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Assessing the flammability of *Molinia caerulea* and mosses using a simplified method

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Abstract

An experimental investigation into the impact of moisture content on the flammability of Scottish heathland vegetation has been undertaken in this work. Two different vegetation types are studied; Molinia caerulea and moss. The approach followed in this work consisted of developing an appropriate sample preparation procedure to ensured homogeneous drying in a conditioning chamber and the development of an apparatus to support a consistent ignition procedure. The probability of ignition is evaluated as a function of fuel moisture. For Molinia caerulea, ignition is very likely to occur for a moisture content of less than 75%. For moss, this transition stage revolves around 20% of moisture content. Additionally, drying curves have been drawn for the specific drying conditions (30 ºC and 90% relative humidity), which can provide insight into the rate of drying of organic materials for these given environmental conditions. Finally, a discussion presents the main findings and limitations of this work, while providing insight into possibilities for future research.

1. Introduction

Previous studies (Legg et al., 2007; Nolan et al., 2016) have identified that the fuel moisture content (FMC) of "thin" or "fine" fuel elements responds more rapidly to changes in the environmental conditions than thicker fuel elements. Often fine vegetative matter is the fuel first ignited in wildfire events and therefore understanding the response of these fuels to drying is essential to accurate wildfire risk mitigation (Viegas et al., 1992; Chuvieco et al., 2011; Davies and Legg, 2011). Within the United Kingdom (UK), *Molinia caerulea* and mosses represent two typical fine fuels found on heathlands. This study seeks to develop an understanding on the drying response of these fuels and the conditions required for ignition using a small flame. The likelihood of ignition of a fuel when subjected to small ignition sources is determined. In this study, the probability of ignition is determined as a function of the fuel moisture content. This approach gives an indication of the relationship between fuel moisture content and ignition and can be used to evaluate when different fuels are susceptible to ignition by small sources. The FMC of live and wet dead fuel can be affected differently by environmental conditions, and this work uses only dead Molinia grass which might not be representative of the behaviour of live grass. A separation between live and dead moss was not possible.

Repeatability of results is important, both in the drying behaviour and the flammability response, given the high level of natural variability that exists in wildland fuels. This idea shaped the methodology employed, which was designed to ensure a homogeneous drying of the fuel and consistent flammability responses in a practicable way.

The steps followed throughout this process and the reasoning behind them is presented to ensure clarity, transparency, and highlight the approach's limitations. The methodology section outlines the tools and equipment used to carry out the experimental procedure. Then the results of that procedure are presented, followed by a discussion on the findings. This last section is supplemented by an explicit declaration on the limitations of this approach.

2. Methodology

2.1. Overview

Different preparation and testing methodologies are developed for the grass and moss samples to account for their differing structure. An illustration is presented in Figure 1 that visualises the processes followed for the grass and moss. Blue boxes indicate a process, and green boxes indicate an outcome of the linked process. These are discussed in more detail in the following sections.

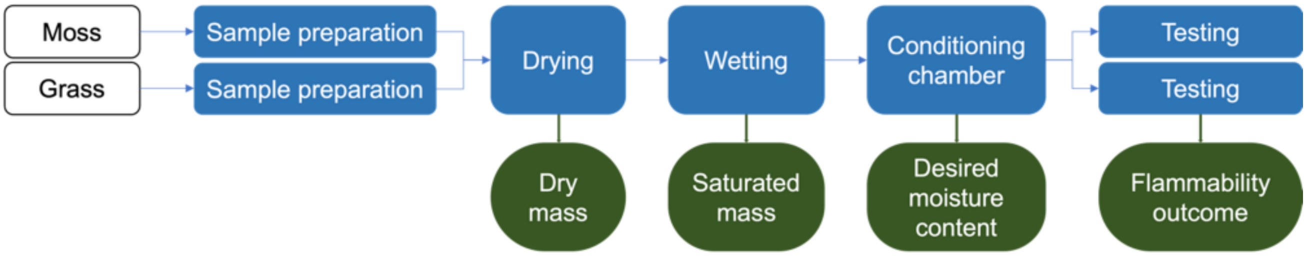

Figure 1. An outline of the process followed for examining relationships between fine fuel moisture (FMC) and flammability

2.2. Sample preparation

2.2.1. Molinia grass

Samples were received in a cured dry condition and required rewetting and drying to obtain the FMC of interest. Repeatable sample preparation was essential to ensure consistent results and homogenous conditioning of the samples. Samples were prepared by attaching a fixed mass of grass to electrical tape. Each sample was of approximately 0.45 g (dry mass). Care was taken to distribute the sample evenly along the tape (Figure 2).

