THE EFFECT OF LAYERING SOIL OVER DEGRADED PEATLANDS ON CARBON DIOXIDE EMISSIONS

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Abstract

Peatlands sequester significant amounts of carbon, but they are vulnerable to degradation through drainage for agriculture. Once degraded, they become sources of carbon dioxide. This study assessed how imported soil layers affect carbon dioxide emissions by measuring soil respiration on native peat and treatments with mineral or peat layers. Soil respiration was highest in native peat and lowest when mineral soil was the top layer. Statistical analysis showed the top layer had the strongest influence. There was no statistically significant difference between treatments with the same top layer. A 40-centimeter mineral soil layer was as effective as an 80-centimeter layer in reducing soil respiration. Current local management practices excavate native peat and place it on top of soil fill, which may create carbon dioxide emissions. The results of this research suggest that placing mineral soil over native peat is a viable strategy for reducing carbon dioxide emissions without disrupting agricultural productivity.

1. Objective

Assess how imported soil surface layers affect peat carbon dioxide emissions by measuring soil respiration on native peat, imported peat layered over native peat, and mineral soil layered over native peat.

2. Introduction

A large portion of Richmond was built on peatlands. Peatlands cover only 3-4% of Earth's land surface but store up to one-third of the world's soil carbon. That is twice as much as the world's forests, which cover one-third of the world's surface (UNEP 2022). They play a disproportionately large role in the global carbon cycle, and yet they are often undervalued and degraded by human activity (UNEP 2022). Given the potential for carbon dioxide emissions, it is imperative to find methods to protect the massive amounts of carbon sequestered in peatlands.

Peatlands are a type of wetland that have accumulated a thick layer of peat. Peat is partially decomposed organic matter accumulated over millennia. Peatlands are waterlogged for prolonged periods of time, which creates an anoxic environment below the soil surface. Decomposition happens very slowly in this environment, and the assimilation of carbon dioxide by photosynthesis outpaces the rate of decomposition (Jauhiainen et al. 2016). As long as peatlands remain waterlogged, they act as carbon sinks.

Degraded peatlands are estimated to emit 2,000 megatons of carbon dioxide per year, which accounts for 4% of anthropogenic greenhouse gas emissions (UNEP 2022). Drainage drastically alters the biogeochemical processes in peatlands since the peat is exposed to air. The altered environment strongly favors the mineralization of soil organic carbon, which turns peatlands into hotspots for carbon dioxide emissions (Säurich et al. 2019).

Drainage for agricultural use is still one of the primary causes of peatland degradation (UNEP 2022). When peatlands are drained and cultivated for agriculture, they make easy-to-work soils called muck soil. Muck soil is ideal for growing high value vegetable crops like carrots, onions, and lettuce. Unfortunately, cultivation and amendment for agriculture accelerates mineralization even more than draining alone (Pronger et al. 2014).

Muck soils are not viable long term. Peatlands altered for agriculture can subside up to 20 centimeters per decade as organic matter is lost to mineralization of carbon (Pronger et al. 2014). Eventually, more drainage infrastructure is necessary, as the soil surface eventually subsides to the level of the water table. Once deeper drainage is installed the cycle repeats itself. Saltwater intrusion can become a problem if the soil surface subsides below sea level. If subsidence goes on long enough, eventually all that will be left is the mineral soil below the peat, which may or may not be desirable for agriculture (Pronger et al. 2014).

Soil respiration is a measure of carbon dioxide emitted from the soil surface. It is measured in flux, which is calculated by measuring the change in concentration of carbon dioxide in a sealed chamber of known volume over a set period of time (Gyawali et al. 2019). Soil respiration measurements are used to evaluate signs of biological activity in the soil, such as mineralization of carbon (Gyawali et al. 2019). In peatlands, carbon dioxide flux is a function of plant root respiration and breakdown of organic matter (Rastogi et al. 2002). Soil respiration provides valuable insight into peat restoration and sequestration efforts (Gyawali et al. 2019).

Alternative management strategies that prioritize soil preservation are necessary. A potential method for preventing the loss of carbon stores is farming mineral soil layered on top of peatlands rather than directly on the peat. In a study conducted in Norway, researchers examined the greenhouse gas emissions associated with cultivating forage on a drained peatland versus cultivating on a layer of mineral soil on top of peatlands. They found lower carbon dioxide emissions from cultivating on top of a layer of mineral soil. They concluded that the layer of mineral soil functioned to protect the peat from exposure to oxygen (Bomford 2023; Rivedal and Øpstad 2020).

