USFS Northern CA Province
Fuel Moisture Monitoring

Contents

Introduction

The moisture content of fuel particles is an important factor affecting wildfire behavior (Rothermel 1972). As a result, reliable, locally obtained, current and historical information on fuel moisture content (FMC) is extremely valuable to fire and fuels management programs for strategic and tactical decision-making. Through their use in fire behavior prediction, these data inform decisions about wildfire response, fire danger ratings, unit staffing levels, prescription parameters for prescribed burns, and enhance our ability to predict fire effects.

For fire and fuels management, FMC is the weight of moisture (water) in a fuel particle, expressed as a percentage of that fuel particle's oven-dry weight (Rothermel 1972). The following is the general formula for determining the FMC of a particular piece of fuel:

((wet weight – dry weight) / dry weight) × 100 = % moisture content

The oven-dry weight of a particular piece of fuel is fixed, thus creating a constant value for normalizing fuel moisture content, and creating a linear relationship between additional moisture and increases in moisture content percentage. Therefore fuels may contain more than 100% fuel moisture when the weight of the water within the plant tissue outweighs the rest of the vegetative material.

As potentially valuable as FMC information is, information that is of low or uncertain quality is of little or no value, and potentially misleading. Much of the potential value of FMC information comes from interpreting individual measurements in the context of other measurements made at different times of year, in different years, or at different sites. In other words, if different measurements are collected in different ways, they become difficult or impossible to interpret. Therefore, the value of FMC information depends heavily on established protocols for data collection, management (storage), and communication; and coordinating these standardization efforts with similar programs in other units, and even other agencies.

The intent of this document is to enhance the value of FMC information for fire and fuels management programs within the four National Forests in the Northern California Province (Klamath, Mendocino, Shasta-Trinity, Six Rivers) by 1) improving the practices for FMC data collection, management, and communication on each unit, and 2) standardizing those practices across units To achieve this goal, this document describes a standard protocol, developed collaboratively by representatives from the fire and fuels programs of all four National Forests, based on a review of ongoing practices as well as the latest relevant guidance and research.

In addition to this guide, individual Forests should maintain a supplemental document that identifies and describes all permanent collection sites including the following information: site name, district name, latitude and longitude, township and range, County, elevation, aspect, slope position, sample species, general description of vegetation type, nearest RAWS, site photos, and road access directions.

I. Fuel Moisture Sites

There are 2 types of fuel moisture collection sites:

1. Permanent sites, where data are collected bi-monthly every year and uploaded to the National Fuel Moisture Database (NFMD). The information from these sites represent the live fuel moisture of the dominant plant species found throughout the Forest and the 1000 Hr. dead fuel moisture. The overall goal for these permanent sites is to produce seasonal trends for assistance in predicting fire season initiation, fire behavior, and fire effects for a planned or unplanned ignition.

2. Project specific sites, where data collection is targeted for specific needs, such as a prescribed fire or wildfire. These sites are collected on an as-needed basis for their specific project.

A. Permanent Site Selection and Preparation

Most permanent sites that already exist on the forests have been ongoing for a number of years and it is suggested that no alterations are made to these on-going sites in order to maintain consistency. However, if an existing site has a poor or inconsistent collection record, discarding it or replacing it in favor of a more advantageous site may be appropriate and should be done in consultation with fire and fuels management staff on each unit. All of the current sites collect either live fuel moisture, dead fuel moisture, or both.

If future permanent sites are added, they should be selected with the following criteria in mind:

- Relatively easy access from April through October, with manageable drive times for sampling personnel.
- Target species should be sufficiently abundant across the potential area to avoid defoliation pressure that would jeopardize the ability of the site to be used each year. An area of at least an acre is desirable for sustained collecting.
- Locations where live and dead fuels can be sampled together are desirable for efficiency.
- Association with a RAWS site is beneficial for both weather observation collection and long term trend analysis; locating sites near RAWS stations is desirable when possible.
- The aspect and exposure of the collection site should reflect the area it is being used to predict. If the area of concern is generally shaded, a more shaded location should be chosen. If worst case scenario is the consideration, then an exposed location on a south or west aspect should be chosen.

