J2.1 Sensitivity of a fire behavior model to changes in live fuel moisture

William M. Jolly*
USDA Forest Service, RMRS, Fire Sciences Laboratory, Missoula, MT

1. Introduction

1.1 Fire Modeling Concepts

Many factors influence fire behavior but they can be loosely divided into three main components: fuels, weather and topography (Countryman 1972). Fuels are comprised of the amount, arrangement, moisture content and physical characteristics of both live and dead plant material. Weather factors such as wind speed and wind direction, relative humidity, solar radiation and air temperature can influence fire behavior directly by influencing fire spread rate and direction and indirectly by changing the fuel moisture content. Topographic factors such as slope steepness directly influence fire spread rate by decreasing the distance between the flaming front of a fire and the fuel ahead of the fire which improves preheating of those fuels and increases fire spread rate. Other topographic factors such as aspect determine the amount of solar radiation that a particular area receives and thus indirectly influence fire behavior by changing the fuel moisture content. Fire models attempt to integrate this triad of controlling factors into metrics that can be used to assess the potential characteristics of a fire such as its spread rate, flame lengths and intensity. These fire behavior estimates can then be used to develop suppression strategies that maximize effectiveness while keeping fire fighters safe.

Models are simplified ways of looking at systems that are often complex and highly variable. When using models, such as fire behavior models, it is important to fully understand its sensitivity to a given set of inputs. Mathematical models are often developed with only one choice of parameters even though those values vary across the landscape and over time. The variability of a given parameter is rarely considered. Sensitivity analyses are useful because they describe model parameters that must be chosen with care and other parameters which may have only a small impact on model predictions.

1.2 Rothermel surface fire spread model

The Rothermel surface fire spread model (1972) integrates many of the aforementioned components of fuels, weather and topography to predict fire behavior characteristics. The parameters for this model can be categorized into two main groups: environmental parameters and fuel parameters (Andrews and Queen 2001). For this test, environmental parameters, as well as dead fuel moistures, were held constant while live fuel moistures were varied over the full range of field-observed values. I examined modeled surface rate of spread, flame length and fireline intensity over this range of live fuel moistures for each of the 53 standard fuel models. These fuel models include the original 13 fuel models described by Anderson (1982) and 40 additional fuel models described by Scott and Burgan (2005). Fuel models are used to simplify the representation of the fuel complex for the fire model. Fuel categories are generally classified as live or dead. Fuel models describe the amount and physical characteristics of each live and dead size class of fuel. Dead fuel size classes are described in terms of how rapidly a given fuel particle size responds to changes in environmental conditions (i.e. one hour, ten hour, etc..,). Many of the 40 fuel models described by Scott and Burgan are dynamic. This means that live herbaceous fuel loadings are shifted into the one hour dead fuel loadings as a function of the live herbaceous moisture content. This is meant to represent the accumulation of dead fuel as herbs cure throughout the season. Predicted fire behavior includes the amount and physical characteristics of each fuel size class and category as determined by a given fuel model. Live fuels are unique because their moisture content is driven predominately by phenological processes or development stages of a plant and they are likely the most poorly understood component of fire behavior (Burgan 1979). I show that the sensitivity of the fire model to changes in live fuel moisture is directly related to the proportion of live fuel in a particular fuel model. I also show that in some cases, very small changes in the live fuel moisture content elicit large changes in predicted fire behavior. Finally, I express this sensitivity in terms of the estimated firefighter safety zone size. I emphasize that extreme care should be exercised when choosing live fuel moisture values for fuel models that are heavily weighted towards live fuels.

2. Methods

2.1 BehavePlus Fire Modeling System

I used the BehavePlus fire behavior modeling system for this study which integrates several fire models into a single, user friendly interface (Andrews and Bevins 2003). This system provides an interface to the surface fire spread model that predicts fire behavior using information about fuels, weather and topography (Rothermel 1972). The user can hold some parameters constant while varying other parameters across a range of values. This mechanism provides an ideal method for assessing the sensitivity of predicted fire behavior across a range of inputs.

