# Impacts of Reconstructed Soils on CO2 Emissions in the Bernese Three Lakes Region

GEO 511 Master's Thesis

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# Geo 511 - Master Thesis

## Geography

## University of Zurich

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**Index:**

## Abstract:

Peat soils formed in the Bernese Three Lakes Region after the last ice age. These soils were formed after the region had been subjected to a system of lakes, rivers and ponds. In these anaerobic soil conditions, carbon-rich soil accumulated and formed the peat soils of today. The soils have been turned into arable land and have undergone several water corrections in the 19th and 20th century. This change of land use has turned these soils from carbon sinks into carbon sources. The goal of this study was to determine if reconstructed peat soils emit less CO2 compared to natural peat soils. In order to do this the CO2 flux of different peat soils was measured in 10 locations across the Three Lakes Region in the Canton of Bern. The results show that there seems to be no correlation between the reconstruction of peat soils and a lower soil CO2 flux.

## Introduction:

After the glaciers retreated at the end of the last ice age, large and small lakes remained in the lower-lying parts of the European landscape. In the landscape of the Bernese Three Lakes Region some of these lakes eventually turned into a moorland with Histosol as a dominant soil type (Egli et al., 2020). Peat soils are soils that are soggy enough so that the carbon content in them is not metabolized by breathing microorganisms. The soils in this area had, due to the nature of the peat soils and the degradation of the soils due to agricultural use, a high groundwater level. The combination of these implicating factors made it difficult for the farmers to further use the soils for agriculture.

The soils in the Bernese Three Lakes Region are subject to degradation due to the intensive agricultural use. The high carbon content in these soils leads to a faster degradation through microbial activity than in other, less carbon-rich soils. Overall, there are several factors which contribute to the degradation of the peat soils. Egli et al. (2021) list the draining of the area, the use of fertilizers, agriculture and the deposition of atmospheric nitrogen as contributing factors to this recent phenomenon. The degradation of peatlands is not only a problem for farmers but it also accelerates climate change because peatlands are a major carbon storage. Further services provided by peatlands are water storage, regulation and purification (Ferré et al., 2019)

Until the mid-19th century, the soil in the Three Lakes Region was barely usable due to constant flooding and malaria outbreaks. Two water corrections were made in the region in order to limit the groundwater level and control the flow of water. A first water correction in 1863-1897 and a second water correction in 1963-1973 (Egli et al., 2020). In recent times, the soil has degraded further and a new push for water corrections has come from the side of the farmers. Many environmentalists disagree with a proposed third water correction however, and there has been a push to turn the Three Lakes Region into a conservation zone. As already mentioned, the Three Lakes Region is mainly used for agriculture and is known as the “vegetable belt” of Switzerland (gemuese.ch). Some of the vegetables that are planted there include for example lettuce, cauliflower, broccoli and rhubarb. Intensive agriculture has also led to a diminishing of the soil’s thickness which prompted some of the farmers to take action into their own hands and add additional soil on top of their peat soils from elsewhere. This was often done illegally and was also often poorly executed. In some cases, the soils suffered serious compaction from the reconstruction efforts (Egli et al., 2020).

## Relevance for Climate and Global Warming

Peat soils are natural carbon sinks but become CO2 sources when they get used for agriculture. This is due to the priming of microorganisms in the peat soil when fertilizers are applied to the soil and/or the water is drained from the soil (Rastogi et al., 2002). These microorganisms then metabolize the available C in the form of soil organic carbon (SOC) or dissolved organic carbon (DOC) into CO2 which is emitted into the atmosphere (Lou et al., 2003). The very high carbon content in these soils also means that peat soils can release far more carbon into the atmosphere than soils with less carbon content (Loisel et al., 2020). The topic of this thesis is therefore important in determining if reconstructed, piled up soils can reduce CO2 gasses from being released into the atmosphere. It is therefore relevant, not only to local farmers and environmentalists but also to the climate change discussion, as CO2 is a crucial greenhouse gas in global warming. The peat soils in the Bernese Three Lakes Region emit about the equivalent of CO2 emissions from a medium-sized town (Egli et al., 2021).

Estimations about the amount of the global soil stored carbon held in peat soils ranges from 25% to about 50% (Loisel et al. 2020) (IUCN.org). Furthermore, peatlands emit about 5% of the global anthropogenic CO2 emissions annually (IUCN.org). This means that new ways to combat CO2 emissions from agriculturally used peat soils could have a significant impact on overall soil CO2 emissions.

Egli et al. (2021) estimated about a 5 t annual mass loss of Carbon per ha for agricultural land in the Bernese Lakes Region which is similar to a value by Gronlund et al. (2008) with a value of 6 t annual mass loss per ha. The amount of Carbon loss from a forest in the Bernese Three Lakes Region is about 2.5 t annual mass loss per ha (Egli et al., 2021)

Besides agricultural use, other reasons for peatland carbon losses include atmospheric pollution (for example through nitrogen pollution), peat fires, loss of permafrost and loss of moisture (drainage). These reasons can also be related to land-use change (Loisel et al. 2020). In total there is an estimation of about 2-3 gigatonnes CO2 emissions from peatlands per year (Joosten, 2009).

## Research Question:

Previous research by Egli et al. in 2020 has suggested that piling up soils on top of natural peat soils (also referred to as soil reconstruction in this paper) could potentially reduce CO2 emissions from these peat soils (Egli et al., 2020). The goal of this thesis is to find out whether these findings can be confirmed by conducting further measurements on the CO2 fluxes of natural and reconstructed peat soils. The area of the Three Lakes Region in the canton of Bern has been chosen for this research project because extensive soil reconstructions on the degrading peat soils have been conducted by the local farmers.

The question that this thesis tries to answer is therefore: Do reconstructed peat soils emit less CO2 than natural peat soils?

### Political Discussion – Farmland or Conservation Zone?

Peat soils can be (when drained) quite fertile due to their high organic soil content (Thiessen et al., 1994). This is one of the reasons why the soils in the Three Lakes Region were heavily used for agriculture (especially vegetable farming) since the first Jura water correction (Egli et al., 2021) (gemuese.ch). In the wake of ongoing debates about global warming there is now the question whether these soils should be further used for agriculture, which would lead to more CO2 outgassing from the soils, or if the region should be turned into a conservation zone and become a carbon sink again.

## Investigation Area:

The Three Lakes Region is located in the western part of the Swiss Plateau between the Jura mountains and the Alps. The area is divided by the Cantons of Bern, Fribourg and Neuchatel.

