5.5 CORRELATION OF MASS LOSS RATE AND FLAME HEIGHT FOR LIVE FUELS

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1 INTRODUCTION

The flame of a wildland fire is the visible manifestation of combustion processes in wildland fuels. The flame is a heat source that affects its immediate surroundings. Energy transferred from a flame to the environment can cause a variety of fire effects to plants, animals, soil, and air. Models predicting fire effects as a function of the flame are widely used. Van Wagner (1973) developed

As part of a larger program studying fire spread mechanisms in live fuels, notably chaparral, experimental work is being conducted at Brigham Young University (BYU), the University of California at Riverside (UCR), University of California at Berkeley (UCB), and the USDA Forest Service Forest Fire Laboratory (FFL) in Riverside, CA, USA. Work at BYU is examining combustion characteristics of live fuels such as time to ignition, ignition temperature, mass loss, etc. by burning individual leaf and branch samples (Pickett et al. (2005), Engstrom et al. (2004), Smith (2004)). At UCR, techniques to determine velocities in the flame using particle imaging velocimetry and a thermal analogue are being developed (Zhou et al 2003, Sun et al (in press)). Experimental work examining marginal burning of 2 m long fuel beds composed of individual chaparral species is being conducted at FFL (Weise et al 2005, Zhou et al 2005). Measurement of fire characteristics in prescribed burns in chaparral is being performed by UCB and at FFL. This paper examines the relationship between flame measurements and mass loss using data from the experiments at BYU, UCR, and FFL.

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A significant amount of work relating flame length to mass loss rate and heat release rate has been performed since the early 1960s. A summary of that work is not presented here, but the interested reader is referred to Drysdale (1999) and Sun et al (2005).

2 METHODS

The experimental setup for the 3 types of data is described in section 2.1. Statistical analysis of the data is described in section 2.2.

2.1 Experimental Setup

Material for all chaparral experiments at BYU, UCR, and FFL were collected at the North Mountain Experimental Area located 50 km east of Riverside, CA at an elevation of 1160 m. Samples of California chaparral were cut and sent by express mail to Utah. Four species were examined: manzanita (*Arctostaphylos parryana*), oak (*Quercus berberidifolia*), ceanothus (*Ceanothus crassifolius*),and chamise (*Adenostoma fasciculatum*).

The experimental apparatus at BYU was designed to closely resemble the conditions of a forest fire flame front. To simulate these conditions the fuel sample (a leaf or branch (chamise)) was attached to a stationary horizontal rod connected to a cantilever-type mass balance. A flat-flame burner (FFB) was positioned on a moveable platform to simulate the flame front. The platform was pulled by a 0.5- hp motor (Leeson) at a constant velocity toward the fuel sample. The postflame gases from the FFB simulated heat transfer by convection. A video camera recorded the burning foliage. Flame length was measured from individual frames on the video.

Circular pans of green and dry chaparral fuels were placed on an electronic scale and ignited. Pans were 30, 45, and 60 cm in diameter and a constant loading of 2.12 kg m^{-2} was used. Each pan was ignited using an alcohol-soaked paper towel put in the bottom of the pan underneath the chaparral fuel. A height marker was placed adjacent to the scale to provide a reference scale. A video camera and thermal infrared camera recorded each experiment. Mass loss was measured using the electronic scale and flame length was determined from still images taken from the video.

The effects of wind, fuel moisture content, fuel bed height and slope on flame propagation in live fuels are being investigated using fuel beds (2m long × 1.0m wide × various depths) constructed of live branch material < 0.64 cm and foliage material. The fuel beds were elevated above the surface of a tilting platform by 40 cm to simulate an aerial fuel. Air could be entrained from the ends of fuel beds; metal sheeting prevented air entrainment from the sides to reduce the curvature of the flame front and simulate a line fire. Plant material was generally collected in the morning so as to minimize moisture loss through transpiration. Dead fuel was removed to the extent possible. A fuel bed was ignited along the 1m side with a flame zone depth of 50 cm section along the length of the live fuel bed. Between 300 and 400 g of excelsior and a small amount of isopropyl alcohol were added uniformly in the ignition zone to initiate and sustain the ignition. A video camera recorded each experiment (over 200) and flame length was determined from the video. Mass loss was determined by placing load cells under the frame holding the fuel bed.