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* Corresponding author address: William M. Jolly, USDA Forest Service, RMRS, Fire Sciences Laboratory, 5775 Hwy 10 W, Missoula, MT 59808; e-mail: mjolly@fs.fed.us

Dead fuel moistures were set to 5%, midflame windspeed was set to 5 miles per hour and slope was set to zero. Live fuel moistures for both herbaceous and woody vegetation were varied from 30% to 300% in steps of 10%. This covers the range of observed values for live fuel moisture (Ceccato et al. 2003). These values were supplied to the surface fire spread model to estimate rate of spread, fireline intensity and flame length. These metrics were estimated for all 53 fire behavior fuel models. A screen capture of the BehavePlus model parameters is shown in Figure 1.

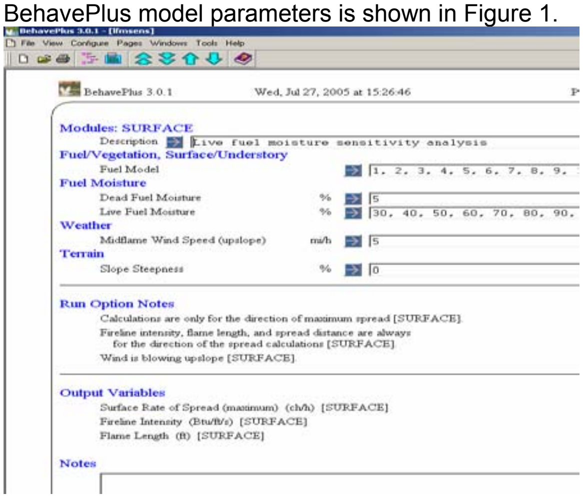


Figure 1 - Screen capture of the BehavePlus input values used to assess the sensitivity of the Rothermel surface fire spread model to changes in live fuel moisture.

2.2 Sensitivity Analyses

Local gradients have been suggested as a suitable means to estimate the sensitivity of a given model (McRae et al. 1982, Isukapalli 1999). I calculated the rate of change of spread rate, fireline intensity and flame length with respect to a unit change in live fuel moistures. I then calculated the maximum change over the entire range of live fuel moistures, hereafter refered to as the Maximum Local Gradient (MLG). An example of the MLG estimated over a range of model-predicted surface fire spread rates is shown in Figure 2. MLG expresses the largest change in rate of spread, fireline intensity and flame length for a one percent change in live fuel moisture. In addition to MLG, I estimated the live fuel moisture value where the model is most sensitive, the largest change in predicted fire behavior over our 10% intervals and I also calculated the variance of predicted fire behavior over the range of input live fuel moistures.

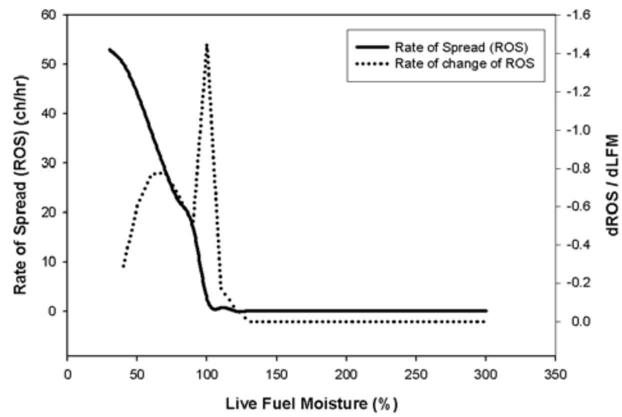


Figure 2 - Illustration of the predicted rate of spread in fuel model gr2 over a range of live fuel moistures and the corresponding rate of change in rate of spread (dROS / dLFM). Large values show areas where model predictions are highly sensitive to changes in live fuel moisture.