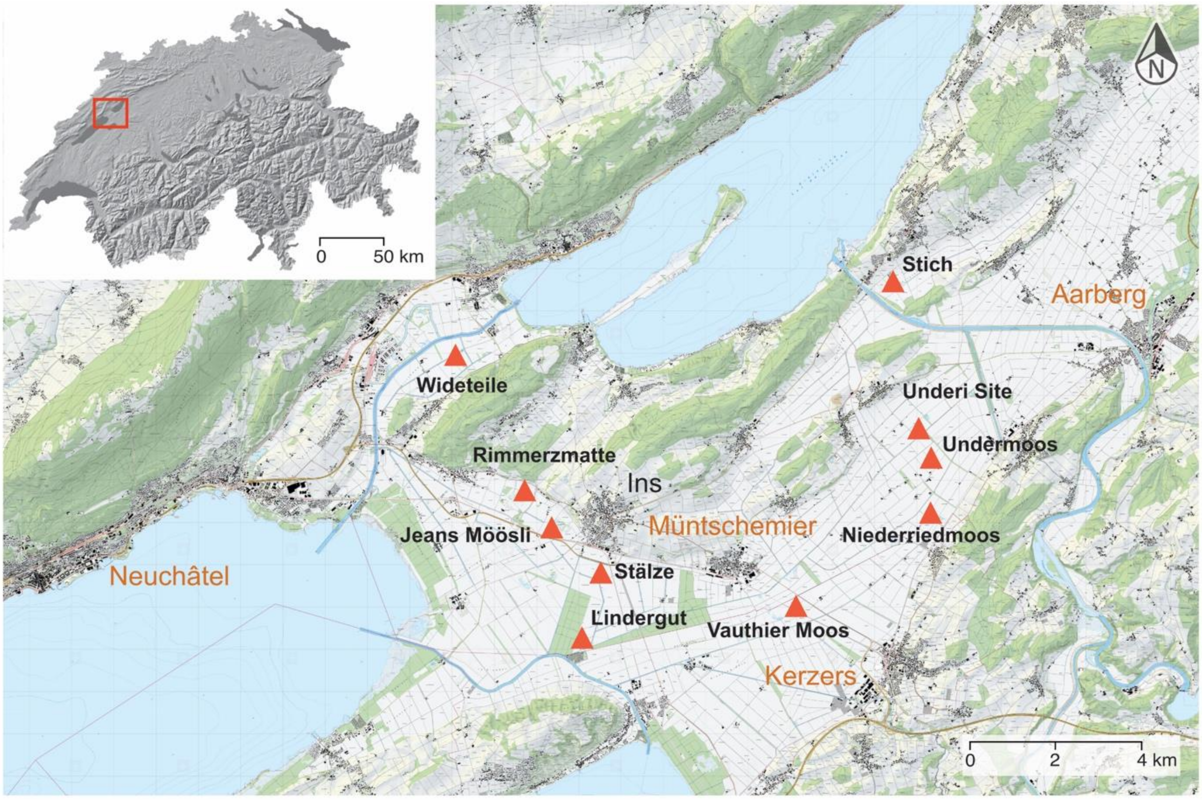

*Figure 1. Location within Switzerland and map of the Three Lakes Region.*

**Soil type:** As already mentioned, the investigation area lies in a former moorland where the most common soil types are Histosols and Fluvisols (Egli et al., 2021). These types of soils formed often in waterlogged soil conditions where breathing organisms could not metabolize the carbon into CO2 (O2 -> CO2: breathing). This led to a high buildup of soil carbon over time, which is why these soils are very capable CO2 sinks when they are not drained. Under the common thin layers of peat in the Three Lakes Region are mostly layers of lake marls and clay (map.geo.admin) (Egli et al., 2021). In the field, many of the peat soil plots had already degraded to the point where the underlying lake marl became visible, especially if the soil had been tilled.

*Figure 2. Research site in Hagneck (Stich). Weather station in front of the field. The measuring devices are dispersed in the field under the green shading material*

*Figure 3. Research site in Gampelen (Rimmerzmatte). Weather station in the field. The measuring devices are dispersed in the field under the green shading material*

*Figure 4. Profile of a peat soil in the Bernese Three Lakes Region*

## Geology:

*Figure 5. Geological map of the Bernese Three Lakes Region (White area: Peat, Sea Chalk. Yellow area: moraine material. Green area: Gravel and fluvial sand (Source: Map.geo.admin)*

The Geology is described as being “Limno-Palustre” as well as “Lake Chalk” in the geological atlas of Switzerland (map.geo.admin). The peatland is painted white in the map. There is also moraine material in the north-eastern part of the great marsh.

**Climate:** The climate of the Three Lakes Region today is relatively mild compared to the rest of the Swiss plateau with an annual temperature of around 8-10 C° and 1000-1200 mm of annual rainfall as well as occasional snow cover during the winter season (Egli et al., 2021). This can be considered to be a temperate climate (https://content.meteoblue.com/en/research-education/educational-resources/meteoscool/general-climate-zones/temperate-zone). During the last ice age (end of the Pleistocene) the temperature was obviously much colder as the area was covered by massive glaciers.

**Landscape evolution:** The land in the Three Lakes Region was formed during the last ice age where big glaciers carved this inundation into the landscape of the Swiss plateau. As can be seen in the map (figure 5) the moraine material that the glaciers carried with them can still be found as plateaus at the edge of the great marsh. The lower lands would often turn into lakes or moorlands after the retreat of the glaciers as was the case for the Three Lakes Region (Egli et al., 2021). These moorlands would then lead to the emergence of the peatlands that still exist today. The draining of the waterlogged peatlands during the Jura water corrections made the land arable but led to the degradation of the peat soils.

**Land Use:** The land of the Three Lakes Region is largely used for agriculture, especially vegetable farming. Some areas are also used for forestry and some are natural conservation zones (Egli et al., 2021).

# Methods:

The goal was to measure and then compare the CO2 fluxes of reconstructed and natural peat soils. Furthermore, the research team also tried to gather information about soil temperature and moisture, air temperature and wind speed and direction. While the main goal of the research was to determine the CO2 fluxes, the measurement of other factors was conducted in order to gather more data for further research as well as to estimate the impact of other factors on CO2 flux besides soil reconstruction.

The locations were chosen depending on where soils were reconstructed and when the reconstruction occurred. It was important that a reconstructed soil and a natural soil plot were close to each other in every location in order to minimize the difference between the underlying natural peat soils. There was also a focus on having varying ages of the soil reconstructions as well as different types of backfilling material. Furthermore, the sites also needed to be accessible with a car.

| Community | Local name | Swiss-Coordinates | Amelio-year | Material | Type of backfilling |
|---|---|---|---|---|---|
| Hagneck | Stich | 2581415/1211540 | ca. 1990 | Sand | Correct setting |
| Kallnach | Undermoos | 2582583/1207833 | ca. 2008 | Moräne | C material |
| Ins | Stälze | 2574430/1204958 | ca. 2012 | Moräne | C material |
| Ins | Lindergut | 2574185/1203195 | ca. 1995 | Sediments | BC material |
| Gals | Wideteile | 2570920/1209796 | 1975 | Moräne | C material |
| Ins | Jeans Möösli | 2573161/1205796 | 2021 | Moräne | C Material |
| Finsterhennen | Underi Site | 2582270/1208290 | 2013 | Moräne | BC material |
| Kerzers | Vauthier Moos | 2579170/1204170 | 2021 | Moräne | Correct setting |
| Gampelen | Rimmerzmatte | 2572652/1206890 | 1971 | Sand | Correct setting |
| Kallnach | Niederriedmoos | 2581932/1206350 | 2021 | Moräne | Correct setting |

*Table 1. Sites with soil restoration (having a varying age; with material from the closer region).*

On each trip the same 10 measurement sites were visited. On every site a total of 12 CO2 measurements were taken (6 measurements on the reconstructed soils and 6 measurements on the natural soil on each site). The CO2 increase at each measurement point was measured for 10 minutes. The Vernier devices measured the increase in CO2 inside the cylinders from which the CO2 flux can then be derived.

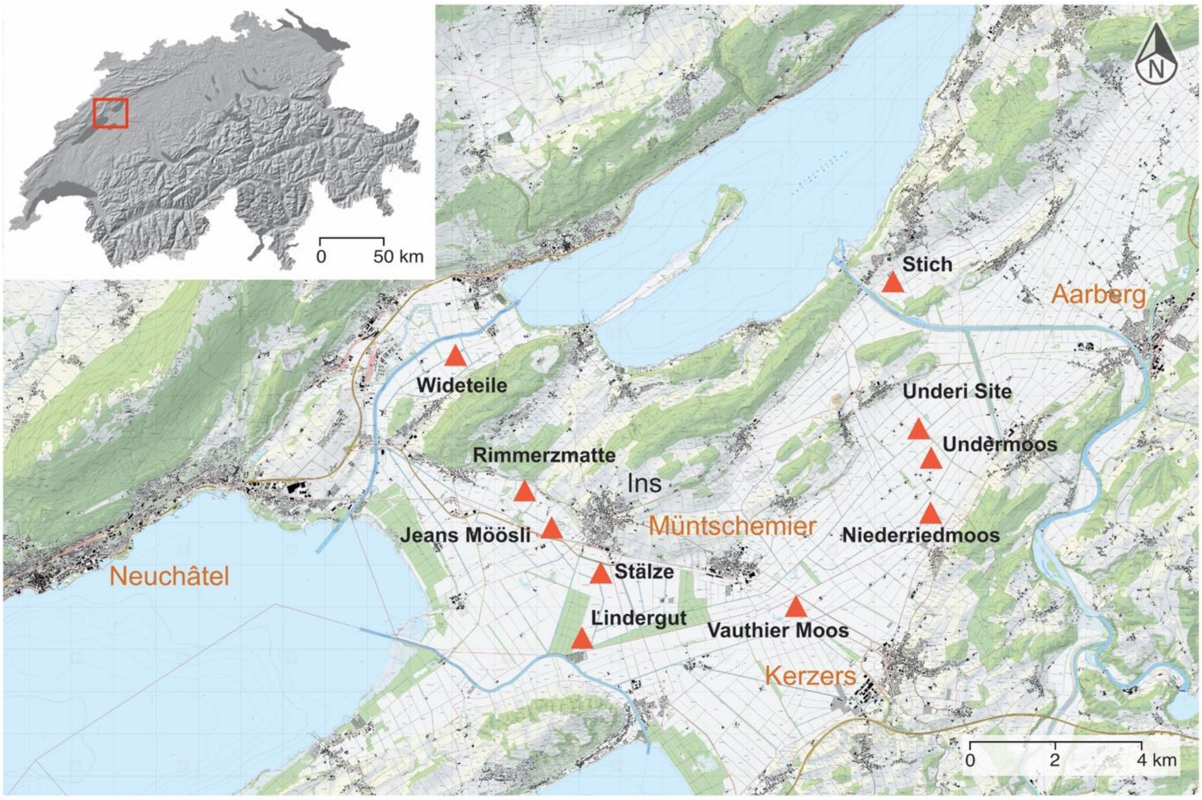

*Figure 6. Map including the 10 measurement sites*

All sites are used as agricultural crop land by the farmers. The sites Vaulthier Moos, Niederriedmoos, Undermoos and Underi Site were located in the "Great Marsh". A flat plane that was originally moorland but is now used for extensive agriculture.

