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Comparison of soil CO_2 efflux between different surface covers on a clear-cut and forest stand in southern Sweden, Hyltemossa

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Abstract

Large amounts of carbon in the terrestrial biosphere are stored in forest ecosystems and its soil. Once the forest ecosystem is disturbed the release of this carbon can drive positive feedback to global warming. Humans impact the forest ecosystem through clear-cutting for wood production and other commercial purposes. Clear-cutting is still a standard forestry management method, but its effect on the global carbon cycle and climate change is not yet fully understood. Soil respiration releases carbon from the soil in the form of carbon dioxide (CO_2), and net ecosystem exchange (NEE) regulates the ecosystem carbon sink, therefore, making it an important component to global carbon balance. This thesis aims to analyze the impact of man-made disturbances, in the form of clear-cutting, on the carbon balance by comparing soil respiration between a forest stand and a clear-cut area on three types of forest surface covers (vegetation, bare soil, and mineral layer). Furthermore, the influence of soil temperature and soil moisture on soil respiration, as well as the influence of photosynthetically active radiation (PAR) on NEE has been analyzed for those forest surface covers.

The results show no distinct difference in soil respiration between the clear-cut and the forest stand, but small differences between the surface covers of the clear-cut and the forest stand. The bare soil and mineral layers have higher (0.15 $\mu mol\ m^{-2}\ s^{-1}$) soil respiration in the form of CO_2 than the vegetation cover. Soil respiration is higher (about 0.2 $\mu mol\ m^{-2}\ s^{-1}$) on the forest stand for all surface covers compared to the clear-cut. This is because of a difference in vegetation specimen leading to reduced microbial activities and root respiration on the clear-cut. The NEE is positive on the forest stand and the clear-cut with a higher net release on the forest stand, while the PAR is lower on the forest stand than on the clear-cut. This is explained by the difference in vegetation type of the forest stand thus affecting its gross primary production (GPP) and ecosystem respiration (R_{eco}) along with factors such as canopy cover that could hinder radiation in the forest. The field measurement in the study was not taken over a longer period, which is why the correlation between the soil temperature, soil moisture, and PAR with soil respiration and NEE cannot be seen. In conclusion, the data on soil respiration and NEE was not enough to see distinct differences between the clear-cut and the forest stand, however there are differences between the surface covers. The full scale of human impact on the carbon cycle through soil disturbances cannot be analyzed with this dataset.

Keywords

Soil CO_2 efflux; Soil respiration; Soil moisture; Soil temperature; Clear-cut; Forest stand; Net ecosystem exchange; Photosynthetically active radiation; Carbon.

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1. Introduction

Rising levels of CO_2 in the atmosphere and its possible effect on global climate change have prompted extensive research on the global carbon cycle (Chen et al. 2014). The global carbon cycle refers to the exchange of carbon between and within the carbon reservoirs: (i) the atmosphere, (ii) the oceans, (iii) terrestrial land (soil, vegetation), and (iv) the lithosphere (Ussiri and Lal 2017). Rising levels of CO_2 implies that more carbon is being released into the atmosphere from other sources such as emissions from fossil fuel burning, forest fires, and land-use changes than it can be absorbed by the reservoirs, and this results in the global carbon cycle playing an important role in the likelihood and timing of global warming (Sedjo 1993). Terrestrial ecosystems are one of Earth's most active carbon reservoirs. The two most important processes that affect the terrestrial ecosystem carbon balance are photosynthesis from aboveground vegetation, and soil respiration (Pumpanen et al. 2004). Forests contribute to the terrestrial carbon sequestration as it procures carbon in its soil and woody biomass (Ma et al. 2013).

Clear-cutting is an easy method of tree removal whereby all trees are removed at once from the forest (Lacroix et al. 2016). A study conducted by Dartmouth University, investigating if clear-cutting can alter the chemical bonds of carbon stored in the soils (as carbon stores itself in the soil by binding to certain soil structures), showed that clear-cutting can mobilize carbon, making it more susceptible to leave the soil and be released into the atmosphere (Lacroix et al. 2016). Experiments have been made to quantify the effect of forest disturbances on the climate (Mamkin et al. 2016; Seidl et al. 2017). In particular, Mamkin et al. (2016) showed that a clear-cut can have a significant effect on forest ecosystems microclimate such as an increase in gross primary productivity (GPP) due to regrown vegetation. It is important to understand how the distribution of carbon in soils changes when we alter forest management practices, as this can enhance our understanding of how different forest management practices and forest management stages can affect the global carbon cycle.

Soils globally contain about 3200 Pg of carbon and are the largest carbon pool in the terrestrial ecosystem (Chen et al. 2014). Soil respiration is defined as the CO_2 flux emitted from the soil surface by organisms (microorganisms and macroorganism) and plant parts (roots and rhizomes) in the soil (Luo and Zhou 2006; Smith et al. 2019). It is the second-largest carbon flux in the global carbon cycle, and an essential process that regulates the carbon cycle on Earth and a change in soil respiration rates will have an impact on the atmospheric CO_2 concentrations (Chen et al. 2014). Disturbances to forest ecosystems such as clear-cutting can cause large net emissions of CO_2 indirectly and directly from either change to the forest biochemical process or loss of soil organic matter (Ma et al. 2013).

Sweden has been practicing monoculture forestry since the 1950s. This implies a cyclic harvest and regeneration pattern by which an even-aged forest stand is clear-cut but followed by replantation to obtain a sustainable flow of wood from the forest (Skogstyrelsen 2015). This means that many forests are clear-cut while awaiting the monoculture tree plantations (Gray 2018). When the forest is turned into a clear-cut it becomes an immediate direct emitter of CO_2. Even if only part of the forest were harvested it would still make the forest a net emitter for about 20 years before becoming a net uptake (Höglund et al. 2013).

Understanding and accurately measuring soil respiration is necessary to fully apprehend the global carbon cycle and the role that the terrestrial ecosystem plays either as a sink or source (Jassal et al. 2012).

The full scale of effects of clear-cutting on soil respiration is not yet fully understood. However, understanding the drivers of the terrestrial ecosystem sink is a crucial step in understanding just how much of the terrestrial ecosystem can aid in mitigating increased atmospheric CO_2. By measuring soil respiration in different types of surface covers in order to perceive the short term response to different environmental factors (i.e. soil moisture, soil temperature) and comparing to two types of forest management stages (a forest stand and a clear-cut) this study is a contribution to the body of research trying to understand some of the processes involved in the carbon cycle.

In this study, a non-steady-state static chamber has been used to collect CO_2 flux measurements from the study site under considerations of the aim and objectives below.

2. Aim and Research Questions

The aim of this thesis is to investigate the difference in soil CO_2 flux between two different forest management stages, a forest stand and a clear-cut. This is to be achieved by comparing soil respiration on three types of surface cover (bare soil, mineral and vegetation cover) between a clear-cut forest and a forest stand classified under two moisture segments (forest dry, forest wet, clear-cut dry and clear-cut wet).

In addition, a comparison of photosynthetically active radiation (PAR), soil temperature, and soil moisture that drives net ecosystem exchange (NEE) on the vegetation cover between a clear-cut and forest stand has been made.

Research questions:

1. How will soil temperature and soil moisture affect soil respiration in the two different management stages, amongst the three surface covers at the different moisture segments?

2. How does PAR, soil temperature, and soil moisture influence NEE on the different forest management stages and moisture segments?

Objectives:

1. Measure soil respiration on the three different types of surface covers in the two different forest management stages and potential influence by soil temperature and soil moisture

2. Analyze how soil temperature, moisture, and PAR effect NEE at the different management stages and at their different moisture segments.

Hypothesis:
The clear-cut will have less soil respiration than the forest stand and the wet plots will have higher soil respiration for all three surface covers. It will be a higher net release on the forest than the clear-cut.

3. Background

3.1 Soil Respiration and Terrestrial Ecosystem

Soils have one of the largest fluxes of CO_2 in the global carbon cycle, and therefore small changes in soil respiration can have a large effect on the amount of CO_2 in the atmosphere (Schlesinger and Andrews 2000). The terrestrial biosphere is well established to be a net sink of CO_2, with about 40% of its carbon sources coming from human-made activities like fossil fuel burning and industrial developments over the past years (Tian et al. 2016). The size estimate of the terrestrial carbon sink due to regrowth of forests varies considerably. Some estimates suggest that regrowth of forests took up about 2.6 Pg C y-1 over 2000-2009, by contrast, global vegetation models estimated regrown forests to be a sink of 0.35–0.6 Pg C y−1 in the 1990s and 0.23–0.43 Pg C y−1 in the 2000s (Pugh et al. 2019).

