Journal of Environmental Management 120 (2013) 27–36

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Controls upon biomass losses and char production from prescribed burning on UK moorland

Fred Worrall[a], Gareth D. Clay[a,*], Richard May[b]

[a] Department of Earth Sciences, Science Laboratories, South Road, Durham DH1 3LE, UK
[b] Moorland Association and the Heather Trust, Sunrise House, Hulley Road, Macclesfield, Cheshire SK10 2LP, UK

ARTICLE INFO

Article history:
Received 16 January 2012
Received in revised form
16 January 2013
Accepted 27 January 2013
Available online 15 March 2013

Keywords:
Prescribed burning
Carbon stocks
Moorland
Char

ABSTRACT

Prescribed burning is a common management technique used across many areas of the UK uplands. However, there are few data sets that assess the loss of biomass during burning and even fewer data on the effect of burning on above-ground carbon stocks and production of char. During fire the production of char occurs which represents a transfer of carbon from the short term bio-atmospheric cycle to the longer term geological cycle. However, biomass is consumed leading to the reduction in litter formation which is the principal mechanism for peat formation. This study aims to solve the problem of whether loss of biomass during a fire is ever outweighed by the production of refractory forms of carbon during the fire. This study combines both a laboratory study of char production with an assessment of biomass loss from a series of field burns from moorland in the Peak District, UK.

The laboratory results show that there are significant effects due to ambient temperature but the most important control on dry mass loss is the maximum burn temperature. Burn temperature was also found to be linearly related to the production of char in the burn products. Optimisation of dry mass loss, char production and carbon content shows that the production of char from certain fires could store more carbon in the ecosystem than if there had been no fire. Field results show that approximately 75% of the biomass and carbon were lost through combustion, a figure comparable to other studies of prescribed fire in other settings. Char-C production was approximately 2.6% of the carbon consumed during the fire.

This study has shown that there are conditions (fast burns at high temperatures) under which prescribed fire may increase C sequestration through char production and that these conditions are within existing management options available to practitioners.

1. Introduction

Vegetation fires are a common occurrence in the UK uplands with the Fire Service attending on average, 71,700 vegetation fires a year (McMorrow et al., 2009). Additionally, many areas of the UK uplands are managed by prescribed burning of vegetation on a regular cycle. Prescribed burning is undertaken to promote new vegetation growth that provides improved forage for sheep and red grouse (*Lagopus lagopus*) and provides ground cover for ground nesting birds including red grouse (Holden et al., 2007). In England, it has been estimated that in areas where dwarf shrub heath and heather (*Calluna vulgaris* hereafter referred to as *Calluna*) moorland are managed by burning, up to 40% of the area shows visible evidence of burn management (Yallop et al., 2006).

There are a number of works that review the impacts of prescribed burning on soils and biodiversity (e.g. Glaves and Haycock, 2005; Tucker, 2003) but recently there has been an emphasis on understanding how prescribed burning affects carbon (C) dynamics in upland peat settings (e.g. Ward et al., 2007). Peatlands in the UK store around 3 billion tonnes of carbon (Cannell et al., 1993) and external pressures such as climate change may lead these stores to become net sources of carbon under future scenarios (Worrall et al., 2004). Therefore it is important to understand role land management plays in C cycling in these upland settings.

Many of the studies that focus on prescribed burning and carbon (e.g. Clay et al., 2010) consider carbon fluxes or carbon stores in peat soils and do not assess the carbon lost or produced during fires, e.g. production of char. Due to the long mean residence time at the Earth's surface (Lehmann et al., 2008) and resistance to natural chemical agents (Bird and Gröcke, 1997) the production of char,

* Corresponding author. Present address: Geography, School of Environment and Development, University of Manchester, Oxford Road, Manchester, M13 9PL, UK. Tel.: +44 0 161 306 6426; fax: +44 0 161 306 6677.
E-mail address: gareth.clay@manchester.ac.uk (G.D. Clay).

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http://dx.doi.org/10.1016/j.jenvman.2013.01.030

a refractory form of carbon (Preston and Schmidt, 2006), may have important implications for carbon cycling in peatlands.

Clay and Worrall (2011) examined the char production of a moorland wildfire (as opposed to a prescribed burn) using a simple stocks change model and showed that approximately 14% of the above-ground biomass survived the fire and of the biomass combusted in the fire around 4% was converted to char. Although this shows a high consumption of fuel it is also within the range of fuel consumption for prescribed burning (Legg et al., 2010). In these settings the desired fire regime would create a quick moving fire that leaves behind a proportion of 'stick', standing dead biomass, (Defra, 2007) without damaging the litter layer or the underlying soil. A well managed burn would perhaps be expected to leave behind some of the biomass undamaged. Indeed, a range of fuel consumptions for prescribed burning has been recorded ranging from <30 to 100% (Farage et al., 2009; Legg et al., 2010; Kayll, 1966).