## Materials & Calculations

In order to measure the CO2 fluxes vernier sensors were placed in aluminium cylinders to measure the rise of CO2 within the cylinder. The cylinders had to be tightly sealed off so that the CO2 would not leak out into the atmosphere but instead build up within the cylinder. The sensor that was placed inside the cylinder then measured the CO2 concentration at different timestamps which was displayed as (most often) a positive increase in CO2 within the gas composition inside the cylinder. Besides the CO2 fluxes, soil moisture and soil temperature were also taken. Furthermore, air temperature was also taken from the second field trip onwards, as well as wind speed and direction on the third field trip. Permission from the land owners (farmers) was given to the research team beforehand.

Effects from of direct sunshine on the vernier devices was taken into account and eliminated as good as possible by using canvas as shading material.

The soil moisture was measured using an HH2 moisture meter from Delta-T with a Trime-pico sensor from Imko. The wind direction and speed were measured using a Wellcraft weather station.

The goal of these measurements was to obtain a dataset where the CO2 fluxes of natural and reconstructed peat soils can be compared whilst eliminating as many external factors as possible

The statistical calculations were done in Excel. The 12 measurements at each site gave us a total of 360 data points for the CO2 fluxes (180 data points for reconstructed soils, 180 data points for natural soils). Box plots were used to compare the CO2 fluxes as well as other parameters of the natural and reconstructed soils. Dot plots were used to compare external factors as well as certain soil parameters with the CO2 fluxes.

On each location there was also a soil sample taken (one sample from the natural soil and one sample from the reconstructed soil). The sample was later dried, sieved and prepared for further lab testing. The samples were than examined for their contents like the composition of their carbon and nitrogen contents. The amount of Soil organic carbon and Soil inorganic carbon were also determined in the samples.

The total carbon (C) and nitrogen (N) contents were measured using elemental analysis isotope ratio mass spectrometry (EA-IRMS) where the soil sample was combusted and the isotopes analyzed via mass spectrometer. The measurements were performed using a Thermo Fisher Scientific Flash HT Plus elemental analyser with SmartEA option equipped with a thermal conductivity detector and coupled to a ConFlo lV to Delta V Plus isotope ratio mass spectrometer. Carbonates were determined by dissolution with HCl. The organic C content was calculated as the difference between total C content and inorganic C content values.

**Field Research:**

Three field trips were undertaken into the Bernese Lakes Region area in the months of March, May and June of 2022 and each one took several days. The farmers were contacted beforehand and they agreed to the measurements on their farmland. Precipitation was avoided in the planning of the trips. In each field trip, 12 measurements (6 on reconstructed and 6 on natural soil) were undertaken at each of the 10 sites. The measurements usually lasted an entire day which means there were varying degrees of air/soil temperature and sunlight.

## Results:

The box plots of all of the data points from the reconstructed soils compared to the natural soils (figure 7) seem to indicate that reconstructed soils have slightly higher CO2 emissions than the natural soils. This would mean that the thesis of the research question on whether reconstructed (piled-up) soils lead to lower emissions in peat soils cannot be supported by the results of these field measurements/observations. In figure 7, the main body of the reconstructed soil box (blue) extends more into the higher values than the natural soil box (orange). Furthermore, the blue figure also has higher values for the whiskers as well as higher outliers.

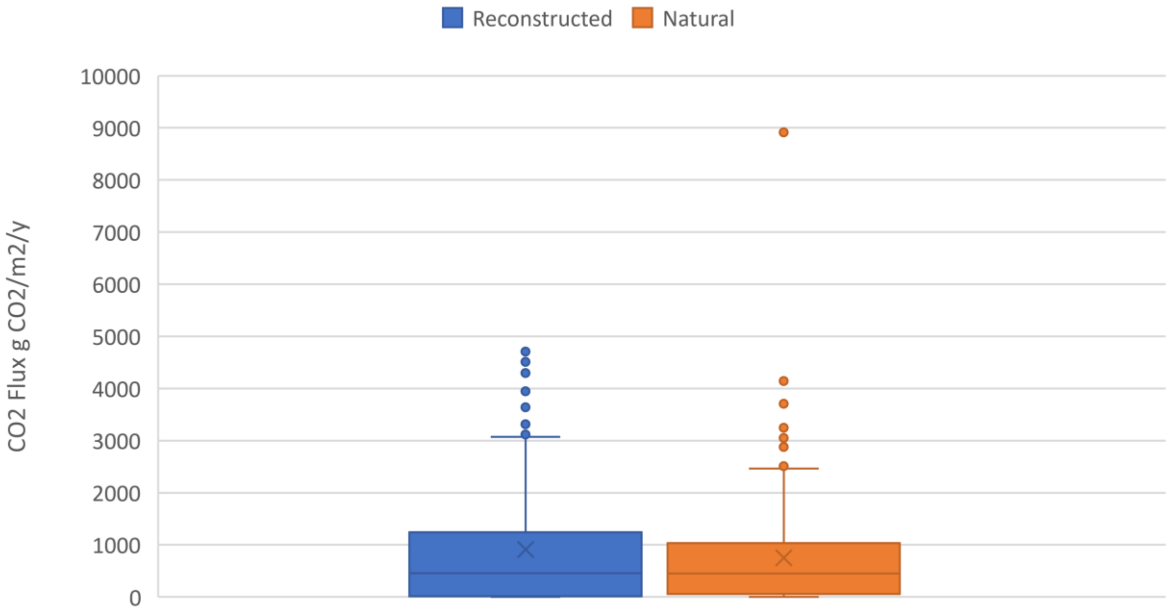

*Figure 7. Compares the CO2 fluxes of reconstructed and natural soils of all data points from all of the three field trips*

While there does not seem to be a correlation between air temperature and the soil CO2 fluxes, there seems to be a positive correlation between warmer soil temperatures and higher soil CO2 fluxes which can be seen when figure 8 and figure 10 are compared. There is also a negative correlation between soil moisture and CO2 fluxes as can be seen in figure 9. There also appears to be a higher than usual standard deviation between the soil moisture contents in figure 9, especially at the higher CO2 flux values. The dew points show a positive correlation with soil CO2 fluxes as can be seen in figure 11.

There are less data points for figures 10 and 11 because the air temperature and dew points were only measured in 2 of the 3 field trips (May and June). Furthermore, only one measurement of air temperature and dew point (figure 10 and 11) was taken per location as opposed to 12 measurements in each location for soil temperature and soil moisture (figure 8 and 9).

