Temperature and Moisture Control of Horticultural Peat Decomposition

by

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ABSTRACT

Peatlands are dominant features of the Canadian landscape and are well-known for their widespread use as a growing media. For use in horticulture, peat is amended with additives to optimize the physical and biogeochemical properties for plant growth. This study investigated how the decomposition rates of horticulturally-amended peat varied with temperature and moisture conditions experienced when peat is used as a growing media. Under changing temperatures, the addition of lime to the horticultural soils decreased the rate of decomposition in amended soils and contributed a secondary carbon pool to the overall CO_2 flux. The effect of changing moisture did not reveal a clear optimal moisture condition for decomposition though showed significant differences between unamended and amended samples. From this, I suggest that it is incorrect to assume a standard temperature and moisture relationship across both natural and horticultural peat types.

CHAPTER 1: INTRODUCTION

In their capacity to act as important stocks of carbon, peatlands have received considerable interest due to their role in the global carbon cycle and potential contributions to climate change. The anaerobic conditions present in peatlands slow the decomposition process, creating ideal conditions for carbon to accumulate (Davidson & Janssens, 2006). In Canada, peatlands cover 7.3×10^5 km^2 of the total landscape, storing approximately 150 Gt C (Bona et al., 2020). However, there is growing concern over peat's contributions to carbon efflux. While the high organic matter content in peat has traditionally been exploited as an energy source globally, peat is extracted for horticulture in Canada. Nationally, 30 900 ha of peatland have been cleared and harvested for economic activities (CSPMA, 2017). Current extraction of peat is done via vacuum harvesting. The surface of the peatland is stripped of existing vegetation, thus modifying the surface land use and subsequent carbon cycling (Glatzel et al., 2004). The extraction process, which generates an emission of CO_2 through the decomposition process, is of particular concern as it constitutes a net source of greenhouse gas emissions to Canada's atmospheric burden (Cleary et al., 2005).

The emissive flux of CO_2 from peatlands is largely governed by two environmental factors: temperature and soil moisture content. The release of CO_2 derives from the root respiration and microbial decomposition of organic matter found in the peatlands, which are sensitive to changing environmental conditions (Davidson & Janssens, 2006). However, it is not known if the general response functions for pristine peatlands apply to extracted peat used in horticulture. There are relatively few studies that combine the effects of both temperature and moisture contents on CO_2 emissions from peatlands in a controlled setting (Kechavarzi et al., 2010). A comparison between the processes in pristine peatlands and extracted peat used for growing media under varying environmental conditions would determine if the rates of mineralization are similar. This is particularly critical for carbon taxing purposes, as Canadian peat companies do not want to be taxed for emissions they are not responsible for.

This study examines how decomposition rates of peat extracted from Quebec peatlands vary with temperature and soil moisture. The range of conditions discussed are normally experienced when peat is used as growing media and the environmental implications for the Canadian peat industry. In Chapter 2, I will first review the literature on peatlands, peat harvesting practices and how temperature and moisture are key factors for peat decomposition. In Chapter 3, I will explain my methodology, including the laboratory and statistical techniques I utilized. This is followed in Chapter 4, where I will present the results of my temperature and moisture experiments. In Chapter 5, I will discuss the context of my findings, provide possible explanations for the temperature and moisture trends seen in Chapter 4 and elaborate on the implications for Canadian horticultural peat practices. I conclude, in Chapter 6, with a summary of my findings and suggestions for future practices.

CHAPTER 2: LITERATURE REVIEW

2.1 Peatlands

Peatland ecosystems are characterized by waterlogged, organic soils consisting of large quantities of partially decomposed organic material wherein the rate of decomposition is much slower than the rate of plant production (Vitt, 1994). Peatlands are largely found in cool climates where precipitation exceeds evapotranspiration such that the cool, anoxic conditions allow for the accumulation of at least 30-40 cm of dominantly organic material (Vitt, 1994). Peat in these landscapes can accumulate to a depth of 1.5 to 2.3m and is unique in the sense that they accumulate in their own substrate (Hugron et al., 2013).

Peatlands are globally important due to their role in the carbon cycle, deriving from their unique ability to accumulate peat. The accumulation of carbon in peat is determined between the difference of primary productivity and decomposition, with the anaerobic conditions characterized by peatlands leading a decrease in decomposition and therefore accumulation of CO_2-derived C (Waddington & Price, 2000). Globally, peatlands occupy 3.8% of the world's ice-free land area, with about three quarters found across northern countries (Kivinen and Pakarinen 1981). Canada is home to the largest area of peatlands in the world, representing 12% of the total land area of the country (Gorham, 1991). Canadian peatland soils represent a carbon stock of 150 Gt C, larger than the pools found in both forests and agricultural soils (Roulet, 2000). Within the peatlands themselves, approximately 98.5% of carbon is stored within the peat, with the remaining 1.5% stored in the vegetation (Gorham, 1991). Peatlands in wet climates are typically dominated by *Sphagnum* mosses across Boreal and subarctic climate zones, representing important stores of sequestered atmospheric carbon (Gorham, 1991). Their role in the carbon cycle, however, is twofold; while they constitute an important store through carbon fixation, peatlands also release considerable amounts of carbon dioxide back into the atmosphere. Peatlands also release methane, an important greenhouse gas with 4-35 times the global warming potential of CO_2 that further contributes to the atmospheric burden (Bridgham et al., 1995). Going forward, the influence of global warming will see modifications to the peatland carbon fluctuations not only directly through increasing temperatures and subsequent greater rates of decomposition, but also via hydrological modifications to the landscape and water table (Gorham, 1991).

