC, fuel consumption (kg m^{-2}).

respectively (P<0.01) (Table 4). The addition of the wind speed as a second independent variable along with the total fuel biomass somewhat improved the variability explained (R^2 = 0.94; P<0.01). The relationship between total fuel loading and observed fuel consumption is shown in Figure 3.

Fire intensity was closely related to wind speed (r = 0.648; P = 0.01), relative humidity (r = -0.598; P = 0.01) and air temperature (r = 0.530; P = 0.05). Wind speed alone explained 39% of the observed variation in fire intensity (P<0.05). Figure 4 shows the relationship between wind speed and observed fire intensity. The addition of mean vegetation height multiplied by vegetation cover (H×VC) as the second and moisture content of live fuels as the third independent variables improved the fire intensity prediction significantly (R^2 = 0.75, R^2 = 0.82; respectively, P<0.01). Mean vegetation height as the fourth independent variable somewhat improved the observed variation of fire intensity (R^2 = 0.87, P<0.01).

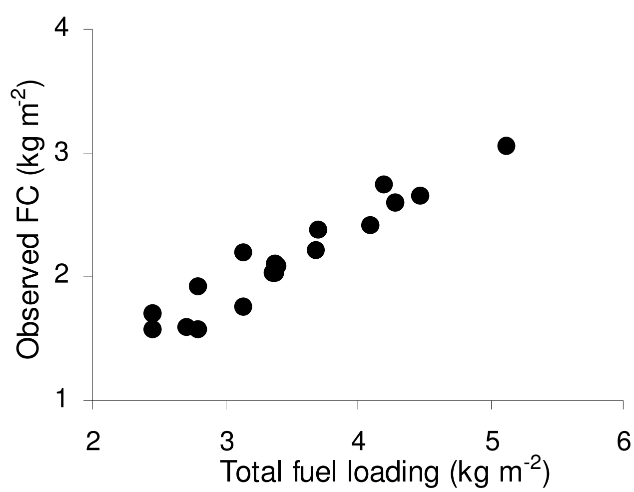

Figure 3. Relationship between total fuel loading and observed fuel consumption.

DISCUSSION

The results presented in this study come from the efforts dealing with the prediction of fire behavior in tall shrub (maquis) fuels in Turkey. In that respect, the study makes a valuable contribution to fire behavior analyses in maquis fuels in the Mediterranean region within the given range of weather and fuel conditions. This study differs from similar works conducted on maquis fuels (Bilgili and Saglam, 2003) in terms of fuel characterization, composi-

Table 4. Regression equations for predicting fire spread, fuel consumption and fire intensity in maquis fuels based on the data in this study.

Dependent Variables	Model Form	Constant and Coefficient	SE	F	R^2	Adj. R^2	SEE
ROS	1a) $Y=a+bW$	a: -3.669 b: 0.695	1.538 0.144	23.456	0.594	0.569	1.352
	1b) $Y=a+bW^2+cVC+dRH$	a: -4.906 b: 0.032 c: 7.634 d: -0.038	2.081 0.006 2.031 0.013	27.037	0.853	0.821	0.871
	1c) $Y=a+bW+cVC+dMC_l$	a: -13.207 b: 0.804 c: 7.171 d: 0.24	2.223 0.094 1.979 0.007	29.024	0.861	0.832	0.845
FC	2a) $Y=a+bF_{lf}$	a: 0.016 b: 1.379	0.207 0.132	108.962	0.872	0.864	0.159
	2b) $Y=a+bF_a$	a: -0.530 b: 1.510	0.225 0.126	143.236	0.900	0.893	0.141
	2c) $Y=a+bF_{lm}$	a: 0.404 b: 1.627	0.138 0.126	167.432	0.913	0.907	0.131
	2d) $Y=a+bF_t$	a: 0.174 b: 0.564	0.147 0.041	186.024	0.921	0.916	0.125
	2e) $Y=a+bF_t+cW^2$	a: -0.005 b: 0.567 c: 0.001	0.144 0.036 0.001	129.546	0.945	0.938	0.108
FI	3a) $Y=a+bW^2+cH\times VC$	a: -4623.159 b: 25.134 c: 2224.039	1067.234 4.344 463.146	25.871	0.775	0.745	819.005
	3b) $Y=a+bW^2+cH\times VC+dMC_l$	a: -6085.143 b: 24.121 c: 2185.034 d: 15.524	1044.575 3.661 388.488 5.727	26.997	0.853	0.821	686.511
	3c) $Y=a+bW^2+cH\times VC+dMC_l+eH$	a: -4427.973 b: 26.460 c: 3500.113 d: 13.484 e: -1804.614	1103.213 3.245 615.945 4.932 583.269	29.648	0.901	0.871	583.269

*Asymptotic Standard Error

position, structure and weather conditions. The results were based on a total of 18 experimental fires. Differences in fire behavior were clearly shown to be a function of wind speed, relative humidity, moisture contents of live fuels, vegetation cover and fuel loadings.

The fuel characteristics, structure and composition of this study differ from a recent work (Bilgili and Saglam, 2003) in maquis fuel type (e.g. mean vegetation height and mean total live fuel load less than 2.5 cm and mean total fuel load were 0.53 m, 1.63 and 2.64 kg m^{-2} in recent work, whereas these were 2.33 m, 2.61 and 3.48 kg m^{-2} in our study, respectively). While our study area includes five dominant and four other species, recent work comprises only four dominant species.