Forests are believed to slow down anthropogenic climate change as they absorb carbon from the atmosphere. The drivers of this sink still remain uncertain, thus any perturbations to the terrestrial ecosystem (including forest harvesting in the form of clear-cutting, forest management practices, or natural disturbances) can cause unpredictable changes, such as enhancing the carbon uptake from the terrestrial ecosystem. These uncertainties limit our ability to predict its continued future capacity in slowing down the rate of carbon dioxide accumulation (Pugh et al. 2019). Clear-cutting is an important forest management practice in many parts of the world, but it disturbs the soil, such as causing a reduction in root concentration, and a change to the soil temperature and soil moisture. Root respiration contributes to half of the soil respiration. The consequences of changed soil temperature and soil moisture can accelerate soil detrital, such as root, litter and woody biomass turnover rates, and change microbial respiration (Ma et al. 2013). Changes to CO_2 fluxes during the years following the clear-cut have been shown to occur, and this includes an increase in GPP due to regrown vegetation, and a reduction in daytime CO_2 fluxes but little change to nocturnal CO_2 fluxes (Mamkin et al. 2016).

This study looks at soil respiration vertically on a surface cover and two soil horizons: vegetation cover, bare soil, and mineral layer comparing a clear-cut area and forest stand. In this thesis the three layers have been termed three surface covers. The forest in the study is managed and owned by Gustafsborg Säteri AB (2020), using a common management method that is plantation forestry. This means trees are replanted after a clear-cut to meet the demand for forest biomass in Sweden, repeatedly (Strengbom et al. 2011). The forest is thus constantly undergoing different management stages, the first stage being the seedling of the managed forest stand, then a thinning (the selective removal of certain trees to improve growth rate (ICOS 2018)) which for the Gustafsborg forest happened in 2009 and 2013, and then finally a cutting.

Vegetation cover refers to the top of the soil covered by vegetation. A study conducted by Rodeghiero and Cescatti (2005) showed a positive correlation of soil respiration with root biomass and aboveground productivity, implying that vegetation cover has an effect on soil respiration, as there was an increase to respiration rates (Rodeghiero and Cescatti 2005; Grand et al. 2016). The bare soil layer refers to the layer that has the vegetation removed. This is on top of the underlying mineral layer. The mineral layer refers to the layer that is dominated by organic matter (FAO 1998). In this thesis the mineral layer consists of undecomposed or partially decomposed litters such as needles, twigs, or moss. In the mineral layer, the soil respiration is the CO_2 released by microbes in the mineral soil layers during decomposition of the soil organic matter (Jiang et al. 2016). The different layers have unique components that can change the soil respiration and gross primary production such as the microbes in the mineral layer, increased decomposition on the bare soil layer and photosynthesis on the vegetation cover which can cause a net uptake or net release of NEE.

3.2 Soil Temperature and Soil Moisture

There is a consensus that soil respiration is controlled by soil temperature and regulated by soil moisture, but also ecosystem productivity (Smith et al. 2019), although more research is still needed to improve the knowledge on the interactive effect of soil temperature and moisture on soil respiration (Meyer et al. 2018). However, many studies have indicated a positive correlation of soil respiration to temperature and moisture using regression analysis showing an interaction between soil temperature, soil moisture and soil respiration (Meyer et al. 2018; Carey et al. 2016; Peng et al. 2014; Bao et al. 2016). Models as the Q_{10} relationship have been used to obtain a positive correlation of soil respiration and temperature. The Q_{10} relationship developed by Van't Hoff is a unitless quantity that explains the temperature sensitivity of soil respiration (expressed as a Q_{10} value) meaning soil respiration will increase for every 10°C increase in temperature (Van't Hoff 1898), and a power relationship proposed by Arrhenius (Lloyd and Taylor 1994). Therefore, it is known that soil temperature and moisture are the main drivers of temporal variation in soil respiration, however, large uncertainties still exist in soil respiration as it is regulated by multiple abiotic and biotic factors, such as nutrient availability and plant productivity, and its different components such as heterotrophic and autotrophic respiration are influenced differently by these factors (Ma et al. 2019).

The variation in soil temperature and moisture can account for the temporal variation in soil CO_2 efflux. When the temperature increases, this stimulates soil respiration by accelerating carbon cycling in the soil leading to respiration. Soil moisture drives net primary productivity and therefore has an impact on soil respiration (Ma et al. 2019).There is much research showing that respiration decreases with increasing temperature and decreasing soil moisture (Flanagan and Johnson 2005; Carey et al. 2016; Janssens and Pilegaard 2003; Kirschbaum 1995; Reichstein et al. 2002, Makita et al. 2018). However, these previous studies have not focused on soil temperature and moisture analyses comparing different surface covers during the day. The limited studies hinder our ability to fully estimate below ground soil respiration and its effect on the carbon fluxes for the future climate.

3.3 Net ecosystem exchange and photosynthetically active radiation

NEE of the terrestrial ecosystem is a measurement that describes the exchange of CO_2 between the terrestrial ecosystem and the atmosphere to approximate the ecosystem productivity. It is defined as the balance between the release of CO_2 (R_{eco}), and the uptake of CO_2 by autotrophs (GPP). NEE is influenced by variations both in GPP and R_{eco} and their response to environmental variables and climate (Singh et al. 2019). A net ecosystem exchange below zero (-NEE) implies an ecosystem accumulates CO_2 from the atmosphere, meaning it is a sink, meanwhile (+NEE) above zero means it emits CO_2 to the atmosphere, a source (Emmerton et al. 2016). GPP is the uptake of carbon by plants through photosynthesis (which is a process that uses sunlight to turn CO_2 into sugar for energy), therefore, it is the amount of energy that is fixed by plants and then used for growing (Lundkvist 2006). GPP is influenced by environmental variables such as e.g radiation, rainfall, temperature, vapor pressure deficit and other biophysical variables (i.e. leaf surface area), meanwhile, R_{eco} is the ecosystem respiration and is regulated by environmental variables like temperature and soil moisture, (Singh et al. 2019).

PAR is the amount of light from 400 - 700 nm wavelengths that are used by plants for photosynthesis, this can change seasonally and during the day. It is measured by the rate in which moles (6.02×10^{23} quanta) of PAR land on a unit surface area (μmol photons m^{-2} s^{-1}) (Carruthers et al. 2001). PAR is an important source of energy for plants, however, if there is a too high PAR this can damage the photosynthetic functioning apparatus of the plant. If PAR is too low, the carbon uptake and growth of the plant can be disrupted, (Kalaji et al. 2014). It is a known fact that PAR is a significant environmental factor for variations in NEE, as PAR levels increase, the carbon uptake from the terrestrial ecosystem increases (Chayawat et al. 2019).

3.4 Chamber Techniques

Soil CO_2 efflux can be measured using various chamber techniques. The two main chamber techniques that are used in the measurement of CO_2 fluxes are (i) non-steady state closed static chamber, and (ii) steady-state open dynamic chamber. In non-steady state chambers, the CO_2 efflux is determined from the amount of concentration increase in the isolated chamber under a known chamber volume and surface for a known period. In the steady-state chambers, the CO_2 efflux is measured from the difference between CO_2 concentration at the inlet and outlet of the chamber (Pumpanen et al. 2004).

These sources (Matthias et al.1978; Hutchinson and Mosier 1981; Anthony et al.1995; Healy et al.1996) have demonstrated that the concentration in the chamber headspace does not increase linearly with time because of the declining CO_2 concentration difference between the soil and the chamber headspace. However, a sample is taken over such a short period of time that this problem can be inexistent in the data or negligible. Therefore, a linear model is used to compare the concentration of CO2 versus time taken for 90 seconds from the IRGA (infrared gas analyzer) (Jassal et al. 2012).

The soil CO_2 flux is measured from the rate of change of CO_2 inside the chambers when placed on the soil surface. There are certain advantages of using a chamber such as low cost, ease of use and possibility of spatial repetitions and disadvantages ranging from the need for a high number of CO_2 flux measurement for a representative surface area, uncertainties on the number of disturbances caused by chambers on the soil and time-consuming measurements (Dugas 1993). The challenging part of the chamber measurements are concentrated on reducing the disturbances to the environment, as well as ensuring good mixing of the air inside the chamber. The items needed to make the measurement are a chamber, a pump, a CO_2 gas analyzer, and a data-logging device (Madsen et al. 2010).

4. Materials and Methods

4.1 Study area

The study was conducted at Hyltemossa research station, which is located in northwestern Scania within the Klippan Municipality (56°06‟N, 13°25‟E (115 m asl)). The forest of Hyltemossa is a managed forest that is dominated by Norway spruce (*Picea abies*) with a small fraction of Downy birch (*Betula pubescens*) and Scots pine (*Pinus sylvestris*). SMHI characterizes the climate to Cfb according to the Köppen classification therefore, it is humid temperate with mild summers and mild winters (ICOS 2018).

The site was chosen due to the location of the research station and the proximity of the differently managed forest stages to each other figure 4.1.