2.2 Peat Harvesting

Anthropogenic activity has been known to modify the carbon stock of peatlands and subsequent greenhouse gas exchange with the atmosphere (Roulet, 2000). Peat harvesting results in substantial modification to the landscape and surface-atmosphere interactions; the process of drainage and removal of vegetation has been shown to increase soil respiration leading to a net loss of CO_2 in addition to the loss of carbon sink potential (Roulet, 2000). Of note, during the process of extraction the vegetation is not retained, resulting in a shift in the primary production of the harvested site to zero (Roulet, 2000). As a result of the land-use changes, there have been impacts on greenhouse gas cycling, particularly concerning the exchange of CO_2 with the atmosphere. Once drained, peatlands undergo a shift from a net sink to a net source of carbon (Moore, 1994). The interaction between the surface of peatlands and the atmosphere is governed by the production, consumption and transport of carbon dioxide within the peat profile (Glatzel et al., 2004). These processes, in turn, are further influenced by both temperature, on the basis of microbial activity, and water table position, on the basis of creating aerobic/anaerobic conditions. Presently, there is a gap in knowledge regarding the production potential of CO_2 at harvested peat sites (Glatzel et al., 2004).

Peat harvesting is a common practice globally, most notably across Europe, North America and Asia (Glatzel et al., 2003). The extraction of peat has seen an increase in the second half of the 20th century, owing to a growing demand for its use as a horticultural soil (Waddington & Price, 2000). In Canada, an estimated 0.03% of the 113.6 million ha of peatlands are being actively extracted for horticulture (CSPMA, 2017). Of particular note, in the St. Lawrence Lowland region of Southern Quebec, approximately 70% of peatlands have been harvested (Petrone et al., 2003). In order to extract peat for horticultural use, the soil needs to be drained which ultimately increases the diffusion of oxygen, speeds up the decomposition process and thereby increases the CO_2 efflux from the peatland site (Cleary et al., 2005). Most of the current extraction of peat is done via vacuum harvesting, a process whereby the surface is stripped of existing vegetation thus modifying the surface land use and subsequent carbon cycling (Glatzel et al., 2004). Following this process, the extracted peat surface is free of vegetation for decades (Strack, 2011). This, in turn, leaves the surface exposed to the forces of wind and water erosion coupled with the effects of temperature fluctuations (Glatzel et al., 2003).

In order to be harvested, peatlands are initially drained via the creation of 1m deep ditches located 30m apart (Petrone et al., 2003). By removing the surface layer of peat, the hydrologic regime of the peatland is altered, influencing the exchange of carbon between the surface and the atmosphere. The modifications to the local carbon exchange of the extracted peatland site are largely a function of change to the local moisture regime, nutrient cycling and vegetation (Petrone et al., 2003).

2.3 Horticultural Peat Amendments

To be used as a growing media, horticultural peat is supplied with additives to optimize the biogeochemical properties and growth rates. Such additives include, but are not limited to, limestone/dolomite, inorganic fertilizers, perlite and surfactants, all of which are added in different proportions and to different ends. In particular, lime has been shown to improve soil conditions by reducing acidity and increasing rates of microbial respiration, thereby modifying net chemical and biological CO_2 emissions (Biasi et al., 2008). However, conventional studies that measure total CO_2 flux measurements in peatland agriculture have neglected to consider carbon derived from lime as part of the overall carbon balance in horticultural soils (Biasi et al., 2008). In order to correctly partition between emissions from peat only, lime-based emissions must also be considered. Stable isotope techniques can be employed to determine the relative contributions of carbon derived from peat and limestone-borne carbon using a two-way mixing model, given the unique isotopic signatures of the two carbon pools (Bertrand et al., 2007).

2.4 Carbon efflux from Peatlands and Greenhouse Gas implications

Given the emissive flux potential of peatlands, there is a growing demand to improve national carbon balance estimates for greenhouse gas budgeting purposes. Altered fluxes of CO_2 are important in considering the total greenhouse effect resulting from the use of peat as a growing media. Currently, only the emissions associated with fossil fuel combustion when used for commercial peat machinery and transport are considered in Canada's greenhouse gas budget

(Cleary et al., 2005). In international estimates, all peat used for horticultural practices is assumed to decompose and be emitted as CO_2 in the year it was extracted. However, empirical evidence suggests that less than 100% of the peat extracted is returned to the atmosphere as CO_2 (Cleary et al., 2005). This has further implications for the Canadian peat industry, as understanding the portion of peat that is mineralized to CO_2 during horticultural practices is critical for carbon taxing purposes. Existing literature has thus far focused on extracted and restored horticultural sites, with little to no knowledge on the processes that govern CO_2 emissions from in situ horticultural extraction.

2.5 Temperature as a factor for peat decomposition

Temperature and moisture content are important factors that regulate the rate of organic matter decomposition in peat via their influence on microbial activity in the soil (Wang et al., 2010). It has, however, been suggested that temperature is a more important factor for carbon mineralization, despite both temperature and moisture working in conjunction to produce CO_2 emissions from peat (Bridgham et al., 1998). As shown by Lloyd and Taylor (1994), when moisture and nutrients are not limiting, carbon mineralization increases in peatlands following an increase in temperature. The release of CO_2 derives from the root respiration and microbial decomposition of organic matter found in the peatlands, which are temperature-sensitive (Davidson & Janssens, 2006). The process of soil respiration itself involves different communities of organisms undergoing a series of chemical reactions, each with varying temperature sensitivities (Lloyd and Taylor, 1994). As a general rule, it is widely accepted that the rate of decomposition of soil organic matter doubles for every 10°C rise in temperature, known as the Q_{10} (Davidson & Janssens, 2006). It is typically assumed that all soil organic matter decomposition has the same temperature sensitivity, though the kinetics of enzymatic reactions have shown to be increasingly sensitive to temperature with increased molecular complexity of the substrates (key nutrients present in the soil for growth and microbial activity) and under varying environmental constraints (Davidson & Janssens, 2006). While certain studies have discussed the influence of soil depth on soil respiration, there remains a general lack of consensus on the relationship between temperature sensitivities and depth at different horizons (Wang et al., 2010).

