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GreenHouse Gas Flux Measurement From Rewetted and Drained Fen Peatland Cultivated with Reed Canary Grass

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Natural peatland are efficient ecosystems in storing carbon and serve as a net sink of atmospheric $CO_2$. However, drainage and use of peatlands for agriculture and forestry may turn these natural ecosystems into net sources of $CO_2$ as the peat degradation is accelerated due to processes such as increased soil aeration, fertilization and priming of soil organic carbon turn-over by root exudates. Thus, many studies have documented a high net emission of $CO_2$ from drained peatlands used for annual arable crop production. As we know peatland covers only 3% of earth's land surface but stores (15-30) % of world's soil carbon as peat. Therefore, it is of paramount importance to monitor of the amount of greenhouse gas emissions from peatland to control Global warming and climate change.

This thesis is based on the research experiment conducted on fen peatland located in Nørre Å river valley, Denmark (44˚N, 56˚W, 96˚E). The main objective of the thesis project was to compare the emission of greenhouse gases from rewetted and drained fen peatland. Rewetted peatland is a land where water is again put back into it after the land has been utilized for agricultural purposes to restore the natural properties of peatland whereas peatland from which water has been drained out for agricultural purposes or peat extraction is a drained peatland. This experiment was carried out on four random plots where each plot consists of two sub plots. In each sub plot, one half

was flooded with water while the other half was kept dry. Gas sample was collected from each sub plot consisting of wet and dry parts by an in line infra-red gas analyzer (IRGA) and opaque chamber method. After the gas was collected, it was then taken to the laboratory for analysis.

The results of the experiment were clear and comprehensible except for fluxes which are due to human error or some sudden change in the soil properties. It is obvious that drained peatland released a higher amount of $CO_2$ than the wet peatland. Drained peatland (unflooded) released 31.25 % more $CO_2$ in average than the rewetted (flooded) one. Similarly, wet part released 81.25 % more $N_2O$ in average than the dry part. Likewise, wet plot released 96.66% more $CH_4$ than dry one. Here, one can be easily misguided by the results of $CH_4$ and $N_2O$ emission, but they are emitted in a minuscule amount, which is in the order of (milligram) compared to $CO_2$, which is in (gram) The average total GHG emission from the dry part is 16.012 g (16 g ($CO_2$) + 0.01 g ($CH_4$) + 0.002 g ($N_2O$)), whereas from the wet part is 11.308 g (11 g ($CO_2$) + 0.3 g ($CH_4$) +0.0085 g ($N_2O$)). This clearly shows that GHG emission from the dry part is higher than the emission of wet part.

## Acknowledgements

I would like to dedicate this thesis to my beloved father and mother for constantly supporting and motivating me in my education.

I also take this opportunity to thank my brother in law Dr. Khagendra Raj Baral for providing internship opportunity in Denmark and Dr.Tanka Kandel and Sr. scientist Poul Erik Laerke for their supervision throughout the experiment.

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# List of Figures

# List of Tables

## List of Abbreviations

atm          Atmospheric Pressure

ANOVA        Analysis of Variance

AOB          Ammonia Oxidizing Bacteria

d            Day

GC           Chromatograph

GHG          Greenhouse Gas

Gt           Gigatons

GWP          Global Warming Potential

GWL          Ground Water Level

ha           Hectare

IRGA         Infrared Gas Analyzer

K            Potassium

L            Liters

m            meter

mg          milligram

mol         mole

N           Nitrogen

NEE        Net Ecosystem Exchange

P           Phosphorous

pH         Potential of Hydrogen

ppb         Parts Per Billion

ppm       Parts Per Million

RCG        Reed Canary Grass

TDR        Time Domain Reflectometer

VWC      Volumetric Water Content

WFPS     Water Filled Pore Space

**Table of Contents**

# 1 Introduction

Peatland covers only 3% of the world's area but contains 30% of the soil organic carbon. It is a very critical ecosystem as it releases three Gt (Gigatons) of $CO_2$ per year, which is equivalent to 10% of global fossil fuel emissions. Natural peatland is a net sink of carbon because of the lower rate of decomposition of organic matter due to the anaerobic conditions present in the soil. Therefore, it captures more carbon dioxide ($CO_2$) than it releases to the atmosphere. Hence, there is net gain of carbon; this soil organic carbon deposits over time and is preserved (Parish *et al*., 2008). However, when it is drained and used for agriculture and forestry, it is turned into significant source of $CO_2$ and nitrous oxide ($N_2O$) due to the decomposition of previously preserved organic carbon in the soil. This accounts for 6% of total anthropogenic source of $CO_2$ emission in the world, which is primarily attributed to fertilization and other agricultural practices such as soil tillage and crop management that influence various factors, for example, ground water table, soil temperature, volumetric water content ,microbial activity and aeration. This can alter the biogeochemical processes in the soil and affects the emission (Clymo, Tolonen and Turunen, 1998.) Now peatland has become one of the important ecosystems on the planet and it's study is gaining popularity.  However, in the past few years, little scientific research has been made on the emissions of GHG from fen peatland cultivated wit Reed Canary Grass. Moreover, the previous studies lacked the detailed investigation on GHG emissions from the RCG cultivated peatland. Therefore, it is considered to answer the fundamental

questions associated with it. The research found that the drained ecosystem was more potent emitter of $CO_2$ and other GHG's than wet ecosystem. However, wet plots were far efficient at releasing $CH_4$ than the dry plots. The emission of methane from the wet part was almost 97% higher than that of the dry one. But this is only on individual scenario not collectively. The research is intended to find out and compare the emissions of different GHG's from a peatland cultivated with reed canary grass under the wet and dry conditions.