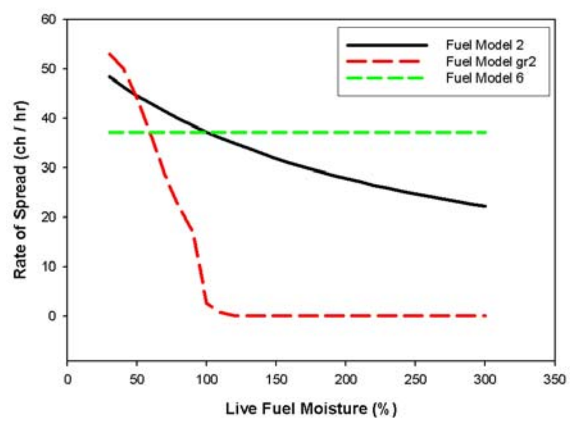


Figure 3 - Predicted rate of spread for three fuel models showing three different sensitivity patterns to changes in live fuel moisture.

3. Results and Discussion

3.1 General Discussion

Fire behavior predictions are, of cource, only sensitive to live fuel moisture changes when a given fuel model contained live fuels. Figure 3 shows examples of three types of sensitivity to live fuel moisture changes: For example, fuel model 2 is moderately sensitive, fuel model gr2 is highly sensitive and fuel model 6 is insensitive. Fuel models generally fell within one of these three categories. Fuel models 2, 6, 8-9, 11-13, tl1-tl9 and sb1-sb4 include no live fuels. The standard deviation of rate of spread, flame length and fireline intensity across the range of live fuel moistures was zero for these models. In general, a fuel model whose predicted fire behavior was sensitive to live fuel moisture changes showed similar sensitivity for spread rate, fireline intensity and flame length. All other fuel models showed some sensitivity to live fuel moisture changes and several models were highly sensitive. Figure 4 shows the maximum local gradients for all fuel models where the standard deviation of its fire behavior prediction was greater than zero. The grass fuel models within the set of 40 new fuels showed the highest sensitivity to live fuel moisture changes. The most sensitive of these models were the dynamic fuels models where fuel loadings are shifted between the live herbaceous and one hour fuels. When herbaceous fuels were included in the fuel model, their loading was a strong determinant of the sensitivity of that fuel model to change in live fuel moisture. This is illustrated in Figure 5 where the maximum local gradients for each fuel model are shown relative to the herbaceous fuel loadings for that particular model.

In addition to determining the maximum local gradient for a given fuel model, I also determined the fuel moisture values where the model was most sensitive. All of the original 13 fuel models, the timber litter models (tl1-tl9) and the slash-blowdown models (sb1-sb4) showed a maximum sensitivity at 30% live fuel moisture but many of the new 40 fuel models showed sensitivities at much higher. Grass models gr1-gr9 were most sensitive to live fuel moisture of 90 – 100%, Grass-shrub (gs1-gs4) models were most sensitive between 70 – 90 % LFM, shrub models were most sensitive between 30 and 110% LFM and the timber understory models (tu1 – tu5) were most sensitive between 30 and 100% LFM.