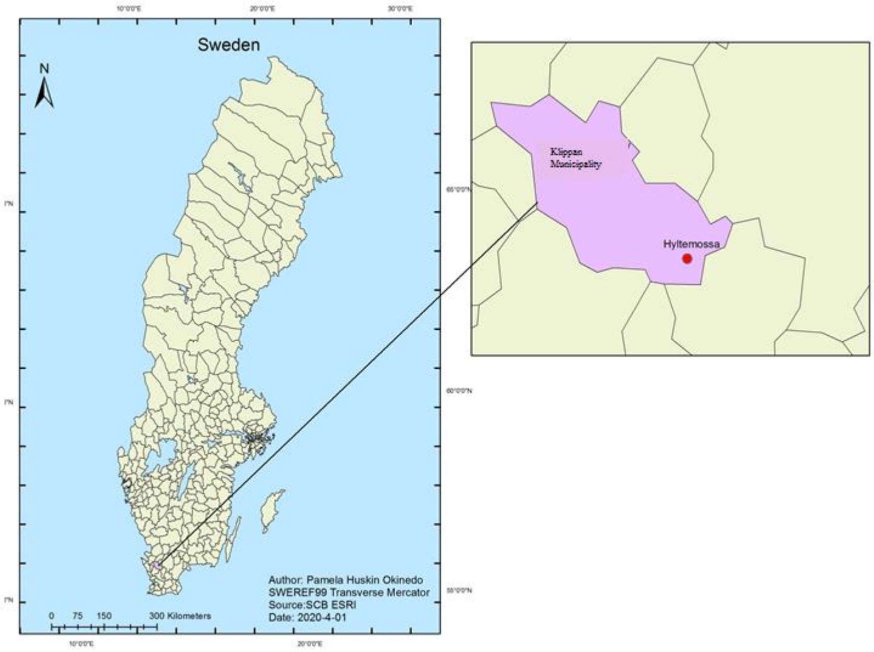

Fig 4.1: Hyltemossa within Klippan municipality, Sweden (SCB 2020).

4.1.2 Physical geography of Hyltemossa study area

The forest tree height ranges between 13 - 19 m tall and holds around 190 m^3 per hectare (excluding branches, stumps, needle biomass and roots). It is about 37 years old. The understory of the vegetation layer is sparse and is covered by a thick moss layer. In 1981 the site experienced storm damage and therefore was clear-cut in 1982 with replantation of 3300 trees per hectare in 1983 (ICOS 2018; van Meeningen et al. 2017).

The forest floor is covered by *Hylocomium splendens* or commonly known as glittering wood moss. It is a perennial clonal moss that has a widespread distribution in the northern hemisphere boreal forest and is commonly found in Europe (Kang et al. 2007). The shoots of the moss can be more than 15cm long. A single shoot will grow one season after which the next year shoot will grow beneath the previous year's shoot. They grow upwards and horizontally giving rise to the floor structure. These mosses are common all over Sweden except in larger agricultural areas (Hallingbäck et al. 2016). The soil at the site is classified as cambisol with a shallow organic horizon and a transition towards podsol is found at certain parts (ICOS 2018). Cambisols are the soil that has an absence of clay, humus, soluble salts, or iron layer. They have a high content of weatherable minerals and are the second most extensive soil group on earth occupying 12 percent of the total continental area (FAO; Britannica 2011).

Figure 4.2: The study area Hyltemossa, the forest stand is on the left and clear-cut on the right.

4.2 Quantification of soil CO_2 exchange

The measurements were conducted using a chamber (CPY-5) along with the gas analyzer (EGM-5) (Figure 4.3). The chamber measures soil CO_2 efflux from the change of CO_2 concentration over time (dc/dt) in the chamber headspace from the starting time at (time = 0) using any empirical model (Jassal et al. 2012).

The CO_2 gas analyzer, (EGM-5) used is manufactured by PP systems (Massachusetts, USA) and is attached to the chamber (Fig 4.3), the gas analyzer is self-contained and includes a pump that produces the sample gas (CO_2) to the IRGA. IRGA functions by transmitting light from the mid-infrared wavelengths through a filter. The filter uses a detector to narrow the bandwidth of the IR source to the target gas molecule (CO_2). CO_2 absorbs IR energy at a particular wavelength, and the reduction in the IR energy is measured from the detector by the Lambert-Beer Law of Attenuation and is then translating this information into gas concentrations (PP systems 2018).

The EGM-5 gas analyzer (Fig 4.3) is attached to the CPY-5 canopy assimilation chamber. It is transparent and made of polycarbonate with an aluminum ring that gives the soil surface a good seal. It has a surface area of $167cm^2$ (145 mm (Height) x 146 mm (Diameter)), and a cable tube of 1.5 meters that connects the GAS IN and GAS OUT (Fig 4.3). When using it to measure NEE, the instrument is exposed to sunlight without obstruction and for soil respiration measurements, it is covered with a dark, opaque bucket. The EGM-5 contains a function that gives the measurement a quadratic relationship $C = a + bt + ct^2$ for CO_2 concentration (C) over time (t) to correct non-linearities caused by chamber leakage.

Figure 4.3: EGM-5 portable gas analyzer with transparent CPY-5 chamber used for closed measurement. The chamber was measuring PAR as well.

4.2.1 Experimental Setup

The experiments started with selecting 4 plots which were about 5 x 5 meters in size. Two of the plots were situated in the managed forest stand and the other two on the clear-cut managed forest, which has been harvested in 2018. The plots were divided into two moisture regimes to find a moisture difference therefore, a low-lying plot was determined to have less moisture on the ground surface. A higher moisture forest plot is termed forest wet (FW), a lower moisture forest plot termed forest dry (FD), a higher moisture clear-cut plot, clear-cut wet (CCW), and a lower moisture clear-cut plot, clear cut dry (CCD).

Each plot contained 9 metal rings which were randomly positioned in the plots. The rings were made of aluminum ventilation pipes (Ahlsell Stockholm, Sweden) with an 80 mm (height) x 160 mm (diameter) and were pushed into the ground in each plot (Fig 1 in appendix 1). The rings were inserted into the soil between 2cm - 5cm deep in 2019 and 2020 (Table 4.1).

The metal rings were subdivided into 3 surface covers (vegetation cover, bare soil layer, and mineral layer) to provide a more representative soil respiration measurement (Fig 1a and 1b in Appendix). Each surface cover has three replicates (Vegetation 1, V2, V3, etc) in each plot, creating 3 rings for each surface cover per plot (Fig 1 in A1) thus in total 9 measurement rings. The precise location and arrangement of the surface cover rings were chosen randomly (Fig 1a in A1). In the vegetation rings, species on the forest stand differs from the clear-cut seen in (Fig 2a in A1). The vegetation species for the forest is approximately 85% wood moss with 15% wildflowers that were not identified, and the clear-cut has about 25 % degraded moss along with

45 % grass. For the bare soil layer, about 3 cm of vegetation cover was removed on the forest plots in (Fig 1b in A1) while the clear-cut layer had already weak vegetation cover therefore less than 3 cm were removed for the bare soil layer (Fig 2b in A1). The mineral layer had about 5 cm removed from the vegetation layer on the forest plots in (Fig 1c in A1) and the same for the clear-cut in (Fig 2c in A1). During the experiment, there was no notable regrowth of vegetation but there was movement of litter and twigs on the inserted measurement rings.

Using a chamber, measurements was taken between 7:30 am to 18:30 pm each sampling day which were between 25th of March to the 2nd of April 2020. All inserted rings had a settling period of at least 24 hours before any measurements commenced.

4.3 Soil Respiration and NEE efflux

Soil respiration was measured in total at 36 positions during the measurement campaign of 4 days, during week 13 and 14 (in March and April) 2020. To take NEE measurement, the chamber was placed tightly on each aluminum ring for every soil respiration measurement without any shadow on the chamber. Each aluminum ring was measured 3 x per day for 90 seconds with a 30 seconds chamber flushing time before each measurement. The soil respiration measurement was taken in a similar way except with a dark bucket covering the chamber to prevent sunlight getting in. The PAR sensors are included in the CPY-5 chamber and logs the data into the EGM-5 gas analyzer during NEE measurement.

Table 4.1. Average volume of each ring collar and the total chamber volume used to calculate the soil respiration. The surface covers are written in abbreviations (V = vegetation, BS = bare soil, M = mineral layer)

Surface covers	**Ring height (cm)**	**Volume (cm^3)**	**Volume (cm^3)**	**Total volume (cm^3) (Ring volume + chamber)**
V1	2	401.92	401.92	3317.3
V2	4	803.84	803.84	3719.2
V3	4	803.84	803.84	3719.2
BS1	5	1004.8	1004.8	3920.2
BS2	5.5	1105.28	1105.3	4020.7
BS3	3	602.88	602.88	3518.3
OM1	3	602.88	602.88	3518.3
OM2	6	1205.76	1205.8	4121.2
OM3	5	1004.8	1004.8	3920.2

4.4 Temperature and Moisture

While measuring soil respiration rates, the soil temperature was measured with a thermistor probe at three soil depths (2, 5 and 10 cm) about 5 cm away from each measurement rings where the soil respiration measurements were taken. The average temperature of the three different depths were taken as the soil temperature. Soil moisture was measured at the same distance as soil temperature using a soil moisture sensor (ML3 Theta Probe, Delta T device, Cambridge, UK) which measures the average over the full length of the instrument pins (5cm).