Peatlands in Richmond are currently used for agriculture. The Agricultural Land Commission (ALC) has approved applications for farmers in Richmond to place soil fill to raise their fields to improve poor drainage. In such cases, they have required landowners to salvage topsoil by stripping it, storing it, distributing fill soil, and then redistributing the topsoil over the fill soil. These requirements are supported by the City of Richmond Bylaw 10200 4.1.1(h)(vi), which states that, if a property is in the Agricultural Land Reserve, a permit for depositing soil must include a plan for topsoil salvage. This research is to assess whether an alternative management strategy, leaving peat topsoil beneath fill soil, could mitigate carbon dioxide emissions.

3. Methods and Materials

3.1 Site Selection

The study site was conducted on the northwest side of Garden City Lands, south of Alderbridge Way and east of Garden City Road in Richmond, BC. Garden City Lands is a fragment of the historically extensive Lulu Island Bog. Urban development has altered the hydrology of the bog at Garden City Lands (Davis and Klinkenberg 2008).

The area surrounding the study site was already covered with imported soil fill. The study site was left uncovered because of the presence of sphagnum moss, an ecologically significant species. It was selected in part because the experiment would not cause additional environmental damage, since the area was scheduled to be covered with soil fill in the near future.

3.2 Soil Layers

Four soil layer treatments were established over native peat to assess their effect on soil respiration. The treatments included layers composed of mineral soil, peat, or combinations of the two. Both soil types were imported from offsite. The imported soil was already stockpiled at the site prior to the study. The exact origin of the imported soil fill is unknown.

Due to limitations with time and equipment, creating large scale soil layers was impractical. Soil layers were constructed using containers. Each experimental unit was constructed with two 18.9 L White All Purpose Pails (Rona, Richmond BC). The bottom of each pail was removed. The open bottoms ensured continuity with the underlying soil. They were stacked on top of each other and filled with imported soil.

The experiment was arranged in a randomized complete block design with four blocks to account for potential variability across the study site. There were two experimental factors: imported soil type (mineral or peat) and its position (top or bottom). Based on these factors, there were four distinct treatments within each block:

1. 80 cm of mineral soil layered directly over native peat
2. 40 cm of mineral soil over 40 cm of peat layered over native peat
3. 80 cm of peat layered directly over native peat
4. 40 cm of peat over 40 cm of mineral soil layered over native peat

This design enabled a controlled evaluation of how soil type and layer position influenced soil respiration.

3.3 Soil Respiration Measurements

Soil respiration was measured using the SRC-2 Soil Respiration Chamber paired with the CIRAS-3 Portable Photosynthesis System. Measurements were taken from the top of the pails for the layered soil treatments. For comparison, additional measurements were taken directly from the surface of the native peat. The chamber was placed on the soil for two minutes for each sample. Each round of measurements was taken consecutively on the same day to minimize variability due to weather. Seven rounds of measurements were taken between August and September.

3.4 Statistical Analysis

Treatments were analyzed using a linear mixed model fit by REML in Jamovi to assess the effects of the treatments on soil respiration. Soil fill type (mineral or peat) and position (top or bottom) were included as fixed effects. Soil respiration was the independent variable. Date of measurement and block were treated as cluster variables to account for the random effects and variability they may have caused.

Tukey's Honestly Significant Difference test was applied to identify treatments that showed a statistically significant difference from each other. Fixed effects omnibus tests were used to determine the influence of the position on soil respiration.

Native peat respiration rates were excluded from the linear mixed model analysis because native peat did not have the experimental factors of soil type and position. However, mean respiration rates were calculated for native peat and all treatments.

4. Results

4.1 Respiration Rates

The highest soil respiration rates were observed on native peat. Treatments where imported peat was the top layer had the second highest respiration rates. Treatments with mineral soil as the top layer had the lowest respiration rates.

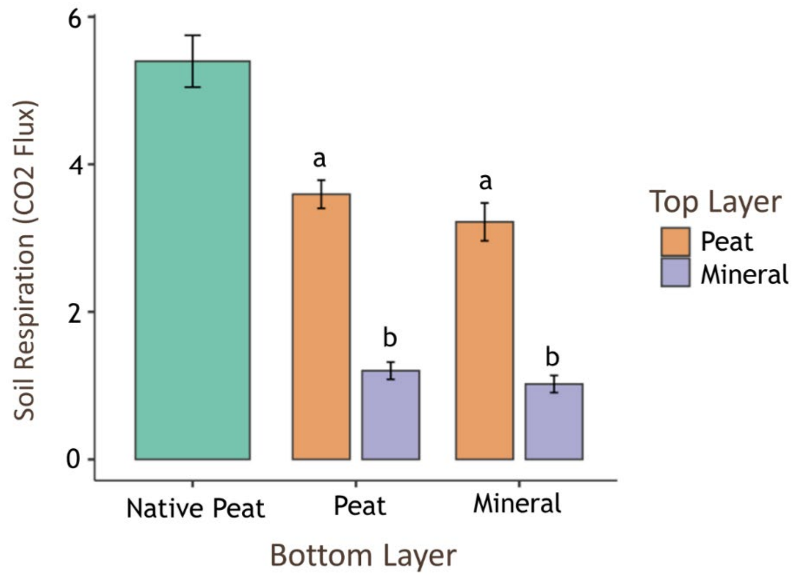

Figure 1. Mean soil respiration rates for native peat and treatment combinations. Error bars denote standard error. Bars labelled with the same letter do not differ significantly (Tukey test, $\alpha = 0.05$)