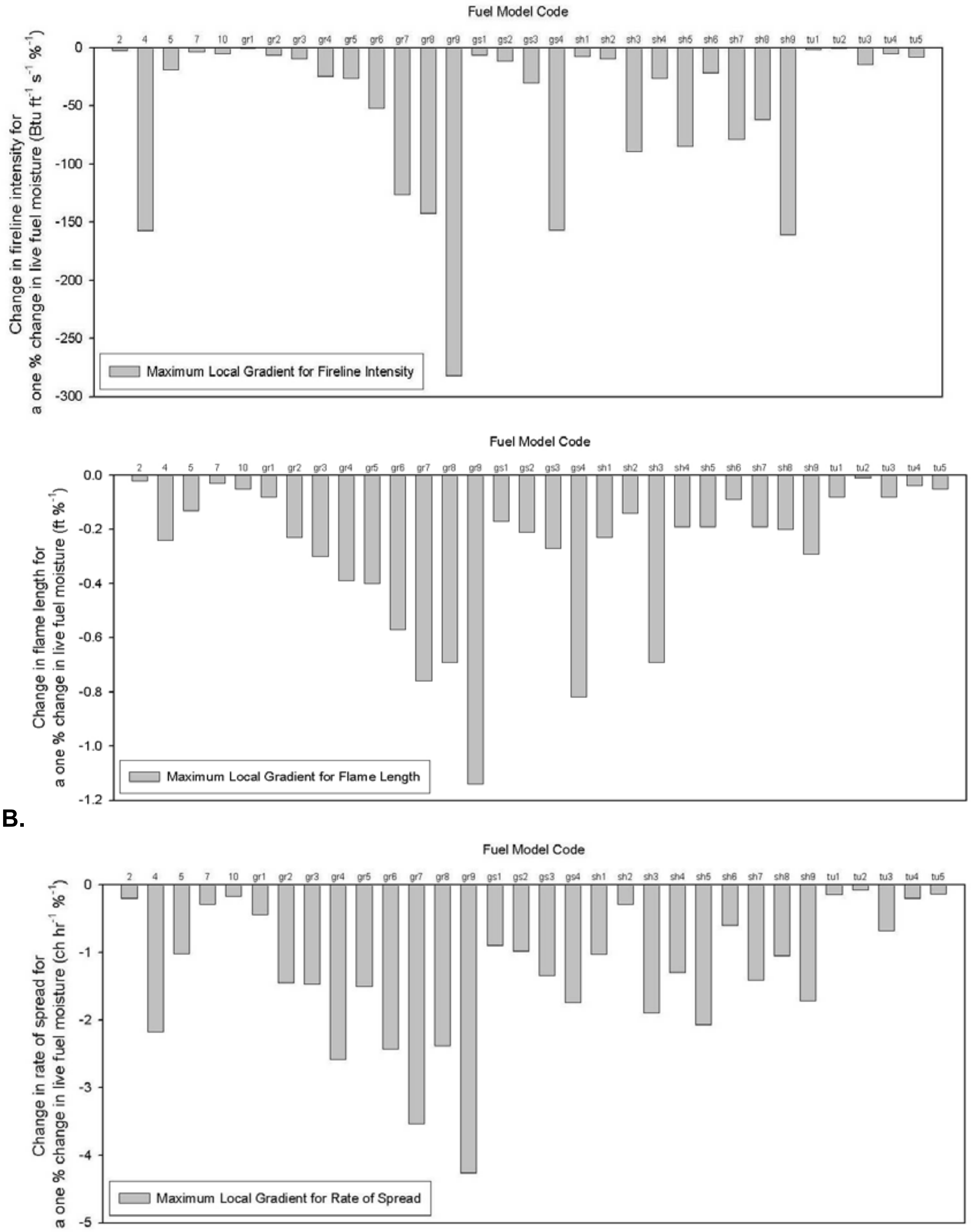
3.2 Implications for Firefighter Safety

Estimated fire behavior can be used to provide guidelines for firefighter safety zone size. Bulter and Cohen (1998) suggest that the minimum safety zone size should be no less than four times the flame height of a fire. BehavePlus estimates a worst case safety zone size by assuming flame length equals flame height (Andrews and Bevins 2003). In models where the moisture of highest sensitivity is near common summertime values, extreme caution should be exercised when choosing moisture values to parameterize the model. For example, the grass fuel models were most sensitive within the range of 90 – 100% live fuel moisture and summertime live herbaceous fuel moistures are common within this range (Mutch 1967). For fuel model gr9, decreasing fuel moisture from 110% to 100% increases predicted flame length from 4.8ft to 16.2ft. This is a 230% increase in predicted flame length for a very small change in moisture content. Subsequently, estimated safety zone size would also need to be increased 2.3 times the size estimated at 110% moisture. It is therefore necessary to exercise extreme caution when parameterizing the model to estimate fire behavior to ensure firefighter safety. A good rule of thumb is to always exercise the 'worst case' scenario to avoid underpredicting potential fire behavior characteristics and ensure firefighter safety.