## 2 Main Aims

The main aim of the project was to determine the effect of rewetting of a drained fen peatland cultivated with reed canary grass on GHG emission. As it is obvious from the previous research experiments that the drained peatland is a net source of GHG emission, it was interesting to compare and quantify the emissions from re-wetted peatland with drained peatland to resolve which land management style would play a significant role on greenhouse gas emission and global warming.

## 3 Peatland

Peatland is formed by the accumulation of partially decayed vegetation and organic matter over thousands of years. Natural peatland is a net sink of carbon as it captures more carbon dioxide ($CO_2$) than it releases to atmosphere. Therefore, there is net gain of

carbon and the soil organic carbon deposits over time and is preserved. However, drained peatland are major sources of $CO_2$ emission and account for 6% of total anthropogenic source of $CO_2$ emission. In natural peatlands, the rate of decomposition of organic matter is slow because of anaerobic conditions, but natural peatland may release huge amount of methane ($CH_4$). However, when the peatland is drained and used for agriculture and forestry, it is turned into significant source of $CO_2$ and nitrous oxide due to decomposition of previously preserved organic carbon in the soil (Joosten *et al.*, 2012; Gunther *et al.*, 2014). This can be attributed to fertilization and other agricultural practices such as soil tillage and crop management, which influences various factors like ground water table, soil temperature, volumetric water content, microbial activity and aeration and can alter the biogeochemical processes in the soil (Maljanen *et al.*, 2010). Therefore, peatland is a very tender and critical land ecosystem, which means that systematic and scientific methods are required when utilizing and managing these lands for agricultural and other purposes such as forestry.

## 3.1 Formation of Peatland

The formation of peatland is accompanied by the formation of organic materials and its deposition. For the formation of peat, the production of biomass or the organic materials must be greater than its breakdown. Peat formation is a biochemical process where aerobic microorganisms act on the biomass deposits on the sub-soil and partly decompose it. As peat is subjected to anaerobic conditions on

the deeper regions of the soil, it is preserved and can literally stay there without any change over time (Clymo, Tolonen and Turunen, 1998). This preservation of partly decomposed organic matter is attributed to various environmental and soil parameters such as temperature, water level, moisture and soil pH. These factors affect the activity of soil microorganisms, which in turn affected the decomposition rate of the biomass. Therefore, in a natural peatland, organic carbon is stored continuously which is the reason why it is also called the carbon factory of the world (Maljanen *et al.*, 2010).

## 3.2 Types of Peatland

Peatland is summoned as wetland because the formation of peat takes place in wet areas where the water table (Ground Water Level) is very close to the surface. It provides the anaerobic conditions for the formation and deposition of peat. The main characteristic of the wetland is the type of soil, plants and animals living there and salinity of the water in the soil. On the basis of these conditions, there are two types of wetland mineral soil and organic soil peatland (Heinselman, 1970).

### 3.2.1 Mineral Soil Wetland

There are two types of mineral soil wetland depending upon the moisture content and types of vegetation present in it.

## Marsh

Marsh is a type of wetland ecosystem present near the river mouth where mineral rich soil is found. It is characterized by the presence of grasses which hold the mineral rich water contribute to the further growth of the area (Heinselman, 1970).

## Swamp

Swamp is a wetland area characterized by mineral rich soil with poor drainage. This type of wetland ecosystem occurs next to the rivers, which supply them with mineral rich water and are usually inhabited by trees (Heinselman, 1970).

## 3.2.2 Organic Soil wetland

The organic soil wetland is basically grouped into two categories based upon the source of the water and plants growing in it.

## Bog Peatland

Bog peatland is another type of wetland ecosystem characterized by the presence of wet, spongy peaty soil and mosses like sphagnum. The water present in it is acidic in nature, poor in mineral content and exclusively fed by the rain. It has a very high water holding capacity due to the presence of *sphagnum* therefore sometimes bog water pool may form within it. (Heinselman, 1970).

## Fen Peatland

A fen peatland is a peaty soil, which is dominated by plants, grasses and reeds. Unlike bog, fen peatland is alkaline in nature with relatively higher mineral content and receives water directly from the surface and ground water sources (Heinselman, 1970).

# 4 Greenhouse gas and global Warming

There are mainly four types of GHG's ($CO_2$, $CH_4$, $N_2O$ and water vapor) which are of significant ones. These gases are naturally present in the atmosphere with a low concentration, which is in the order of ppm. However, their concentration is gradually increasing due to emissions from anthropogenic (human related) and natural activities with the former having a share of more than 65% on the global emission of GHG. Among them, the major individual GHG is carbon dioxide ($CO_2$) and a least significant one is water vapor. These gases have intrinsic properties of absorbing heat and remaining in the atmosphere for a long period (lifetime). These innate properties of them increase the temperature of the earth by trapping incident and reflected solar energy causing global warming and climate change. More detailed discussion of these gases is presented below (Ramaswamy *et al.*, 2001).

## 4.1 Major Greenhouse Gases

There are four types of GHG's ($CO_2$, $CH_4$, $N_2O$ and water vapor) which have a significant role in modern global warming and climate

change. However, there are also other greenhouse gases like nitric oxide (NO), chlorofluorocarbon and ozone, but their contribution in global warming is less significant than the above four GHG's because of the low greenhouse gas potential and life time.

## 4.1.1 Carbon dioxide

$CO_2$ is a major individual GHG which is formed by the decomposition of carbonaceous organic matter in the presence of oxygen and released in the atmosphere in a large proportion compared to other greenhouse gases such as $CH_4$ and $N_2O$. The natural concentration of $CO_2$ in atmosphere is 200 ppm, but it is continuously increasing now. Today, carbon dioxide is the main greenhouse gas responsible for the global warming and climate change because it is emitted in a huge quantity through natural and anthropogenic sources with the later accounting for a significant (>65 %) share in the emission (Ramaswamy *et al.*, 2001).