Sampling courses or transects can be marked/flagged to assist outside personnel who may assist in sample collection, but are not required. Keeping sites as discrete as possible helps reduce likelihood of dead fuel sample logs being removed or used as firewood by the public.

Sites with 1000 Hr. samples should have the samples prepared and placed as far in advance as possible. These can either be peeled logs prepared by the fuels staff or 4” diameter peeler cores (Figure 2). Sample logs should be free of bark (Zahn and Henson, 2011a). If 1000 Hr. fuel logs are brought in from off-site, sampling should not be attempted for at least 5 weeks from the time of placement on site, to allow the logs to properly condition (if logs are green, they should be placed the previous season to fully cure). Logs should be kept slightly elevated (6”-12”) in order to avoid becoming buried in the litter or duff layer and to obtain consistent moisture throughout the sample log (Figure 1). Only sound samples should be used, no decayed logs.

Figure 1 Example of 'crib' used to ensure 1000 hr. fuels are not buried in litter or duff layer.

Figure 2 Example of 4" Doug Fir Peeler core. Use of this log type reduces variation and removes the step of peeling sample logs.

B. Project Site Selection and Preparation

Collection of fuel moistures, both live and dead, is not limited to permanently located, bi-monthly collection sites. Project level sampling may be advantageous for meeting planning or prescription requirements. In these cases, permanently dedicated transects and pre-placed 1000 hr. samples may not always be available. In such cases, record the location including date, time, latitude and longitude, and general description of the area in order to replicate the sampling should further evaluation be needed. Keep in mind that for this type of sampling, multiple sites may be required to get a complete picture of the fuel moisture across a project unit. Similar to permanent sites, a large enough area and representative species should be present. Data from temporary, project level collection sites should not be uploaded to NFMD.

II. Fuel Moisture Data Collection Protocols

A. Sampling Schedule

Sites should generally be sampled during the period from April through October, access permitting. However, units should use their understanding of the historical relationship between recent weather and FMC to inform their decisions about when to begin and end sampling. During the sampling period, FMC at permanent sites will be collected twice per month at each sampling site, as close to the 1st and 15th as possible. If staffing is limited and time constraints dictate, 1000 hr. sampling may be reduced to a minimum of one collection per month, with the goal of two collections per month when at all possible. Longer or shorter periods may be dictated by seasonal access, weather patterns and needs of the forest or management unit. If sampling is conducted outside of the standard period, the same protocols should be used for collection and data storage. If a sampling date is missed, leave that month's numbers blank (null) in data storage locations, DO NOT put values of "0" in any data location.

Project level sampling is done at the period and frequency needed to fit the needs of each specific project. Due to the slow changes in 1000 hr. fuels, sampling these more frequently than bi-monthly is not likely to result in significant changes. Live FMC also changes relatively slowly, and generally bi-monthly is sufficient to capture this as well. However, for specific projects, sampling in the days after precipitation events may capture variations driven by increases in available soil moisture and may be beneficial for tracking short spikes in live fuel moisture.

In all cases, sample only during the hottest and driest portion of the day (1100-1500). Do not sample if water is present on plant surfaces from rain, dew etc. Shaking the sample to remove excess water or attempting to dry the sample in any way is ineffective. If the sample is wet with surface water, do not collect until later in the day when leaves have dried naturally, or return to the site on another day.

