SOUTHERN Fire Exchange
Uniting Fire Science and Natural Resource Management

JOINT FIRE SCIENCE PROGRAM

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FIRE INTENSITY AND FIRE SEVERITY: HOW HOT IS YOUR FIRE AND WHY IS THAT IMPORTANT?

Dale Wade

This is one of a series of fact sheets authored by Dale Wade, a prescribed burn researcher and specialist in the South for over 45 years. They are designed to meld current technology with Dale's unequaled experience with fire and science. The fact sheet series is available at www.southernfireexchange.org/SFE_Publications/Fact_Sheets.html. The Southern Fire Exchange thanks Dale for these contributions from his wit and wisdom, which, in Dale's words, "was sharpened by the many people he worked with over the years."

Achieving natural resource objectives typically requires the application of periodic fire because fire is truly THE ECOLOGICAL IMPERATIVE! But how does one measure success or failure? Determining how close a fire came to meeting your objective(s) is a difficult but crucial part of every burn evaluation and is not always immediately obvious. As John Bethea[1] used to say "*You can no more get to where you don't know where you're going than you can get to where you think you are from when you don't know where you've been.*" To be successful, you need to know when to use fire and what dosage to apply. If your lands are aesthetically unpleasing and appear rough and overgrown, remember that it takes years, maybe decades, of fire exclusion for a plant community to reach this condition, so one can't expect to rectify all problems with one or two burns. And be forewarned: Fire is a two-edged sword that can make matters worse if incorrectly applied. One should thus have an idea of the appropriate fire regime necessary to meet management goals before proceeding, and be prepared to apply fire several times before the rewards become visually clear.

Most terrestrial plant species evolved with periodic fire and thus developed strategies to survive in these conditions. Thin-barked species, such as maple and sweet gum, are often top-killed, but typically sprout from dormant/adventitious buds, especially along the lower stem and roots. Trees with thicker, less dense bark, such as southern pines, usually survive low intensity fire. Some trees that develop protective bark with age (e.g., white oak, yellow poplar) have the ability to resprout when young. A few southern species, such as Ocala sand pine and table mountain pine, rely on a single stand replacement fire that kills the trees, but unseals attached cones to release large amounts of seed that take advantage of post-fire mineral soil seedbeds. Information on the survival mechanisms of many tree and shrub species can be found at www.feis-crs.org/beta. Getting up to speed regarding heat release during the combustion process is a more difficult proposition and is discussed below.

Knowledge of species survival strategies, the amount of heat to be released, the rate at which it is to be released, and the consequences of the heat release processes are prerequisites for a successful burn. Photo by David Godwin.

FIRE INTENSITY

As a general rule, the number and girth of plants top-killed by fire increases with an increase in either the rate or total amount of heat energy released. Estimates of the rate and

[1] John Bethea was Florida's distinguished State Forester from 1970 to 1987 and is remembered for his vision and his witty anecdotes.

amount of this heat release are thus important descriptors of fire behavior. Terms like 'hot' and 'cool' can be used and each has an associated mental image, but there are major shortcomings with such general terms: 1) your mental image of 'cool' may differ from mine and 2) lumping fire intensity into just a few qualitative categories is not very useful because fire effects change along a wide continuum of fire behavior from 'barely able to sustain flaming combustion' to 'a wall of flame extending well above the overstory.' Fire managers have settled on the term 'fireline intensity' to express the rate of heat release from each linear foot of the flame front regardless of the depth of the flame front and 'reaction intensity' to express the rate of heat released per square foot of burning area in the flame front, but neither can be measured directly. Both these terms pertain only to heat release from combustion in the flaming front of a fire and do not include the substantial amount of heat energy that can be released (particularly when a unit burns with the wind) during intermittent flaming and smoldering combustion after the flame front has passed.

Fireline Intensity

The terms fireline intensity, Byram's intensity, and frontal intensity are synonyms and defined as the rate of heat released per unit length of fire front from the leading edge of the flame zone to the trailing edge regardless of that distance, per unit time (Byram, 1959). Most resource managers prefer English units which are Btu's (British thermal units) per second per foot of fire front. See Figure 1 for a graphic depiction of fireline intensity. This is the term commonly used to compare fires in the South as well as throughout much of the world, but be forewarned "Byram's fireline intensity should not be used to compare fires in fuel types which are structurally very different" (Cheney, 1990).