Natural sources of $CO_2$ emission are as follows:
- volcanic eruptions;
- forest fire;
- respiration in the natural ecosystem.

Anthropogenic sources of $CO_2$ emission include the following:
- burning of carbon based fossil fuels like coal, oil, petrol and wood for energy;
- deforestation;
- land use change (converting agricultural land to urban areas.

The general chemical reaction of carbon dioxide formation is as follows:

Carbonaceous matter (C) + air ($O_2$) = $CO_2$ + $H_2O$
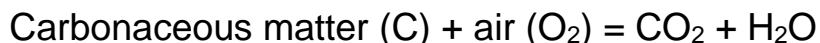
## 4.1.2 Methane

Methane, also called marsh gas and a potent GHG having a global warming potential (GWP) 25 times greater than $CO_2$ (Ramaswamy $et$ $al.$, 2001). It is formed by a process called methanogenesis which predominantly occurs in wetland, swam forest and marshy area where anaerobic oxidation of organic matter takes place due to poor diffusion of oxygen in water (1000 times slower than air). Methane is the second most prevalent GHG after carbon dioxide. It is also released through both natural and anthropogenic sources with the later having a greater percentage on contribution. At present, anthropogenic emission of methane accounts for more than 60% of the global methane emission. However, it is released in small quantities but has a significant effect on global warming because of high efficiency in trapping radiation than $CO_2$ (Dinsmore $et$ $al.$, 2009; Karki $et$ $al.$, 2014).

Naturally, methane is released from the following:
- marsh, wetland and swamp;
- volcanic eruption;
- wildfires and oceans.

Anthropogenic source of methane emissions is as follows:

- production, processing, storage and transportation of natural gas and crude oil;
- livestock (cow, buffalo, goat, sheep) rearing;
- waste management system like landfill and waste to energy conversion.

Depending upon the pH, temperature and substrate concentration methanogenesis takes place by the following reactions as given below:

- $CO_2 + 4H_2 = CH_4 + 2H_2O$
- $CH_3COOH = CH_4 + CO_2$

## 4.1.3 Nitrous Oxide

Nitrous oxide also known as laughing gas is formed in both oxic and anoxic conditions by the biogeochemical process called nitrification and denitrification respectively. Nitrous oxide has a global warming potential of 300 times more than carbon dioxide (Ramaswamy *et al.*, 2001). Therefore, it is considered the most potent GHG for causing global warming and climate change. It's natural concentration in the atmosphere is 318 ppb (parts per billion) but the increased emission due to natural and anthropogenic activities has led to rapid rise in its concentration level in the past (10-20) years. The Interesting aspect of it is that the natural source of emission (68%) of nitrous oxide is greater than human related emission (32%) (Solomon et al., 2007).

Naturally nitrous oxide is released from:
- Nitrification and Denitrification of nitrogen Compounds in soil;

- Oceans.

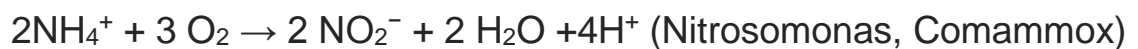Anthropogenic source of emissions includes:

- Burning of fossil fuels;

- Agricultural use of synthetic fertilizer and pesticides;

- Livestock manure;

- Wastewater treatment (Solomon et al., 2007).

The two natural biogeochemical processes which controls the emission of $N_2O$ from soil are:

## Nitrification

Nitrification is a biochemical process by which ammonia ($NH_4$) gets converted to nitrate ($NO_3^-$) by ammonia oxidizing bacteria (AOB). The first process is the oxidation of $NH_4$ into nitrite ($NO_2^-$) by microbes of genus such as *Nitrosomonas* and *Nitrosococcus* followed by further oxidation of nitrite to nitrate ($NO_3^-$) by bacteria of genus *Nitrobacter* and *Nitrospira*. During the process $NO_2^-$ is also reduced to NO and $N_2O$ by AOB (Smith *et al.*, 2003).

The chemical reaction is presented below:

$$2NH_4^+ + 3\ O_2 \rightarrow 2\ NO_2^- + 2\ H_2O + 4H^+ \text{ (Nitrosomonas, Comammox)}$$

$$2NO_2^- + O_2 \rightarrow 2\ NO_3^- \text{ (Nitrobacter, Nitrospira, Comammox)}$$

$$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$$

$$NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$$

## Denitrification

Denitrification is a biochemical process by which nitrates present in soil ($NO_3^-$) is reduced to molecular nitrogen ($N_2$) in a series of reduction processes. The first reduction process converts nitrate ion ($NO_3^-$) to nitrite ion ($NO_2^-$) followed by another reduction process which converts nitrite ($NO_2^-$) to atmospheric nitrogen ($N_2$). This process is facilitated by microbes of genus such as *Pseudomonas*, *Paracoccus denitrificans* present in the root nodules or soil.

The complete denitrification reaction can be expressed as a redox reaction: (Smith *et al.*, 2003).

$$2NO_3^- + 10e^- + 12H^+ \rightarrow N_2 + 6H_2O$$

## 5 Environmental factors controlling GHG emissions from soil.

Greenhouse gases emission from soil is heavily influenced by the interaction between soil physical factors and microbial processes that occurs in the soil. Microbes in the soil facilitate the production and consumption of GHG but the fluxes from the soil is governed by soil physical factors. There are many soil physical factors which affect the production and emission of greenhouse gases such as soil temperature, soil moisture, ground water table, soil pH, organic matter content and C/N ratio but the most prominent one includes (Smith *et al.*, 2003).

- Soil Temperature;
- Aeration and Soil Moisture;
- Ground water table;
- Soil pH.