As suggested by Davidson and Janssens (2006), substrate concentrations may also vary with temperature. With the onset of increasing temperatures, the diffusion of gases and soluble material increases. However, the transport of the soluble carbon substrates in soils may be limited by the general drying out of soils at increased temperatures. This in turn, has the potential to limit microbial respiration in soils given a reduction in available carbon substrates. As a result, the respiration rate may decrease beyond a critical temperature as substrate limitation dominates.

2.6 Water saturation as a factor for peat decomposition

While a number of studies have addressed the importance of temperature as a control on peatland carbon mineralization (Davidson & Janssens 2006; Lloyd & Taylor 1994; Weiping et al. 2014), the influence of moisture content has been less studied. Moisture dependence in soils is understood to modify the oxygen availability in soils, ultimately creating conditions that either favour or slow down the microbial decomposition process that determines the carbon emission from soils. Generally, it is agreed that carbon efflux is higher under drained peatland conditions (Wang et al., 2010). It has also been established that the moisture availability and water table position hold a strong influence on the rate of carbon mineralization in peatland soils (Wang et al., 2010). When extracted, the drainage of the peatlands modifies the moisture levels within the soil. Upon draining, the increased aeration of the soil allows for microbial oxidation to proceed more strongly, speeding up the decomposition process and contributing to the emissive flux of the peatlands (Kechavarzi et al., 2010). The optimal soil moisture content conducive to microbial activity (θ_{max}) has been shown to be slightly above or below the point at which soil respiration decreases (Weiping et al., 2014). The two primary limiting factors to soil microbial respiration are the diffusion of substrates and the diffusion of oxygen, both of which can be constrained by fluctuating soil moisture contents (Kechavarzi et al., 2010). Soil moisture content is also shown to have an effect on root respiration in peatland systems and therefore may work in conjunction with temperature to affect the Q_{10} values of the peat system including heterotrophic and autotrophic contributions (Weiping et al., 2014).

2.6 Research Objectives

The overarching aim of this research is to investigate how decomposition rates of extracted Quebec peat vary over a range of temperature and soil moisture conditions that would normally be experienced when peat is used as growing media and the environmental implications for the Canadian peat industry. From this, I have 3 objectives:

1. To determine the effect of varying temperatures on the decomposition rate of horticultural peat
2. To determine the effect of varying soil moisture contents on the decomposition rate of horticultural peat
3. To determine if the carbon efflux from horticultural peat follows the same pattern as natural peatlands

From these objectives, the determination of the portion of mineralized carbon from extracted peat that is returned to the atmosphere as CO_2 will have implications for the Canadian peat industry in their efforts to meet environmental sustainability goals.

CHAPTER 3: METHODOLOGY

In this chapter, I will present the methodology I employed for my analyses. I will first present the study site from which my samples were collected. I will then discuss the methods I used to collect data on the biogeochemical properties of the two soil groups. From there, I will outline the overall set up of my incubation experiments for both temperature and soil moisture. I will further present the methods for my isotopic analyses then conclude with the statistical analyses used to analyze my data.

2.1 Study Site

The samples were collected from a large vacuum-harvesting peat complex located in Rivière-du-Loup, Québec (47°48’21 N, 69°32’55 W). The region is located on the banks of the St. Lawrence River, near the foothills of the Appalachians. The climate of the region is cool temperate, with a mean annual temperature of 4.2°C and a mean annual precipitation of 1124 mm (Environment Canada, 2021).

2.2 Soil Analyses

Samples were categorized as Grade A (best grade) with a von Post index of 1 (undecomposed) and organized into two categories: unamended and amended. Unamended soils refer to the natural state of raw peat without any added amendments. These samples were provided directly from the extraction field. The amended peat samples refer to peat combined with additives, notably lime, for use as a growing media. These samples were provided once they were processed and ready to be shipped to growers. Both types of samples were collected in plastic bags and transported to the laboratory, where they were stored at 4°C until analysis.

The bulk density of the samples was determined by weighing the initial wet mass and then the dry mass after being placed in the oven at 60°C for 24 hours, then calculated from the mass of the dried soil and the volume of the sample container. The gravimetric soil moisture content (% water) was calculated using the weight loss of the samples and expressed as a percentage of the initial wet mass of the soil. Loss on ignition for carbon content was measured in a muffle furnace at 550°C for 4 hours. Soil pH was measured in triplicates from the oven dried samples using a 1:35 soil: water ratio. C:N ratios were calculated after samples were oven-dried at 60°C for 120h and ground to a fine powder to determine total C and total N values. Fourier transform infrared (FTIR) spectroscopy was employed to determine the humification indices of both sample groups following the methods outlined by Broder et al. (2012).

2.4 Laboratory Analyses

CO_2 emissions were studied at five different temperatures (5°C, 10°C, 15°C, 20°C, 25°C) using laboratory incubations of peat. The use of five temperature points was to quantify the Q_{10} value for peat decomposition, requiring variations over 10°C (Davidson & Janssens, 2006). Calculation of a Q_{10} across a smaller temperature range with a larger step (>5°C) has the potential to affect the fit of the exponential curve and thereby reduce reliability (Li et al., 2021). At each temperature, five replicates were prepared of both unamended and amended samples. For each replicate, the samples were kept at a constant volumetric moisture content of 50% over the course of the temperature experiment.

Soil moisture content was analyzed at five different gravimetric moisture contents (20%, 40%, 60%, 80% and 100%) using the same incubation methods as the temperature experiment. At each soil moisture percentage, all five replicates of both unamended and amended soil samples were kept at a constant 25°C over the course of the experiment.

