PREDICTING FIRE BEHAVIOR IN HERBACEOUS FUEL COMPLEX AT DOI ANGKHANG, CHIANGMAI PROVINCE.

SAN KAITPRANEET[1]   BUNVONG THAIUTSA[1]

บทคัดย่อ

การคาดคะเนพฤติกรรมของไฟในแหล่งเชื้อเพลิงพวกพืชล้มลุก ได้ทำการศึกษา
ที่บริเวณดอยอ่างขาง อำเภอฝาง จังหวัดเชียงใหม่ ในเดือนมีนาคม พ.ศ. ๒๕๒๖ โดยมี
วัตถุประสงค์เพื่อกำหนดแบบลักษณะเชื้อเพลิง (fuel model) บริเวณดอยอ่างขาง และเพื่อ
คาดคะเนพฤติกรรมของไฟในแหล่งเชื้อเพลิงดังกล่าว โดยใช้สมการคำนวณของ Rothermel
ในการศึกษานี้ได้สำรวจวัดเก็บข้อมูลและวิเคราะห์หาปัจจัยตัวแปรต่าง ๆ เพื่อประกอบกันขึ้น
เป็นแบบลักษณะเชื้อเพลิงแล้วนำปัจจัยตัวแปรต่างๆ นี้ไปคำนวณในสมการ ของ Rothermel
ปัจจัยต่าง ๆ ที่ต้องวิเคราะห์หาได้แก่ ปริมาณความร้อนของอนุภาคเชื้อเพลิง ค่าความ
หนาแน่นของอนุภาคเชื้อเพลิง ปริมาณแร่ธาตุทั้งหมดของอนุภาคเชื้อเพลิง ปริมาณแร่ธาตุ
ที่ไม่รวมซิลิกาของอนุภาคเชื้อเพลิง อัตราส่วนพื้นที่ผิวต่อหน่วยปริมาตรของอนุภาคเชื้อเพลิง
ปริมาณความชื้นของเชื้อเพลิงที่ไฟไม่ลุกลาม ปริมาณความชื้นของอนุภาคเชื้อเพลิง ปริมาณ
น้ำหนักแห้งของเชื้อเพลิงต่อหน่วยเนื้อที่ ความหนาของแหล่งเชื้อเพลิง ความเร็วลม และ
ความลาดชันของพื้นที่ ผลการคำนวณด้วยคอมพิวเตอร์โปรแกรม FIREMOD โดยกำหนด
ให้ปัจจัยตัวแปรต่าง ๆ ที่เป็นคุณสมบัติของเชื้อเพลิงคงที่ เพื่อให้ค่าพฤติกรรมของไฟเปลี่ยน
แปลงไปตามปัจจัยสิ่งแวดล้อมต่าง ๆ โดยกำหนดให้ความเร็วลมผันแปรในช่วง ๐–๑๐ ไมล์
ต่อชั่วโมง ความลาดชันของพื้นที่ในช่วง ๐–๔๐ เปอร์เซ็นต์ และความชื้นเชื้อเพลิงผันแปร
ในช่วง ๖–๒๐ เปอร์เซ็นต์ ปรากฏว่าศักยภาพพฤติกรรมของไฟบริเวณดอยอ่างขางมีค่า

[1] Department of Silviculture, Faculty of Forestry, Kasetsart University, Bangkok.