## 5.1 Soil Temperature

It is one of the important soil factor that directly controls the amount of GHG emitted and consumed in the soil by the influence on soil microbial activity. The Soil temperature influences the microbial activity by affecting the proteins found in their enzymes. As enzymes are very prone to temperature change, both high (>70) and low temperature (< 10) is known to denature their proteins and eventually kill them while they flourish under the moderate temperature range of (25- 55 °C) Consequently, decomposition of organic substrate in the soil decreases in both high and low temperature zones because of which there is low $CO_2$ emission. However, the release of $CO_2$ generally increases exponentially as temperature increases over a moderate range of soil temperature (Smith *et al.*, 2003). The emission of $N_2O$ also has the similar properties to that of $CO_2$. Under the mild conditions, the rate of nitrogen conversion is low, but increases as the temperature increases. However, in a wider range $N_2O$ emission exponentially increases as soil temperature increases. This clearly explains the dependency of greenhouse gas emission on the soil temperature.

## 5.2 Aeration and Soil Moisture

Aeration and soil moisture is another important factor after temperature which governs the production and consumption of GHG

in the soil. The water filled pore space mainly influences the two ways of gas diffusion, the one is diffusion of GHG from soil to the atmosphere and the other one is diffusion of oxygen into the soil by controlling the soil porosity. The soil porosity (aeration) is inversely related to soil water content which means high soil water content results in low soil porosity and vice-versa. The soil porosity in turn controls the flow of air (oxygen) in and out of the soil governing the aerobic oxidation of organic matter and thus emitting substantial amount of $CO_2$ into the atmosphere. The high WFPS which means high water content also creates an anaerobic atmosphere inside the soil promoting anaerobic decomposition of organic matter and releasing methane in the atmosphere. Likewise, the emission of $N_2O$ is also influenced by of WFPS (soil water content). In general, the greater the soil moisture, the greater will be the $N_2O$ emission. However, high soil water content decreases the $N_2O$ emission because low soil water content increases the microbial activity but high water content inhibits it. Therefore, the aeration and soil water content has a clear impact on GHG production and emission (Smith *et al.*, 2003).

## 5.3 Ground Water Table

Ground Water level (GWL) is a depth from the surface of the ground at which mineral water is available. Ground water is available in the soil pores space and fractures of the rock. The depth at which soil pore spaces and fractures of the rock becomes completely saturated is called ground water table. The deeper the GWL, the higher is the soil respiration and the emission of $CO_2$. This is because of the

increase in soil aeration and porosity at higher GWL, which allows the gas and oxygen to move in and out freely. In contrary, the emission of $CH_4$ is opposite to the emission pattern of $CO_2$. The emission of methane increases as GWL decrease and vice-versa. The decrease in GWL provides the anaerobic condition because of the high WFPS (water filled pore space) which results in anaerobic decomposition of organic matter releasing methane as a product. On the other hand, the emission of $N_2O$ decreases as the GWL decreases and becomes highest at intermediate GWL and then again decreases on further decrease of GWL. The one reason is the availability of The reason behind it is that at lower and higher GWL the emission of $N_2O$ is entirely due to denitrification (anoxic) and nitrification (oxic) respectively whereas at intermediate level it is due to both nitrification and denitrification (Karki *et al.*, 2015).

## 5.4 Soil pH

Like temperature and moisture, soil pH is another important variable, which controls the biogeochemical reactions in the soil by influencing the microbial activities. The bacteria, which are accustomed to certain pH, performing certain reactions, cannot perform well in other pH ranges. Certain biochemical reactions like soil respiration, methanogenesis and nitrification or denitrification generally happen optimally at near neutral (pH = 6.5-7.5) range. However, outside the above pH range the activity of archaea performing the similar specific process starts to decrease. In fact, the more we go up or down from the neutral (pH = 7) point on the pH scale, the more the microflora and the associated biogeochemical process get disturbed. As a fact

of matter, high (pH > 12) and low (pH < 2) soil pH are known to denature the enzyme and kill them. Therefore, continuous monitoring of these factors is crucial for controlling the emission of GHG (Thomsen, Geest and Cox,1994)

## 6 Reed Canary Grass

Reed canary grass (RCG) (*Phalaris arundinacea*) is a tall perennial grass commonly found in the wetland areas like peatland, near river valleys and marshy place. Nowadays, it is mainly cultivated as a bioenergy crop to produces biogas and as a source of fuel in biomass power plant but in other countries it is considered as an invasive species. The plant can survive in the wet soil or water logged soil due to the presence of aerenchymatous tissue that delivers oxygen to the roots in anaerobic zones. However, the cultivation of RCG can have an impact on the emission of GHG like $CO_2$, $CH_4$ and $N_2O$ causing effect on overall GHG balance. It stimulates the production of GHG by supplying the labile organic carbon via root exudates. It also stimulates the degradation of organic matter in anaerobic zones by supplying oxygen through the root while at the same time it oxidizes the $CH_4$ gas produced and suppresses the $CH_4$ flux. Also, RCG can decrease the production of $N_2O$ from the soil by assimilation of mineral N thereby decreasing the availability of soil nitrate for the denitrifying microorganisms. Therefore, the presence of RCG in wet peatland areas can alter the amount of GHG production and the underlying mechanism of GHG emission (Karki *et al.,* 2015).

## 6.1 Biogas Production from Reed Canary Grass

At present context, biogas production from anaerobic digestion of biomass has become a promising method for replacing fossil fuels. Traditionally, biogas was produced from manure, industrial waste and sludge but there is a growing interest in using biomass from plants as a substrate for energy production. It is a clean and efficient way of producing energy because of lower amount of emissions to the environment and higher conversion rates compared to direct burning of biomass (Dubrovski *et al.*, 2009). There are many bioenergy crops like maize, festulolium, tall fescue and miscanthus for biogas production. However, one of the emerging and prominent energy crops in use is RCG. It is an interesting alternative feedstock for biogas production because of various advantages over other energy crops as it is perennial, cheaper to cultivate and has lesser environmental impacts during cultivation. Biogas production takes place after the crop is harvested, ensiled and sent to the biogas reactor where the digestion takes place and releases gas. The gas is composed of several gases like methane, oxygen, water vapor, hydrogen sulfide, and trace amount of $NO_x$. The SMY (specific methane yield :) ;( volume of methane produced per unit biomass) and the SBY (specific biogas yield :); (volume of biogas produced per unit biogas are also calculated during the process to determine the concentration of the substrate and the quality of biomass. Therefore, cultivation of energy crop like RCG could be one important source of sustainable clean renewable energy and reduce the dependencies on fossil fuels for energy production. (Kandel *et al.*, 2013).