Fireline intensity is the product of the low heat of combustion (which does not vary much), the amount of fuel consumed per unit area in the flaming front and the forward rate of spread (a backing fire is also moving forward). An in-depth discussion of this term, its usage, and calculations pertaining to it can be found in Byram (1959), Alexander (1982), Wade (1986), and Cheney (1990). Combustion products released in the flaming front are entrained into the convection column and thus lofted into the atmosphere near the top of the Mixing Height (a height of at least 1650 feet required to secure a burn permit in many states), transported, and dispersed downwind with minimal impact on visibility and human health near the fire. For a given amount of fuel consumed, an increase in rate of spread implies an increase in fireline intensity. Fireline intensities of backfires in southern fuels rarely approach 100 Btu's per second per foot while prescribed headfires are typically below 200 Btu's per second per foot.

Byram derived the mathematical relationship between flame length and intensity which allows observers to estimate intensity without having to attempt to estimate available fuel weight, which is difficult even for very experienced burners. All one has to do is estimate flame length and plug that number into the equation to calculate an intensity value, but as usual the devil is in the details. Flame length is constantly fluctuating in response to fuel and topographic variation in the burn unit and to changes in weather, especially wind speed and direction. Numerous studies have demonstrated that even when a fire is burning in a uniform fuel on flat land under uniform weather conditions, flame length estimates vary widely both among observers and over time by the same observer (see Johnson, 1982). Adkins (1995) developed a procedure whereby a fire can be filmed and flame length precisely determined frame by frame, but setup is time-consuming and requires an additional crew member. Therefore, this methodology is seldom used on operational burns, although it has proved to be a very reliable research tool.

Combustion Rate

George Byram coined this term to describe "the rate of heat release per unit of burning area [within the flame front] per unit of time" (Byram, 1959). Byram went on to state that it "should not be confused with fire intensity which is a different type of variable." That said, Dick Rothermel 'rediscovered' this concept a decade later and called it **reaction intensity**. It is now also commonly called Rothermel's intensity. See Figure 2 for a graphic depiction of this concept. In order for it to accurately estimate fireline intensity or combustion rate, a fire has to be burning in a uniform fuel bed and consuming fuel at a constant rate. Such conditions can be found in fairly homogeneous fuelbeds, including open areas dominated by bunchgrasses such as

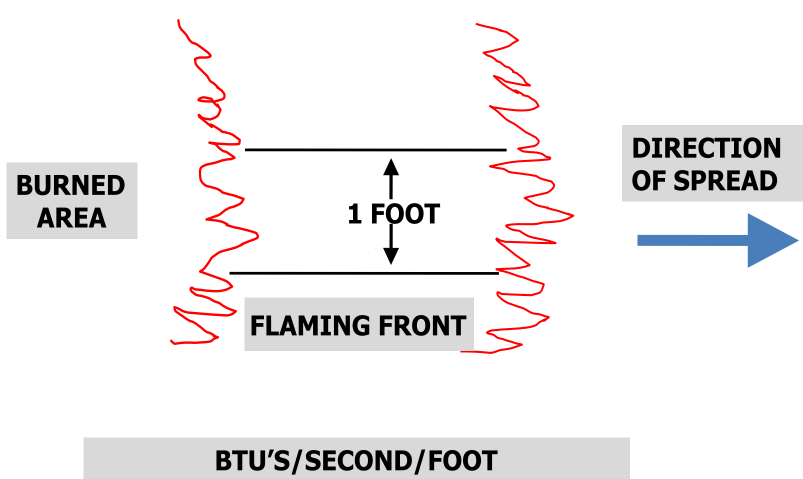

Figure 1. Fireline, Byram's or Frontal Intensity is a measurement of the rate of heat release per linear foot of the fire front.

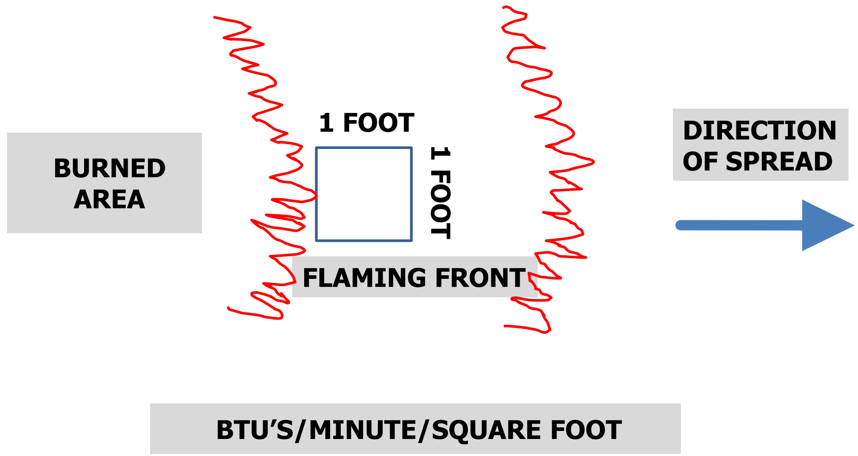

Figure 2. Combustion rate, Reaction or Rothermel's Intensity is a measure of the rate of heat release per square foot of the flame front.