4.5 Data Analysis

The soil CO_2 fluxes were calculated using the information from the EGM-5 gas analyzer, the CO_2 concentration were given in (ppm), chamber pressure (mb), and the air temperature (T °C) of the chamber along with the volume and area of the chamber and the ring space used calculated in table 4.1.

The CO_2 flux is calculated through equation 1:

$$F_{co2}(\mu molm^{-2}s^{-1}) = \frac{dC}{dt}\frac{[\mu mol]}{[mol\ s^{-1}]} \times \frac{P\,[mbar]}{1013\,[mbar]} \times \frac{273\,[K]}{(273\,[K]+T_0[°C])} \times \frac{1\,[mol]}{22.414\,[L]} \times \frac{V\,[m^3]}{A\,[m^2]} \times \frac{10^3\,[L]}{[m^3]}$$

(PP systems 2018)

1. $\frac{dC}{dt}$ is the rate of CO_2 change per time
2. $\frac{P}{1013}$ is the correction for barometric pressure with P measured in mbar by the EGM-5
3. $\frac{273}{(273+T_0)}$ is the correction for air temperature with Tair input in °C
4. $\frac{1\,[mol]}{22.414\,[L]}$ is the volume of one mole at standard temperature and pressure
5. $\frac{V\,[m^3]}{A\,[m^2]}$ is the chamber volume and soil surface area,

And the remaining terms are unit conversions.

4.6 Statistical Analysis

A Pearson correlation was calculated to describe the relationship between the dependent variable soil CO_2 efflux (SCE) and the various independent variables; PAR, soil temperature and soil moisture amongst the two different forest management stages (clear cut, forest stand), at four different locations based on the moisture segments (Clear-cut dry, clear-cut wet, forest dry, forest wet) on the three surface covers (vegetation cover, bare soil, mineral soil layer).

The Pearson correlation is a measure of the linear relationship between two variables (a dependent and an independent) using the coefficient (r). The stronger the relationship between the two variables, the closer the Pearson correlation coefficient, (r), will be to either -1 or +1.

The Pearson correlation does not consider which variable is dependent and can be sensitive to outliers, therefore, it is still useful to have a graphical overlook of the data (Laerd 2018). In this study the r^2 value which is the coefficient of determination was used, the r^2 is just a squared coefficient of r and describes how much variation in the dependent variable can be explained by the independent variable. For instance, if the r^2 equals 0.5 this means that only half of the variation in the dependent variable can be explained from the regression model.

For the tests performed in this study a p-value $<= 0.05$ was used for significance along with Scatter plots created in Microsoft Excel. The scatter plots were presented as means to increase readability. This was used to answer research question 1 and question 2, while the above-mentioned Pearson correlation was used to compare the correlation differences of NEE and PAR on vegetation cover of the four plots.

The Soil Carbon efflux (SCE) means and standard deviations was compared amongst the three different surface covers for similarities and differences. The significance of the SCE differences amongst the surface covers was tested out using the analysis of variances (ANOVA). The one-way ANOVA test was used to compare SCE means from the four different plots to each surface cover. Therefore, it is answering the question if there are differences in SCE for each surface cover amongst the four plots.

ANOVA tests if the differences between the means are statically significant by comparing the p-value to the significance level (alpha = 0.05, the significance level denotes a 5% risk to accepting a difference exist when there is no difference), to assess the null hypothesis, which states that all means are equal and there are no differences. Therefore if the P-value is ($<=0.05$) It means that the difference between some of the means is statistically significant while a P-value >0.05 means the difference between the means are not statically significant (Minitab 2019).

A post hoc test is conducted after the ANOVA test, if the result indicates a statistically significant difference in the group means. The post hoc test works in the same manner as the ANOVA test, using the (alpha = 0.05) to control the error rate. For this study, a Bonferroni post hoc test was chosen. The Bonferroni post hoc test reduces the alpha level with the number of samples to limit the possibility of getting a statistically non-significant result. By correcting the increased error rate in the hypothesis testing of multiple groups, when carrying out the testing between the groups or plots to find which one is statically significantly different (Kenton 2019). This was used to answer research question 1.

5. Results

5.1 Soil temperature and soil moisture impact on soil respiration

The relationship between soil respiration and soil temperature and soil moisture for the two forest management stages (clear-cut and forest stand) in the two different moisture segment (clear-cut dry, forest dry and clear-cut wet, forest wet), and the three different surface covers (vegetation, bare soil, and mineral) is presented in the tables and figures below. The soil temperature was about 1°C higher on the forest stand compared to the clear-cut, while the soil moisture was about 10% higher on the clear-cut plots and lower on the forest plots between the surface covers in Table 5.1 and 5.2.

In table 5.1 there are distinctions in soil temperature between the clear-cut and forest stand with the forest stand being slightly higher about 1-2°C than the clear-cut, but negligible differences amongst the different surface covers. The soil temperature increases slightly about less than 1°C with depth. This is seen on the mineral layer.

Table 5.1. Averaged soil temperature (T °C) value and the SD (standard deviations)

Plots	**Vegetation cover (mean T °C +- SD)**	**Bare soil layer (mean T °C +- SD)**	**Mineral (mean T °C +- SD)**
CCD	2.9 +- 1.3 °C	2.9+-1.2 °C	3.7+-1.9 °C
CCW	2.4+-0.8 °C	2.9+-1.0 °C	2.9+-1.3 °C
FD	3.5+-0.8 °C	3.5+-0.5 °C	3.8+-0.5 °C
FW	4.5+-0.6 °C	4.9+-0.4 °C	4.8+-0.5 °C

The mean soil moisture is highest on the clear-cut wet plot compared to all other plots, although both clear-cut plots have about 10 – 20% higher volumetric water content amongst the three different surface covers than on the forest plots. The water content increases with depth on all plots except for the FD and CCD plots.

Table 5.2. Averaged soil moisture (sm %) value and the SD (standard deviations)

Plots	**Vegetation cover (mean sm %+-SD)**	**Bare soil layer (mean sm %+-SD)**	**Mineral layer (mean sm %+-SD)**
CCD	39 +- 13 %	41+-14 %	37+-12 %
CCW	48 +-26 %	62+-34 %	75+-21 %
FD	20+-4 %	29+-6 %	22+-5 %
FW	24+-7 %	34+-7 %	39+-13 %

Figures 5.1a to 5.3b below display the soil temperature and soil moisture relationship to soil respiration for the 4 different plots and their 3 different surface cover types, based on the dependent variable soil CO_2 efflux and the independent variables soil temperature in degree Celsius and soil moisture in percentage.

The r^2 value is displayed in table 2 – 4 in Appendix 2. On the vegetation cover in (Fig 5.1a) no correlation could be found between soil temperature and soil respiration for all plots exempt for CCW plot with a very weak correlation of ($r^2 = 0.2$). Soil moisture and soil respiration had no correlation in (Fig 5.1b) except for a weak correlation on CCD and FD plot. On the bare soil layer, in (Fig 5.2a) soil temperature and soil respiration showed no correlation on the plots except for a very low correlation from CCD ($r^2 = 0.05$). In (Fig 5.2b) there was no correlation between soil moisture and soil respiration on the bare soil layer. Lastly on the mineral layer, in (Fig 5.3a) the soil temperature and soil respiration showed no correlation except for the wet plots CCW ($r^2 = 0.06$) and FW ($r^2 = 0.02$). Relating soil moisture to soil respiration in (Fig 5.3b), FW ($r^2 = 0.06$) was the only plot that had a very small correlation of soil CO_2 to soil moisture meanwhile the other plots had no correlations.

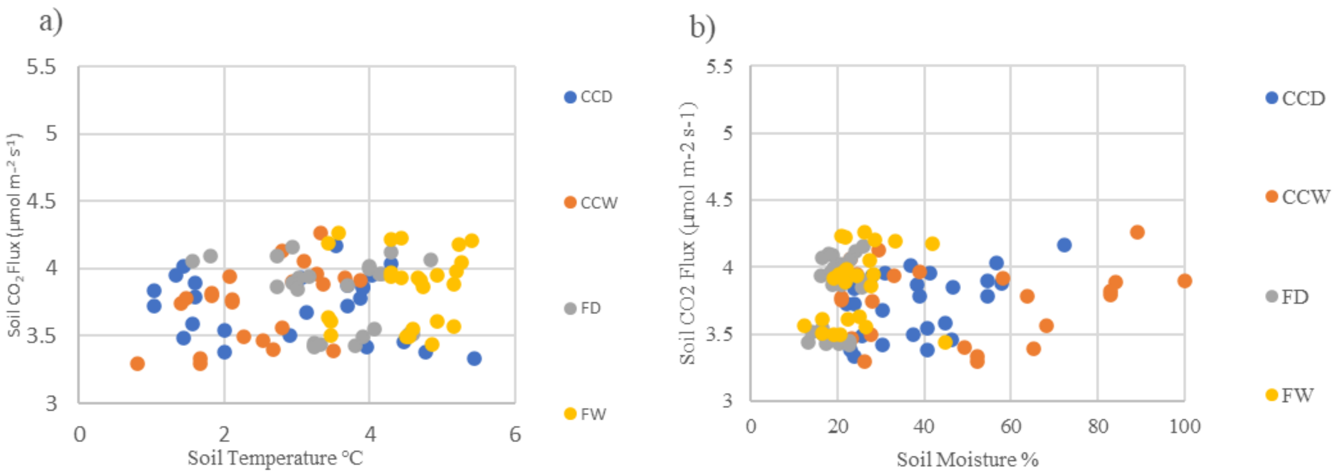

Figure 5.1: Soil temperature and soil moisture relationship to soil CO_2 flux on the vegetation cover. a)soil temperature relation to soil respiration for the four different plots, no linear correlation can be observed. b) soil moisture in percentage relation to soil respiration for the four different plots. A slight linear correlation for CCW plot can be observed.