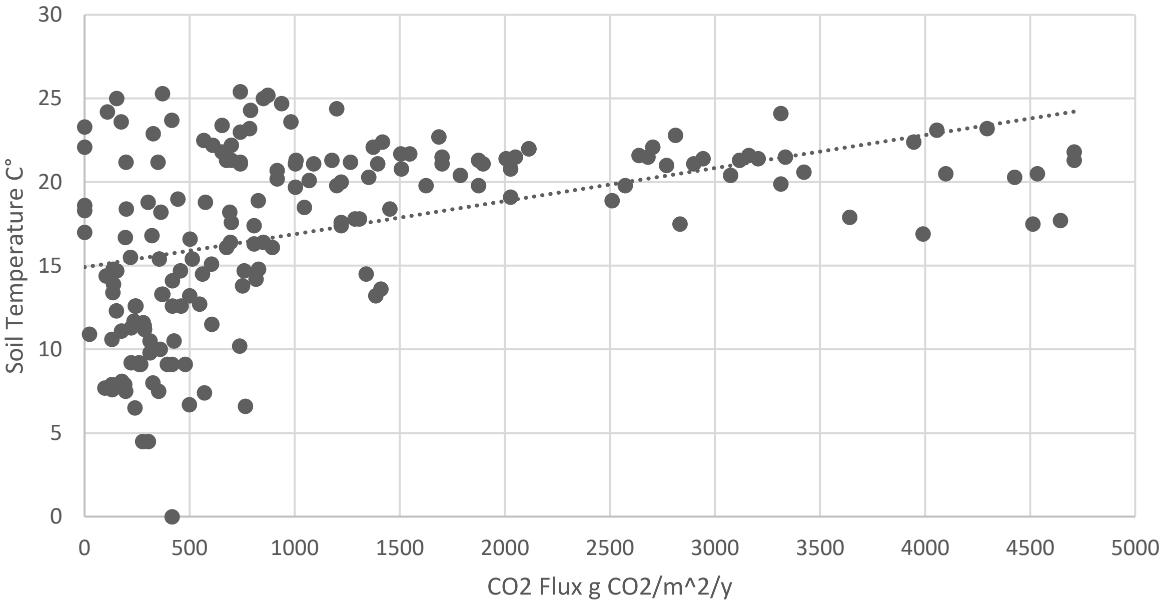

*Figure 8. Comparison of the soil temperatures with the CO2 fluxes from all of three field trips*

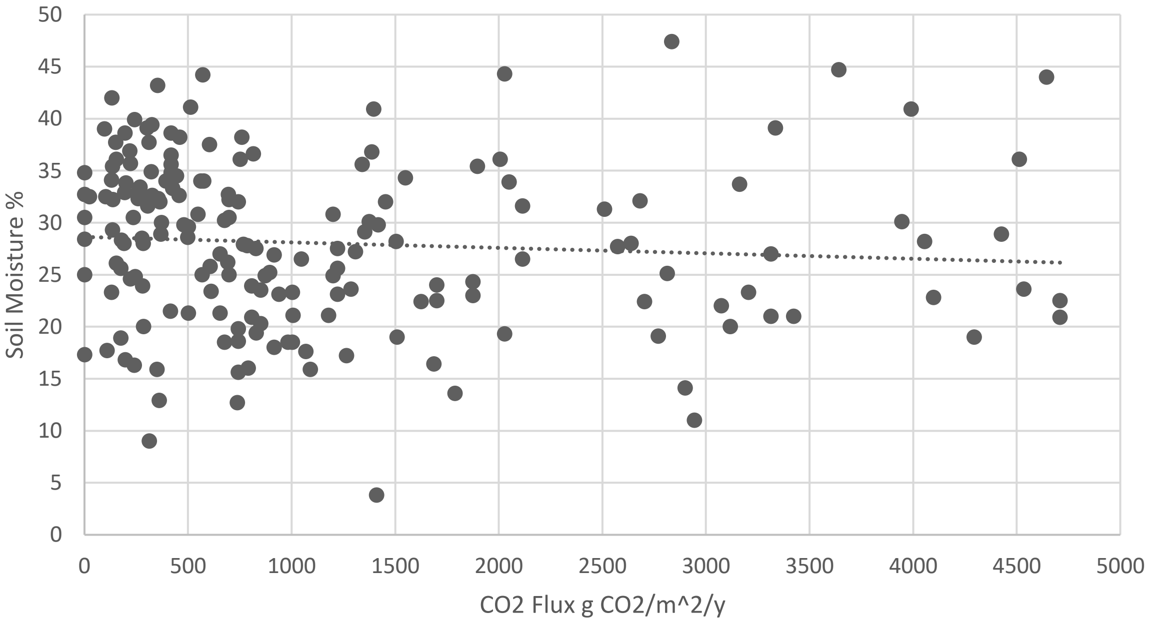

*Figure 9. Compares the soil moisture measurements with the CO2 fluxes from all three field trips*