broomsedge and wiregrass, improved pastures, marsh grasses such as *Spartina*, sawgrass strands, and the forest floor under pine plantations when no understory is present. However, these conditions are definitely not found in many common southern fuel types such as southern rough, mixed brush, mixed pine/hardwood, bays, and pocosins. Perhaps the biggest problem is that the Rothermel spread model uses particle residence time[2] rather than fuelbed residence time which is considered by many experts to be a fatal flaw.

These problems would be of little concern to southern burners except that Rothermel's intensity is used in US Forest Service mandated models, such as the National Fire Danger Rating System (NFDRS) and BEHAVE (a fire prediction model). Along with the above problem, the fact that the underlying assumptions (uniform fuel bed and constant burning rate) are typically violated when used in the South, their outputs (predictions) generally do not match what actually happens on the ground unless correction factors are applied. According to Cruz and Alexander (2010) and Alexander and Cruz (2012), any model that uses Rothermel's intensity to calculate fireline intensity will consistently and often substantially under predict fireline intensity!
Another problem with many fire behavior models is that they assume 10-hr time-lag fuels (duff and dead branches between ¼ and 1 inch diameter) determine fire spread rather than 1-hr time-lag fuels (grass, litter and twigs less than ¼ inch diameter). A number of correction factors have been developed to improve the accuracy of various fire danger and fire behavior models, but they are simply band-aids that do not address the underlying issue and can themselves create other unexpected problems. One of my 'rules of thumb' is that if a timely (which can be a problem with complex models) model prediction does not jibe with observed fire behavior; trust your eyes and not the model. As Gary Achtemeier[3] has reminded me on numerous occasions, "models give predictions, not facts."

Heat Per Unit Area

Energy can neither be created nor destroyed, so a given piece of fuel holds a finite amount of potential energy, some or all of which is converted to heat energy in a fire. Thus the total amount of heat released within a burn is almost equal to the total available fuel (the amount of fuel consumed under a given set of conditions which is rarely equal to the total amount of fuel that would be consumed under worst case conditions). This means that for a given amount of fuel consumption (including both flaming and smoldering combustion), a given amount of heat is released. See Figure 3 for a graphic depiction of this concept. Although fireline intensity of a prescribed headfire is often double that of a backfire, the total heat released will be the same as long as the same amount of fuel is consumed (a headfire just releases it faster than a backfire). Under good prescribed burning conditions, the fact that headfires consume more understory foliage (because of their higher flames) can be, up to a point, offset by the fact that backfires consume more of the forest floor, and this is often the case where the understory is sparse. However, the more typical situation in the South is a rank understory that contributes to headfire spread thereby resulting in significantly more energy being released from headfires than from backfires. Where both heading and backing fires are used, it is usually easy to separate the area burned by backing fire because some of the foliage will still be present on understory

Fire intensity and fire severity are both terms used to characterize a fire, but they describe entirely different concepts. Fire intensity is a measure of the heat energy released during flaming combustion whereas fire severity is a measure of a fire's impact on the site—in other words, fire effects (see Keeley 2009).

[2]Particle residence time" refers to the length of time a fuel particle is flaming, and that residence time increases as particle diameter increases. Thus, a log may still be flaming long after the main flame zone passed through the fuelbed in a longleaf pine grassland.

[3]Gary Achtemeier is a fire meteorologist and smoke modeler with the USFS Southern Research Station in Athens, GA.