**7 Methods and Measurements**

The conduction of the experimental process from the start to the end was done by following a certain method and guidelines in which the research measurement, collection and analysis of the data was based on. A specific technique and materials was employed to carry out any specific measurements during the experimental phase and obtain the necessary data for the support of the research. The more detailed discussion on this matter is presented below.

## 7.1 Site Description

The experiment was conducted on fen peatland located in Nørre Å river valley, Denmark ( 44°N, 56°W, 96°E). The site is characterized by mean annual precipitation of 770 mm, mean annual temperature of 7.8°c , peat depth of (h>1 m) and drainage depth of (60-70 cm) which was established in the beginning of 20th century and has since been used for agricultural purposes. The experimental plots on the peatland cultivated with RCG were established in 2009. The soil analysis of the peatland (0-20 cm) had the following properties: highly decomposed peat, bulk density (0.27 g/cm$^3$), total soil organic carbon (37.8%), total nitrogen 3.2% and pH 6.1-7.1.

## 7.2 Experimental Design and Agricultural Management

RCG was grown on four replicated plots in a completely randomized design. Each plot was divided into two subplots where one half of the subplot in every plot was flooded while the other half was kept dry. Flooding was done in a controlled way by pumping water through PVC

pipes inserted at 15 cm below the ground by the water tanks located near the experimental field. A rigid plastic layer was inserted between the flooded and un-flooded half as a barrier to prevent the water flow to the dry part. When the growth of RCG started, the plots were fertilized with 60-13-77 kg ha^{-1} N-P-K mineral fertilizer in spring 2015 and after few months' biomass from the plots were harvested in June 2015.

## 7.3 Soil properties Measurement:

Peat soil at different depths (0–20, 20–50, 50–75 and 75–100 cm) was sampled from the experimental field to determine bulk density. Bulk density was determined following oven drying of volumetric soil samples at 80 °C to constant weight. The average peat thickness at the studied site was more than 1m. The bulk density of the peat soil decreased gradually from 0.29 g cm$^{-3}$ at the surface to 0.12 g cm$^{-3}$ at 1 m depth. Total organic C content in the peat ranged from 27 % to 40 %, while total N ranged from 2.2 % to 3.1 % resulting in peat C: N ratios of 11:13. The soil pH ranged from 6.1 to 7.1.

## 7.4 Gas Measurement
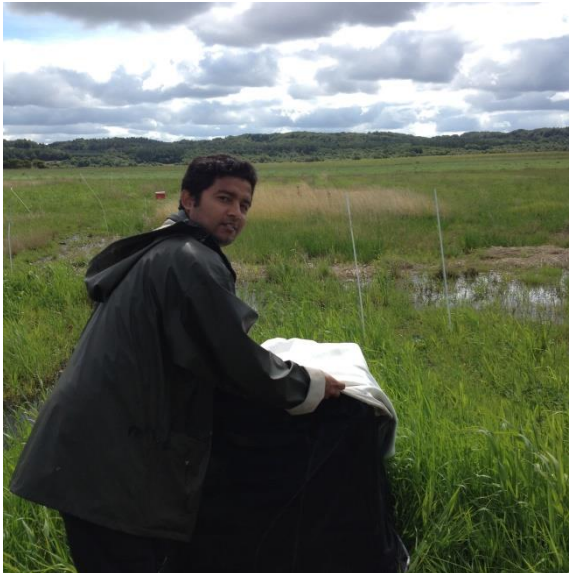
Static chamber technique (Dark chamber method) was used for the quantification of the GHG fluxes from the soil. This technique allows to monitor the rate of change of concentration of the gases inside the chamber while using an opaque, air-sealed chamber (length 40 cm, breadth 40 cm and height 50 cm) equipped with fans and pressure equilibrium vents. Apart from that, the PVC collars of (55*55) $cm^2$ were inserted 2 cm below the soil and the chamber was placed onto it. It was done to prevent gas leakage, establish stability and establishment of the area to be measured. During the gas collection period, the sampling of the gases was done weekly to fortnightly basis for a period of 1 month from June to July. Five gas samples (10 ml) were taken from each chamber during 1 hour of chamber enclosure from chamber headspace with polypropylene syringe and transferred to the evacuated vials. Similarly, three small circular collars having only bare soil was inserted in every subplot to measure the $CO_2$ emission from soil only. A device called in line infra-red gas chromatography (IRGA) was placed on the collar. After the completion of the sample collection, the vials were taken to the

laboratory where gas chromatography was performed to calculate the concentration of the GHG's.

## 7.5 GHG Flux Calculation

## 7.6 Biomass Growth Measurement

Biomass growth in each frame was monitored on every gas sampling occasions by spectral reflectance expressed as a ratio vegetation index (RVI). RVI is a canopy reflectance of the photo synthetically active green biomass present in the plant, which tells about the amount and quality of biomass present in the plant. It utilizes an instrument called (spectrosense 2+) fitted with light sensors which is attached on the handheld pole. The sensors measure the incident and reflected red and near infrared light (NIR). Then RVI is calculated as the ratio of NIR and R, which indicates the amount of active green biomass present. The higher the RVI, the higher is the amount of active biomass and vice-versa (Kandel *et al.,* 2013)

## 7.7 Environmental Variables Measurement

Various environmental parameters like Soil temperature, VWC, GWT and precipitation were measured as a part of the research process. Soil temperature at various depths of 1, 5 and 10 cm were measured every time GHG sampling was done with a digital thermometer. Similarly, soil moisture content or VWC was measured by TDR (Time Domain Reflectometer) by 21 cm long two metal probes inserted in to the soil. GWT at each sub plots were measured during the time of

research by piezometers of 10 cm diameter and 80 cm long below ground length.