3.3 Implications for Fire Behavior Predictions

In addition to the human safety aspects of understanding model sensitivity to live fuel moisture changes there are also some general fire behavior prediction aspect to consider. The original 13 fuel models all showed sensitivity well below the range of live fuel moistures that would commonly be used to initialize the surface fire spread models. In contrast, many of the recently added 40 fuel models were sensitive within the range of values that are commonly observed during periods of high fire potential, particulary the dynamic grass models. If users select a live fuel moisture value that is too high, they could be severely underpredicting fire behavior depending on the fuel model that they have chosen. This could lead to bad decisions depending on the intended purpose of the fire behavior predictions. It is therefore important to fully understand the sensitivity of each fuel model to live fuel moisture changes when predicting fire behavior with the Rothermel surface fire spread model.

A.



B.

C.

Figure 4 - Maximum local gradient for predicted fire behavior over a range of live fuel moistures. Fuel models with no live fuels are excluded for clarity. Graphs are shown for each of the three fire behavior characteristics test: Fireline intensity (A), Flame length (B) and Rate of Spread (C).

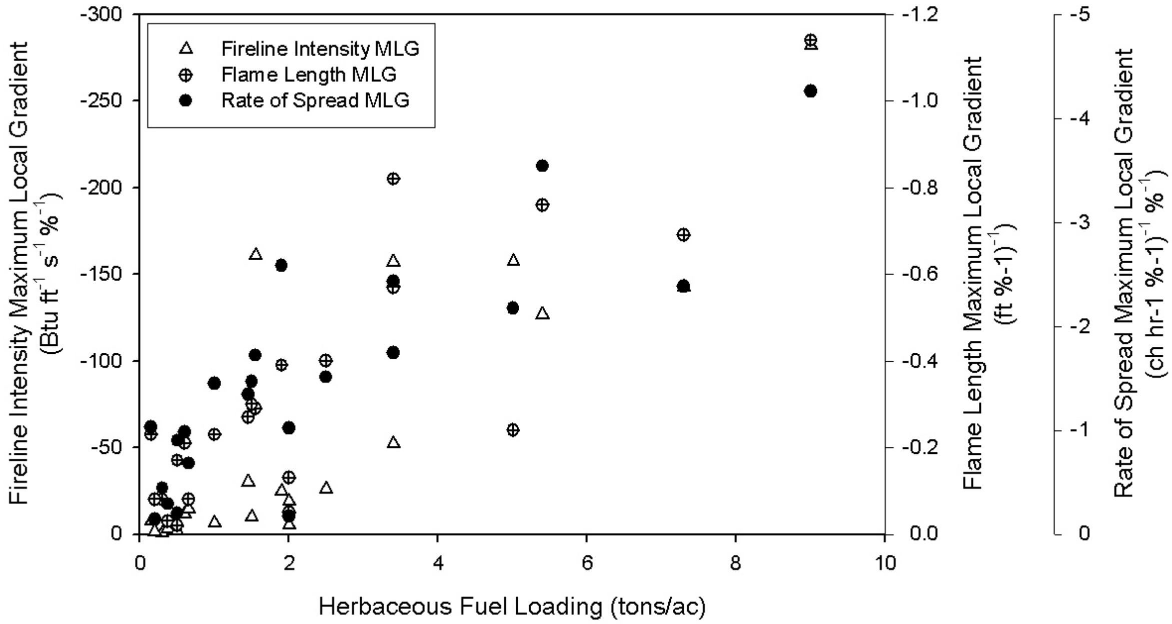


Figure 5 - Relationship between the maximum local gradient of three predicted fire behavior characteristics over a range of live fuel moistures and the herbaceous fuel loadings of a given fuel model. Fuel models without live herbaceous loading are omitted for clarity. In general, model sensitivity increased with increasing herbaceous fuel loadings for all three variables.

4. Acknowledgements

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