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SFE Fact Sheet 2013-5

FUEL MOISTURE AND PRESCRIBED BURNING

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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 in the "Prescribed Fire" section 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."*

INTRODUCTION

Moisture is the overriding factor governing fuel flammability. It determines whether ignition will take place and to what depth the forest floor will be consumed. If one uses enough torch mix, he/she can ignite the immediate area, but if fuel moisture is much above 22% in pine litter or 16% in hardwood litter, a headfire is mandatory and even then the burn will be patchy at best when the terrain is relatively flat. Although I am not aware of any supporting field data, laboratory fires on steep slopes (typical of the Piedmont and southern Appalachians) will spread with dead fuel moisture approaching 35%. Both pine needles and hardwood leaves are classed as 1-hr time-lag fuels (see below), but pine litter dries faster and burns better than hardwood litter because of chemical and physical differences (i.e., needles are round and thus shed water, whereas most hardwood leaves lie flat on the ground and tend to hold water after rain like a saucer). Scrub oak leaves on xeric sites such as sand hills and ridges are an exception; they tend to dry quickly and have a nasty habit of being 'rolled' across control lines by the wind while burning. In general, loosely-packed fuelbeds, such as longleaf pine/wiregrass dry faster, allow better air movement and promote radiant and convective heat transfer, as compared to compact fuelbeds such as shortleaf pine litter.

From a wildland fire management standpoint, fuel moisture is defined as the amount of moisture in a fuel expressed as a percentage of the ovendry weight of that fuel. The higher the fuel moisture content, the more heat energy required to drive off the moisture and raise fuel temperature to the ignition threshold ($\sim500^{0}$F). As a fuel is heated, the water it contains evaporates and produces the white smoke characteristic of damp fuel combustion. This vaporized water is not a pollutant, but it can drastically reduce visibility. Burning under drier conditions will reduce the amount of water vapor produced per unit of fuel consumed. On the other hand, the drier the fuel, the more will be consumed, thereby increasing smoke production. Backfires produce significantly fewer pollutants than other firing techniques, but the drier conditions necessary to use a backfire result in more available fuel and the smoke will be released over a longer period of time. The bottom line is that although a backfire is usually recommended when downwind smoke management concerns are an issue, the choice is not always straightforward.

When using a backfire, fuel moisture must be lower for the fire to carry because there is little preheating ahead of the flame front. I am not aware of any published information, but over the years have found that at least a 2-yr rough is needed with litter moisture below about 14% in pure pine and 11% in pure hardwood to ensure a successful growing-season burn using a backfire. In pine stands, moisture content of the duff layer can exceed the fiber saturation point of 32% and still result in substantial consumption because a backfire typically releases enough heat energy downwards to dry at least the top of this layer. Backfires consume more of the forest floor than headfires because the shorter flames concentrate heat release closer to the litter surface. For the same reason, backfires are the technique of choice if a burn objective is to girdle (topkill) hardwoods larger than a few inches in diameter or to consume coarse woody debris (CWD). It takes less heat energy to ignite punky wood than to ignite sound wood.

The forest floor moisture gradient is fairly steep soon after precipitation, which generally is to the burner's advantage, but the curve flattens out within a week or two, especially on

Fuel moisture determines whether ignition will take place and to what depth the forest floor will be consumed. Photo by David Godwin.

sandy soils. When the moisture content of a duff layer (greater than ~1 inch deep) is within about 10% of the litter layer moisture content, it is a good idea to review the burn objectives and consider the consequences of overachieving. If, however, the objective is to consume the duff layer, the following guidelines will prove useful:

- When the duff moisture content is less than 30%, this layer will burn on its own once ignited.
- With moisture content between about 30 and 120%, the amount of duff consumed will depend on consumption of adjacent fuel, particularly branchwood.
- When the moisture content exceeds about 120%, the duff becomes too wet to ignite unless under a pile of branchwood.

Burning when the temperature is below about 27^0F, with all other conditions the same, results in visibly obvious differences in fire intensity. Below this temperature, water in the plant cells will be ice and substantial heat energy has to be devoted to first change the moisture from a solid to a liquid before evaporating it. Along the same lines, annual low intensity, dormant season fires typically burn across areas in flatwoods communities with a herbaceous ground cover but no overstory, because the herbs are cured. However, growing-season fires in the same location often go out because of succulent new plant growth and lack of pine litter to sustain the fire.