อัตราการลุกลามของไฟอยู่ในช่วง ๐.๐๒๒–๒.๙๗๘ เมตรต่อวินาที ความรุนแรงของไฟ
อยู่ในช่วง ๔๙๑.๑๒๑–๙๗๙๗๑.๗๖๒ กิโลวัตต์ต่อเมตร และความยาวของเปลวไฟอยู่
ในช่วง ๑.๓๔–๑๕.๓๓ เมตร เมื่อนำค่าการคาดคะเนไปเปรียบเทียบกับค่าที่ได้จากการ
ทดลองเผาในสภาพแวดล้อมระดับเดียวกัน ปรากฏว่าผลการคาดคะเนความรุนแรงของไฟ
และความยาวของเปลวไฟมีค่าใกล้เคียงกับค่าที่ได้จากการทดลองเผา ส่วนการคาดคะเนอัตรา
การลุกลามมีค่าน้อยกว่าการทดลองเผา ๕ เท่า ทั้งนี้อาจเนื่องมาจากไม่ได้วัดความเร็วลม
ขณะไฟกำลังลุกลาม ความเร็วลมที่วัดก่อนจุดไฟย่อมน้อยกว่าความเร็วลมในขณะที่ไฟกำลัง
ลุกลาม แต่ว่าอัตราการลุกลามของไฟที่คำนวณจากสูตร Rothermel ก็สมเหตุผลกับความเร็ว
ลมที่กำหนดให้ อย่างไรก็ดีศักยภาพพฤติกรรมของไฟบริเวณดอยอ่างขางจัดอยู่ในสภาพ
อันตรายปานกลางถึงขั้นอันตรายมาก ถ้าเกิดไฟขึ้นควรดับไฟโดยวิธีอ้อม ส่วนการป้องกัน
ไฟโดยการสร้างแนวกันไฟนั้นควรมีความกว้างอยู่ในช่วง ๑๕–๓๐ เมตร อย่างไรก็ตาม
ผลการศึกษานี้มีประโยชน์อย่างมากในการวางแผนการจัดการไฟป่าและการเผาตามกำหนด
เพื่อลดอันตรายไฟ

ABSTRACT

Predicting fire behavior in herbaceous fuel complex was conducted in
Summer, 1983 at Doi Angkhang, Fang District, Chiangmai Province, in order to
construct fuel model for herbaceous fuel complex and to predict fire behavior in
the herbaceous fuel complex at Doi Angkhang using Rothermel's fire spread model.
The herbaceous fuel complex was characterized and variables were adjusted for
use in Rothermel's (1972) spread model. The fire behavior predictions were
attempted in various conditions of wind speeds ranged from 0 to 10 miles per hour,
slopes ranged from 0 to 40 percent, and fuel moisture contents ranged from 6 to
20 percent. The program outputs were predicted rates of fire spread ranged from
0.022 to 2.978 meters per second, the predicted fire line intensities ranged from
491.121 to 97971.762 kilowatts per meter, and the predicted flame lengths ranged

from 1.34 to 15.33 meters. Two experimental fires were conducted to test against the predicted fire behaviors. The predicted values of fire line intensities and flame lengths were closely agreed with the observed values, except, the predicted rate of fire spread was five times less than the observed value, it might be due to wind speed was not measured at the time of burning. However, the predicted values of rate of fire spread are more reasonable to the given ranges of wind speed, thus, the information of this study still be useful in fire management planning and in land use planning.

INTRODUCTION

As known that most forests on mountainous areas in the northern part of Thailand have been illegally cut for shifting cultivation and then most areas have been abandoned covering with dense grasses and forbs. During dry season, the herbaceous plants are desiccated and inflammable the fires occur almost every year. Because of frequent fire, no any economic tree takes place in the burned area. For land use planning and fire control activity, the herbaceous plants as fuel complex must be evaluated in term of fire behavior.

Recently, fuel evaluation in term of fire behavior in most part of the United States of America by using Rothermel's fire spread model (Rothermel, 1972) has been well succeeded. The method consists of fuel modelling and fire behavior prediction. In fuel modelling, a fuel model, is a set of parameter inputs, required for the solution of Rothermel's fire spread model, must be established by either simulation or measurement. The parameter inputs include fuel loading, fuel bed depth, heat content, particle density, total ash fraction, silica—free ash content, surface area—to—volume ratio, moisture content, moisture content of extinction,

wind speed and slope of terrain. Fire behavior prediction, the parameter inputs are specified and are solved via a computer program library, FIREMOD, which was organized by Albini (1976). The program outputs are rate of fire spread, fire intensity and flame length. The Rothermel's model predicts fire behavior well enough if the fuel is relatively homogeneous, single layer and contiguous to the ground but it can not be employed to predict crown fires and spotting conditions (Rothermel, 1972).