Table 1. Mean soil respiration rates by treatment

Treatment	Mean Soil Respiration (CO_2 Flux)
Native Peat	5.40
80 cm Peat	3.59
40 cm mineral over 40 cm peat	1.20
80 cm mineral	1.02
40 cm peat over 40 cm mineral	3.22

4.2 Influence of Soil Layers on Respiration Rates

The top layer soil type had a significant effect on soil respiration rates ($p<0.001$). The bottom layer also had a significant effect on soil respiration; however, the significance was not as strong ($p<0.05$). No significant interaction was detected between layers.

Table 2. Fixed effects omnibus tests for the influence of top and bottom layers on soil respiration

Source	**p-value**
Top	< 0.001
Bottom	0.024
Top * Bottom	0.425

There was no significant difference detected between layers with the same soil type as the top layer, regardless of the soil type of the bottom layer. However, treatments with different soil types on the top layer showed a statistically significant difference ($p<0.001$).

Table 3. Tukey's HSD post hoc comparison for the difference between treatments

Comparison					
Top	**Bottom**		**Top**	**Bottom**	***p*-value**
Peat	Peat	*vs.*	Peat	Mineral	0.135
Peat	Peat	*vs.*	Mineral	Peat	<0.001
Peat	Peat	*vs.*	Mineral	Mineral	<0.001
Peat	Mineral	*vs.*	Mineral	Peat	<0.001
Peat	Mineral	*vs.*	Mineral	Mineral	<0.001
Mineral	Peat	*vs.*	Mineral	Peat	0.719

5. Discussion

The results demonstrate that soil layers have a significant effect on soil respiration in peatlands. Exposed native peat had the highest respiration rates, indicating high carbon dioxide flux from the soil, which supports the notion that degraded peatlands are vulnerable to organic matter loss through mineralization once their hydrology is disturbed, resulting in carbon dioxide emissions.

The most substantial reduction in soil respiration was observed in treatments with mineral soil as the top layer. These findings support previous research that showed mineral soil can reduce carbon dioxide emissions from peatlands cultivated for agriculture. Treatments with peat as a top layer had higher soil respiration than those with a mineral top layer, but still lower than native peat, suggesting having any protective layer reduced carbon dioxide emissions.

There was no significant difference between treatments with the same top layer, regardless of the soil type on the bottom layer. This suggests that the top layer plays a dominant role in regulating carbon dioxide emissions. A mineral soil layer of 40 centimeters was as effective as a mineral layer of 80 centimeters. These results indicate that a relatively thin layer of mineral soil may be sufficient to achieve substantial reductions in carbon dioxide emissions.

6. Conclusion

The ALC and City of Richmond require topsoil salvage regardless of soil type, which means salvaged topsoil is placed on top of soil fill where their carbon stores are vulnerable to mineralization. In the long term, peat soils placed on top of soil fill will subside, potentially leaving the soil fill exposed or requiring the purchase of new drainage infrastructure. It also creates carbon dioxide emissions at a time when mitigating such emissions is crucial.

This study highlights the potential of mineral soil layers over degraded native peat to mitigate carbon dioxide emissions. These findings suggest that placing soil fill on top of peat is a viable strategy for preserving the carbon stores in former peatlands cultivated for agriculture. The soil fill top layer can function to protect the peat below, as it can remain waterlogged while the soil fill is cultivated. The current topsoil salvage process requires the inverse, placing peat on top of soil fill.

Even protecting heavily degraded peat soils is a worthwhile endeavor. Research indicates that soil respiration patterns of degraded peat soils do not begin to mimic mineral soils. Respiration does not seem to plateau or stop, even as heavily degraded peat soils approach the SOC content of mineral soils (Säurich et al. 2019). The carbon stores in peat soils remain vulnerable to mineralization. By prioritizing strategies that reduce soil respiration rates it is possible to slow the loss of SOC.

Strategies that reduce carbon dioxide emissions are critical to meeting global climate targets. The carbon stored in peatlands is thousands of years old. It would exacerbate climate change if it was released into the atmosphere. Healthy peatlands are active carbon sinks and should be protected. In regions where peatlands are overtaken by agriculture and urban development, emissions can be emitted by carefully considering land management strategies.

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