B. Supplies and Equipment

- Sampling containers – with matching label on lid and container. Approved containers:
    - 1 quart metal paint cans with tight fitting lid – use paint key if possible, screw drivers can damage the seal.
    - Polypropylene (Nalgene) containers with threaded lids
    - 16 oz. aluminum soil sampling cans with tight fitting lids
- Pruning clippers
- Saw for 1000 hr. samples – chainsaw, reciprocating saw or hand saw
- Data collection forms
- Clipboard and writing utensil
- Portable ice-chest (if not field weighing samples)
- Belt weather kit, kestrel or access to co-located RAWS data
- Map of sampling area (if needed)
- Species identification book (if needed)
- GPS – if installing new location or navigating to project-specific sampling site
- Flagging – if installing new/project site or altering collection transect.
- Sturdy hand shovel or trowel, for litter and duff sampling.
- Drying oven – electric forced air- convection oven with thermostat and ability to hold specific temperature indefinitely.

- Digital electronic balance (scale), capable of weighing 250 grams to accuracy of 0.1 grams – battery operated preferred.

C. Number of Samples

For each species or size class at a site, a minimum of 3 samples should be collected, where a "sample" refers to a single container's-worth of material, or a single wafer. Two samples are the minimum requirement in order to obtain both a site average and an understanding of the within-site variability. The third sample allows better estimation of the average and the variability, and also provides some insurance in the event that one of the samples is lost, spilled, or gives an anomalous reading.

D. Weighing Samples

All weights should be obtained using an electronic balance capable of reading to 10ths of a gram (1 decimal place). If the balance reads to more decimal places, standard rounding methods should be applied.

The tare weight (empty weight) of each container should be obtained, with the lid secured, before each sampling event and recorded in the data sheet. This should be done every collection as the weight of containers can increase as sap and plant oils become baked onto the interior surface.

When weighing containers in the field immediately after collection, place the scale on a level surface out of the influence of the wind. Weighing full containers in the field yields the gross wet weight of the filled container.

When weighing dried samples, take samples from the oven one at a time, replace the lid, allow to cool and weigh the container. Only open the oven door long enough to remove one sample at a time to prevent moisture in the room from entering the oven and altering the moisture of dried fuels (Pollet & Brown, 2007). Weighing full containers upon removal from the oven produces the gross dry weight of the sample (filed container).

Use the same scale for field and office weights for any given sampling event, do not switch scales.

If a reading is lost due to spilled container, omit it from the final average for that species or size class. If an anomalous reading is obtained and re-weighing the sample does not alter the results, consult with local fuels officer and forest fire ecologist to determine if a reason can be determined for the outlier value. The determination to discard an outlier without any known cause should be made within this consultation. In some cases, this value may be omitted or samples re-collected the following day.

E. Live Fuel Moisture

Collection of live samples should be done using hand-held pruning shears or clippers and include only live needles, leaves and twigs up to 1/8 of an inch in diameter. Past protocols have utilized separate cans of new and old growth, this has been shown to increase collection time with no statistical change in overall value when all cans are averaged (Brown at al. 20009). Because of this, **the standard protocol is to collect a minimum of 3 cans for each species recorded at the site, with each can containing an approximate mix of old and new growth representative of the mix found on the plants in the collection area**. This removes the need to alter methods late in the season as new growth becomes

unavailable, and avoids confusion when sampling a species that loses all leaves each season. For each of the samples, the following steps should be followed (Pollet & Brown, 2007, Zahn and Henson, 2011a, and Zahn and Henson, 2011b):