Doi Angkhang in Chiangmai Province is one of the problem areas as described earlier and the existing fuel condition in also corresponded to the assumptions in Rothermel's fire spread model. Yet, characteristics of fuel and fire behavior at Doi Angkhang have not been documented. Thus, the purposes of this study were to construct a fuel model of herbaceous fuel complex and to estimate fire behavior in the herbaceous fuel complex using the Rothermel's fire spread model. Besides, two experimental fires were conducted to observe actual fire behavior. The predicted fire behavior was compared against observed fire behavior so that adjustments could be made prior to use in critical application.

STUDY AREA

The study area is a part of Ang—Khang mountainous range, near Royal Ang—Khang Station at Fang District in Chiangmai Province. The general area is mountainous and undulating with the average elevation of 1400 meters above mean sea level. The soil is classified into two great soil groups namely : yellow podzolic and reddish brown lateritic soils within Pak—Chong Series. Soil textures of upper and lower soil layers are clay loam and clay which are derived from shale and limestone (Mantanont, 1977)

The area is now classified as abandoned shifting cultivation covering with dense grasses and forbs. The common species are Ya—kha (*Imperata cylindrica*. Beauv.), Sab—maa (*Eupatorium adenophorum*. Spreng.) and Goat—Chula—lampa (*Artemisia pallens* wall. ex Bess.) and the less common species are Khlong—kheng—khee—nok (*Metastoma malabuthricum*. Linn.), Khai—poo—yai (*Rubus alceifolius*. Poir.), Naam—khai—goong (*Rubus ellipticus* Sm.), Shown—pai (*Pteridium aquilium* (L) Knhn.), Dua—plong—din (*Ficus semicordata* J.E. Sm), Paya—dong (*Polygonium chinense* Linn.), Plug—plab (*Commelina of palndosa* BL.), Plai—sarn (*Eurya acuminata* DC.), Ma—dua—hom (*Ficus hirta* Vahl.), and Ma—mui (*Macuna gigantea* DC.), The vegetation is a single layer and exists in large expanses of continuous fuel that is contiguous to the ground.

The climate of the area is cool and wet all year round due to high elevation and mountainous area. However, the climate can be classfied into three seasons namely : Rainy season starts from May to September, Winter starts from October to February, and Summer starts from March to May. The climatic data recorded at Angkhang experimental station about ten years revealed that the average monthly precipitation is about 107.7 mm., the average temperature is about $17.5^{\circ}C$ with the average values of maximum and minimum are $23.4^{\circ}C$ and $11.5^{\circ}C$, respectively, and the average relative humidity is about 70.9% with the average values of maximum and minimum are 91.5% and 50.2%, respectively (Chunkao, 1982).

METHODS

Site Selection and Plot Layout

Site selection was made in November, 1982. The selected site would be a representative site in the area. Two sample plots, 20×20 m^2 size of each, were laid out side by side, approximately 30 meters apart. Thirty meter wide fireline was made around each sample plot.

Data Collection

The aims of this study are to construct fuel model and to estimate fire behavior using Rothermel method. The parameter inputs required by the method are heat contents, fuel particle density, mineral content, silica free minerals, surface area-to-volume ratio, fuel loading, fuel depth, fuel particle moisture content, moisture content of extinction, wind speed, and terrain slope. To complete the parameter input set, the data sources include field procedure, laboratory procedure and literature citation as following :

Field Procedure

Fuel moisture content

Six vegetative samples both live and dead were collected in plastic bottles which were sealed for subsequent analysis.

Fuel depth

Fuel depth, here in, is the height of vegetation which was measured in March, 1983. Six measurement were taken in each plot by random sampling and the average value was then computed as a representative fuel depth in the area.

Fuel loading

Fuel loading is the ovendried weight of vegetation per unit area. Six vegetative samples within 1×1 m^2 plot in size of each were clipped closed to the ground and weighed. Then, the fresh weight was converted to overdried weight when its moisture content was known.

Wind speed

Wind speed was measured using pocket wind meter for several times in summer to obtain representive values of minimum and maximum in the area.

Terrain slope

The terrain slope was measured by using Haga hypsometer.