Laboratory incubations to assess the CO_2 production rates were conducted similarly to Moore and Dalva (1993). For each of the five temperature experiments and five moisture experiments, the preparation and collection of samples took place over a one-week schedule. On day 1, the samples were prepared by placing 5g of soil in a glass Mason jar with the corresponding volume of water to achieve the desired moisture content and left covered (not sealed) in a 4°C fridge for 5 days to allow for the microbial community to adjust to the moisture content, but at a low temperature. At this stage, the height of the peat in the jar as well as the height and diameter of the jar itself was recorded in order to calculate the volume of the headspace. On day 4 of the experiment, the incubator was calibrated to the desired temperature. On day 5 of the experiment, all 10 (5 replicates x 2 conditions (unamended and amended)) incubations were transferred to the incubator. The jars were incubated at constant temperature in a Fisher brand isotemp 37020A incubator over a 48-hour period to minimize emissions related to disturbance. On day 7 of the experiment, the samples were collected and analyzed on the gas chromatograph.

Analyses were conducted on a Shimadzu 2014 Gas Chromatograph equipped with a flame ionization (FID) detector and methanizer. Standards of 0, 356, 2503 and 5000 ppmv CO_2 were employed. Concentrations were determined relative to the standards and corrected for changing headspace volume over time (Moore & Dalva, 1997). 5 ml samples were collected using a syringe at four different times (t_0, t_1, t_2, t_3), each two hours apart. Following each collection, the incubations were backfilled with the same volume of CO_2-free air to maintain the headspace volume.

2.5 Isotopic analyses

For all amended samples of peat, incubation experiments of the 5 replicates at each of the five temperatures (5°C, 10°C, 15°C, 20°C, 25°C) and five moisture conditions (20%, 40%, 60%, 80%, 100%) were sampled for isotopic analyses. 20ml samples were collected using a syringe at four different times (t_0, t_1, t_2, t_3), each two hours apart, and run into a Picarro $\delta^{13}C\text{-}\,CO_2$ analyzer. As with the other incubation experiments, the amended samples were backfilled with the same volume of CO_2-free air to maintain the headspace volume. The isotopic signature ($\delta^{13}C$) of the CO_2 flux was calculated using the methods outlined by Keeling (1958). The calculation to partition the CO_2 flux into lime and peat-based fluxes for the amended samples was determined by following a two-way mixing model as outlined by Biasi et al. (2008):

$$f = \frac{\delta - \delta_0}{\delta_1 - \delta_0}$$

Where f is the fraction contribution of CO_2 derived from lime to total carbon flux, δ is the isotopic signature of C for amended soils, δ_0 is the isotopic signature of unamended peat and δ_1 is the isotopic signature of lime.

2.6 Statistical Analyses

Statistical analyses were conducted using the Stata statistical software package (IC 15.0, StataCorp LLC, 2015). Linear or best-fit quadratic regressions were used to quantify the strength of the relationships between peat fluxes and changing temperature and moisture values. Regressions with p-values <0.05 were considered as significant. One-way ANOVAs were used to calculate significances between soil properties of the unamended and amended samples. CO_2 emission rates to changing temperature sensitivity (Q_{10}) of CO_2 was determined following Lloyd and Taylor (1994).

CHAPTER 4: RESULTS

In this chapter, I will present the results of my experiments. I will first look at the results of selected key biogeochemical properties of the unamended and horticulturally amended peat samples. I will then present my findings for the temperature experiment, including the Q_{10} values and isotopic data associated with the amended soil group. I will conclude by presenting the results of my peat moisture sensitivity experiment for both natural peat and when used as a growing media.

4.1 Soil Properties

The unamended and amended peat samples were analyzed for select key biogeochemical properties in the laboratory. A difference of means test revealed significant differences ($p < 0.05$) (Table 4.1).

Table 4.1. *Key biogeochemical properties of unamended and amended peat samples*

Property	Mean	Standard Error	P-value
SOM (%)			
Unamended	98.9	0.04	0.0495
Amended	80.1	0.34	
pH			
Unamended	4.3	0.04	0.0495
Amended	5.9	0.12	
Carbon Content (%)			
Unamended	49.4	0.02	0.0495
Amended	40.1	0.17	
% Water			
Unamended	40.5	0.57	0.513
Amended	40.9	0.37	
Density (g/cc)			
Unamended	0.06	0.002	0.0495
Amended	0.08	0.001	
Humification Index			
Unamended	0.47		
Amended	0.65		
C:N Ratio			
Unamended	54.3		
Amended	47.7		

The mean % SOM and carbon content values revealed significant ($p=0.0495$) differences between the unamended and amended samples. % SOM and carbon content concentrations in unamended samples were significantly larger than in amended samples as a result of minerals added to amended samples. Mean pH was significantly ($p=0.0495$) lower in the unamended samples due to the addition of calcium carbonate in the amended samples to neutralize acidity. The density of both samples was quite low–largely as a by-product of the mechanical alteration by the harrowing of top peat layer at the collection site - though the amended samples had significantly higher density owing to the addition of denser mineral additives. Water content did not show a significant difference between the two peat types ($p=0.513$). The humification index, used to assess the degree to which the samples were degraded, was higher for the amended samples as a result of extraction and amendments. The ratio of carbon relative to nitrogen (C:N) was higher for the unamended samples as the more decomposed amended samples lost relatively more carbon through the consumption of carbon-based substances and the release of CO_2 via microbial respiration.

4.2 Temperature sensitivities of peat decomposition

There were significant differences in the behaviour of CO_2 flux in response to increasing temperatures between the unamended and amended samples. The mean amended peat samples exhibited a relatively consistent increase in peat flux with increasing temperature, displaying a linear pattern (Figure 1). In contrast, the unamended samples displayed a more non-linear relationship; the pattern exhibits low initial peat flux values, increasing with greater temperatures. The peat flux relationship for the amended samples was significant ($p<0.05$) and could explain up to 99% ($r^2=0.99$) of the temperature variability. The peat flux relationship for the unamended samples was also significant ($p<0.05$) and could explain up to 85% ($r^2=0.85$) of the temperature variability.