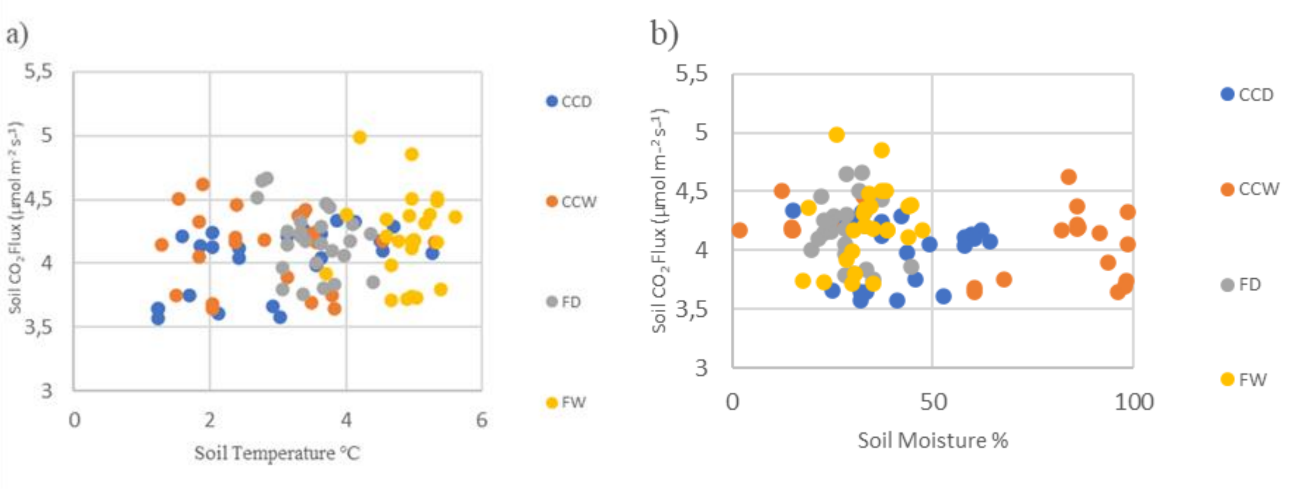

Figure 5.2: Soil temperature and soil moisture relationship to soil CO_2 flux on the bare soil layer. a)soil temperature relation to soil respiration for the four different plots, no linear correlation can be observed. b) soil moisture relation to soil respiration for the four different plots. The water content is very high for the CCW plot.

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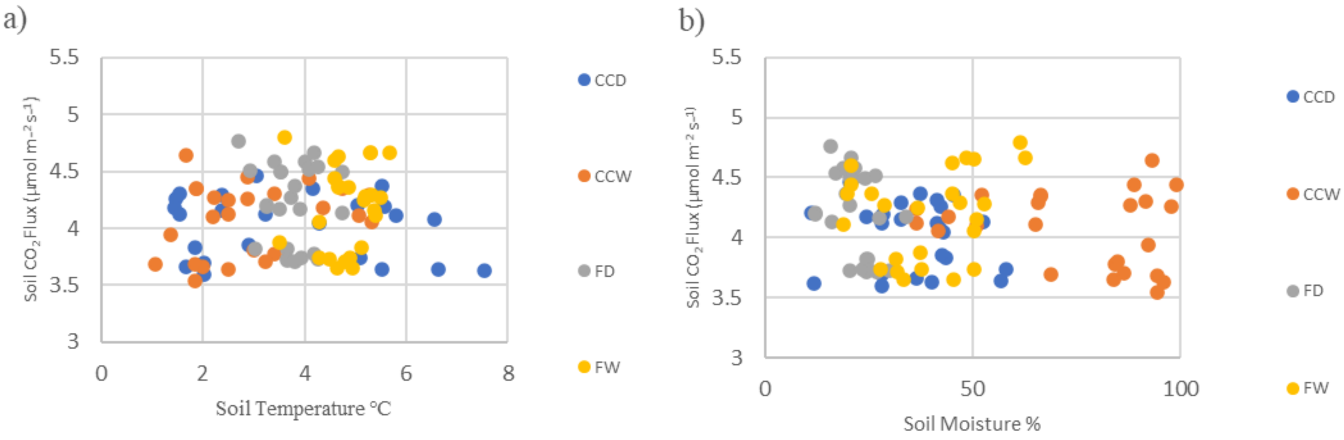

Figure 5.3: Soil temperature and soil moisture relationship to soil CO_2 flux on the mineral layer. a)soil temperature relation to soil respiration for the four different plots, no linear correlation can be observed. b) soil moisture relation to soil respiration for the four different plots. CCW shows a high-water volumetric content.

The four plots showed little to no correlation between soil temperature and soil moisture to soil respiration amongst the three surface covers. Clear-cut wet has about 10 – 50 % higher volumetric water content see table 5.2 compared to other plots. CCW showed a small correlation between soil respiration and soil temperature on the bare soil layer than with soil moisture see table 2 in the appendix2. The forest plots have a higher soil temperature but lower soil moisture than the clear-cut plots. Soil temperature and soil moisture increased on the mineral layer for most plots.

5.2 Soil respiration between two forest management stages

The ANOVA test was used when comparing the soil respiration means of the four different plots (CCD, CCW, FD, FW) for each surface cover (Table 1 in A2). It resulted in no significant difference between the averaged soil respiration on the four plots for the vegetation cover and bare soil layer. However, there is a significant difference on the mineral layer. The p-value resulted in P = 0.003 from the ANOVA test, which is lower than the alpha (a = 0.05).
The Bonferroni test gave a p-value of P = 0.0005 for the mineral layer which is lower than the alpha level (alpha = 0.05) meaning that there was a significant difference between the clear-cut dry and forest dry plots. The averaged soil respiration (µmol m-2 s -1) value and the SD (standard deviations) for the two forest management stages (Clear-cut and forest stand) in the four different plot locations and the three different surface covers is given in table 5.3. The forest plots have a slightly higher (0.01 µmol m-2 s -1) averaged soil respiration than the clear-cut plots on the three surface covers with more variability on the forest plots as seen from the standard deviations.

Table 5.3. Averaged soil respiration (µmol m-2 s -1), and its standard deviations for the four plots and their three surface covers

Forest Plots (Dry and wet)	**Vegetation cover (mean+-SD) (µmol m-2 s -1)**	**Bare soil layer (mean+-SD) (µmol m-2 s -1)**	**Mineral layer (mean+-SD) (µmol m-2 s -1)**
Clear-cut dry	3.75+- 0.10	4.01+-0.08	4.04+-0.08
Clear-cut wet	3.79+-0.20	4.11+-0.13	4.09+-0.11
Forest dry	3.81+-0.06	4.15+-0.19	4.21+-0.08
Forest wet	3.87+-0.11	4.18+-0.15	4.19+-0.13

Figures 5.4 a.b.c. below are the individual soil respiration samples for the 4 different plots amongst the 3 different surface covers. In (Fig 5.4a) the forest plots had a slightly higher soil respiration about 0.2 µmol m^{-2} s^{-1} than the clear-cut plots on the vegetation cover. On the bare soil layer in (Fig 5.4b) the forest plots had about 1 µmol m^{-2} s^{-1} higher soil respiration than the clear-cut. On the mineral layer in (Fig 5.4c), there was a slightly higher soil respiration on the clear-cut wet plot compared to the other plots.