Figure 2. Molinia grass sample prior to testing fixed with electrical tape

2.2.2. Moss

The nature of moss means that it must be supported on a frame prior to testing. A set size of 10 x 10 x 5 cm was chosen for the moss sample holders because this enabled consistency amongst the sample sizes and weights, (Figure 3). Moss samples were prepared by removing grass or other litter to prevent this from impacting on the results. The height of the moss samples was approximately 20 mm.

Figure 3. Moss sample preparation prior to testing

2.2.3. *Drying*

Both Molinia and moss samples were dried straight after preparation in an oven at 60°C to determine their dry mass. The samples remained in the drying oven until their mass remained stable over 4 consecutive hourly measurements. This typically took less than 24 hours. This temperature was chosen to avoid the loss of any volatile organic compounds which can occur in organic fuels when dried at higher temperatures (Samuelsson, Nilsson and Burvall, 2006).

2.2.4. Wetting

After the grass samples were prepared and totally dried, they were placed in groups of 4 in a 500 ml glass beaker of tap water and were left submerged overnight to saturate, covered with aluminium foil.

After the moss samples were prepared and totally dried, they were placed in large tank with tap water and were left submerged overnight to saturate.

2.2.5. Drying for moisture content control

An environmental chamber (TAS ECO MTCL400) was used for the controlled drying of the samples before every experiment. The conditions in the chamber were set at 30°C and 90% relative humidity (RH). These conditions were chosen as suitable for providing a rate of sample drying that allowed for measurements to be taken while maintaining a manageable timeframe of every experimental run. Mass readings were made using a precision balance (Mettler Toledo NewClassic MS), with readability of 0.01 g.

2.2.6. Calculations

The dry basis moisture was used for the calculation of the samples' moisture content, which is defined as the amount of water over the dry sample. This is calculated through the formula:

$$MC = 100\frac{m_w}{m_{ds}}$$

Where:

- MC is the sample's moisture content in percentage form,
- m_w is the mass of the water contained in the sample,
- m_{ds} is the mass of the dry sample.

The drying curves were based on the drying rate normalised per each sample's dry mass, calculated as follows:

$$DR = \frac{m_{i+1} - m_i}{t_{i+1} - t_i}\frac{1}{m_{di}}$$

Where:

- DR is the sample's drying rate normalised to its dry mass,
- m_i is the mass of the sample at a given time t_i,
- t_i is the time of the measurement.

2.2.7. Ignition source

A small flame ignition source was used. This was obtained using a commercially available wax candle. The flame was approximately 15 mm high. This was chosen to give a consistent ignition source both in terms of size and burning duration and seeks to represent a small ignition source. The results presented in this work are strongly dependent on this choice of ignition source.

2.3. Molinia apparatus

For the grass samples, the developed and used apparatus is shown in Figure 4. The sample and sample holder remained in a fixed position while the ignition source could be positioned manually. The vertical orientation of the apparatus was chosen to provide conservative results.