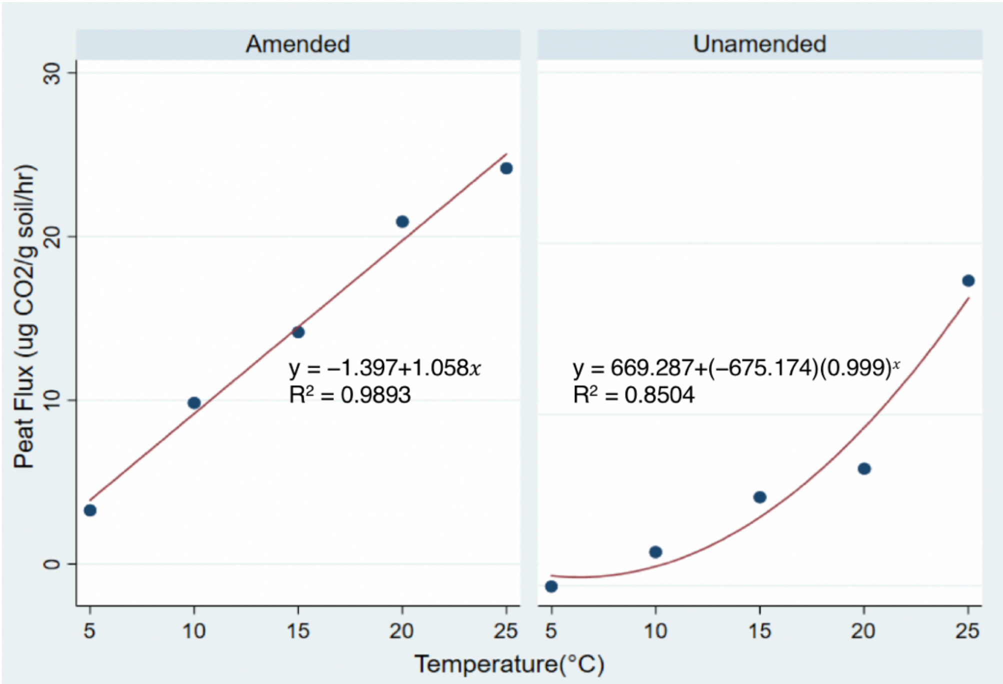

Figure 4.1. Temperature variability of mean unamended and mean amended peat fluxes at constant 50% volumetric moisture content; best-fit linear or quadratic trend lines are shown.

As with the temperature-dependent carbon flux trends, the CO_2 production rates for every 10°C rise in temperature (Q_{10}) differed between the two sample types. Three different increases of 10°C in amended and unamended peat (5-15°C, 10-20°C, 15-25°C) were separately averaged and compared (Figure 4.2; Table 4.2). For the unamended samples, an increase of 10°C resulted in an increase of CO_2 emission rates by an average of 3.3 times. In contrast, an increase of 10°C for the amended samples resulted in a lower increase of CO_2 emission rates, at an average of 1.9 times. The overall smaller range of the amended plot of Figure 4.2 suggests more consistent Q_{10} values, reflected by the more linear response to temperature shown in Figure 4.1.

Table 4.2. *Mean, median and standard error of Q_{10} values for unamended and amended peat samples*

Quality	**Mean**	**Median**	**Standard Error**
Unamended	3.3	2.6	0.94
Amended	1.9	1.9	0.45

Figure 4.2. Q_{10} responses for amended and unamended samples at constant 50% volumetric moisture content. Bars range is the first and third quartile for Q_{10}. The median is indicated by the horizontal line.

The linear amended temperature relationship is further explored in the relationship between the isotopic fraction and temperature (Figure 4.3). Due to the multiple carbon pools contributing to the carbon flux in amended samples, the $\delta^{13}C\text{-}CO_2$ was measured to partition between the lime added to the amended peat and the natural carbon emissions of the peat itself. A negative, non-linear relationship between isotopic fraction and temperature was found. At cooler temperatures, a less negative isotopic fraction suggested a greater portion of the carbon emissions deriving from the lime pool ($\delta^{13}C$-CO_2=2.5 $^0/_{00}$). As the temperature increased, the isotopic fraction became increasingly more negative, shifting towards the isotope signature of the natural peat component ($\delta^{13}C$-CO_2= -25$^0/_{00}$). This relationship is significant ($p<0.05$), with up to 75% of the isotopic variability explained by the temperature response (r^2 = 0.75).