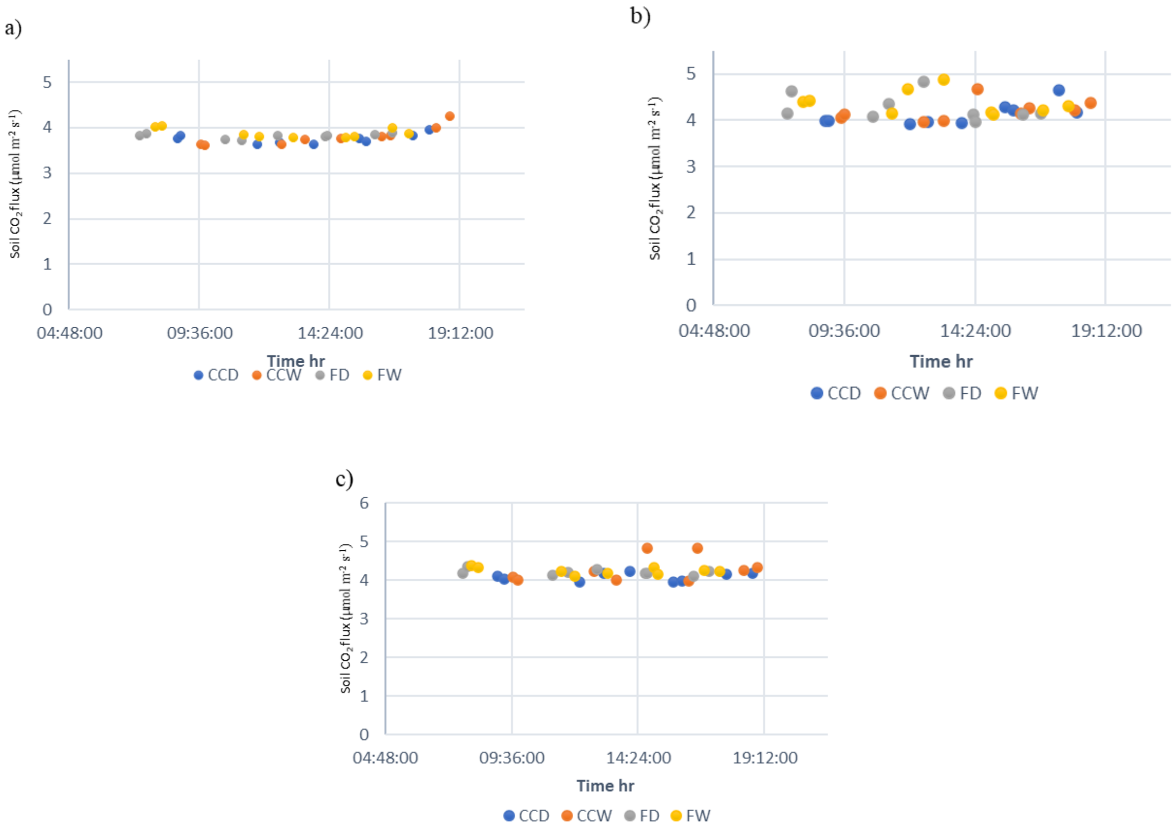

Figure 5.4: Diurnal course of soil respiration for the different forest management stages and their surface covers. a) the diurnal pattern of soil respiration on the vegetation cover. b) the diurnal pattern of soil respiration on the bare soil layer c) the diurnal pattern of soil respiration on the mineral layer.

The mean soil respiration for the forest in both wet and dry plots was higher on the three surface covers than on the clear-cut, with a higher soil respiration on the mineral and bare soil layer than on the vegetation cover (see table 5.3). There was not much of a difference in soil respiration amongst the different layers but a small difference between the forest and clear-cut.

5.3 Soil temperature, soil moisture and PAR on NEE

The total means from all the sample measurements of NEE was positive, indicating a net release. The total mean for CCD plot was 3.73+-0.12 (mean+-SD) µmol $m^{-2}s^{-1}$ and CCW was 3.69+-0.14 µmol m-2 s -1. The total mean PAR for the CCD was 646 µmol (photons) m^{-2} s^{-1} and for CCW 493 µmol (photons) $m^{-2}s^{-1}$.The total mean NEE for the forest dry plot resulted in 3.81+-0.05 µmol $m^{-2}s^{-1}$ and for forest wet was 3.86+-0.11µmol m-2 s -1. The total mean PAR for the forest dry plot was 49 µmol (photons) m^{-2} s^{-1} and for the forest wet 29 µmol (photons) m^{-2} s^{-1}.

The correlation of average NEE and PAR samples for the clear-cut dry and wet plots resulted in a strong correlation for CCW ($r^2 = 0.7$) in Fig 5.5a, however, there is a decrease in carbon uptake with PAR on CCW plot. In Fig 5.5b, there was no correlation with NEE and PAR for the forest plots. There is a noticeable difference between the PAR values on the forest plots and on the clear-cut plots. The clear-cut plots had a higher range of PAR between 100 to 1100 µmol (photons) m^{-2} s^{-1} compared to the forest plots which is visibly much lower about 10 to 250 µmol (photons) m^{-2} s^{-1}. Looking at the mean NEE of all plots, the forest plots had higher net release of CO_2 and lower PAR values (see Fig 5.5).

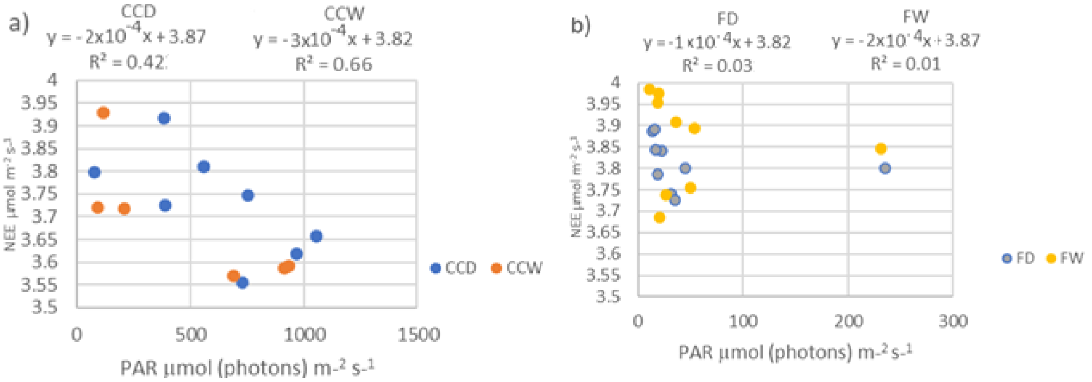

Figure 5.5: The correlation of averaged NEE and PAR with the R2 value given of the different forest management stages. a) the clear-cut forest management stages and its two moisture segments. NEE and PAR are negatively correlated. b) the forest management stages and its moisture segments, NEE and PAR are negatively correlated and there are two points outliers.

The wet Clear-cut site had the highest correlation ($r^2 = 0.6$) of NEE and soil temperature in (Fig 5.7a) with a negative slope on the vegetation cover. The correlation between NEE and soil moisture showed that CCW has a very weak correlation ($r^2 = 0.2$) while the other plots have no correlation in Fig 5.6.

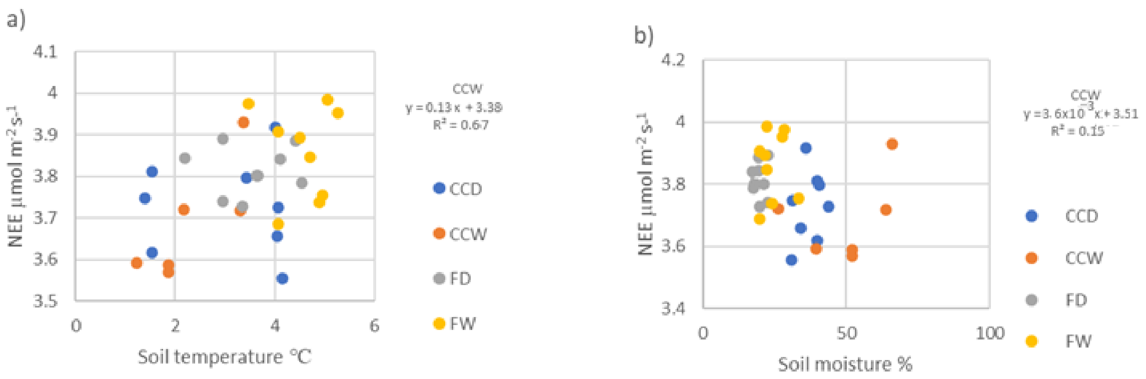

Figure 5.6: The mean NEE correlation to soil temperature and soil moisture of the two different forest management stages divided in two moisture segments. a) the correlation of the mean NEE and soil temperature for the four different plots. b) the correlation of the mean NEE and soil moisture for the four different plots.

There was no correlation of NEE with PAR that could be found on the forest plots. Soil temperature was strongly correlated to NEE on the clear-cut wet but weakly correlated on the other plots. Soil moisture was weakly correlated to NEE on clear-cut wet, but even more weakly on the other plots.

6. Discussion

6.1 Soil temperature and soil moisture impact on soil respiration

The correlation between soil respiration with soil temperature and soil moisture was weak on the forest stand and the clear-cut plots. Several factors contribute to this. Firstly, the soil temperature in figures 5.1 to 5.3 had a maximum of 8 °C which is very low hence no correlation between soil respiration and soil temperature. Secondly, the soil moisture and soil temperature were observed over a short period of time and within unchanged season which makes it difficult to see any variability in the data. In addition, some of the processes affecting soil respiration (such as decomposition of litters and root activity) are soil temperature and soil moisture driven but happen on longer timescales which is why a correlation between soil respiration with soil temperature an soil moisture could not be observed in the study.