TIME-LAG

The time-lag concept was developed as part of the National Fire Danger Rating System (NFDRS) to separate dead fuels into one of four categories depending upon how fast they

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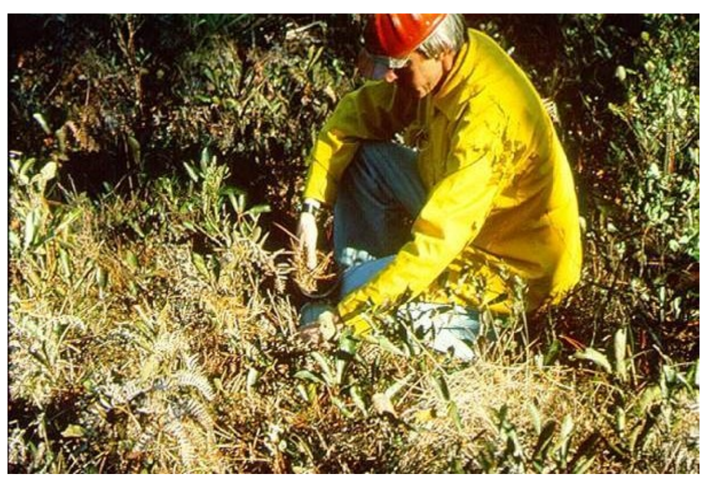
respond to weather changes. For example, a 1-hr fuel will lose approximately 63% of the difference between its initial moisture content and the moisture content it will eventually reach under standard equilibrium conditions (80^0F and 20%RH) within one hour. 1-hr time lag fuels (also called fine fuels) include dead/cured herbaceous plants, the surface litter, and twigs less than ¼ inch in diameter. As weather conditions change throughout the day, these fine fuels will respond, which, along with horizontal and vertical spatial variation within the burn unit, typically produce a wide range in diurnal fuel moisture. 10-hr time-lag fuels are comprised of material between ¼ to 1 inch in diameter as well as approximately the next ¾ inch of litter below the surface layer. 100-hr fuels are comprised of dead fuels 1 to 3 inches in diameter as well as the forest floor from ¾ to 4 inches below the surface. 1000-hr fuels include dead woody material between 3 and 8 inches in diameter plus the forest floor below a depth of about 4 inches.

ESTIMATION METHODS

The fuel consumed in a fire is, by definition, 'available fuel.' This value is required to estimate both fireline intensity and smoke production. It is crucial to predict available fuel before lighting the match, which means estimating the moisture content of litter, duff, dead branches, and larger debris. This is easier said than done, however, because the only way to determine the actual moisture content of a fuel is to collect samples and distill, titrate, or ovendry them. This process is not operationally useful because moisture conditions on the unit will have changed long before an answer is determined. There are, however, several viable alternatives. I do <u>not</u> recommend using the NFDRS predictions because these are area predictions and will not likely reflect actual on-site conditions. Moreover, some states, such as Georgia, set fine fuel moisture equal to 10-hr fuel moisture in their daily forecast. I prefer using a lumber moisture probe (available from many forestry equipment suppliers) because it gives accurate consistent readings. The only drawback is the price, which is several hundred dollars. Don't waste your money on a cheap one, and make sure the display can be read in bright sunlight. The probe is easy to use. Take your hand and 'rake up' a handful of surface litter, wad it tightly to minimize voids, and stick the probe into it. I recommend wearing a glove to avoid stabbing your hand. You can also stick the probe into a piece of branchwood or CWD.

Table 1 provides moisture content estimates of 1-hr fuels, but I always check actual on-site conditions by getting my hands dirty. Is the surface litter damp or dry to the touch? How about the duff layer? If you can squeeze water out of it, it is unlikely to be consumed. If longleaf, slash, or loblolly pine needles are a major forest floor component, the snap test can also be used to estimate moisture content. This involves selecting a cured needle from the litter surface, bending it into a loop, and slowly pulling the 2 ends past each other to constrict the loop. If the needle breaks into pieces when you make the loop, conditions are too dry; if you can pull the loop tight without it breaking, it is too wet; if it breaks when the loop is about ¼ to ½ inch wide, a backfire will carry. In hardwood litter, the McCarthy test (McCarthy 1927) can be used. Pick up a cured hardwood leaf from the litter surface and bend it at a right angle. If it crumbles when you pick it up, the moisture content is less than 10%; if it breaks apart, or does so except at the veins, the moisture content is 10 to 14%; if it just creases or does not break cleanly when bent at a right angle, the moisture content is over 20% and too wet to burn. When using the snap or McCarthy test, take several samples in both sunlight and shade and if on a slope, at the top, middle, and near the bottom of the unit.