## 7.8 Net Ecosystem Exchange

Net Ecosystem Exchange (NEE) also called net carbon exchange is defined as the net exchange of carbon between atmosphere and ecosystem (soil and plants). It is a key variable, which tells whether a land is sequestering carbon or losing to the atmosphere. In other words, it is a cause for the carbon balance in an ecosystem. It is expressed mathematically by:

$NEE = GEP - R_{eco}$

Where

$GEP$ = Gross Ecosystem Production and

$R_{eco}$ = Ecosystem respiration

Scholars define GEP as the total amount of carbon fixed in photosynthesis by plants in an ecosystem. While an ecosystem, respiration is the loss of carbon during respiration by an ecosystem as $CO_2$. Consequently, if the GEP in an ecosystem overcomes respiration then, carbon gets deposited; otherwise, it is lost as carbon dioxide emission (Kandel *et al.,* 2013).

NEE was measured by transparent chamber method. A transparent chamber (3 mm) thick made up of Plexiglas was deployed for the measurement of NEE. The chamber was installed with two thermometers to check the temperature of the air inside and outside of the chamber. The tightness of the chamber was ensured by installation of rubber gasket on the lower edge of the chamber.

# 8 Results

In this research, gas sample from both dry and wet plots were collected and tested in the laboratory followed by the statistical analysis. The various graphs were obtained after the data were fed into the statistical software such as R and Microsoft Excel. After that, the data were analysed with as many possible ways to ensure the disambiguity of the result and to reach the appropriate conclusion. The results are interpreted through various data and figures presented below.

## 8.1 Input parameters and flux calculation

Table 1 below shows the various input parameters associated with the flux calculation.

***Table 1. Input parameters for flux calculation***

| Air temperature (Kelvin) | 289.6 |
|---|---|
| Chamber base ($m^2$) | 0.3025 |
| Chamber Volume ($m^3$) | 0.15 |
| Volume of 1 mol of ideal gas ($m^3$) | 0.0238 |

The table 2 below shows the flux calculation procedure for carbon dioxide. Here, the concentration of carbon dioxide is calculated in laboratory by gas chromatography. The slope is calculated from the concentration using linear regression.

Note: The units of measurement for different parameters are as follows:

Time: h

Concentration: ppm

Flux_1: µg/m$^2$/h

Flux_2: µg/m$^2$/d

**Table 2. Flux calculation method for CO$_2$**

| Frame | Time | Duration | CO$_2$ conc. | Slope | Flux_1 | Flux_2 |
|-------|------|----------|--------------|-------|--------|--------|
| 1 | 0:00:00 | 0.00 | 377.307 | 194.89 | 180739 | 4.337 |
| 1 | 0:15:13 | 0.254 | 420.740 | | | |
| 1 | 0:29:28 | 0.491 | 498.405 | | | |
| 1 | 0:44:06 | 0.735 | 508.088 | | | |
| 1 | 1:00:12 | 1.003 | 576.109 | | | |

The table 3 and table 4 below show the flux calculation method of N$_2$O and CH$_4$. The method of the calculation of the flux is like that of CO$_2$. All the concentration of the GHG's were calculated in the laboratory by gas chromatography and the slope was calculated by linear regression of the concentration.

**Table 3. Flux calculation method for N$_2$O**

| Frame | Time | Duration | N$_2$O | Slope | Flux_1 | Flux_2 |
|-------|------|----------|--------|-------|--------|--------|
| 1 | 0:00:00 | 0.00 | 0.315 | 0.34 | 320 | 7.676 |

| 1 | 0:15:13 | 0.254 | 0.474 | | | |
|---|---------|-------|-------|---|---|---|
| 1 | 0:29:28 | 0.491 | 0.525 | | | |
| 1 | 0:44:06 | 0.735 | 0.598 | | | |
| 1 | 1:00:12 | 1.003 | 0.682 | | | |

*Table 4. Flux calculation procedure for $CH_4$*

| Frame | Time | Duration | $CH_4$ | Slope | Flux_1 | Flux_2 |
|-------|------|----------|--------|-------|--------|--------|
| 1 | 0:00:00 | 0.00 | 2.790 | 23.03 | 21361 | 512.671 |
| 1 | 0:15:13 | 0.254 | 4.685 | | | |
| 1 | 0:29:28 | 0.491 | 13.092 | | | |
| 1 | 0:44:06 | 0.735 | 20.563 | | | |
| 1 | 1:00:12 | 1.003 | 23.6 | | | |

## 8.2 Analysis of the data and figures

The figure 1 shows the spatial variation of the GHG's among dry and wet plots. It is clear from the figure that $CO_2$ was dominant GHG emitted in terms of amount from every plot compared to $CH_4$ and $N_2O$. In every plot, emission of $CO_2$ was higher from the unflooded (dry)

part than the flooded part (wet). However, there was a spatial variation in $CO_2$ emission among the dry subplots and on the wet subplots too. The spatial variation is obvious from the figure as the highest emission of $CO_2$ among dry subplots was 18.5 g /m$^2$/d and lowest emission was 9 g/m$^2$/d. while highest emission of $CO_2$ among wet subplots was approximately 17 g/m$^2$/d and lowest was 6 g/m$^2$/d.

