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A laboratory study of the effect of moisture content on the spread of smouldering in peat fires

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Abstract

Smouldering is a slow, flameless form of combustion which greatly affects peatland and soil layers with high organic matter content. Once these organic rich layers begin smouldering they can burn for months, be difficult to extinguish, consume large quantities of material, damage root systems and soil biota, lead to habitat losses and produce substantial carbon emissions. The moisture content (MC) distribution in organic soils and peats is known to be one of the most important variables affecting the dynamics of smouldering combustion. The rate of propagation of the smouldering front and mass consumption of the fuel are two of the most sensitive variables influenced by changes in MC. After a successful ignition, propagation for different MC is not yet fully understood. Here we focus on characterizing the smouldering combustion of organic layers under different MC and present the results from a series of small-scale experiments (in a 20x20x5cm tray), looking at the effect of moisture on fire propagation in terms of rate of spread of the smouldering front, burn duration and mass lost. The results show the influence of moisture on the propagation behavior of smouldering fires.

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1 Introduction

Peatland wildfires are becoming more frequent both in Ireland and internationally. However, the study of smouldering fires has been limited in comparison with flaming wildfire studies. Peatlands cover over 3% of the Earth's land surface and are important ecosystems for a wide range of wildlife habitats and an important store of carbon since it contains one third of the world's terrestrial soil carbon. Smouldering combustion is different from flaming because it is a heterogeneous reaction which burns slowly and without flame, spreading into the organic material of peatlands or in shallow forest layers like duff, humus or peat (Rein, 2013).

Most studies to date have been focused on analyzing the factors limiting the ignition of smouldering (Frandsen, 1987; Rein et al., 2008, Benscoter et al., 2011). Once started, smouldering is difficult to extinguish and can propagate into a wide area and reach deep layers. The importance of understanding the limits of smouldering combustion led to publications focused on determining what factors play a role in self-sustaining spread. For that, laboratory experiments were carried out with peat under different moisture and inorganic content (Frandsen, 1987; Rein et al., 2008), varying the bulk density and depth (Benscoter et al., 2011), changing the oxygen concentration (Rein et al., 2008; Belcher et al., 2010; Hadden et al., 2013) and some field studies of past smouldering events (Benscoter et al., 2011) and for managing purposes (Reardon et al., 2007).

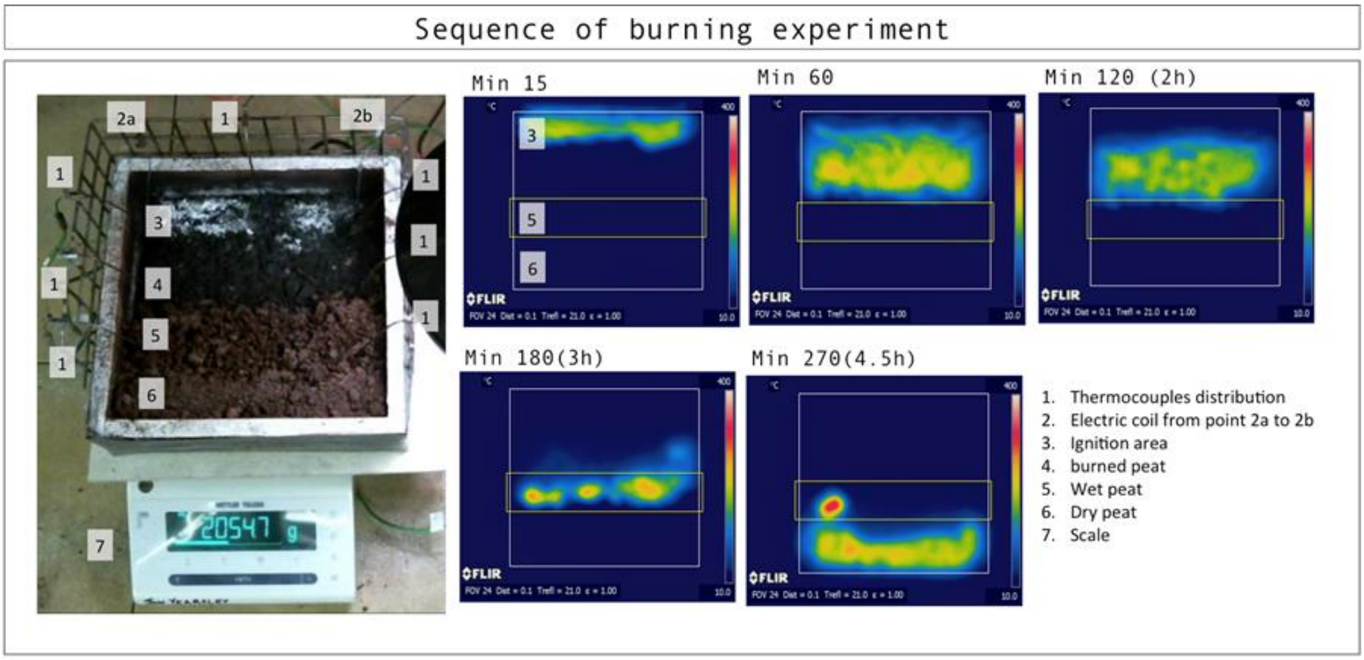

Figure 1. Smouldering experiment. Left, components. Right, front moving through the peat, dry peat is 0% MC and yellow rectangle is 200%. The moisture configuration is used for illustrative purposes.