Always check actual on-site conditions as part of your fine fuel moisture estimate by using the snap test or a lumber moisture probe. Photo by Wayne Adkins, USFS Southern Research Station.

TABLE 1. ESTIMATING FINE FUEL MOISTURE BASED ON RELATIVE HUMIDITY (RH) AND TEMPERATURE WITH ADJUSTMENTS BASED ON SEASON, TIME OF DAY, SHADING, AND A SOUTHERN CORRECTION FACTOR.

FINE-FUEL MOISTURE CONTENT TABLE

REFERENCE FUEL MOISTURE

	DAY TIME 8:00 AM - 7:59 PM												NIGHT TIME 8:00 PM - 7:59 AM											
	RELATIVE HUMIDITY												RELATIVE HUMIDITY											
Dry Bulb Temperature (°F)	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89
30-49	5	6	7	7	7	8	9	9	10	10	11	12	7	8	9	9	11	11	12	13	14	16	18	21
50-69	5	6	6	7	7	8	8	9	9	10	11	12	6	8	8	9	10	11	11	12	14	16	17	20
70-89	5	5	6	7	7	8	8	8	9	10	10	11	6	7	8	9	10	10	11	12	13	15	17	20
90-109	4	5	6	7	7	8	8	8	9	10	10	11	6	7	8	9	9	10	10	11	13	14	16	19

NOV. DEC. JAN.						FEB. MAR. APR. AUG. SEP. OCT.						MAY JUNE JULY						ALL MONTHS
Daytime 8AM - 8PM						Daytime 8AM - 8PM						Daytime 8AM - 8PM						NIGHTTIME
8→	10→	12→	2→	4→	6→	8→	10→	12→	2→	4→	6→	8→	10→	12→	2→	4→	6→	No adjustment needed
Exposed – Less than 50% shading of surface fuel																		
5	4	3	2	4	5	4	2	1	1	2	4	3	1	0	0	1	3	
Shaded – equal to or greater than 50% shading of surface fuel																		
5	5	5	5	5	5	5	4	4	4	4	5	4	4	3	3	4	5	

This set of tables will provide a close estimate of the fine dead fuel moisture on your burn unit. Simply take on-site temperature and RH observations and use the top table to find the reference moisture and record it. Then go to the next table and select the month, time of day, and amount of shading to find the adjustment value and add this number to the reference moisture you recorded. These tables are from Rothermel, R.C. 1983. *How to predict the spread and intensity of forest and range fires.* US Forest Service Gen. Tech. Rep. INT-141, with adjustment values for South aspect, 0 slope.

In the southern USA, add 2 to the adjusted value if that number is 10 or more and add 1 if the adjusted value is less than 10 to arrive at a more accurate estimation.

Example: It is 1130am on December 16th and you just took on-site observations of 69% RH and 72°F temperature in open flatwoods with 30% canopy cover on a cloudless day. Your reference moisture is thus 8. The adjustment value for 1130am in December is 4 which gives you 8 + 4 = 12. Then add the southern correction value of 2 because the adjusted value is more than 10 to arrive at a fine fuel moisture content of 14%.

DUFF MOISTURE AND OLD GROWTH MORTALITY

Sandy soils of the Atlantic Coastal Plain are nutrient poor with most of the nutrient capital typically tied up in living vegetation, thereby limiting additional growth. As plants die and decompose, nutrients are mineralized and again become available for plant uptake. Both decomposition and fire are oxidation processes; fire just accomplishes the process in a matter of minutes, releasing the nutrients all at once rather than over a period of years. Without disturbance such as fire, a duff layer begins to form in 4 to 5 years and is rapidly colonized by tree feeder roots because this is the zone where nutrient mineralization takes place. Any fire that consumes this duff layer will kill these roots. Young healthy trees can replace thermally-killed feeder roots fairly quickly, but as a tree matures this process takes progressively longer. Respiration almost equals photosynthesis in biologically over-mature trees, so even minor root damage often results in old-growth mortality, particularly if a tree is already stressed. When burning stands with a duff layer approaching about an inch in depth, care should be taken not to consume the whole layer. as the fire-free interval extends past 10 to 12 years, it becomes imperative that the first several fires consume very little of the duff layer as root systems are slowly pushed deeper.

KEETCH-BYRAM DROUGHT INDEX

After rain (or snow), fuels begin to dry out and become increasingly flammable until the next precipitation event. Many burners use the Keetch Byram Drought Index (KBDI) (Keetch & Byram, 1968) to keep track of this drying process. It ranges from 0 (field capacity) to 800 (wilting point); it increases each rainless day until the top value is reached. The increase depends upon the daily high temperature, and decreases depend upon the rainfall received (8 inches will reset it to 0). It is part of the daily fire weather forecast in many states.