In prescribed burning, biomass is turned into volatile organic compounds, inorganic gas oxides, solid fine particles and charcoal. Some biomass may remain as unburnt but possibly dead material, therefore representing an additional litter input. The production of CO_2, CO and VOCs represent a loss of carbon from the ecosystem and the loss of live vegetation means the loss of litter production in years subsequent to the burn until there is full recovery. Fine particulates are carried from the immediate area but may be re-deposited elsewhere. In opposition to the losses, the production of char and dead biomass litter represents an input of carbon into the peat. This means that at the time of the fire litter input is substituted for char inputs. Litter is a high volume, low carbon content, labile organic matter relative to char that is a low volume, high carbon content material. Char has been shown to have mean residence times of up to 10,000 years in soils (Swift, 2001) while typical turnover times of soil organic matter in soil surface layers is between 6 and 20 years (Torn et al., 2005). Indeed, repeated cycles of burning may build up char within the soil adding to the carbon store. However, this will be at the cost of reductions in litter production in the years following the fire and the risk of fires burning into the longer residence carbon reserves in the litter layer of soil itself. Clay et al. (2010) compared carbon fluxes between burnt and unburnt plots on a *Calluna*-dominated peatland between periods of burning and showed that while the net C budget on unburnt plots was a source of 156.7 gC m^{-2} yr^{-1} that on burnt plots was net C source was 117.8 gC m^{-2} yr^{-1}, i.e. burnt plots of *Calluna* showed an avoided loss of carbon relative to unburnt plots of *Calluna*. The budget of Clay et al. (2010) did not measure the change in biomass, however, the study estimated that even with up to 100% loss of biomass at the time of burn there were burn frequencies where burning would still be beneficial for C sequestration. Furthermore, the study of Clay et al. (2010) did not estimate any char additions from burning.

This study seeks to understand the impact of vegetation burning on the loss of carbon to the atmosphere and the production of char products. These processes could add to carbon storage within the peat or could detract from carbon storage. The approach of this study is to use laboratory studies to explore the controls on mass loss and char production, then to ground-truth the laboratory results against field observations of prescribed burns.

2. Materials and methods

2.1. Laboratory studies

2.1.1. Sample collection and preparation

The laboratory study simulated burning conditions on three common vegetation types found in upland peat ecosystems of England. All samples were collected fresh from the Moor House National Nature Reserve in Upper Teesdale (N 54:41:45 W 2 2:24:46) which was the site of the burning plot trials studied by Garnett et al. (2000), Ward et al., (2007), and Worrall et al. (2007). The vegetation types chosen were heather (*C. vulgaris*), cotton grass (*Eriophorum spp*. hereafter referred to as *Eriophorum*), and sphagnum mosses (*Sphagnum spp*. hereafter referred to as *Sphagnum*). A sample of approximately 250 g of each vegetation type was clipped using secateurs from within three randomly chosen locations within 5 m of the burning plots (though not on the plots themselves), bulked together and placed in sealed plastic bags so that moisture loss was limited prior to experimentation.

To replicate a range of burning conditions the samples of vegetation were treated in a factorial designed experiment. The factors considered were:

i) Burning temperature – for the burning of heather, fire temperatures between 220 °C and 886 °C have been observed (Hamilton, 2000; Whittaker, 1961). In order to divide the range, three burning temperatures for vegetation were chosen: 400, 600 and 800 °C. On the basis of the first set of experiments, a second set of experiments were then performed for vegetation types in which the following additional burn temperatures were considered – 450, 500, 550, 650 and 700 °C. The furnace (Carbolite Eurotherm furnace) was heated to the desired temperature then the samples were swiftly put into the furnace to reduce the amount of time the furnace door was open.

ii) Burning time – the samples were exposed to two different burn times – two and five minutes. These times were chosen to cover typical fire speeds of upland burns (SEERAD, 2001). Shorter exposure times would be difficult to replicate in the laboratory, as the shorter the time the greater the proportion of that exposure time that is represented by placing or removing the sample in the furnace. Burning times of two and five minutes were considered in the second set of experiments where additional burn temperatures were considered.

iii) Initial temperature – burning in the field takes place at range of ambient temperatures determined by the weather conditions on the day of the burn and so the samples were stored before exposure to the furnace at three different temperatures – room temperature (22 °C), refrigerated (4 °C) and frozen (-5 °C). Prescribed burning in the UK occurs between October and mid-April (Defra, 2007) so this range of temperatures allows range of meteorological conditions to be modelled. Samples were left at these respective temperatures overnight before being placed in the furnace. Only room temperature was considered in the second set of experiments.

iv) Return temperature – as stated above the ambient temperature experienced by burnt vegetation varies and so it is useful to consider materials at different starting temperatures, but also once the fire front has passed over vegetation in the field the burn products experience different temperatures. It is possible that in particular cold conditions the effects of burning are effectively quenched and smouldering is restricted which in turn limits the loss of carbon or production of burn products. Thus samples in this experiment having been in the furnace are returned to conditions at a known temperature overnight before analysis. The temperatures used were room temperature (22 °C), refrigerated (4 °C) and frozen (-5 °C). These temperatures were chosen to match the range of ambient temperatures conditions that could be expected on an English peatland during the burning season. However, it should be noted that this is a complete factorial design and so samples were not necessarily returned to the