2.2 Data Analysis

Mass loss and flame length data from up to 4 species were analysed. Mass change and mass loss rates were calculated for each test. Representative plots of mass change and mass loss are presented. Species differences and effects of moisture content on mass loss rates will be analyzed but is not presented here. Mass loss rates for all data were plotted against flame length and a simple linear regression model was fit to the data. Additional analyses will be performed and presented.

3 RESULTS AND DISCUSSION

The results presented here include a summary of the experiments that the mass loss and flame length data came from as well as several plots and a simple linear regression model. Additional analysis and results will be presented.

3.1 Test summary

Over 1000 leaf samples have been tested in the BYU flat flame burner. Of these, mass loss rate (MLR) and flame length (Lf) were available for 442 tests (Table 1). The mean initial sample masses ranged from 0.03 to 0.25 g for the leaf tests, were approximately 550 g for the pan tests, and was 1159 g for the 2 bed tests. The mass data represent a range of 5 orders of magnitude. The mass loss rate data spanned 4 orders of magnitude and the flame length data spanned 3 orders of magnitude with flame lengths of 0.035 m (laminar flames) to 1.4 m (turbulent flames).

Size	Species	N	Mass (g)	MLR (g/s)	Lf (m)
Leaf	Cean	94	0.09	0.009	0.049
Leaf	Cham	10	0.17	0.015	0.035
Leaf	Goak	41	0.16	0.024	0.062
Leaf	Manz	114	0.25	0.022	0.062
Leaf	Mapl	77	0.17	0.028	0.054
Leaf	Quer	83	0.23	0.022	0.062
Leaf	Sage	3	0.03	0.008	0.047
Pan	Cean	18	547.50	8.23	1.275
Pan	Cham	27	551.94	11.85	1.492
Pan	Manz	18	560.67	10.13	1.210
Bed	Cham	2	1159	18.35	1.42

Table 1. Summary of experimental tests of live California chaparral and Utah species. Chaparral species included: Manz – manzanita, Cean – ceanothus, Cham – chamise, Quer – scrub oak. Utah species included: Mapl – bigleaf maple, Sage – sagebrush, Goak – Gambel oak.

3.2 Mass change profiles

The change in mass amongst the 3 sets of experiments was similar (Figure 1). The mass loss rates for the same tests are presented in Figure 2.