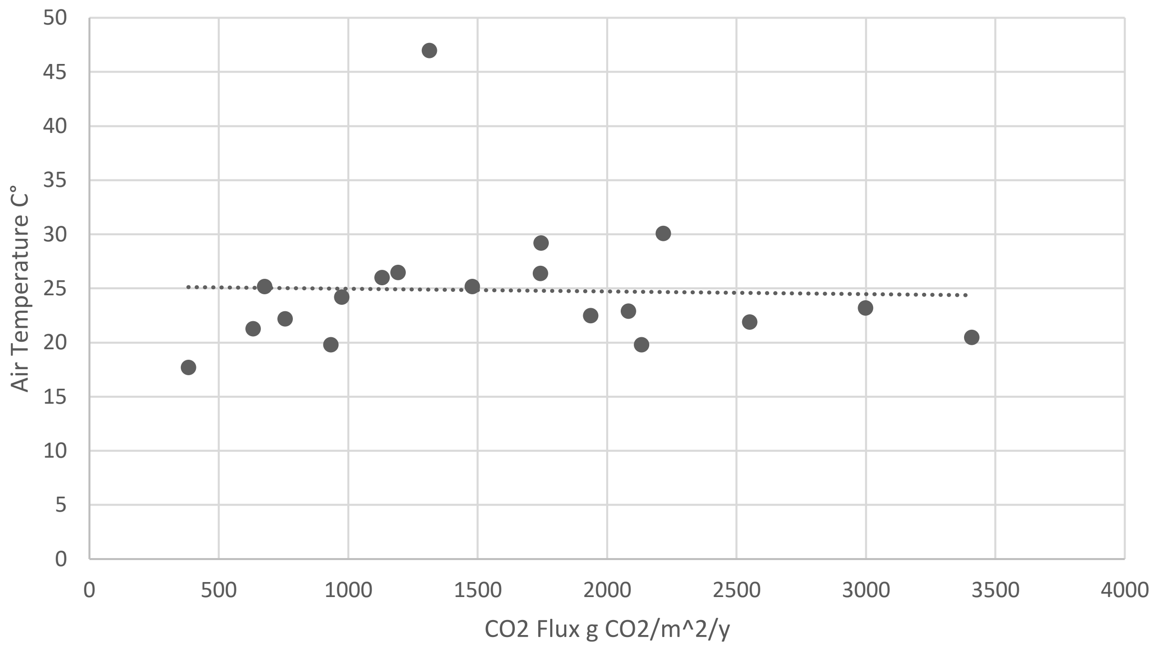

*Figure 10. Compares the air temperature with CO2 fluxes from May and June*

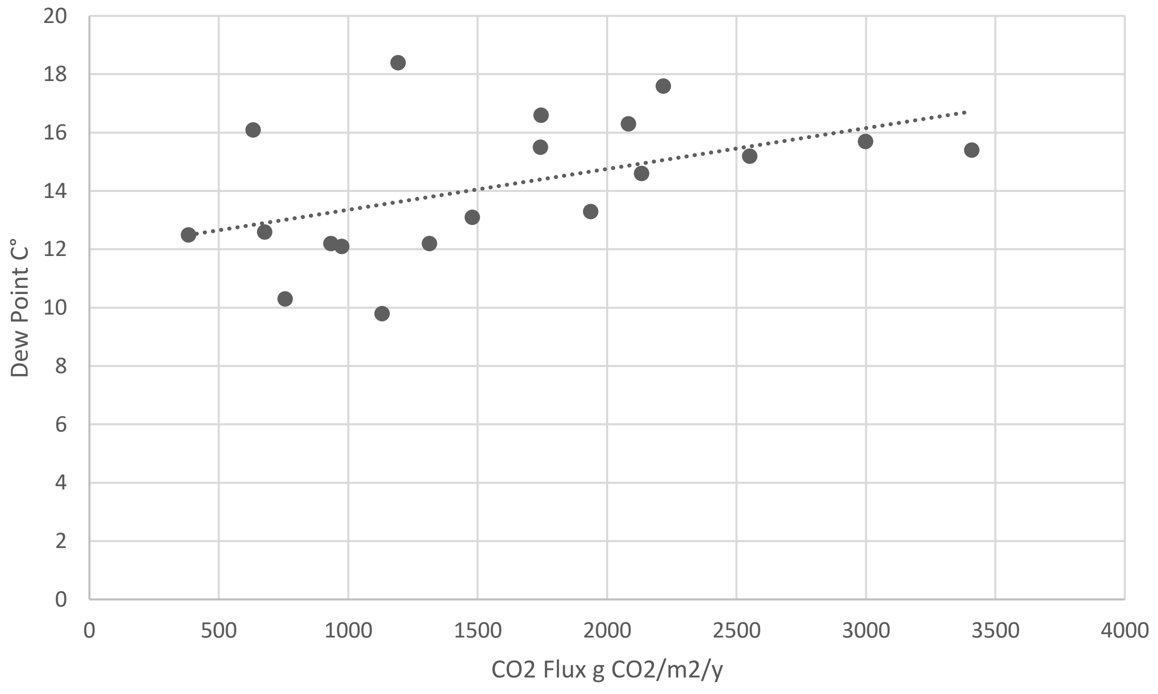

*Figure 11. Compares the dew points with CO2 fluxes from May and June*

In the figure 12 where C/N values of the soils are compared with CO2 fluxes, there appear to be two different trends that are visualized in the graph. There is a positive correlation of reconstructed soil C/N values with reconstructed soil CO2 fluxes while natural soil C/N values show a negative correlation with natural soil CO2 fluxes. The positive C/N vs. CO2 flux trend for the reconstructed values could also have been distorted by two very high C/N values for the reconstructed soils.

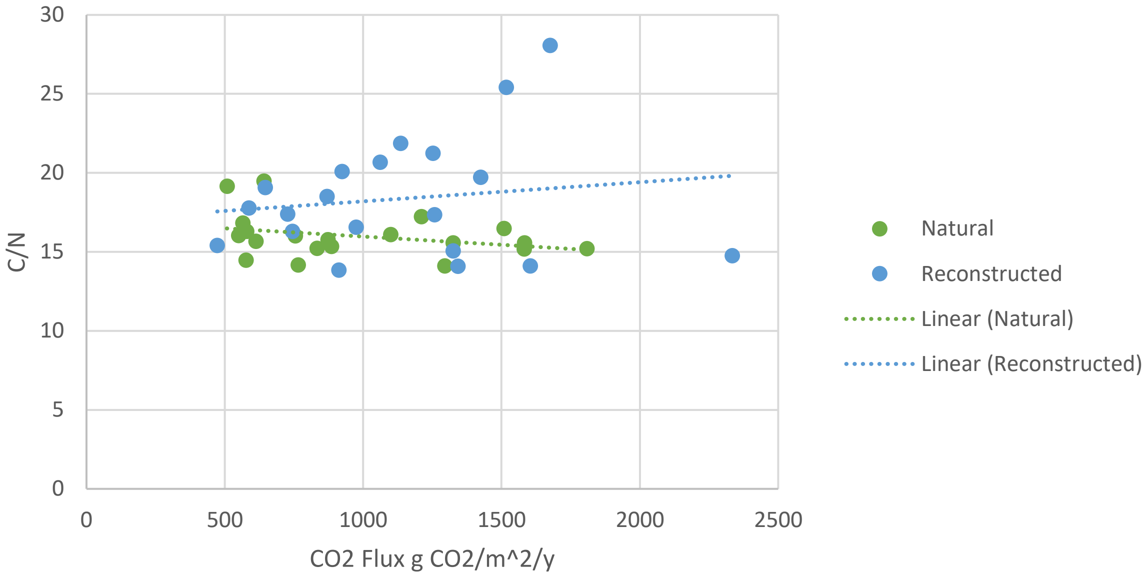

Figure 12. Compares C/N (organic carbon content %/nitrogen content %) ratios of the soils with CO2 fluxes for both natural and reconstructed soils

Figure 13 compares the N (nitrogen) values with the CO2 fluxes of the soils. The results indicate that a higher N content correlates with higher CO2 fluxes, especially in natural peat soils. The trendlines are very similar to Figure 13 where soil CO2 fluxes and soil Carbon content are compared.

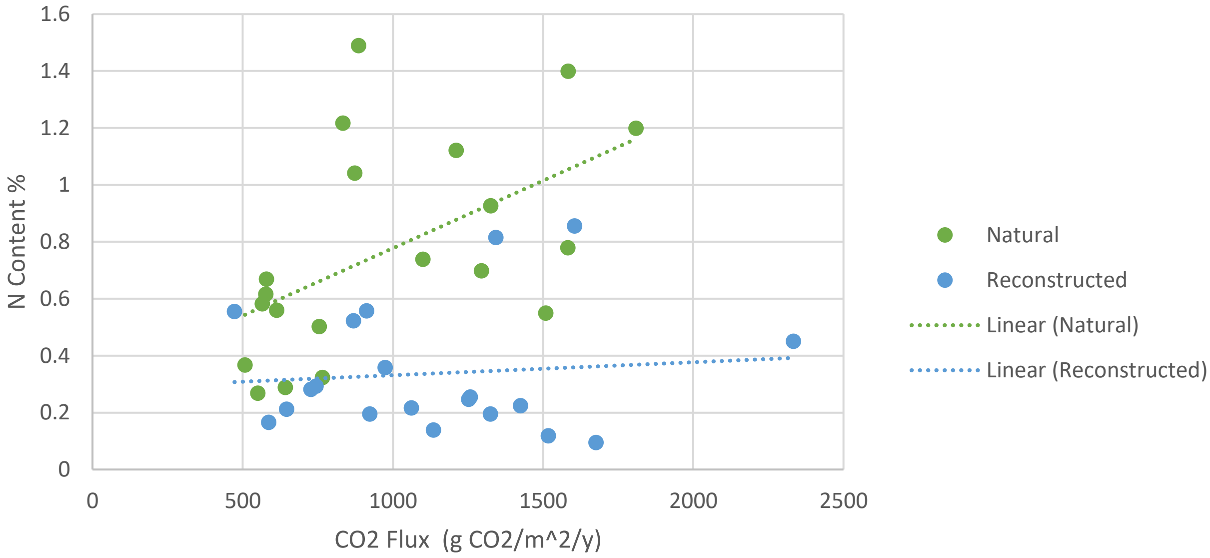

*Figure 13. Compares nitrogen contents % with CO2 fluxes for natural and reconstructed soils*

Figure 14 shows a correlation between higher C content and higher soil CO2 fluxes in both natural and reconstructed soils. The resulting trends are remarkably similar to Figure 13.

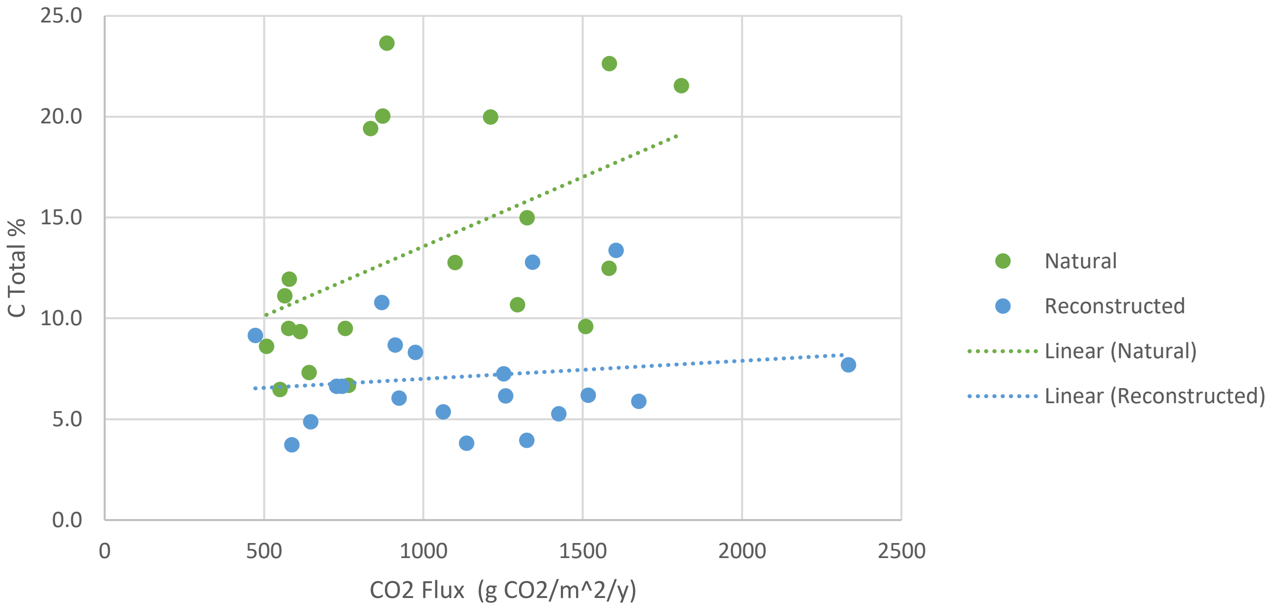

*Figure 14. Compares total Carbon content in the soil vs. soil CO2 fluxes*

In figure 15, there is a significant difference between the total carbon (C) content of natural and reconstructed soils. The natural soils expectedly seem to contain generally higher amounts of carbon.