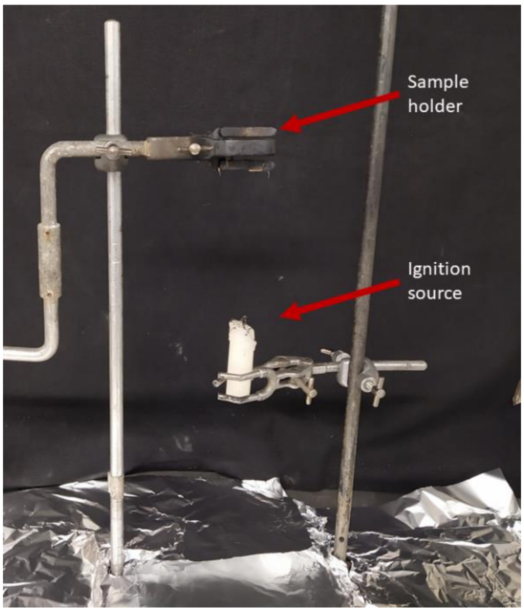

Figure 4. The Molinia grass ignition testing apparatus

2.3.1. Molinia procedure

Once a sample reached the desired moisture content, it was rolled into a clump with diameter of approximately 15 mm at the tied end and placed in the sample holder. This shape was chosen so that the full sample area would be simultaneously exposed to the ignition source, and grass strands would be in such proximity with each other that would be representative of their field condition. The ignition source was placed just below the sample for 5 seconds. Then the ignition source was removed and the resultant burning (or otherwise) of the sample observed.

2.3.2. Moss apparatus

The apparatus used for the moss samples, is shown in Figure 5. The wire mesh was assembled to place the sample holder and ignition source in position. The horizontal orientation of the apparatus was chosen to emulate conditions in which moss is likely to be found.

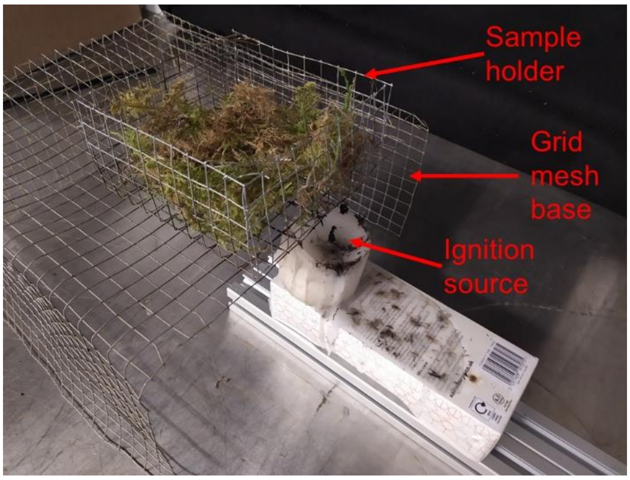

Figure 5. The moss testing apparatus: sample holder, base mesh grid, and ignition source are indicated.

2.3.3. Moss procedure

Once a sample reached the desired moisture content, it was placed on a metal grid above the ignition until the estimation flammability was definitive; either sustained burning or local ignition but no propagation.

2.3.4. Probability of burning

Subjective probabilities were used for the assessment of flammability. This is a type of probability that expresses the observer's belief on a system or outcome, derived from their personal judgment or experience. In this work, these were defined by the amount of fuel consumed by the ignition source alone, and the ability of the sample to sustain burning individually after the ignition source is removed (0 – no fuel consumed, 0.25 – some fuel consumed but no burning, 0.5 – some fuel consumed and some smouldering followed, 0.75 – fuel consumed and some flaming follows, 1 – sample fully consumed in flaming combustion).

3. Results

In this section the results from the measurements and experimental procedure are presented. Initially the indicative moisture loss graphs and the drying curves are presented for Molinia grass and moss, respectively. Following that, the moisture loss graphs up to ignition, and the flammability graphs linking the moisture content with the probability of ignition are provided.

3.1. Moisture loss graphs and drying curves: Molinia

The findings from the 20 indicative samples of grass that were dried from saturation to dryness are presented in the figures below. Figure 6(a) presents the loss of moisture over time. Figure 6(b) also shows the drying curve for these grass samples. The drying curve is characterised by a decreasing drying rate as a function of time. After 60 minutes, the drying rate approaches zero and the samples reach equilibrium with the environmental conditions in the chamber.