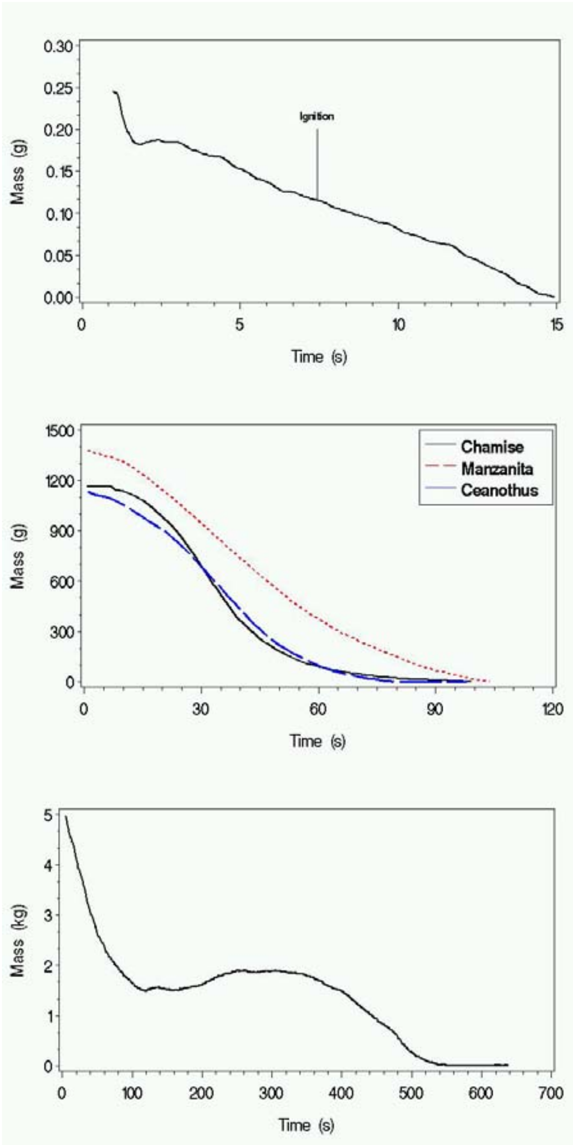

Figure 1. Mass change of live chaparral fuels while burning. Data from an individual manzanita leaf (top), leaves and branches < 0.64 cm in 60 cm circular pans (middle), and a 2 m long x 1 m wide fuel bed of chamise (bottom).

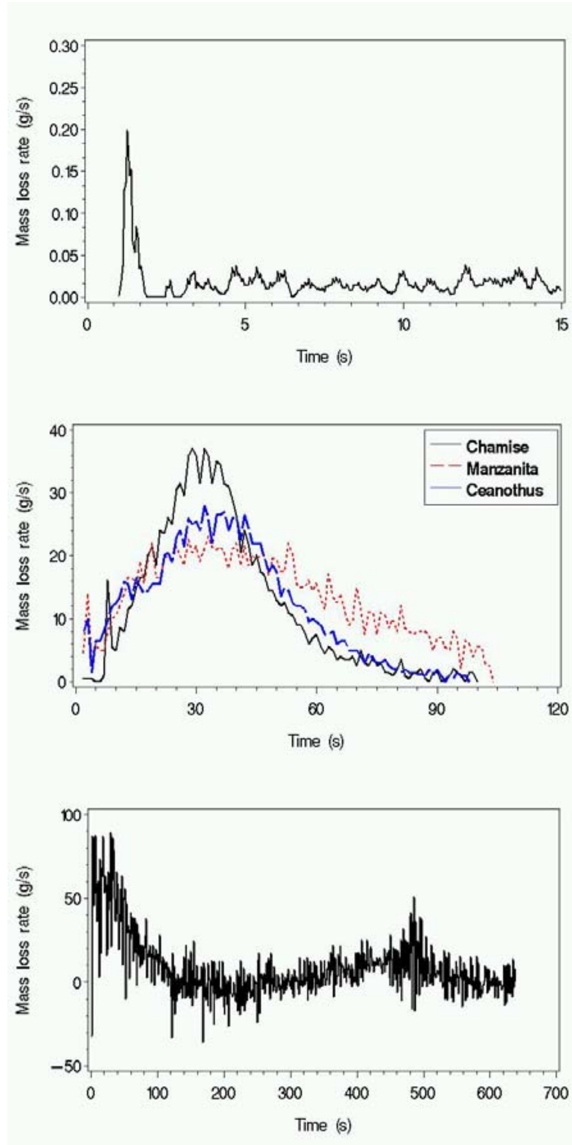

Figure 2. Mass loss rate of live chaparral fuels while burning. Data from an individual manzanita leaf (top), leaves and branches < 0.64 cm in 60 cm circular pans (middle), and a 2 m long x 1 m wide fuel bed of chamise (bottom).

For the leaf test presented (top), note that the ignition does not occur until significant mass has been lost. This may be due to vaporization of liquid water in the leaf, but we have not identified a technique that we could use to sample the gases in the high temperature environment of the FFB. Pickett et al. (this proceedings) present detailed photographs of preignition changes in manzanita leaves which include bursting of the leaf surface.