Office and Laboratory Procedure

Fuel moisture content

The collected vegetation samples were weighed and were ovendried at 70°C for 24 hours. Dried samples were weighed and fuel moisture contents were determined as follow :

$$\% \text{ Moisture content} = \frac{\text{Fresh weight} - \text{Ovendried wright}}{\text{Ovendried weight}} \times 100$$

Fuel loading

Fresh weight values of fuel loading were converted to ovendried weight and then average value from six samples was calculated.

Mineral or ash content

Ash content was determined in a muffle furnace. The collected vegetation samples were ovendried at 105°C for 24 hours and weighed. The ovendried samples were ground and were put in crucibles. All of the samples were then ashed in the furnace at 750°C for 3 hours, cooled in a dessicator for 15 minutes and reweighed (Mingle and Boubel, 1966)

Literature cited data

Due to either low natural variability of some fuel properties within same vegetative species or low sensitive data to the model, the following data were taken from the literature are heat content, surface area—to—volume ratio, particle density, moisture content of extinction and silica free mineral content.

Conducting Experimental Fire

To test the Rothermel spread model, two sample plots were burned in March, 1983. On tested burn, climatic data were recorded, are relative humidity

and wind speed and fire behavior parameters, rate of fire spread, flame length, and fireline intensity, were measured and determined. The fireline intensity was determined by Byram (1959) equation.

Data Analysis

Fuel model

Due to each parameter input to be a single value, therefore, the measured data must be calculate to obtain average value which was then converted to English unit system as required by FIREMOD computer program.

Fire behavior predication

All collected data as the parameter input set was used to compute fire behavior by using Rothermel's equation via computer program (FIREMOD) written by Albini (1976). The program outputs were forward rate of fire spread, fireline intensity and flame length.

RESULTS AND DISCUSSION

Fuel Model of Herbaceous Fuel Complex

The vegetative community at Doi Angkhang, Chiangmai Province consists mostly of herbaceous plants include grasses and forbs which can be regarded as a source of fuel, and its components are thus a fuel complex. For fire management purposes, the fuel complex must be characterized and evaluated in terms that relate to fire behavior. Rothermel method (Rothermel, 1972) is handled readily to serve the purposes. The herbaceous plants at Doi Angkhang exist in large expanse of relativety continuous, single layer vegetation that is contiguous to the ground. Thus, the herbaceous fuel complex satisfies the assumptions of Rothermel fire spread model. Fuel model of the herbaceous fuel complex was then constructed and shown in Table 1.

Table 1. Fuel model of herbaceous fuel complex at Doi Angkhang, Chiangmai Province

Parameter inputs		Sources
fuel particle low heat content (Btu/lb)	8000	Albini (1976)
fuel particle density (lb/ft^3)	32	Albini (1976)
fuel particle total mineral content (fraction)	0.05	this study
fuel particle effective mineral content (fraction)	0.01	Albini (1976)
fuel particle surface area—to—volume ratio (ft^{-1})	1500	Albini (1976)
fuel moisture content of extinction (fraction)	0.25	Albini (1976)
fuel particle moisture content (%)	6,9,14,20	this study
total fuel load (lb/ft^2)	0.451	this study
fuel bed depth (ft)	4.4	this study
wind speed (miles/hr)	0,2,4,6,8,10	this study
terrain slope (%)	0,10,20,30,40	this study

The input values of fuel particle properties include low heat content, particle density, effective mineral content, and surface area—to—volume ratio were taken from the Northern Forest Fire Laboratory (NFFL) Fuel Model L (Tall grass) in U.S.A. (Albini, 1976) due to low natural variability of the fuel properties within same vegetative species. Especially, low heat content, particle density, total mineral content and effective mineral content were also treated as constant parameters in modelling due to their low natural variability or the Model's low sensitivity to them (Rothermel, 1972). For surface area—to—volume ratio can be considered constant within each fuel species' size class, the value was taken from the literature due to the same fuel type (grass fuel). Although the total mineral content was analyzed in this study, the value of 0.05 was the same as in literature (Albini, 1976). This, in return, proved that the parameter input was species dependent.