1. Live Fuels – Brush

1. Clip live foliage and pliable, green twigs, up to 1/8" diameter, and place in collection cans. Remove all unwanted living and dead material (i.e. nuts, berries, flowers, flower buds, fruit, dead twigs, insects, etc.) from cans. Clip small, pliable stems into small pieces and drop them into collection container. Remember to clip a representative portion of new and old growth, based on seasonal growth cycle (e.g., if 90% of shrub exhibits new growth, clipped sample should reflect same proportion).
2. Sample randomly from multiple plants, being sure to sample multiple sides/aspects and at different heights above the ground, both shaded and unshaded. Clip leaves and twigs to fit neatly into container, cutting large leaves and stems into pieces.
3. Fill each can with 40 to 80 grams of material, ¾ full is a good estimate. Do not fill to the point where placing the lid on the can will compress fuels and prevent proper drying of the sample in the oven. Do not pack sample into can or compress fuels as this can reduce air circulation and alter the drying of the fuels.
4. If moving some distance between plants for sample collection, place lid on the container to avoid loss of moisture from previously collected material in the can.
5. When can is ¾ full, place lid tightly onto collection container.
6. Weigh each can as soon as possible, ideally in the field, with the scale on a flat surface out of the influence of the wind. If samples must be brought back to the office for weighing, carry with lids secured, and preferably, in a cooler to reduce ambient moisture from entering the sample. This is the 'gross wet weight'.
7. Prior to leaving the collection site, record weather conditions, including, DB temp., Rh, winds and sky weather (if collecting live and dead fuel samples at the same site, only one weather observation is required). This step can be omitted if site is co-located with a RAWS.
8. Prior to leaving the collection site, record growth characteristics of the live fuels, such as, new bud break, new growth developing, flowering stage, leaf color, level of summer senescence, etc. Record this in the notes/remarks section of the data form.
9. Place each can, uncovered, in the fuels oven preheated to 100°C (212°F) with lids placed securely on the bottom of each can.
10. Weigh each can after being in a hot oven for 18-24 hrs. (overnight), record this as the 'gross dry weight' on the data sheet.
11. After each dried sample is weighed, cover tightly with lid and save the sample until the fuel moisture content is calculated. If an obvious error appears in the calculation, the sample can be weighed again and the source of the error may be found.
12. If at any point after leaving the field material is lost or spilled from a container, throw out that sample.

2. Live Fuels – Trees

Follow steps above for shrubs with the following clarifications. Collect only leaves or needles and small diameter stems that are still pliable and green, avoid brown, woody stems. Ensure that each container includes material from multiple trees. As with brush, sample from various heights and various aspects, including shaded and unshaded needles/leaves. Include proportions of new and old growth equivalent

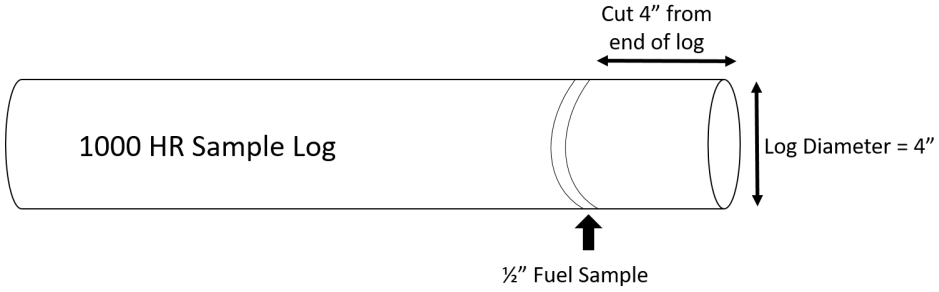
to that present throughout the sampling area. Do not include diseased or dead foliage or twigs (Zahn and Henson, 2011b). Some sites may be designated as needle or leaves only as a means to determine strictly foliar moisture content. If this is the case, this should be indicated clearly in the site data and on the data collection sheet.

F. Dead Fuel Moisture

1. 1000 Hr. – Permanent Sites

The same protocol for sampling live fuel moisture should be observed, with the following specific requirements for 1000 hr. dead fuels:

1. Cut one wafer, ½" thick, from **3 different logs** with a chainsaw, electric saw, or handsaw using the following steps (Zahn and Haase, 2006):
    a. Cut and discard a wafer from each sample log that is at least the thickness of the radius of the log.
    b. Cut a second wafer, ½" thick – this is your sample. Place wafer in container, breaking as needed to fit in the can.
2. Weigh each can after 18-24 hrs. (overnight), record this as the 'dry weight' on the data sheet. Very wet 1000 hr. fuels may need additional drying time. If numbers seem high or it is early season, additional drying may be required in order to ensure that all moisture has been evaporated. If this is the case, continue drying and periodically re-weighing the sample, and when the weight no longer declines with additional drying, enter this latest weight as the "dry weight" on the data sheet.