Similarly, $CH_4$ was the second most abundant GHG flux emitted. A huge difference in emission of $CH_4$ between two treatments was observed in every plot. The methane flux had a very little variation among the dry subplots, but larger variation among the wet subplots which can be seen easily from the figure. The highest emission of $CH_4$ among wet part was 1000 mg/m$^2$/d while lowest emission was approximately 30 mg/m$^2$/d. In contrast, dry parts had almost  same amount of emission of about 25 mg/m$^2$/d.

Likewise, of all the greenhouse gases, $N_2O$ was the least amount of GHG emitted. The highest amount of $N_2O$ emitted was 25 mg/m$^2$/d which was very small compared to the emission of $CH_4$ and $CO_2$. It is also clear that emission of $N_2O$ was higher from the wet subplots than the dry ones. The wet plots had the highest and lowest emission of 25 mg/m$^2$/d and 1 mg/m$^2$/d respectively and dry parts had the highest and lowest emission of 3 mg/m$^2$/d and 0.5 mg/m$^2$/d, which indicates the variation in the emission among the wet and the dry subplots.
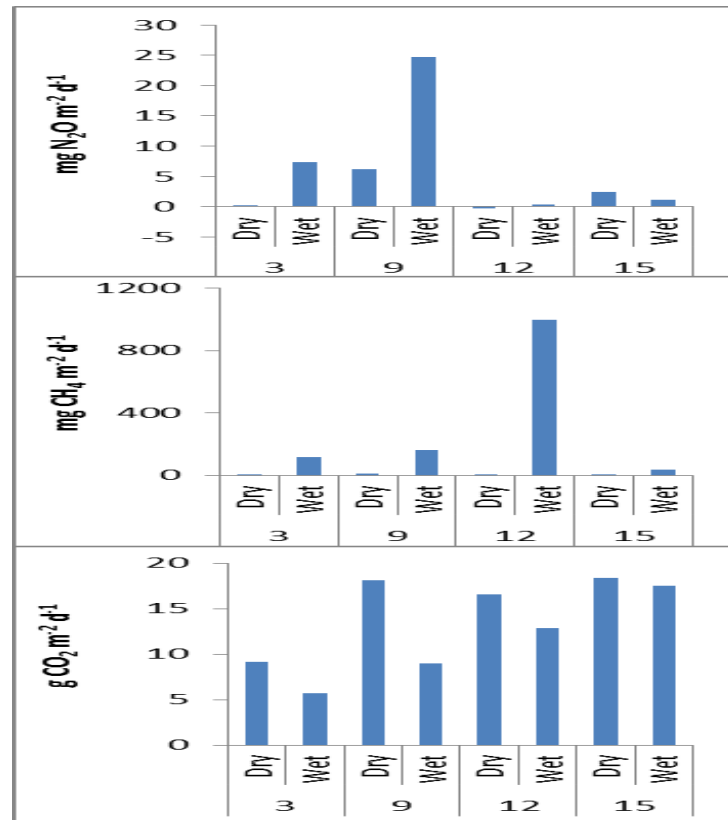
*Figure1.Spatial variation of $CO_2$, $CH_4$ and $N_2O$*

Figure 2 below shows the average emission of $CO_2$, $CH_4$ and $N_2O$ from dry and wet subplots. The emission of $CH_4$ and $N_2O$ from the flooded (wet) part was higher than that of unflooded (dry) part, but the situation was vice-versa in the case of $CO_2$.

The average emission of $CO_2$ from the dry part was about 16 $g/m^2/d$ while from the wet part was about 11 $g/m^2/d$. Therefore, it is evident that the dry subplots emitted 31.25% more $CO_2$ in average than wet subplots.

Similarly, the emission of $CH_4$ from the flooded part was significantly higher than that of the unflooded part. The average flux of $CH_4$ from the wet part was about 300 $mg/m^2/d$ whereas from the dry part was about 10 $mg/m^2/d$, which was 96.66% higher than that of dry part.

The $N_2O$ emission shows a similar trend to that of $CH_4$. It was emitted higher from the wet part than the dry one. The average emission of nitrous oxide from wet part was about 8.5 mg/m$^2$/d, while from the dry part was 2 mg/m$^2$/d, which resulted in 81.25% higher emission from the wet part.
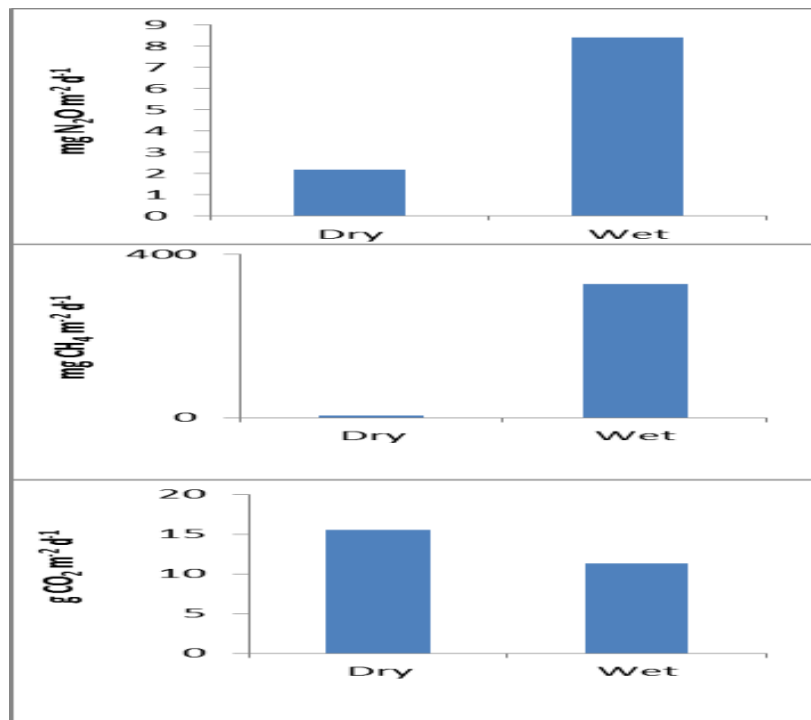