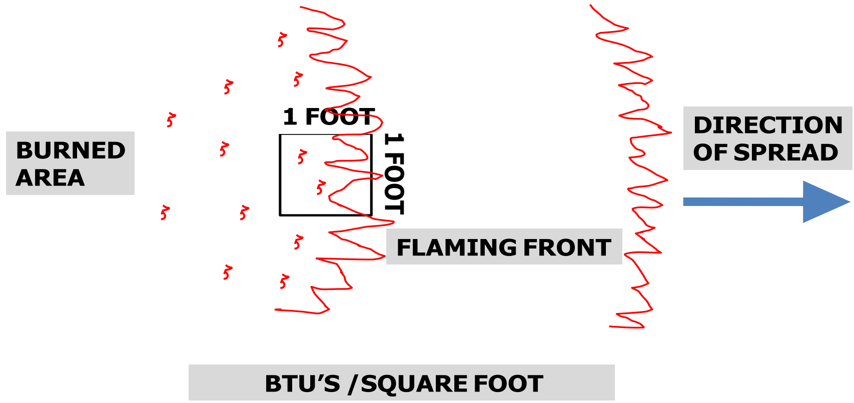

Figure 3. Total heat yield is a measure of the heat energy released per unit area from both flaming and smoldering combustion.

shrubs, such as gallberry and palmetto. Combustion rate or reaction intensity estimates the amount of this heat released per unit area per unit time in the flame front. Total heat yield estimates the amount of heat energy released from both flaming and smoldering combustion.

FIRE SEVERITY

Fire severity is a qualitative measure of a fire's effect on the plants and animals involved. Although fire severity is dependent upon the rate and total amount of heat energy released, as well as the height over which it is released, it is not necessarily strongly correlated with fire intensity. As more of the forest floor is consumed, additional heat is transferred downward where it impacts roots and soil fauna, horizontally where it impacts plant stems, and vertically where it impacts live canopies. For example, on a windy day during severe drought, a fire backing across a narrow wetland depression containing small hardwoods and southern pine that has not burned in a decade, would be classed as low intensity (slow moving and short flames) but very high severity because it would consume the duff and humus down to mineral soil killing every tree root that had colonized this zone. On the other hand, a headfire crossing this depression under the same conditions would be both high intensity (fast moving and high flames) and high severity. If, however, a headfire were to blow across this narrow depression on a windy day soon after enough rain had fallen to soak the duff, it would be classed as high intensity but low severity because none of the duff layer would be consumed and species composition would remain unchanged (any topkilled hardwoods would typically resprout).

A backfire under these same conditions could not sustain itself, because the forest floor would be too damp. Thus, depending on a number of factors such as type of fire, age of rough (number of years since the last fire), and steepness of the forest-floor moisture gradient, a given severity can result from a wide range of fireline intensities and conversely, a given fireline intensity can produce a wide range in fire severity. This is why it is very important to estimate both the surface litter moisture content and the forest-floor moisture gradient before conducting a burn. On xeric sites such as sandhills where a duff layer is slow to form, or on sites where the fire return interval is 3 years or less, a drought won't translate into higher severity because almost any fire on such a site will consume most, if not all 1- and 10-hr time-lag fuels. The live plant community composition will remain unchanged, although species abundance and density can change depending on the number of sprouts. But once rough age exceeds 3 or 4 years on mesic sites, the moisture gradient will determine how much of this layer is consumed. Estimating dead fuel moisture is thus necessary but easier said than done. Various estimation methods are discussed in the *Fuel Moisture and Prescribed Burning* fact sheet.

When hardwood stringers associated with intermittent streams occur within a burn unit, care must be taken to make sure the duff is damp enough in such areas that it will not burn, otherwise substantial tree damage will likely result. Some objectives do, however, call for significant duff reduction on such areas (e.g., where the objective is to kill woody stems and restore native grasses such as river and switch cane). Another problem commonly found in the flatwoods is that hardwood brush species, such as lyonia and titi, continually move up-slope out of swampy areas, invading longleaf and slash pine communities; natural resource managers often run fairly high-intensity headfires 'down slope' to knock this encroaching vegetation back into wetlands, but when using this tactic, one must make sure the accumulated forest floor material in these swampy areas does not ignite because fire can smolder in such areas for weeks, smoking in nearby roads and towns, and making occasional runs onto upland sites that may be outside the burn unit.

If you are interested in the effect of prescribed fire on vegetation, I urge you to read a 2-page report by George Byram (1958): *Some basic thermal processes controlling the effects of fire on living vegetation*, USDA Forest Service, Southeastern For. Exp. Stn. Research Note 114, available online at http://southernfireexchange.org/SFE_Publications/etc/Byram_1958.pdf.

A given fire severity can result from a wide range of fireline intensities and conversely, a given fireline intensity can produce a wide range in fire severity.

In intermittent hardwood or wetland areas, care must be taken to ensure that the duff is damp enough that it will not burn (unless duff reduction is a management objective). This prescribed fire stopped at the ecotone without a hard line. Photo by USFS Southern Research Station.

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