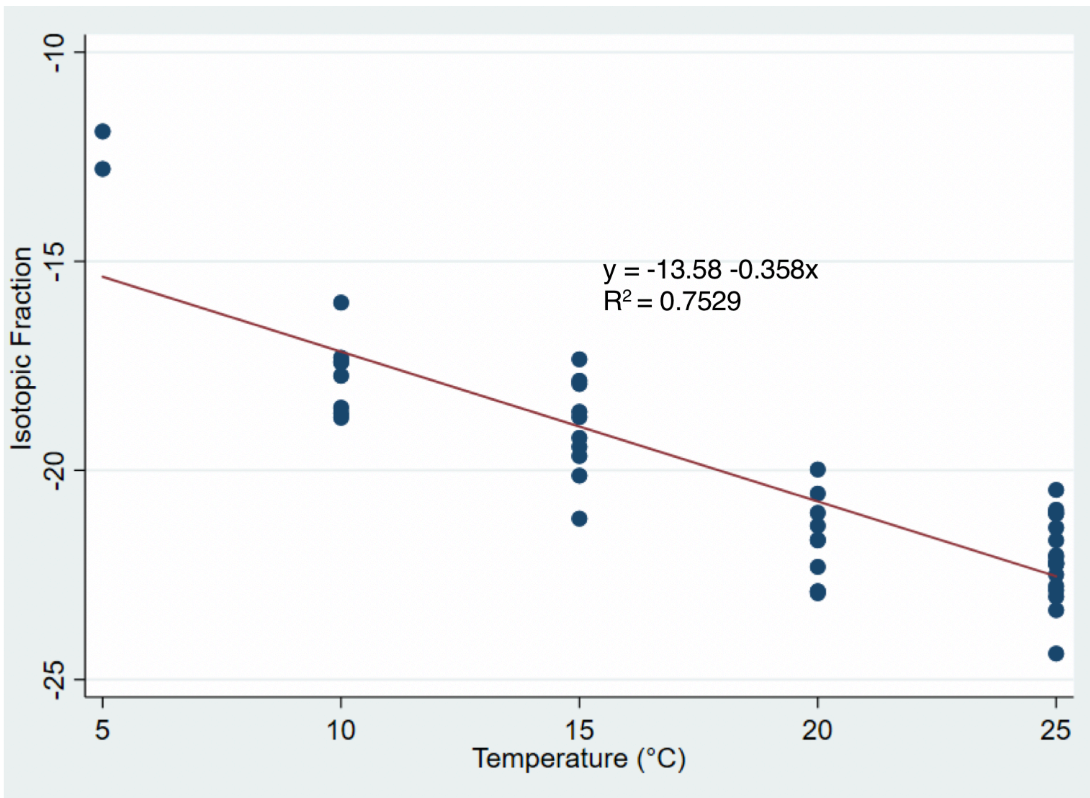

Figure 4.3. Temperature sensitivities of isotopic fractionation of CO_2 for amended peat samples

The isotopic relationship between temperature and total CO_2 flux derived purely from the addition of lime to the amended samples followed a similar trend. As temperatures increased, the total lime-borne CO_2 flux increased as well. Figure 4.4 shows a positive, linear trend between increasing temperature and total lime flux. This relationship is significant ($p<0.05$), with up to 29% of the total lime flux variability explained by temperature (r^2 = 0.29).

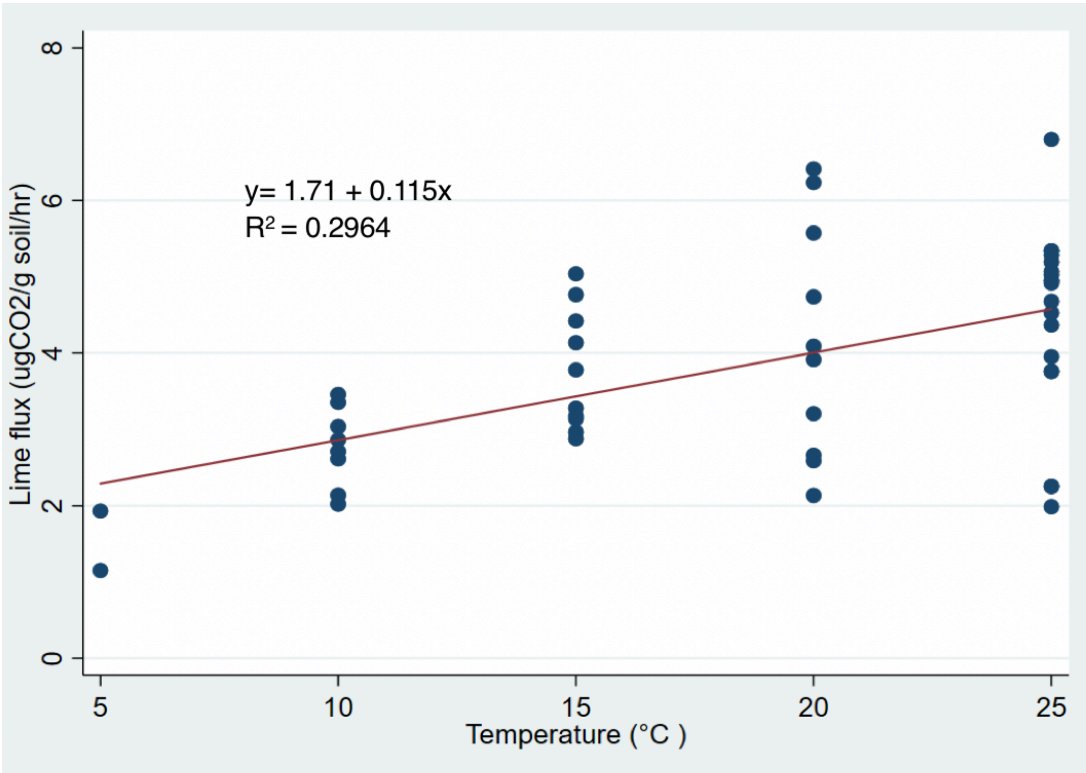

Figure 4.4. Temperature sensitivities of total lime CO_2 flux for amended peat samples

4.3 Soil moisture sensitivities of peat decomposition

The different simulated moisture conditions did not produce the same consistent trend for peat decomposition as displayed for temperature. The amended samples generally showed a positive, increasing relationship between CO_2 emission and moisture content until 50% moisture content, then leveled off (r^2= 0.41) (Figure 4.5). In contrast, the unamended samples had a weaker relationship, showing a general trend towards increasing peat flux with increased moisture content, though with greater variability at <50% moisture (r^2=0.29). While the individual trends did not demonstrate strong relationships between peat flux and moisture content, the peat flux overall was significantly ($p<0.05$) higher for the amended samples across all moisture levels.