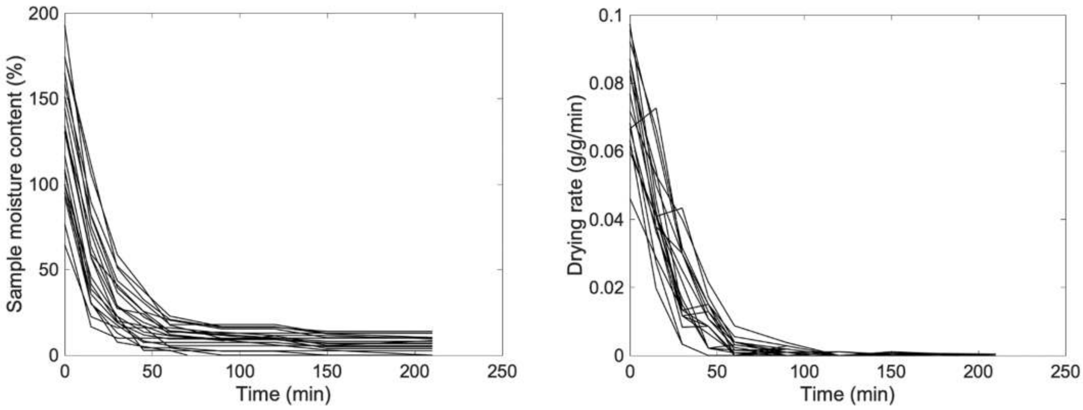

Figure 6. (a) moisture loss, (b) drying curve; for Molinia grass

Change in FMC as a function of time from the 13 indicative samples of moss that were dried from saturation over a period of seven hours are presented in Figure 7(a). Compared to the Molinia samples the characteristic time of the drying is much longer with none of the samples reaching a stable FMC over the time period available. There is a higher degree of variability in these results compared to the Molinia. This is attributed to the differing thickness and more complex structure of the samples compared to the grass. Figure 7(b) below shows the drying curve for these moss samples, which as was presented in the Calculations sub-section, is the drying rate normalised by dry sample mass. Again, given the nature of the fuel structure there is some scatter in the results but for a moss sample in this condition, the drying rate appears to be on the order of 0.01—0.03 g/g/min.

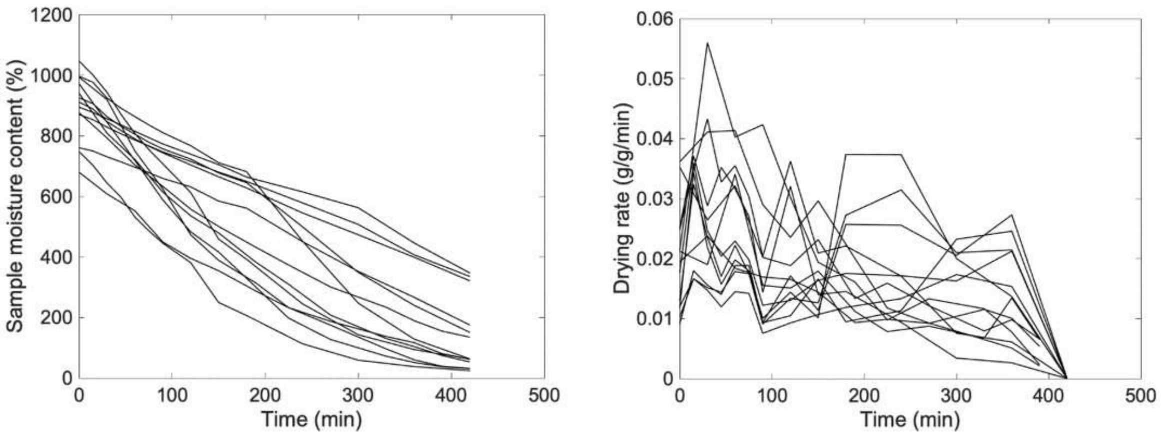

Figure 7. (a) moisture loss, (b) drying curve; for moss

3.2. Flammability graphs

Characterising the drying times allows for target moisture contents to be reached for testing. New samples were prepared, wetted, and dried for a duration required to achieve the desired FMC for testing. Figure 8 shows the resulting probability of ignition for Molinia grass as a function of FMC.