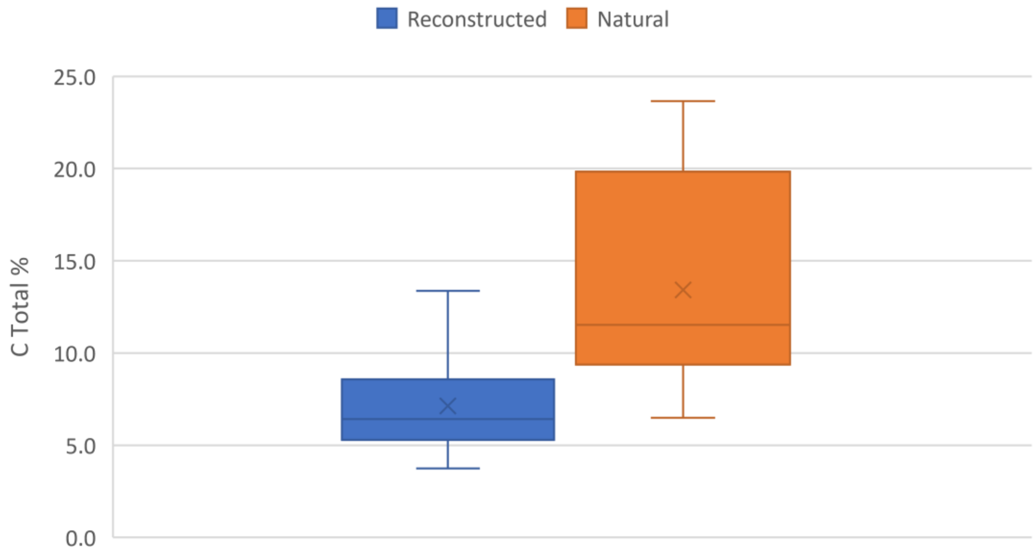

*Figure 15. Compares Carbon content % in natural vs. reconstructed soils*

Figure 16 shows the soil nitrogen (N) content in %. The reconstructed soils contain higher amounts of N compared to the natural soils.

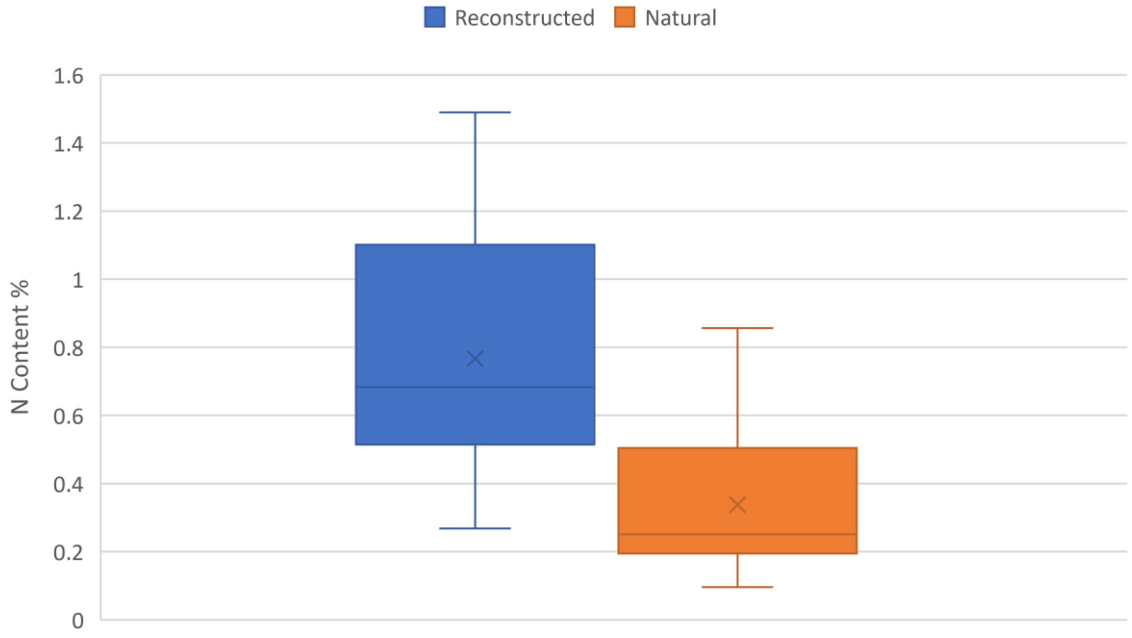

*Figure 16. N (nitrogen) content % in both natural and reconstructed soils*

Figure 17 shows the C/N ratio in the soil. This ration compares the organic carbon content against the nitrogen content in the soil. The C/N ratio is one of the main determining factors for the structure of soil microbial communities (Wan et al., 2014).

*Figure 17. C/N (organic carbon content %/nitrogen content %) of reconstructed vs. natural soils*

Figure 18 shows the amount of organic carbon content in the soils. The amount of soil organic carbon is the difference between the amount of total carbon and inorganic carbon in the soil. The amount of organic carbon appears to be much higher in the natural soils. This is due to the fact that the natural peat soils in this study also have a higher total C content in general (organic and inorganic) as shown in figure 12. Therefore, the higher amount of organic carbon in the natural peat soils is not surprising.

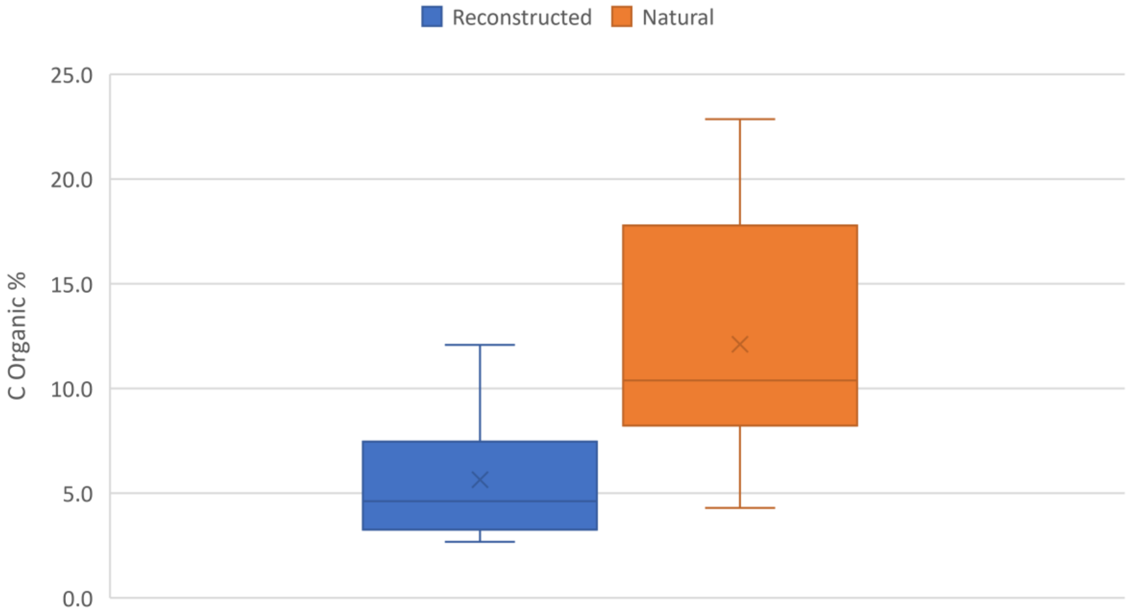

*Figure 18. Organic C content (%) in natural vs. reconstructed soils*

Furthermore, one can also observe the increase in CO2 flux in the warmer months in figures 19, 20 and 21. The average CO2 flux for the natural soils changed from 295 g CO2/m^2/y in March to 795 g CO2/m^2/y in May to 1318 g CO2/m^2/y in June. For the reconstructed soils the CO2 flux value changed from 304 CO2/m^2/y in March to 806 CO2/m^2/y in May to 1744 CO2/m^2/y in June. The increased soil CO2 flux during warmer seasons can be explained by the increased activity of microorganisms during periods of warmer soil temperatures, as already seen in figure 8.