The moisture content of extinction is required by the Rothermel spread model, but it is not easily determined for most natural fuel. This parameter is also treated as a constant due to a lack of quantitative data. Therefore, a value of 0.25 for herbaceous plant was taken from NFFL fuel model L (for tall grass) (Albini 1976).

The values of fuel load and fuel bed depth were determined in present study because they are distinguished one fuel array from another. The two input values were the average of collected samples and should be the representive values of the area.

Fuel moisture content of dry herbaceous fuel is a specific time—and space—measurable parameter because it is sensitive to surrounding environment. In addition, it can be specified in prescribed burning prescriptions. The moisture contents of dry herbaceous fuel were determined in this study. Four values of the fuel moisture content were assigned to the model for predicting fire behavior in various weather conditions during Summer. These values were also covered the ranges of minimum and maximum moisture contents of dry herbaceous fuel in Summer.

Values for mid—flame wind speed were varied from zero through 10 miles per hour in 2 miles per hour increments which were assigned to the model for predicting fire behavior in various wind speed conditions.

The values for terrain slope were varied from zero through 40 percent in 10 percent increments which were modelled for predicting fire behavior in various slope conditions.

The two latter input values were covered the ranges of mininum and maximum values of field measurement.

Fire Behavior Prediction

Before interpreting or applying any of the results of the following fire behavior predictions for herbaceous plant community, it should be noted that fire behavior predictions from the Rothermel model are valid only for uniform wind conditions and a continuous, homogeneous fuel layer that is contiguous to the ground. Wind speed, wind direction, and the characteristics of the fuel layer will vary on actual fires, causing divergence of predicted values from observed fire behavior. Thus, the predictions will be compared against observed fire behavior, and adjustment made prior to use. Other concerns not currently included in the fire behavior model are the influence of spotting on fire spread and intensity, and crown fires. Finally ,the spread model assumes that fire behavior has reached a quasi–steady state. However, the resulting information should still be useful in fire management planning. Since computer access is not always available the results have been presented as tables.

Table 2 shows changes in the predicted rates of fire spread in herbaceous fuel complex at Doi Angkhang, Chiangmai Province with various conditions of terrain slopes, wind speeds and fuel moisture contents. For a given level of fuel moisture content, the predicted rate of fire spread increases with increasing wind speed and it also increases with increasing slope, and a combined effect of wind speed and slope result in faster rate of fire spread. The reasons are due to wind directly affects the rate of oxygen supply to the burning fuel and strong winds increase the rate of fire spread by tilting the flames closer to unbruned fuel, so does the slope for the latter reason of wind (Brown and Davis, 1973; Steward, 1974). Regardless of wind speed and percent slope, the predicted rate of fire spread increases at lower fuel moisture content which is due to the pro-

Table 2. Predicted rates of fire spread (m/s) in various conditions of fuel moisture content, wind speed and terrain slope.

Slope (%)	Fuel moisture content (%)	wind speed (miles per hour)					
		0	2	4	6	8	10
0	6	0.056	0.379	0.855	1.419	2.045	2.716
	9	0.045	0.307	0.704	1.162	1.676	2.229
	14	0.039	0.251	0.569	0.944	1.363	1.816
	20	0.022	0.162	0.363	0.604	0.866	1.157
10	6	0.073	0.397	0.872	1.436	2.056	2.733
	9	0.056	0.324	0.715	1.173	1.688	2.241
	14	0.050	0.263	0.581	0.956	1.375	1.827
	20	0.028	0.168	0.369	0.609	0.877	1.162
20	6	0.123	0.441	0.922	1.486	2.107	2.780
	9	0.101	0.363	0.754	1.218	1.727	2.279
	14	0.078	0.296	0.615	0.989	1.408	1.855
	20	0.050	0.189	0.391	0.631	0.894	1.185
30	6	0.201	0.525	1.006	1.565	2.190	2.867
	9	0.168	0.430	0.821	1.285	1.794	2.347
	14	0.134	0.352	0.671	1.045	1.464	1.911
	20	0.084	0.224	0.425	0.665	0.933	1.218
40	6	0.319	0.637	1.118	1.682	2.302	2.978
	9	0.257	0.525	0.916	1.375	1.889	2.442
	14	0.212	0.425	0.749	1.123	1.537	1.989
	20	0.134	0.274	0.475	0.715	0.978	1.268

duction of sufficient water vapor during the preheating processes so as to dilute the volatile gas-air mixture ; if a sufficient amount of vapor is present, the mixture becomes so dilute that subsequent ignition and spread can not occur (Berlad et al., 1971). Thus, the higher the wind speed, the higher the slope, the lower the fuel moisture content, the faster the rate of fire spread.