Even though no correlation between respiration, temperature and moisture could be found in this study, there has been substantial research documenting the effects of environmental factors on soil respiration. Chen et al. (2014) used measurements taken over a year-long period in an upland and humid environment and showed that soil temperature correlates more strongly to soil respiration than soil moisture. This is because soil moisture had an insignificant effect on the soil respiration since the study area was in an upland and humid environment. This area experienced abundant moisture, making soil temperature the limiting factor. When the area experienced a drought (a lack of moisture), soil moisture became significant to the soil respiration in the study. This changes the limiting factor and the relative influence of temperature and moisture on soil respiration.

In the Chen et al (2014) study soil respiration reacted to the limiting factor more than the readily available environmental factor. The same can be seen in this study where there is a small correlation between soil respiration and soil temperature on the clear-cut wet plot but almost nonexistent on the other plots. Table 5.1 shows that the soil temperature is about 1-2°C higher on the other plots (forest dry, forest wet, clear-cut dry) but about 10 - 50% lower soil moisture than the clear-cut wet plot in table 5.2. This means the clear-cut wet plot had high volumetric water content. Soil moisture becomes an abundant factor for the clear-cut wet plot and not a limiting factor which can explain why it has a small correlation of soil temperature to soil respiration.

Another example of this is seen in a study done by Tang et al. (2019) where they experimentally increased the temperature of the soil with 2 °C. This resulted in a decrease of temperature sensitivity to soil respiration as it became an abundant factor instead of a limiting factor (Tang et al. 2019). Soil respiration is a physiological process of microbes and plants and it responds to the most limiting factor. Soil respiration becomes insensitive to moisture content under low temperatures but more responsive to moisture at high temperatures, and vice versa (Luo and

Zhou 2006b). However, the forest stands showed no correlation to soil respiration even with higher soil temperature and lower soil moisture (see table 5.1 and table 5.2) because there are other factors that are important to controls of soil respiration that this thesis has not taken into consideration. These are factors that also interact or are influenced by soil temperature and soil moisture such as the regulation of pH, soil organic matter, and microbial activities (Luo and Zhou 2006b).

The different surface layers did not have strong distinctions in soil respiration although the bare soil and mineral layer had slightly higher soil temperature and soil moisture (see table 5.1 and 5.2). This could be because they receive more litter to be decomposed as they became exposed to the surface than usual as the layers covering them were removed. This can increase their soil respiration as seen in table 5.3 and described by Ma et al.(2013).The forest stand still had higher soil respiration than the clear-cut on the three surface covers, and this can be explained by the type of vegetation species. The clear-cut had a small covering of grass for vegetation compared to the wood moss on the forest stand.

Another explanation as to why the clear-cut had lower soil respiration than the forest stand, other than looking at the two environmental factors, can be that other factors such as root and microbial activities were reduced on the clear-cut. A study done in a mixed forest in southern Sweden finds that soil temperature explains 82% of root soil respiration but just 42% of total soil respiration (Saiz et al. 2006). This is supported by Ma et al (2013) in a study of clearcutting silviculture effect on soil respiration in China. The Ma et al. (2013) study highlights that clearcutting affects soil respiration because of losses of or changes to features that a forest stand has, that is, there is a reduction in roots, aboveground biomass, and change in microbial activity. Root respiration accounts for half of the soil respiration, when reduced this will terminate or change the soil respiration.

The reduction in aboveground biomass reduces microbial activities and the disturbances caused by clearcutting changes the temporal and spatial variability of the soil temperature and moisture, thus effecting the microbial activities (Ma et al. 2013). This can also be seen in table 5.1 and 5.2 as soil temperature and soil moisture varies between the clear-cut and the forest stand plots therefore, causing changes to microbial activities, decomposition, and photosynthetic activity. In the Ma et al (2013) study there were some changes to the soil CO_2 emissions in the first 4 months, because root respiration suddenly decreased, which was followed by a decrease in the decomposition of litters and organic matters in the soil, but later on, this enhanced the microbial activity and counteracted the decline in root respiration (Ma et al. 2013).

Contrary to this, a study from Chen et al (2014) compares soil respiration on three subalpine ecosystems on a clear-cut, primary, and secondary forest, using a static chamber. This supports the notion that clearcutting increases soil respiration. The result of the study shows a 40.4 % increase of soil respiration in a clear-cut forest than the 20.5 % increase of soil respiration in a primary forest, which is about 3330.2 g carbon dioxide m-2 y-1 for the primary forest, 2358.9 g CO_2 m-2 yr-1 for secondary forest and 4162.8 g CO_2 m-2 yr-1 (Chen et al. 2014). This study is taken over a year in China and it cannot be directly comparable to the study by Ma et al. (2013) due to the difference in the environment. However, both studies reported increases of soil respiration on the clear-cut even, though it happened on different temporal scales. Ma et al. (2013) also indicates a larger difference of soil respiration between a forest and a clear-cut, but also a higher influence of temperature on the clear-cut than the forest. Moreover, there are several more studies with conflicting results on the effect of clear-cut on soil respiration such as an increase of soil respiration in clearcutting in the years following harvest (Laporte et al. 2003) and decrease of soil respiration on clearcutting (Ponder 2005).

In this study, there was no significant difference between the forest management stages, but clearer differences amongst the three surface covers. This could be due to how the environmental factors change between the surface covers and the very short fieldwork time. It is also interesting to see a reduction in the soil respiration on the dry plots of the clear-cut and forest stand. A study by Davidson et al. (1998) in the amazon forest compared soil respiration in the dry and wet season. It concluded that soil respiration decreases with decreasing moisture content, and that some of the soil respiration was higher during the rainy season due an increase of microbial activity and CO_2 production in the soil. However, this can also depend on several factors influencing how well the soil receives moisture such as infiltration, structure, and porosity of the soil, which has not been considered. Looking into other studies implies that moisture content strongly influences the rate of microbial activity to the soil. Lab experiments have shown a rapid increase in soil respiration because of an increase in microbial activity caused by increased moisture content (Orchard and Cook 1983). Therefore, the increased moisture of the wet plots leads to higher soil respiration rates than on the dryer plots.

The controls of soil temperature and soil moisture on soil respiration can be significant to global climate change, but climate change will also affect soils respiration (Giardina et al. 2014). An increase in global temperature can lead to increased decomposition rates of the soil organic matter, further increasing the amount of carbon into the soil, then through respiration releasing more carbon to the atmosphere. The result of the study implies that soil moisture plays a big part of soil respiration. Soil moisture can enhance microbial activity and if higher temperatures would lead to a dependency on soil moisture then soil respiration would still be increasing.

6.2 Soil temperature, soil moisture and PAR on NEE

The PAR values were distinctly lower on the forest plots (Fig 5.6b), and higher on the clear-cut (Fig 5.6a), also the average NEE values were still slightly higher for the forest plots than the clear-cut plots. The differences in PAR between the forest and clear-cut plots can be due to the canopy cover obstructing the light on the forest floors, while the clear-cut is more exposed. Therefore, the amount of light the forest floor receives was less than the clear-cut. The forest plot had a shade reduction which increased the PAR on the chart in (Fig 5.5b) creating outliers for the forest stand. The net release of CO_2 is higher on the forest than the clear-cut and this can be due to the amount of GPP and R_{eco} on the vegetation of the forest stand compared to the clear-cut (see Fig 5.6a and 5.6b). Table 5.3 shows that respiration is higher on the forest plots than the clear-cut. This means that respiration was higher than GPP on the forest stand leading to net carbon release.

The results showed no correlation of NEE to soil temperature and soil moisture. The clear-cut wet has a high volumetric water content (see table 5.2), but it still had lower net release than the forest stands. This could mean that the clear-cut wet plot had excessive moisture and that could cause stress to the photosynthesis capacity of the plant. Although the vegetation on the clear-cut was not as large as on the forest and was not the same specimen, the forest had a higher percentage of wood moss and the clear-cut had a lower percentage of degraded grass. Contrary to this, the forest has more resources to intensely grow its moss, herbs, and flowers than the clear-cut and therefore has a higher amount of photosynthetic activity. In a study by Mamkin et al. (2016), NEE rates were analyzed on a clear-cut from April to August which is the growing season and shows both a net release and net uptake of carbon from mid-June to August, thus concluding that it was because of the increased photosynthetic activity of the shrubs and juvenile trees that began intensive growing from the middle of May. The daily NEE values ranged from +4.0 to −3.0 $g\ C\ m^{-2}\ d^{-1}$ (CO_2 sink) and depended on radiation, temperature, and soil moisture of the soil (Mamkin et al. 2016).