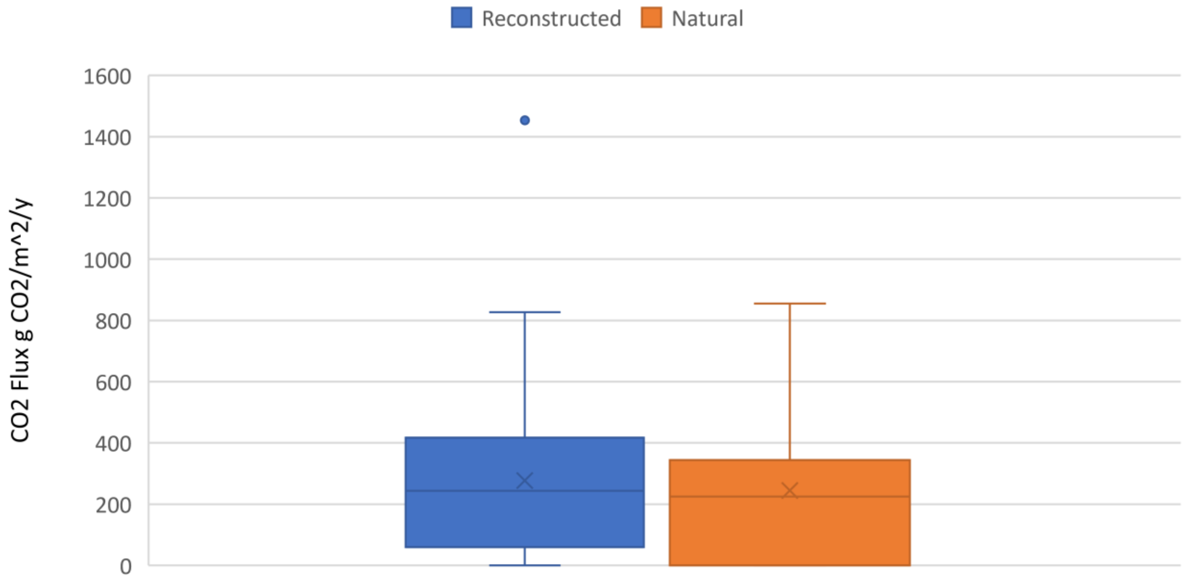

*Figure 19. CO2 fluxes in March*

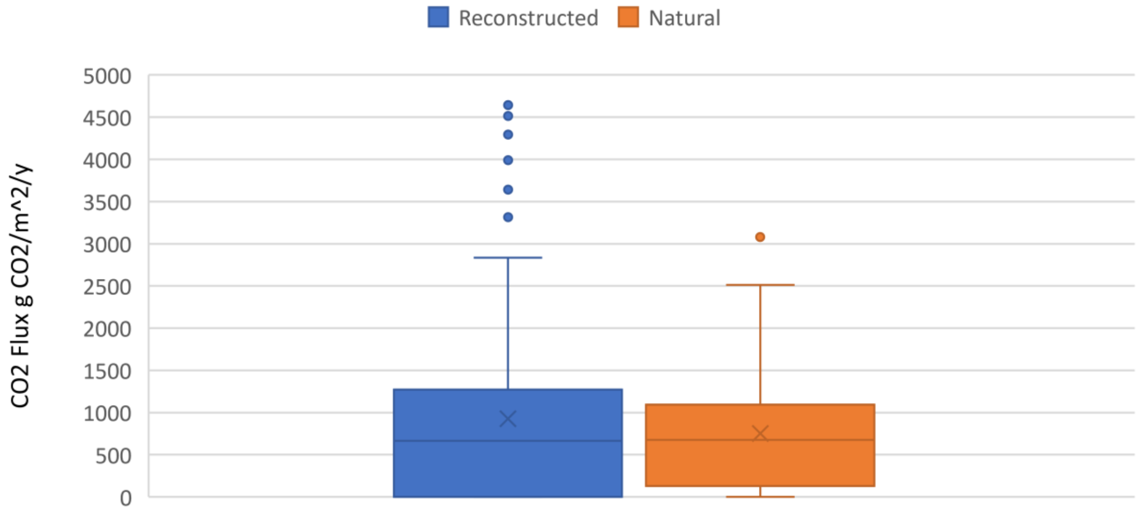

*Figure 20. CO2 fluxes in May*

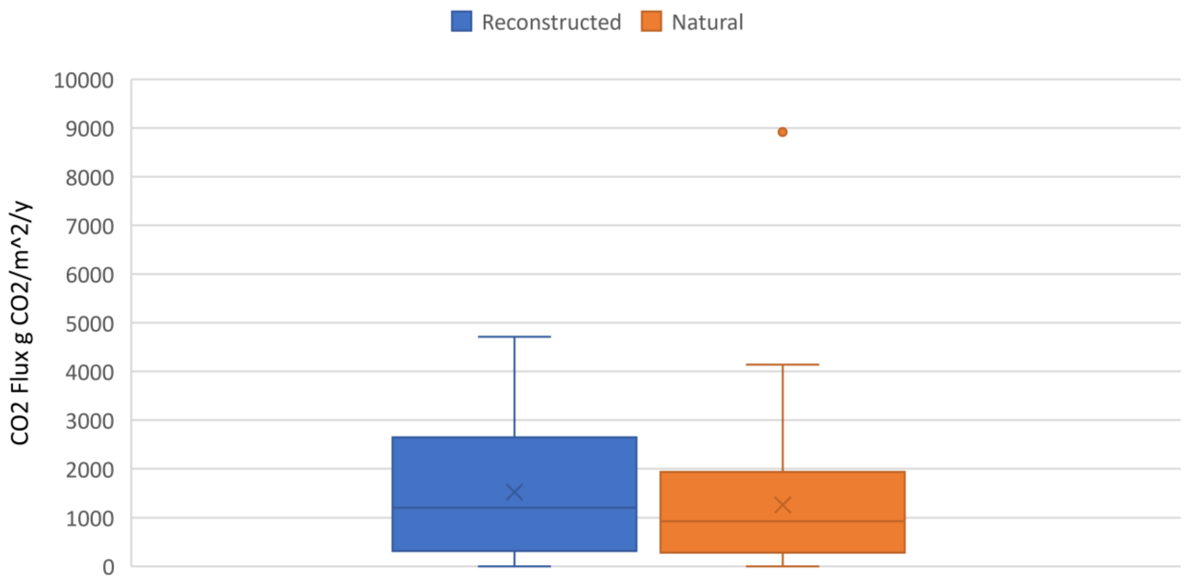

*Figure 21. CO2 fluxes in June*

The Table 2 below gives an overview over different soil parameters in each location.

| Location | CO2 flux natural | CO2 flux reconstructed | N content % natural | N content % reconstructed | C organic content % natural | C organic content % reconstructed |
|---|---|---|---|---|---|---|
| | | | | | | |
| Stälze | 656.984178 | 1473.25127 | 0.29561785 | 0.83587948 | 4.43912971 | 11.7883797 |
| Stich | 926.629589 | 1087.31618 | 0.62034115 | 0.22077743 | 9.96710879 | 4.57742602 |
| Wideteile | 1453.38783 | 1596.02644 | 0.85286523 | 0.10696133 | 13.1290755 | 2.84542694 |
| Rimmerzmatte | 594.643444 | 1279.66727 | 0.58829855 | 0.18139798 | 8.84833463 | 3.72644917 |
| Jean’s Möösli | 1340.55709 | 1115.77608 | 1.11993545 | 0.30649805 | 17.325762 | 5.1743929 |
| Lindergut | 1396.60247 | 965.102956 | 1.26043575 | 0.36933698 | 20.5569181 | 7.07072149 |
| Underi Site | 859.342678 | 955.477044 | 1.35348513 | 0.18041395 | 20.6918618 | 2.94282177 |
| Undermoos | 574.392456 | 735.571967 | 0.32793618 | 0.28728675 | 6.3275086 | 4.83670306 |
| Niederrietmoos | 1401.7727 | 1622.46258 | 0.62405323 | 0.50422223 | 9.45732505 | 7.19137089 |
| Vaulthier’s M. | 571.4107 | 559.2354 | 0.62558983 | 0.38380488 | 10.3461664 | 6.30341224 |

*Table 2. A list of all study locations with an overview of soil parameters. The highest values in each column are highlighted in yellow.*

**Significance:** For figure 7**,** the t-test with an alpha value of 0.05 shows a t-value of 1.59 that is lower than the critical t-value of 1.965 which means that the chance of the datasets (natural vs. reconstructed) being the same is more than 5%. This means there is likely not a significant difference between the CO2 flux of the natural and the reconstructed soils.