Table 3. shows the changes in predicted fire line intensities in herbaceous plant community at Doi Angkhang, Chiangmai Province with different combinations of terrain slopes, wind speeds and fuel moisture contents. For a given level of fuel moisture content, the predicted fire line intensities increase with wind speeds and with slopes as would be expected. The predicted fire line intensities decreasing fuel moisture content, for all levels of wind speeds and slopes. For all combinations of wind speeds, slopes, and fuel moisture contents, the predicted fire line intensities range from 491.121 to 97,971.762 kW/m. According to Andrew (1980), the ranges of predicted values are classified as medium to extreme fire hazards. The predicted values ranged from 491.121 to 3458.60 kW/m, could be controlled by indirect method of fire suppression. The predicted values above 3458.60 kW/m may present serious control problems due to they are over limit of machine control. However, prescribed burning could be done at higher fuel moisture content, lower slope and calm conditions for fire hazard reduction.

Table 4 shows the changes of the predicted flame lengths in herbaceous fuel complex at Doi Angkhang, Chaingmai Province with different combinations of wind speeds, slopes, and fuel moisture contents. For all levels of fuel moisture content, the predicted flame lengths increase with wind speeds and with slopes as would be expected. The predicted flame lengths decrease with increasing fuel moisture content, for all levels of wind speeds and slopes. According to Andrew

Table 3. Predicted fireline intensities (kW/m) in various conditions of fuel moisture content, wind speed and terrain slope.

Slope (%)	Fuel moisture content (%)	wind speed (miles per hour)					
		0	2	4	6	8	10
0	6	1815.765	12457.126	28163.379	46642.679	67172.929	89380.599
	9	1348.854	9241.379	20924.530	34655.172	49907.598	66408.579
	14	1037.580	7103.964	16082.490	26638.137	38362.791	51405.477
	20	491.121	3358.301	7602.003	12589.304	18129.981	24123.735
10	6	2351.848	12973.209	28699.463	47178.763	67712.471	89916.683
	9	1750.052	9639.118	21322.269	35052.911	50308.796	66806.318
	14	1345.395	7408.321	16390.305	26945.953	38670.607	51349.834
	20	636.382	3500.103	7747.264	12734.565	18275.242	24268.996
20	6	3963.556	14584.916	30311.170	48790.470	69320.719	91528.390
	9	2946.727	10835.794	22518.945	36249.587	51505.471	68002.993
	14	2265.383	8328.309	17310.293	27865.940	39590.591	52273.280
	20	1068.707	3935.887	8183.048	13170.349	18711.026	24704.779
30	6	6650.888	17272.248	32995.044	51477.802	72008.052	94212.264
	9	4942.339	12831.406	24514.557	38245.199	53501.083	69998.605
	14	3797.543	11863.927	18845.911	29398.100	41122.754	53805.440
	20	1795.013	4662.193	8905.895	13893.196	19437.332	25431.086
40	6	10410.386	21031.747	36754.542	55237.301	75767.550	97971.762
	9	7733.429	15625.955	27309.106	41039.748	56292.174	72793.164
	14	5945.333	12011.718	20990.243	31545.891	43270.545	55953.231
	20	2808.383	5675.563	9919.265	14910.025	20450.702	26444.456

Table 4. Predicted flame lengths (m) in various conditions of fuel moisture content, wind speed and terrain slope.