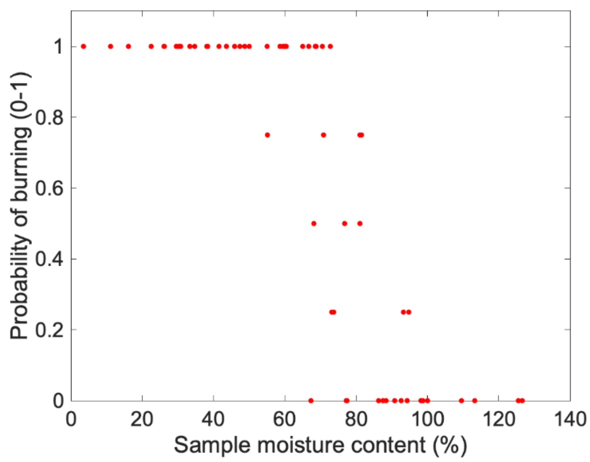

Figure 8. ignition probability as a function of fine fuel moisture content (FMC) for Molinia grass.

From Figure 8 above it can be inferred that there is not a critical FMC at which the behaviour of the fuel changes. Instead, the ignition probability increases from 0 to 1 in the range 85—65% FMC. FMC lower than 65% are almost certain to ignite and burn to completion.

Figure 9 shows the resulting probability of ignition for moss as a function of FMC. Similar to the behaviour of Molinia grass, for this graph too it can be inferred that there is not one point where the behaviour of the fuel immediately changes, but it is rather defined as a region in between 10 and 20% FMC.

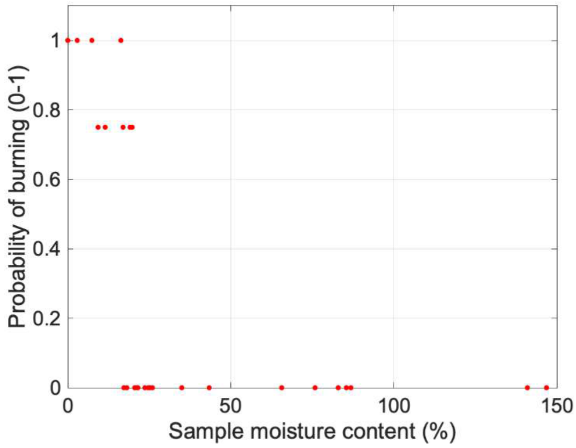

Figure 9. ignition probability as a function of fine fuel moisture content (FMC) for Molinia grass.

4. Conclusions

This study has highlighted the ignition probability for Molinia and moss subject to a small flame source. These fuels were chosen as they are found on the ground where small ignitions sources may arise accidentally e.g. dropped matches, discarded cigarettes. The approach employed in this work is not intended to replace standardised methods of assessing fuel flammability, where a well-defined exposure and combustion environment exists, but provide complementary, easy-to-acquire insights on the behaviour of wildland fuels when exposed to these small ignition sources. These results, however insightful, may not be appropriate as direct inputs in fire models, but the approach could be used as a practical means to provide threshold values in local wildfire risk indices, such as any adaptation to the Canadian Forest Fire Weather Index System, that are relatively easy and quick to produce experimentally.

The Fuel Moisture Content (FMC) for ignition of Molinia grass was found to be in the range below 85%. With a high probability for samples with less than 65% FMC. The ignition of moss was found to occur at FMC below 20% with a high probability at FMC less than 10%. These results serve to calibrate ignition thresholds and to evaluate the relative hazards posed by different fuels. Combining the drying rate data and the ignition probabilities allow an estimation of the timescales required for the different fuels to become ignitable. For Molinia this is on the order of 30 minutes. For the moss, this is on the order of 5 hours. These differing timescales are strong indicators that the hazard associated with different fuel elements requires careful consideration, while acknowledging that they can be affected differently by any wind present and the climatic conditions of the region

When interpreting these results, there are some limitations that should be considered. Firstly, the nature of the ignition source and the duration of the application will have an impact on the results. Particularly it may be possible to ignite samples with FMC outside the ranges quoted here with larger heat sources or longer durations. For example, these results would not be appropriate for determining the ignition arising from discarded barbeques. The variability in the natural structure of the fuel and its impact should be acknowledged. Additionally, qualitative observations suggest that the FMC of the samples after drying was not uniform in some cases, mainly for the moss samples, which would suggest that a thinner sample might be more appropriate. Finally, the extent of burning used to derive probabilities was subjective.

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