The diurnal pattern of the NEE is governed by its radiation, temperature, and ground vegetation (Mamkin et al. 2016). As the clear-cut had higher solar radiation but lower vegetation, this can explain the high PAR values but lower net release NEE values. This is also supported by other research, such as an analysis of CO_2 fluxes performed in the southern taiga on a clear-cut demonstrating that the clear-cut served as a CO_2 source for the atmosphere compared to the forest stands, as well as several other studies (Amiro et al.2006; Williams et al.2014; Aguilos et al.2014, Paul-Limoges et al.2015). In the first years following harvest the clear-cut acts as a source, but with a considerably lower net release of carbon than the forest stands, but the years following that the NEE begins to decline even further with vegetation growth and becomes a CO_2 sink. Therefore, the GPP became higher than the respiration which makes the clear-cut a net uptake. The research by Mamkin et al. (2019) shows that it takes about 10 – 20 years for the ecosystem to restore its normal function as a CO_2 sink, however, reports by (Hirata et al., 2014) has shown that in Japan it can take as long as 52 years. Therefore, the NEE rates as a net uptake for the clear-cut will take many years before it matches up to the forest stand but the differences can be accounted to seasonal, temporal, and vegetation types of the plots.

6.3 Sources of errors and future study improvements

Firstly, to improve this study measurements over a longer period of time should be taken to make it easier to interpret the data. Moreover, the controls over soil respiration were not observed under various conditions, such as increased water content or increased air temperature. Instead they are observed on a short period without variations in temporal patterns, making it unsuitable to rely on but instead used as a model to facilitate a future study. Additionally, other factors influencing soil respiration, such as pH, soil organic matter and microbial activities, were not considered in the study. An improvement would be to take these into account by having measurements of several controls of soil CO_2 efflux to better analyze the results, and naturally as many measurements as possible to better aid in the interpretation of the data. Due to the short measurement period, different factors and changes over seasons were not seen in the data. The low sample volume also makes it more difficult to account for human errors when using a chamber.

Secondly, the instrument used for measuring is one of the newest versions, and not many previous publications have used it to measure CO_2 fluxes. The lack of documentation on the instrument increased the time to find the solution to the technical questions on some functions and features of the instrument and increased the risk of human errors. However, with more time and ample preparations, it is very possible to get more familiar with the instrument ahead of time and minimize this risk as well as time loss.

Thirdly, the study used mostly bivariate statistical analysis, in which only one variable is plotted against a dependent variable, meanwhile a multivariate analysis would have made certain things visually clearer and easier to interpret. For example, plotting soil temperature and soil moisture together with the soil CO_2 fluxes to observe the dependent and the various independent variables together could potentially show a more realistic picture of the processes involved. To improve the study, a larger dataset should be considered as it helps determine and differentiate the controls on soil CO_2 fluxes better, but also observe various things as the diurnal variation. An automatic chamber might help produce a larger dataset and reduce human errors and labor.

7. Conclusion

This study investigated soil CO_2 fluxes at two different forest stages, a clear-cut and a 37-year old forest stand under three different surface covers, and at two moisture segments.
The clear-cut had higher soil moisture and lower soil temperature than the forest stand. The forest stand had higher soil temperature and less soil moisture than the clear-cut, therefore soil respiration was affected differently. The clear-cut soil respiration was more temperature driven, due to having soil temperature as a limiting factor, meanwhile on the forest stand the soil respiration was more soil moisture driven as it had soil moisture as a limiting factor. The clear-cut has less soil respiration than the forest stand. The data in the study was not collected over a long enough period to see any correlation between soil temperature, soil moisture and soil respiration. However, looking at other studies for an explanation indicated that the clear-cut has a more disturbed surface cover, which can cause a reduction in root respiration and microbial activities that normally contributes to soil respiration. No definitive statements on the relative importance of soil moisture and temperature to soil respiration in a clear-cut and a forest stand can be made from this study as there was not enough data, and as other factors that drive soil respiration (microbial activities, decomposition of SOC, soil pH) were not investigated.

There was however variation on the three types of surface covers. The bare soil and mineral layer had higher soil respiration compared to the vegetation cover, which could mean there were more decomposition as they were now exposed to more concentration of litter and soil detrital increasing soil respiration. Furthermore, the drivers of NEE were investigated at the clear-cut and the forest stand showing that PAR is less on the forest stand and higher on the clear-cut. The NEE values were higher on the forest stand than on the clear-cut. This is because the forest stand had more respiration and lower GPP leading to more net carbon release.

Lastly, human impacts on the forest ecosystem through clear-cutting can have an even deeper effect on the global climate. Research have shown that the controls of soil temperature and soil moisture on soil respiration can be significant to global climate change. That is the effects of increased global temperature on soil includes increased decomposition rates of the soil organic matter further increasing the amount of carbon into the soil, then through respiration releasing more carbon to the atmosphere. The study indicates a small difference in soil respiration between the clear-cut and forest even under a short period of time. This implies that the there is a change in the terrestrial biosphere with different forest management stages which is why it is still important to assess how the removal and change of the soil through management practices will affect the terrestrial carbon sink in the future.

8. Acknowledgments

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10. Appendix

Appendix A1: Vegetation cover images

An example from the forest and clear-cut plots of the surface covers that the soil CO_2 efflux measurements were taken from.

Figure A1: surface covers (vegetation cover, bare soil layer and mineral layer) and the three replicates for the forest plots with the aluminum rings inserted. a) from the left displays the vegetation surface cover, b) is the bare soil layer and c) is the mineral layer

Figure A2: surface covers (vegetation cover, bare soil layer and mineral layer) for the clear-cut plots with the aluminum rings inserted. a) from the left display the vegetation surface cover, b) the bare soil layer and c) the mineral layer.

Appendix A2: Tables displaying R2 values and ANOVA

Table A1: displays the means for the soil CO_2 fluxes (µmol m^{-1} s^{-1}) for each plots under the different layers, (Veg = vegetation, bare soil, mineral layer), and the average, the calculated variances and p value from the ANOVA test conducted.

VEG	**CCD umol m-1 s-1**	**CCW umol m-1 s-1**	**FD umol m-1 s-1**	**FW umol m-1 s-1**
	0.037	0.037	0.038	0.037
	0.039	0.042	0.038	0.038
	0.038	0.036	0.038	0.040
	0.036	0.037	0.038	0.037
	0.038	0.039	0.038	0.039
	0.037	0.036	0.038	0.040
	0.036	0.036	0.037	0.038
	0.036	0.037	0.037	0.037
	0.036	0.038	0.037	0.037
Average	0.037	0.037	0.038	0.038
Variance	1.10E-06	4.17E-06	3.14E-07	1.17E-06
P value	0.25			

Bare soil	**CCD umol m-1 s-1**	**CCW umol m-1 s-1**	**FD umol m-1 s-1**	**FW umol m-1 s-1**
	0.040	0.041	0.039	0.040
	0.041	0.043	0.041	0.042
	0.039	0.041	0.046	0.044
	0.039	0.040	0.040	0.040
	0.040	0.042	0.041	0.042
	0.039	0.040	0.041	0.043
	0.039	0.039	0.040	0.041
	0.039	0.039	0.040	0.040
	0.040	0.040	0.041	0.041
Average	0.040	0.041	0.041	0.042
Variance	6.13E-07	1.56E-06	3.65E-06	2.24E-06
P-value	0.09			

Mineral	**CCD umol m-1 s-1**	**CCW umol m-1 s-1**	**FD umol m-1 s-1**	**FW umol m-1 s-1**
	0.039	0.039	0.041	0.040
	0.041	0.043	0.042	0.042
	0.040	0.040	0.043	0.043
	0.040	0.040	0.042	0.040
	0.041	0.042	0.041	0.042
	0.040	0.040	0.041	0.043
	0.039	0.040	0.041	0.042
	0.040	0.039	0.042	0.041
	0.039	0.040	0.041	0.041
Average	0.040	0.040	0.042	0.041
Variance	7.12E-07	1.23E-06	6.30E-07	1.67E-06
P-value	0.003			

Table A2: The R2 values for the correlation between soil respiration and soil temperature on the three surface covers (vegetation, bare soil, and mineral layer) for the four different plots. For the charts in section 5.1.

Plots (Dry and wet)	**Vegetation Cover R2**	**Bare soil layer R2**	**Mineral layer R2**
CCD	0.03	0.06	0.01
CCW	0.22	0.00	0.07
FD	0.06	0.12	0.12
FW	0.01	0.00	0.02

Table A3: The R2 values for the correlation between soil respiration and soil moisture on the three surface covers (vegetation, bare soil, and mineral layer) for the four different plots. Displayed on the charts in section 5.1.

Plots (Dry and wet)	**Vegetation Cover R2**	**Bare soil layer R2**	**Mineral layer R2**
CCD	0.02	0.06	0.04
CCW	0.02	0.12	0.04
FD	0.14	0.02	0.14
FW	0.05	0.07	0.06

Table A4: The R2 values for the correlation between NEE and soil temperature, PAR, and soil moisture on the vegetation cover for the four different plots. Displayed on the charts in section 5.3.

Plots (Dry and wet)	**PAR R2**	**Soil temperature R2**	**Soil moisture R2**
CCD	0.42	0.00	0.08
CCW	0.66	0.67	0.15
FD	0.03	0.00	0.00
FW	0.01	0.00	0.00