Burning when the Index is below 200 will generally prevent duff consumption. When the Index is between 200 and 450, increasing amounts of duff will be consumed. Postpone burning when the Index exceeds about 450 to avoid root damage, particularly as the fire burns across drainages, hardwood stringers, and gullies. Where no duff layer is present, such as in well-maintained longleaf/wiregrass ecosystems that are burned every year or two, one can safely burn with somewhat higher numbers. Consider postponing routine burns whenever the Index approaches 550 because local fire control agencies are likely to be tied up suppressing other fires and unavailable if needed. Do not be in a hurry to burn units with large amounts of CWD after a hard rain lasting a few hours breaks a drought, as KBDI values will be artificially low. The surface of large diameter fuels will get wet but the interiors will remain bone dry and after two or three days of good drying weather, they are likely to ignite and produce significant residual smoke. Melton (1996) is a good summary article of the use of KBDI in prescribed burning.

The KBDI is site-specific, so a given value will likely differ between a planned burn unit and the weather station at which it was calculated. It therefore behooves fire managers to know the location of the local fire weather station because it's relative topographic position and proximity to large water bodies (think sea breeze although these diurnal breezes are also a feature of large lakes) may differ from that of the burn unit necessitating a mental adjustment to the calculated value. Underlying soils also play a role. Piedmont soils have a higher clay content than sandy Coastal Plain soils, and thus slower percolation rates. This means they retain water near the surface longer, so dead fuels on the forest floor will dry more slowly.

Plant species and stand characteristics also strongly influence fuel moisture. Plant communities comprised primarily of flashy 1-hr fuels, such as *Spartina*, sawgrass, wire grass, and broomsedge, dry quickly and can often be burned within hours after a morning shower if the sun comes out and the wind picks up. Dead fuels with a specific gravity below 0.45, such as pine and hardwood litter, and sloughed bark will burn with increasing intensity as fuel moisture drops below 15%. The amount of sunlight reaching the ground, and in-stand windspeed depend upon the presence and density of ground, understory, midstory and overstory vegetation as well as season of the year. Thus, any general prediction of fuel moisture will only give a rough approximation, necessitating on-site measurements/corrections. On well-stocked areas with a closed overstory and/or midstory canopy, or with a rank understory such as southern rough, prescribed fires will often continue through a hard but brief rain shower because these canopy layers act as an umbrella above the forest floor. The first few minutes of rain will saturate exposed 1-hr fuels, but with 100-hr and 1000-hr fuels, duration is much more important than amount.

ORGANIC SOIL

When contemplating a burn where organic soils (peat or muck) are present, be very conservative and do <u>not</u> burn unless the water table is at, or above the surface; otherwise the soil is likely to ignite. Listen to the voice of experience. Any 10-hr branchwood present that ignites will dry and ignite surrounding peat. Even when the water table is just below the surface, small mounds of elevated peat can easily ignite. If this happens, one then has to deal with a smoldering fire that, once established, is extremely difficult and expensive to extinguish and that will likely cause air quality problems. Thus, even poster-size areas of burning peat should be liberally drenched with water as soon as possible. The very slow smoldering combustion rate will dry adjacent peat and allow spread with moisture contents greater than 150%.

As fire managers hone their skill in balancing fuel moisture against wind speed to maintain the desired fireline intensity, they will find that successful prescribed burns are as much art as science; and like any artist, the more they practice, the better they become—providing they learn from their mistakes. This is why, for example, the Southern Region of the US Forest Service will not burn when the NFDRS fine fuel moisture is predicted to drop below 7%, or surface winds are predicted to exceed 20 mph (although under special circumstances, exceptions may be granted).

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ACKNOWLEDGMENTS

Over a decade ago, Paula Seamon encouraged me to write a series of short summaries of prescribed fire topics. I finally ran out of excuses Paula. The author thanks Marty Alexander, Ralph Nelson, and Alan Long for their careful review of this factsheet and Annie Oxarart for her editing, design, and layout skills and especially her patience in dealing with my continual suggestions.

Postpone burns when the KBDI approaches 550, as local fire agencies are likely to be tied up suppressing other fires and unavailable if needed.

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(Revised by A. Dixon on 01-Feb-2021)

SOUTHERN Fire Exchange

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The Southern Fire Exchange is funded through the Joint Fire Science Program, in agreement with the United States Forest Service, Southern Research Station. This institution is an equal opportunity provider.