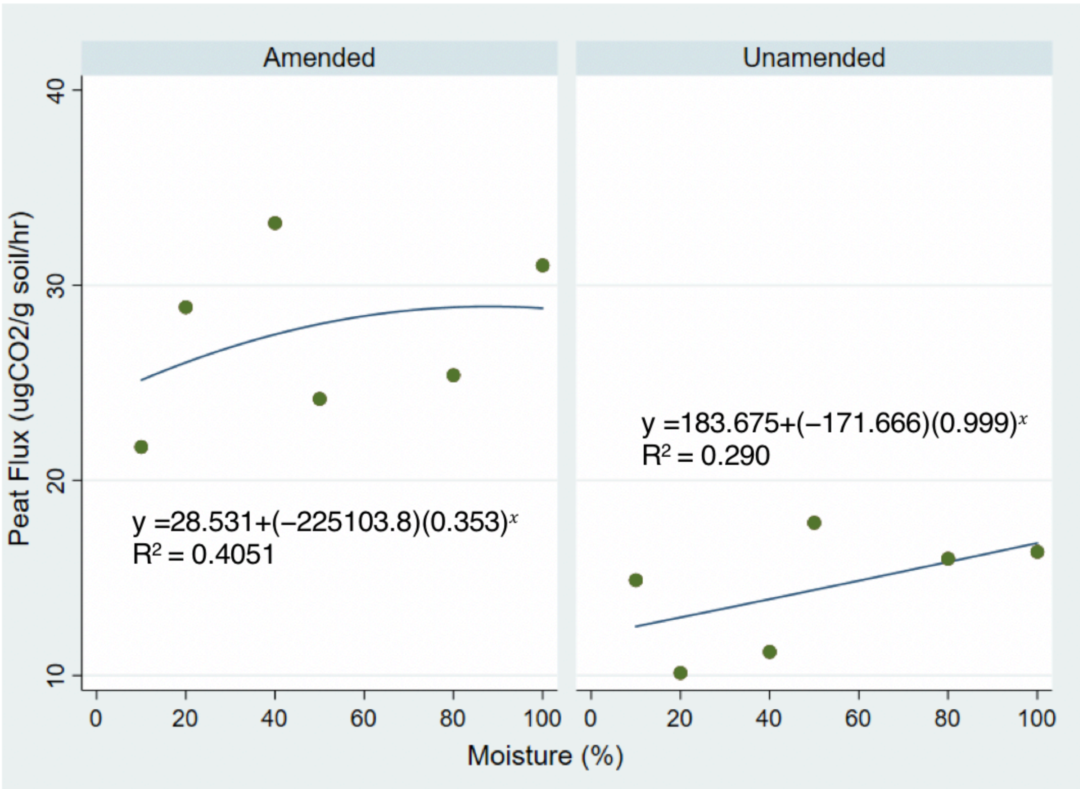

Figure 4.5. Moisture variability of mean unamended and mean amended peat fluxes at constant 25°C temperature; best-fit trend lines are shown

CHAPTER 5: DISCUSSION

In this chapter, I will discuss the context of my results and offer plausible suggestions for the trends shown in the findings. I will begin by elaborating on the differences that arise in the biogeochemical properties of the natural and horticultural peat. I will then provide a framework supported by the isotopic analysis for understanding the temperature relationship for the amended samples and how it compares to the unamended samples. I will further discuss and contrast the responses to changing soil moisture between the two soil types, and then conclude with the implications of my findings in terms of assessing carbon efflux at Canadian horticultural sites.

5.1 Biogeochemical properties of natural and horticultural peat

As a whole, the soil properties of unamended samples were similar to the natural peat baselines found in previous studies. The SOM, pH, carbon content and % water of pure peat were within the expected range of values that have been reported previously for the same type of peat growth medium (Byrne et al., 2021; Biester et al., 2014). The properties of the amended samples were different, though deviated from the properties of the natural peat in a way that would be expected given their use as a growing media. The addition of lime and carbonate was likely responsible for lowering both the fraction of organic matter and corresponding carbon content of the amended soil samples relative to the natural baseline of the unamended samples. As expected, a similar effect was also shown in the overall higher pH values of the amended samples. The addition of dolomitic limestones to horticultural peat reflects the intentional buffering role of these additives for use as a growing media.

In contrast, both soil types reported lower density values than supported in the literature (Kitir et al., 2018). The lowering of the density of the samples is likely attributed to the mechanical alteration of the peat extraction process, reflected by the harrowing of the top surface of the peat samples taken from horticultural harvesting sites. By breaking up the peat in the top 3-4 cm through harrowing, the hydraulic conductivity between the layers of the peat is broken and density of the samples is reduced. The density of the amended samples was significantly higher than the amended samples, likely due to the addition of denser mineral material.

As predicted, the two sample types also differed in their degree of decomposition. Notably, the overall clear distinction for the two sample types was highlighted in their respective humification index and C:N ratios. The C:N ratio of the horticultural peat samples was within the range of other peat types used for growing media, likely as a result of the addition of minerals in the samples that supplied an additional source of nitrogen (Byrne et al., 2021). The overall lower C:N ratio displayed in the amended samples suggests a larger proportion of the sample mass was lost through the consumption of C-rich substances and CO_2 release via microbial respiration, while the higher humification index value supports this as a secondary means of assessing the greater degree of peat decomposition in the amended samples. Ultimately, the differences in soil properties of the unamended and amended samples follow expected trends and support the underlying assumption of the differences in their response to changing temperature and moisture.

5.2 Effect of temperature on CO_2 flux

As with the key biogeochemical properties, the unamended peat showed a temperature response similar to that reported in the literature. As expected, the relationship followed a positive, non-linear response to increased temperatures. The mean Q_{10} value of the unamended samples (3.3), however, was higher than the corresponding literature value of approximately 2.2 (Moore & Dalva, 1993). This may in part be skewed by the larger increase in peat flux between 15-25°C (Q_{10} = 5.2) (Figures 1 and 2). The overall variability of the Q_{10} values between the different temperature ranges may also in part be explained by the limitation of substrate availability at higher temperatures. As the soils become warmer and drier, the decreased rates of solute diffusion enhance the substrate limitation and limit the temperature sensitivity.