When the smoulder propagation is self-sustaining, the front advances if the amount of heat being released from the oxidation front and transferred to the fuel is high enough to overcome heat losses (preheating of the fuel, water evaporation) and support the pyrolysis reaction (Rein, 2013). The main limiting factor for smouldering propagation has been identified as oxygen availability (Belcher et al., 2010; Frandsen, 1987; Rein, 2013; Hadden et al., 2013), but factors like MC, bulk density, mineral content and depth of the peat are considered to have important roles in the smouldering process (Frandsen, 1987).

From all these factors, moisture content of the organic layers has been determined as the main affecting ignition and propagation of the smouldering (Frandsen, 1987; Rein, 2013) since latent heat of vaporization represents a significant heat sink and decreases the heat available for the pyrolysis front to advance (Rein, 2013). The smoulder-ignition limits were established at a MC of 110-125% in a dry base (Frandsen, 1987; Rein et al., 2008). But after a successful ignition the behavior of the propagation front is not well understood. Therefore this study is focused on parameterizing the smouldering propagation under the influence of different MC.

2 METHODS

A series of small-scale experiments with commercial sphagnum peat are used to get data of the smouldering process in insulted trays of 20x20 with 5cm depth (the same scale as previous set ups). Moisture content, bulk density and mineral content are controlled. Peat is ignited in one side of the tray with a heating coil (Figure 1) with 100W during 30 min (Rein et al., 2008) giving a strong ignition to make peat starts self-propagating. The position of the smouldering front is recorded with an infrared camera, temperature evolution is tracked with thermocouples and a scale measures the mass loss during the experiment. Values of smouldering propagation such as spread rate of the front, burn duration and mass loss, are estimated from the data registered during the burnings. The results from a range of MC under the ignition limit (<110% - dry base) and one example over 200% MC are presented. Dry peat is considered at 0% MC, but should be noted that rapidly equilibrates with the room humidity, rising the peat MC around 3%.

The advantage of laboratory experiments is the control of the variables and that fuel is kept homogeneous, repetitive experiments are possible and the difficulties of studying spread directly on the field or with real peat samples are

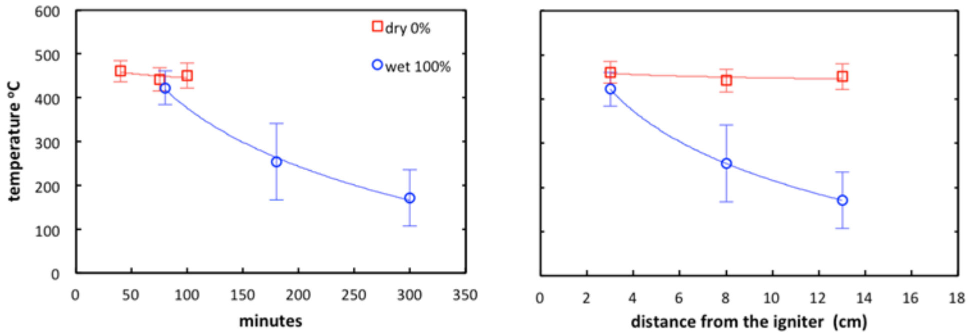

Figure 2. Mean peak temperatures of smouldering peat as a function of time (left) and distance (right) from the igniter. Error bars represents one standard deviation.

Table 1. Average measurements of smouldering fire propagation in different MC. (*) peat with 200% MC is over the ignition limit, smouldering propagates in contact with dry peat (see Figure 1).

Moisture (%)	Velocity (cm/h)	Front Temp (°C)	Mass consumed (%)	Mass loss rate (g/min/m^2)	Duration (minutes)	Replicates (number)
0	10.04±1.42	446±27	93.7±2.1	0.994±0.10	300±39.8	5
25	3.72	458	94.7	0.496	403	1
50	3.44±0.48	438±29	89.3±2.9	0.507±0.01	386±19.1	5
75	2.42	414	82.4	0.431	460	1
100	2.48±0.39	212±85	84.3±4.9	0.347±0.01	430±41.1	5
0/200*	6.60±0.04	207±33	--	--	--	2

not a problem.

3 Results and Discussion

The influence of the MC on the maximum temperatures reached during the smouldering (figure 2) shows a strong effect of the MC on self-sustaining spread. Propagation is self-sustaining for the dry peat. Dry peat burns fast, at an average spread rate of 10cm/h, reaching peak temperatures of 450ºC and an average mass lost of 94%. While for the wet peat average propagation velocity of the front is 2.5cm/h, reaching peak temperatures of 400ºC (figure 2) and decaying to extinction. This decay is not observed for dry peat. Average values from MC between 0 and 100% (table 1) show the influence of the MC on smouldering propagation. Maximum temperatures of the front vary little when MC is ≤75%, while velocity behaves roughly the same when MC is ≥25%. Mass consumption changes gradually between dry and wet peats.

The smouldering propagation is sensitive to changes in the MC. The results presented are consistent with previous experiments done with MC testing the ignition limit (Rein et al., 2008). We measured the behavior of the front for a range of MC below the ignition limit and we include the first results of controlled experiments showing the propagation in peats under heterogeneous distributions of moisture content, where patches are over the ignition limit (figure 1, table 1). Peat burning over that ignition limit has been reported in real peats experiments (Reardon et al., 2007).

4 Conclusions

These experiments are novel, as they look at the influence of moisture content to the horizontal propagation of self-sustaining combustion. As well, this study is a step from small-scale laboratory experiments to a more realistic natural smouldering scenario. Peatlands are characterized for have heterogeneous peat moisture distributions, which fires have to propagate through. How the smouldering front propagation occurs in heterogeneous configurations is not well studied, but from experimental results after a successful ignition, smouldering self-propagates through peat layers with higher MC (>125%). A next stage in the research will be to characterize the propagation front with the presence of heterogeneous distributions of MC.

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