Slope (%)	Fuel moisture content (%)	wind speed (miles per hour)					
		0	2	4	6	8	10
0	6	2.438	5.913	8.626	10.881	12.893	14.691
	9	2.134	5.182	7.529	9.509	11.247	12.802
	14	1.889	4.572	6.675	8.412	9.967	11.339
	20	1.341	3.231	4.724	5.974	7.041	8.047
10	6	2.743	6.035	8.717	10.942	12.924	14.720
	9	2.407	5.273	7.589	9.540	11.278	12.832
	14	2.134	4.663	6.736	8.473	9.947	11.369
	20	1.524	3.322	4.755	6.005	7.071	8.077
20	6	3.505	6.370	8.931	11.125	13.076	14.844
	9	3.048	5.578	7.803	9.693	11.399	12.954
	14	2.713	4.938	6.888	8.595	10.089	11.460
	20	1.920	3.505	4.877	6.096	7.163	8.138
30	6	4.450	6.888	9.296	11.399	13.289	15.057
	9	3.871	6.005	8.108	9.936	11.613	13.136
	14	3.444	5.334	7.163	8.808	10.272	11.643
	20	2.438	3.779	5.090	6.248	7.285	8.223
40	6	5.456	7.559	9.754	11.765	13.625	15.330
	9	4.755	6.584	8.504	10.272	11.887	13.350
	14	4.206	5.802	7.529	9.080	10.516	11.826
	20	2.987	4.145	5.334	6.431	7.437	8.382

(1980), the predicted flame length in Table 4 can be interpreted as follows: the predicted values between 1.341 and 3.35 meters are under machine control; the predicted values over 3.35 meters are over limit of machine control. These interpretation are in the line with the predicted fire line intensities as bescribed earlier. In addition, the predicted flame lengths provide a rough guide to the minimum width of fireline required, a width of fireline would have to be at least equal to the flame length in order to achieve containment at the fire head.

Experimental Fires

To test predicted fire behavior, two sample plots of 20×20 m^2. size of each were burned in March, 1983 in conditions of 24 percent relative humidity, wind speeds ranged from 4 to 8 miles per hour, 30 percent slope, and 9 percent fuel moisture content. The results of observed fire behavior were compared to predicted values in the same environmental condition as shown in Table 5.

Table 5. Comparison of predicted fire behavior and observed fire behavior in the same environmental condition.

Fire behavior descriptors	Predicted values	Observed values
Rate of fire spread (m/s)	1.3*	6.67
Fireline intensity (kw/m)	38753.613*	38627.831
Flame length (m)	9.89*	10

Noted* : The averages of underlined values in Table 2, 3, and 4.

Interestingly, the predicted values of the fireline intensity and the flame length are very closed to the observed values, but the observed rate of fire spread is five times as much as the predicted value. The striking differences of the two rates of fire spread might be due to wind measurement was not recorded during actual burning. According to Rothermel (1972), the fire spread model is most sensitive to the wind speed parameter, a change in wind speed generally affects a proportional or greater than proportional change in the spread rate, in addition. More over, the accuracy of the Rothermel model is a factor of two, thus, if wind measurement was taken during fire, the predicted values would closely agree with the observed values. However, all of the predicted values seem reasonable within the ranges of given environmental conditions.

CONCLUSIONS

Fuel model of herbeceous fuel complex at Doi Angkhang in Chiangmai Province was constructed. Predicting fire behavior in the herbaceous fuel complex using Rothermel's fire spread model was successful within the ranges of environmental conditions. With the given conditions fuel moisture contents ranged from 6 to 20 percent, wind speeds ranged from 0 to 10 miles per hour and terrain slopes ranged from 0 to 40 percent, the predicted rates of fire spread ranged from 0.022 to 2.978 meters per second, the predicted fire line intensities ranged from 491.121 to 91971.762 kilowatts per meter, and the predicted flame lengths ranged from 1.342 to 15.33 meters.

Regarding to tested fires, the predicted values of fireline intensities and flame lengths were closely agreed with the observed values. But the observed rate of fire spread was five times as much as the predicted rate of fire spread, it might be due to the most sensitive parameter of the fire model, wind speed,

was not measured at the time of burning and the given wind speed might be lower than the actual wind speed. Regardless of the error wind measurement, the Rothermel method is a very useful tool for fuel evaluation. Thus, to improve fire control efficiency, other fuel types should be attempted.

However, the information of this study should still be useful in fire management planning and land use planning.

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