The rate of spread is a result of the combined effect of fuel, weather and environmental conditions on fire behavior (Arca et al., 2007). The results obtained in the present study indicated that wind speed and air temperature were positively correlated with the rate of fire spread, but that relative humidity was negatively correlated. The dominant effect of wind on fire spread has been reported previously for many vegetation types (e.g. Bilgili and Saglam, 2003; Williams et al., 2003; Viegas, 2004). The positive effect of wind speed on rate of fire spread is generally attributed to the increased supply of oxygen to the fire (Trollope et al., 2004) and to the tilting

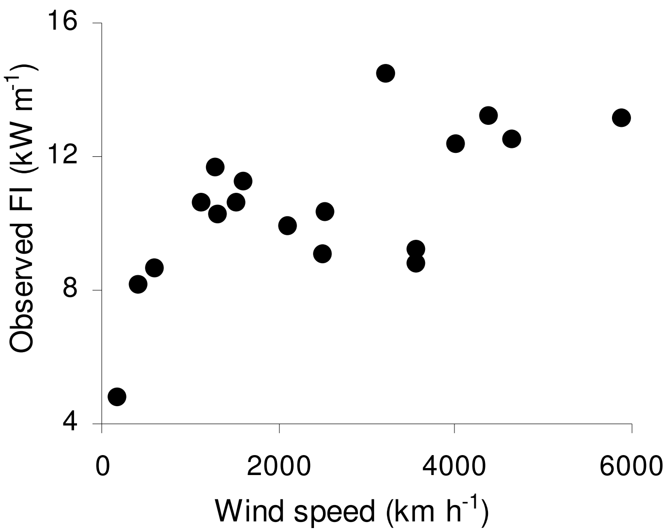

Figure 4. Relationship between wind speed and observed fire intensity.

of flames forward closer to the unburned fuels ahead, thereby increasing the radiation impinging on the fuel, and thus the rate of spread (Bessie and Johnson, 1995; Santoni et al., 2006; Savadogo et al., 2007). However, a threshold in wind speed is required for wind to influence the rate of fire spread (Catchpole, 2002; Gambiza et al., 2005). This is especially true when fuel continuity is low, and dead surface fuels are low to nonexistent. The analysis of fuel, weather and site conditions in the present study indicated that, coupled with the effects of fuel moisture contents and relative humidity, the effect of wind on the rate of fire spread was relatively low at low wind speed values. Moreover, the lack of dead surface fuels or discontinuity in surface fuels due to the underlying landform composed of rocks or boulders in some experimental plots decelerated the rate of spread especially at low wind speed values. The initiation and sustainable development of a shrubland fire requires fire to spread vertically and then horizontally though the shrub layer (Plucinski and Catchpole, 2002). In the burning plots dominated by *Arbutus andrachne*, although not statistically significant, low rates of spread were observed. In the light of Bessie and Johnson's (1995) explanation this can be attributed to the absence of vertical continuity of fuels due to lack of dead or live fuels (ladder fuel) of *A. andrachne,* which carries the fire from surface to crown.

Heterogeneities in species which have different flammability characteristics causes variation in the observed fire behavior. Shrubs that burn easily can facilitate the drying and burning of the surrounding vegetation that do not burn easily through generating great amount of energy (Santoni et al., 2006). Similarly, it was observed in the present study that when *Quercus coccifera* surrounded *Arbutus andrachne* or *Cistus creti-cus*, these species also burned easily due to the drying effects of *Q. coccifera* burning and to the filling in the gap between surface and crown, especially under relatively high wind speed conditions.

Fuel consumption in the experimental fires was significantly related to fuel loading (live fine, live moderate, available and total) and wind speed. In this regard, the results of the present study agree well with other relevant studies (Bilgili and Saglam, 2003; Savadogo et al., 2007). Fuel consumed was related to the intensity of burnings. The higher the intensity of fires, the larger the size of the fuels consumed in the flaming front.

It is generally accepted that fire intensity is the most important fire behavior property as it provides the amount of heat released during the fire and is therefore a useful indicator of its impact on plants (Alexander, 1982; Gambiza et al., 2005; Savadogo et al., 2007). Fire intensity in this study was related to wind speed, vegetation height×vegetation cover, moisture content of live fuels and vegetation height. Fire intensities observed in the present study ranged from 188.72 to 5906.48 (mean 2476.59 kW m^{-1}). These results are comparable to and agree well with the relevant literature (Trabaud, 1979; Bilgili and Saglam, 2003). Differences may be attributed to the vegetation composition and heterogeneities in the study area and in burning conditions.

Fuel moisture contents are expected to have a significant effect on ignitability (e.g. Wilson, 1985) and combustion rate (Rothermel, 1972; Catchpole et al., 1998). Moreover, the heterogeneity of vegetation was also reported to play an important role in fire behavior (Santoni et al., 2006). However, the effect of live or dead fuel moisture contents on fire behavior could not be established in this study due mostly to the great variation in vegetation structure and composition. There was little or no surface fuels and very little dead fuels, and live fuels were an important fraction of the total fuel load. Species such as *Arbutus andrachne* that do not necessarily accumulate standing dead fuel also represent discontinuity and, thus, lower moisture contents (Baeza et al., 2002). Under these conditions, it may be concluded that dead fuel moisture content has a limited influence on the overall moisture content, and, as a result, it is logical to expect that the effect of dead fuel moisture content on fire spread will be limited (Fernandes, 2001).

Given that the study is based on a relatively small number of fires with relatively narrow range of weather and fuel conditions in an open area conditions, further studies should be conducted under broader weather and fuel conditions to analyze and understand fire behavior more comprehensively in tall maquis fuels. However, the relationships developed from this study are reasonably good, and could be used as a tool in fire management planning.

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