Contrary to the natural peat, the amended samples revealed key differences in CO_2 peat flux in response to increasing temperature, reflecting differences in the makeup of the amended peat substrates. The overall response in the amended samples showed a linear increase to rising temperatures and a significantly reduced Q_{10} response relative to the unamended peat (Figure 1-left panel and Figure 2). The lime contribution in the amended samples appeared to linearize the overall CO_2 flux trend and reduce the rate of CO_2 emissions (Figure 1). Without the consideration of the lime contribution, this may have falsely been interpreted as difference in microbial respiration between the two sample types. Rather, the isotopic data provided a framework for understanding the response to increased temperature for peat utilized as a growing media. At lower temperatures, the CO_2-C isotopic signature was more positive, indicating a greater portion of the total CO_2 being lime-derived (Figure 3). As temperature increased, the overall isotopic fraction shifted away from the isotopic signature of the lime carbon pool and towards the peat carbon pool, reflecting a rise in biological activity in the peat at higher temperatures and overall increased microbial respiration. From this, I can speculate that the lime-borne carbon pool dominates at lower temperatures in horticultural peat in the absence of favorable temperature conditions for microbial activity.

In Figure 4, the presence of lime-borne carbon as a significant portion of total carbon efflux in horticultural soils was confirmed. At higher temperatures, the relative increase of lime-derived CO_2 flux was likely a result of limestone weathering, which increases constantly with temperature. Within the individual samples, there was a great degree of variability at each temperature point. This may in part be due to the lime not being well distributed through the peat profile. Given the relatively small sample (5 g of soil for each incubation), the samples may have had varying degrees of lime distribution, leading to greater variability within the individual points.

Ultimately, I can speculate that the addition of lime to the peat used as a growing media decreased the Q_{10} response and linearized the otherwise exponential relationship of natural peat in the unamended samples (Figures 1 and 2). The CO_2 flux response of the amended samples deviated due to the perturbation brought on by the lime addition; the total flux consisted of the exponential rate of decomposition driven by microbial respiration in addition to the linear, chemical weathering process of the lime. Thus, I propose that the agricultural lime applied to peat used as a growing media both directly contributes to the total CO_2 flux and modifies the peat's response to temperature. It would therefore be incorrect to assume a standard temperature relationship for all peat decomposition.

5.3 Effect of moisture on CO_2 flux

The relationship between varying soil moisture and peat respiration response did not produce a clear pattern for the natural peat samples. My results deviated from the conventional relationship outlined by Skopp et al. (1990) where microbial activity peaks at an optimal volumetric moisture content where substrate diffusion and oxygen supply are equal. Based on the results and the methodology of my study, it is likely that the aerobic conditions present in my sample incubations eliminated the impedance of oxygen into the peat by water. The large volume of oxygen relative to peat mass (5 g) in the headspace of my incubations may be the primary explanation for the lack of clear decline in peat flux beyond the "optimal" moisture conditions for microbial activity shown in Figure 5. The overall pattern instead shows a relative increase in respiration up to a moisture level of 60% as the soil is provided with the necessary conditions for microbial respiration before leveling off slightly without a clear decline beyond this level due to a lack of unfavorable conditions.

For the amended samples, an assessment of the results is more challenging. Existing studies have only focused on the relationship between moisture and respiration in natural peatlands and therefore a reference for the conventional behavior of horticultural peat does not exist. My results showed an overall lack of a clear relationship, with a slight positive association between increasing moisture levels and peat flux. Another critical point to consider is the length of my incubations in the study. Samples were only prepared to be studied over one week-long experiment at each moisture level. In both the unamended and amended samples, I would expect a clearer pattern to emerge in longer-term incubations with greater time for microbial activity to take place. As a whole, my findings, while significant, should be considered with caution for transferability. The results of my moisture control study are conditional to the methodology I employed and cannot be applied for peat in anaerobic conditions or beyond short-term experiments.

5.4 Implications for Canadian horticultural peat practices

Going forward, I suggest the incorporation of isotopic analysis of both amended and biotic carbon pools within carbon balance studies in order to more accurately determine total emissions at horticultural sites. The differences in temperature response between natural and amended peat show a non-standard decomposition process across all peat types; the direct lime-borne CO_2 emissions resulting from the horticultural additives are an additional carbon source that must be accounted for. While the largest fraction of greenhouse gas emissions related to peat extraction comes from the decomposition of peat over time, the relative contributions from the carbon pool associated with the horticultural additives provides a framework for challenging the assumptions of standard temperature and moisture responses across both natural and horticultural peat types. This further highlights the importance in distinguishing between the natural processes that govern peat decomposition and those attributed to horticultural additivities that should be considered in overall greenhouse gas emission models of active horticultural sites.

CHAPTER 6: CONCLUSION

This study presented an overview of the processes that govern CO_2 emissions from active horticultural peat sites. By performing laboratory-based incubations and analyses, I demonstrated that horticultural additives, specifically lime, may decrease the rate of decomposition of amended soils under increasing temperatures. While changing moisture contents did not produce clear CO_2 flux-response patterns, further long-term incubations and the introduction of anaerobic conditions would provide more clarity in terms of the water moisture content relationship for horticultural soils. Going forward, more CO_2 flux measurements from active horticultural sites will be necessary to allow for transferability of the temperature and moisture relationships shown in my study.

By showing the overall lime-borne carbon fluxes partitioned from the biotic carbon fluxes, I suggest that the greenhouse gas potential of horticultural sites may be underestimated if additives are not considered in the net carbon balance. The separation of biotic and lime-derived mineralization of carbon will have further implications for the Canadian peat industry and marks a key distinction to be further studied for carbon taxing and budgeting purposes. Under the existing IPCC assumption that 100% of extracted peat is returned to the atmosphere as CO_2, the interactions of horticultural additive-borne carbon sources may require a re-thinking to this traditional approach and should be factored into national carbon budgets.

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