2. 1 Hr., 10 Hr., 100 Hr., & 1000 Hr. Dead Fuels at Project Sites

If field sampling is required, samples of dead and down woody fuels should be taken from several twigs and branches resting on the ground, or slightly elevated above the ground. For 1, 10 and 100 hr. samples, do not fill each sample container from a single branch. Do not collect from dead twigs still attached to a live plant or are in any way still rooted in the ground. Collect twigs of as many sizes as possible within the size class. All samples must be collected from dead wood that is detached from its growth point. Do not collect parts buried in the litter, duff, or soil. Do not collect dead branches attached to the base of live trees or shrubs. Each piece of collected woody material should be 1"-2" in length. Remove all lichen or other debris and very loose pieces of bark from the samples. The wood collected does not have to be completely sound but should not be decayed to the point of being easily rendered into powder or splinters when rubbed. Some splitting caused by drying is acceptable (Zahn and Henson, 2011b).

Cutting of wafers will be required of 1000 Hr. samples, and may be necessary for 100 Hr. samples. Cut each cookie or wafer using the steps outline in the section for 1000 hr. samples at permanent sites. Sound logs without bark are preferred.

For each size class, collect sufficient material to fill a minimum of 3 containers, and follow same weighing and drying procedure as at the permanent fuel moisture collection sites.

If 10-hour fuel sticks are available at sampling stations, these may be used to estimate 10-hour fuel moistures rather than actual field sampling. If a 10 Hr. fuel stick is used, it should be placed on a stand, elevated above the ground approximately 6", in a representative location for the project. This may be shaded or unshaded depending on the specific project and the activity the data is being collected for. Allow the 10 Hr. fuel stick at least 72 hours of acclimation for most accurate reading. The preferred tool for field weighing of these 10 Hr. fuel sticks is a spring scale, such as the Pesola Medio-Line 300g spring scale.

*3. Litter & Duff**

Not commonly sampled. For litter, gather undecomposed needles, leaves and cone debris from the top ½" to 1" of the litter layer. Do not collect compacted, damp leaves as these will not support surface fire and their moisture is usually not of interest. Be sure not to pack samples into cans, as this will prevent air circulation and drying of the sample. Collect samples from representative shaded and unshaded locations in proportion to their presence in the unit or sampling area. A uniform project area will require less variability in sampling and therefore less samples (Zahn and Henson, 2011b).

When collecting duff samples, be sure to remove the litter layer from on top of the duff. Litter is generally less compacted and recognizable as to the organic source of the material. Duff is partially decomposed and the organic origin is uncertain or unidentifiable. Remove all rocks, moss, live material and fungal rhizomes from duff samples. Do not sample from large duff or moss mounds unless they are truly representative of the entire unit or project area. Do not include mineral soil in the sample. If you observe or feel more than 50% mineral soil in your sample, consider it to be too much soil and retake the sample or discard and rely on other observations (Zahn and Henson, 2011b).

As with other collections, basic sampling procedure is for three cans each of litter and duff at a site. For a large project or burn unit, multiple sites within the project are may be needed to represent the project as a whole.

III. Common Sources of Error

A. Field Errors

- Placing the samples in a container with a different number than is listed on the field data sheet
- An incorrect lid on a container
- Incorrectly recording the container number on the data sheet
- Drops of rain or other free water contaminating the sample
- Small rocks, animal droppings, and other material are included in the duff, soil, or litter samples
- Woody stems, flowers, berries or dead/diseased plan parts included in sample
- Inadequate amount of material is collected. Remember to collect 40 to 80 grams of material, generally fill the container to ¾-full
- Failure to collect material from several heights, aspects, and plants on a site
- Heating a sample prematurely with excessive exposure to the sun or leaving in a vehicle prior to getting initial gross wet weight. This is detectable by condensation on the inside of the container's lid
- Using the scale on a sloping surface or exposed to disturbance from the wind