## Discussion

The number of data points that were measured give a reasonable significance to this field research. The different results in this study compared to the measurements by Egli et al. (2020) when comparing the CO2 fluxes of reconstructed vs. natural peat soils can likely be explained by the limited amount of data regarding CO2 fluxes in Egli et al.'s 2020 study.

It is important to take into account that the CO2 flux was measured in different soils that were in different kinds of agricultural usage states (barren, tilled, growing crops, sowed). Also, it has to be mentioned that even the measurements within each field trip were taken at different hours during the day and during varying weather conditions which means the soils were subjected to different external factors. There could also be spatial differences in weather conditions for the different soils over the course and in between the different field trips which might have impacted the soils moisture content or microbial life. Another factor may be the use of fertilizers or other forms of N deposition which could affect the CO2 fluxes of the soils. In general, the CO2 flux values seem to correspond with values measured by other researchers (Thomas et al., 1995) (Huissteden et al., 2006) (Gronlund et al., 2008).

Soil temperature (Figure 8) was the environmental factor that had the largest impact on CO2 fluxes in both types of soils (reconstructed and natural), while other factors like air temperature and soil moisture didn't have as much of an impact on the CO2 flux. As already mentioned in the results, the higher CO2 flux results for the reconstructed soils could also be explained by the addition of the soil that was added on top of the natural peat soil, which could have resulted in a higher CO2 flux (this higher CO2 flux would be evened out by the lack of topsoil in the location that the soil that was used for the soil reconstruction originated from). While soil thickness does not correlate with higher CO2 emissions (Yli-Halla et al., 2022) the addition of the landfill outgassing to the total outgassing of the reconstructed soil could still have an impact on the CO2 flux as different soil types tend to have different amounts of CO2 emissions. Another factor that might have an impact on the CO2 flux of the reconstructed soil is the type of soil which was used for reconstruction. The most used material seems to be moraine material which naturally contains a lot more skeletal soil content and generally less soil organic matter than peat soil.

The negative correlation of soil moisture content and CO2 fluxes is not surprising since breathing microorganisms (CO2 emitters) need air to breath and might be inactivated in waterlogged soils. An interesting result is the positive correlation of the dew point temperature with soil CO2 fluxes. This might be explained by the lack of data points due to the fact that other atmospheric factors barely had an impact on soil CO2 flux. The higher carbon content of the natural soils in comparison to the reconstructed soils could be explained through the materials that are used to restore the reconstructed soils. Moraine, sand and other mineral soils generally have less carbon content than peat soils (Agus et al., 2011).

The figure 12, where the soil C/N ratios are compared to CO2 fluxes seems to indicate that soils with a higher C/N ratio correlate with higher soil CO2 fluxes in reconstructed soils while soils with a lower C/N ratio correlate with higher CO2 fluxes in natural peat soils. This might be due to C being the limiting factor for microbial activity in reconstructed soils while N could more of a limiting factor for microbial activity in natural soils due to the abundance of C.

Higher soil N content as well as higher soil C content both correlate with higher CO2 fluxes in both reconstructed and natural peat soils. There is, however, a much stronger correlation of both higher N and C contents with higher CO2 effluxes in natural peat soils. A higher N content can indicate a higher amount of N fertilization (Morell et al., 2011) which might result in increased microbial activity (priming). The correlation between N and CO2 flux is stronger in natural peat soils which might indicate a stronger CO2 efflux response when natural peat soils are fertilized compared to reconstructed peat soils. The higher CO2 effluxes in soils with a higher carbon content can be explained by the higher availability of SOC in carbon rich soils which can then be metabolized into CO2.

It should also be mentioned that the research results are naturally a result of their location, which in this case is the study area in the Three Lakes Region. Other locations might have different climates, soil types, geology and agricultural practises which may lead to different results. Further research with different landfill materials in different locations could give an even better understanding of the relationships of (peat) soils that have been reconstructed with backfilling material. Another factor that could have an impact on the CO2 emissions of the reconstructed soils is how well the two soils were mixed together during agricultural use practises. Expectedly, older reconstructed soils should have a more homogenous mix due to the amount of tilling and bioturbation that they have been subjected to over time.

Furthermore, the varying amounts of backfilling material used for the soil reconstructions of each field could also have impacted the results.

A way to combat the rise in CO2 efflux from peat soils could be to “rewet” the soils. The rewetting of peat lands has shown to reduce CO2 efflux levels in previously dried up peat lands (Komulainen et al., 1999), which might be explained due to decreased microbial activity of breathing microorganisms after the rewetting. In the longer term, the restoration of the cultivated peatlands could also lead them, not only lowering their CO2 emissions, but to also become carbon sinks again. This process would be, of course, to the detriment of the agricultural usability of these peat lands.

The benefits of the region becoming a conservation zone and potential peatland restoration has to be weighed against the interests of the local farmers and questions about Swiss food security.

# Conclusion

The results seem to indicate that reconstructed soils do not have lower CO2 emissions. The t-test for figure 7 shows that there is no significant difference between CO2 fluxes of natural and reconstructed peat soils. The number of 180 data points of individual measurements for each of the two variables (natural and reconstructed) gives a statistically representative result to the study.

Despite these results, there seems to be a correlation between higher N ratios and higher CO2 effluxes in peat soils in figure 13 which could indicate a potential by soil reconstructions to mitigate the impacts of additional soil CO2 emissions caused by soil fertilization.

A factor that may have influenced the results could have been the different land uses for each field and the varying use states throughout the seasons when the field trips took place. Different vegetable crops were planted during different seasons which could have influenced the CO2 measurements. Another potential issue was the influence of sunshine on the measuring devices. The influence of this factor was reduced by the use of shading material but might still have had an impact on the results. Of course, errors in measurement or data collection in the field could have also happened due to human error but this was likely offset by the size of the data collection.

A suggestion for further research that could be conducted in this field of research would be to compare what impact the type of soil that is used for the soil reconstruction does have on the soil CO2 flux. There are not enough data points in this study to confirm a correlation between soil CO2 emissions and the type of soil material that was used for the reconstructions, even though it is noticeable that, for example, the soils that were reconstructed with Sand have appear to have lower emissions. Also, it might be of interest to measure the impact of soil reconstructions on the flux of other greenhouse gasses such as methane.

Suggestions for the use of the agricultural peatland in the Bernese Lakes Region are difficult to give out. The farming of vegetables can be an important factor for food security in Switzerland. From an ecological standpoint however, it is clear that agriculturally used peatlands have a negative impact on the climate (Joosten, 2009) (Komulainen et al., 1999).

As already mentioned in the text, natural peatlands are important carbon sinks (Loisel et al., 2020) that fulfil a crucial role in soil carbon sequestration. The restoration of the peatlands in the Bernese Three Lakes Region can therefore play an important role in helping Switzerland fulfil its own CO2 mitigation goals in the future.

The further degradation of these peatlands that is resulting from the current agricultural use also mitigates the ability of the peat soils to fulfil their ecosystem services (carbon storage, water filtration, bio-habitat etc.) (Ferré et al., 2019). Therefore, a conservation zone with a rewetting of the peatlands might be worth to be taken into consideration (Komulainen et al., 1999).

# References

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## Personal declaration:

**I hereby declare that the material contained in this thesis is my own original work. Any quotation or paraphrase in this thesis from the published or unpublished work of another individual or institution has been duly acknowledged. I have not submitted this thesis, or any part of it, previously to any institution for assessment purposes.**

**Lukas Wallimann, 1.2.2023**

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