The mass changes in the 3 pan experiments presented in Figure 1 were similar for the 3 species. This is also the case for mass loss rate for the same tests (Figure 2). The plot of the mass change for one of the two bed tests indicates that we have some unexplained factors influencing the measurements. Four load cells are placed under the four legs of the fuel bed holder which weighs approximately 30 kg. As the fuel bed is burn, heat from the fire may be causing the aluminum frame to warp which would be detected by the load cells. Other factors could also affect these data. Figure 2 indicates that there is noise that must be removed in order to use these data.

3.3 Mass loss rate-flame length

A plot (Figure 3) of the untransformed mass loss rate and flame length data suggest a significant relationship and the possibility of developing a correlation between the 2 variables. Based on earlier work by several author, this is not unsurprising. Sun et al (2005) found a significant correlation between mass loss rate and heat release rate with flame length for the pan data.

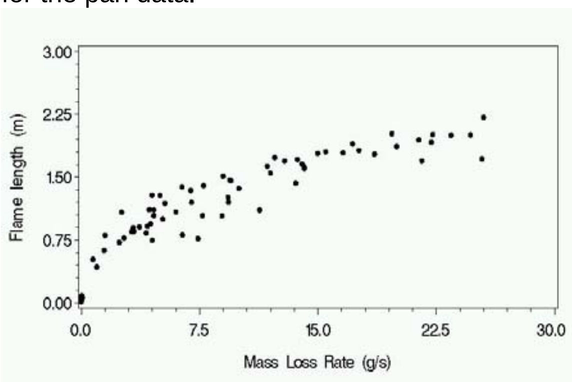

Figure 3. Plot of flame length and mass loss rate for live chaparral and Utah fuels derived from three sets of experiments burning individual leaves, pans of leaves and branches < 0.64 cm, and 2 m long fuel beds of the same material.

Because others have found a power relationship between mass loss rate and flame length, a log-log plot of the data was made (Figure 4).

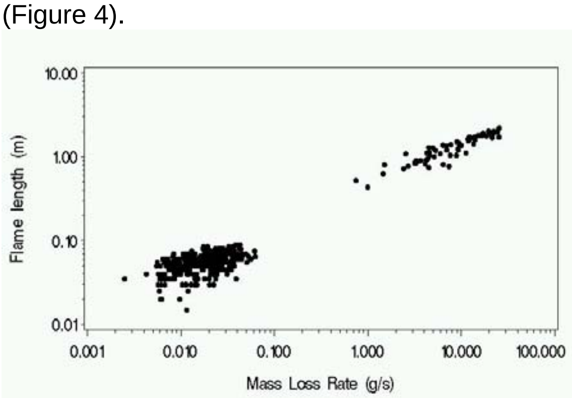

Figure 4. Log-log plot of flame length and mass loss rate for live chaparral and Utah fuels derived from three sets of experiments burning individual leaves, pans of leaves and branches < 0.64 cm, and 2 m long fuel beds of the same material.

This figure illustrates the variability observed in the data from the individual leaf experiments which may be due to species and moisture content differences. The figure also indicates that data at the scale between a single leaf and a small fuel bed in a pan are missing. As noted earlier, the flames in the leaf tests were primarily laminar while the pan and bed tests produced turbulent flames. It is possible to conduct experiments are this middle range; however, experiments at field scale where flame lengths may be larger by an order of magnitude (10s of meters) should prove more enlightening.

Since Figure 4 suggested a strong linear relationship, a simple linear model was fit to the log-transformed data (Equation 1) where L_f is flame length (m) and $\dot{m}$ is mass loss rate (g/s). This equation accounted for 94% of the variation in the flame length data.

$$\log(L_f) = -0.38 + 0.5\log(\dot{m}) \qquad (1)$$

The results presented here are preliminary; however, they suggest that it may be possible to correlate mass loss and flame length data for live fuels across a range of scales. If possible, such a correlation may prove useful to improve our ability to model fire spread in live fuels. Additional data analysis and experimentation is necessary.

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