B. Laboratory/Office Errors

- Failure to check the container numbers against the sample contents as recorded on the calculation sheet
- Some material falls out of the container while drying
- Failure to set the scale to zero before weighing
- Placing samples in oven with lids on
- The scale is misread
- Errors are made during the entry of values into the calculator or while doing the calculations (this is possibly the greatest single source of error – double-check!)
- Leaving oven door open while taking samples out for weighing,
- Metal cans that have rusted; clean or discard if this occurs.

IV. Data Distribution, Storage & National Database

A. Permanent Sites

Data storage should occur in three places for each sampling event:

1. A folder that is organized and kept at the district or unit of all hard copy material.
2. Digitally within the excel spreadsheet/data collection form and stored on the drive or cloud space designated by the unit. Forests/units may have different storage locations, check with forest fuel moisture coordinator to ensure data storage is consistent.
3. Input into the National Fuel Moisture Database, https://www.wfas.net/nfmd/public/index.php . If your site(s) does not exist in the national database, or you have issues entering data, contact forest fuel moisture coordinator to assist in creating your site or for assistance entering data.

If a sampling date is missed, leave that month's numbers blank (null) in data storage locations, **DO NOT** put values of "0" in any data location.

In addition, some units may have distribution preferences after each sampling event, such as emails to district FMO, district fuels personnel, forest chief officers, forest fire ecologist and other personnel. Check with your forest coordinator for details on distribution.

B. Project Sites

All data collect for project level fuel moisture sampling should be stored in the same location as the district's permanent fuel moisture data, labeled using the following convention:

Management Unit_Project/Unit Name_FuelMoisture_Year,

Example: "SMMU_Highway89_FuelMoisture_2016"

The district will also keep hard copies in the project file for which the fuel moisture samples were collected.

Project level fuel moisture samples are not entered into the national database.

V. Fuel Moisture Data Sheets

The following pages contain two examples of data sheets that can be used to record fuel moistures. Both are available in excel form to allow for automatic calculation of moisture percentages when all three recorded weights are input into the appropriate cells. In the excel version of these forms, each sampling event can be added as a tab, creating an excel workbook for each year at fixed sites or for each project site for non-fixed sites, such as a prescribed burn unit.

Fuel Moisture Content Form

Agency:	State	Field Office		Site Name:	

Collection Record	Moisture Determination Record		
Observer	Observer	Date in oven	Time in oven
Date			
Time			

		A	B	C	D	E	F
Container Number	Species (Live) Size Class (Dead)	Gross Weight Wet(g)	Gross Weight Dry(g)	Tare Weight	Water Weight	Dry Weight	Percent Moisture

Sample Material Collected	Calculation Summary				
	A - B = D	B - C = E	(D / E) * 100 = F		
Dead Fuels [ ] Live Fuels [ ]	Species / Size Class 1				Overall Average
	Species / Size Class 2				Overall Average
	Species / Size Class 3				Overall Average
	Species / Size Class 4				Overall Average

Weather				
Dry Bulb:	Wet Bulb:	Rh:	Winds:	Cloud cover:

Remarks

Agency	State	Field Office				Site Name/#		
Collection Record			Moisture Determination Record					
Observer	Date	Time	Observer		Date in oven		Time put in oven	
								Averages:
Species/Size Class	Live/ Dead	Can #	A	B	C	D	E	F
			Gross Weight		Tare Weight	Water Weight	Dry Weight	Percent Moisture
			Wet(g)	Dry(g)				
						A-B	B-C	D/E*100
						A-B	B-C	D/E*100
						A-B	B-C	D/E*100
						A-B	B-C	D/E*100
			Calculation Summary					
			A - B = D		B - C = E		(D / E) * 100 = F	
Weather								
Notes								

VI. References

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