*Figure 2. Average emission of $CO_2$, $CH_4$ and $N_2O$ from the dry and wet subplots.*

Figure 3 below shows the total average emission of GHG's ($CO_2$, $CH_4$ and $N_2O$) from 4 replicated plots. It is rather clear from the graph that the emission of GHG's from the dry part was larger than the wet part. More precisely, the dry part emitted 45% more GHG's than the wet part. This is a solid proof that the peatland, which was drained and used in cultivation, is a greater source of GHG emission for global warming and climate change than the wet peatland.
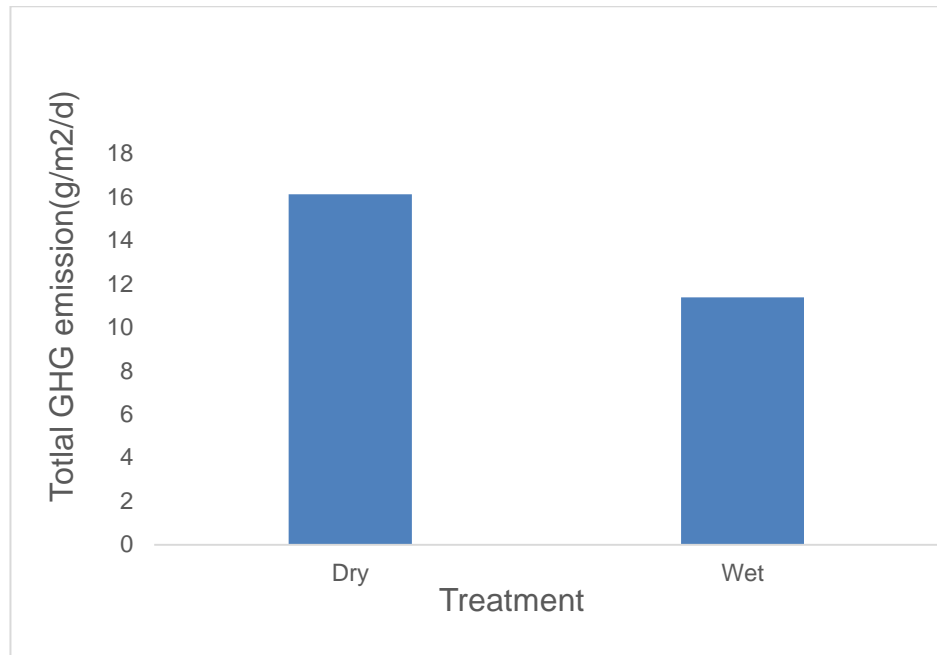
*Figure 3.Total emission of greenhouse gases from Dry and Wet subplots.*

The Figure 4 below shows the emission of $CO_2$ over time. It is clear from the graph that the concentration of $CO_2$ inside the chamber was linearly increasing with time. In other words, carbon dioxide was found to be emitted in a fixed rate, with the slope given by the fitted equation. In addition, the high value of R- squared in this case indicates that the data best fit with linear equation.
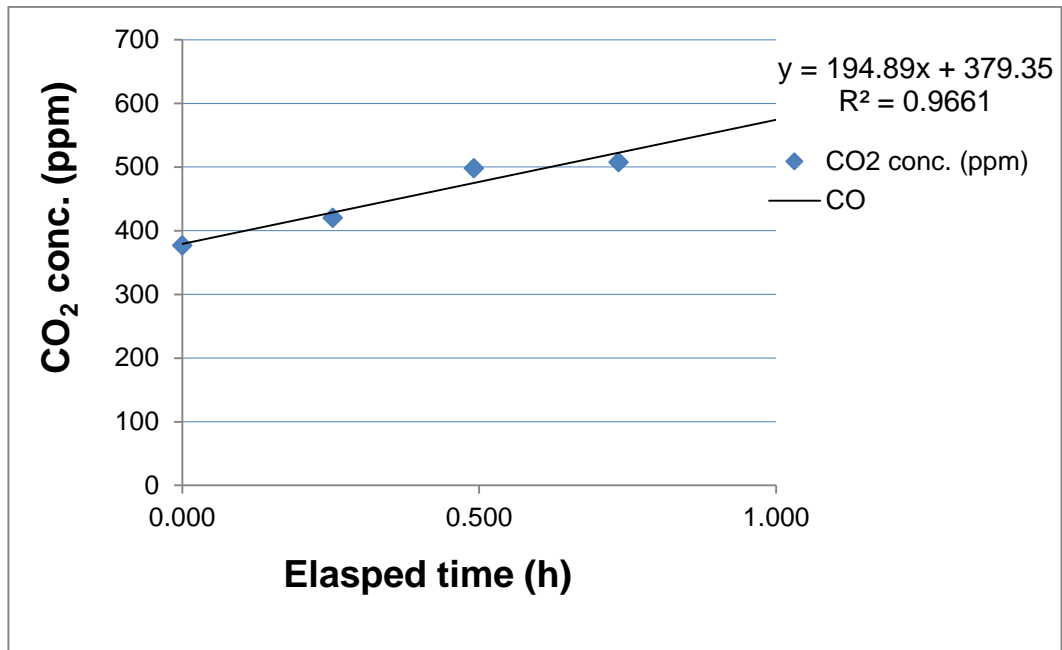
*Figure 4.Emission of CO₂ as a function of time.*

The figure 5 below shows the methane emission relative to time. From the figure, it is easy to see that the concentration of methane is increasing linearly with time inside the chamber. However, the rate of emission is very low compared to that of $CO_2$ as indicated by the small slope.
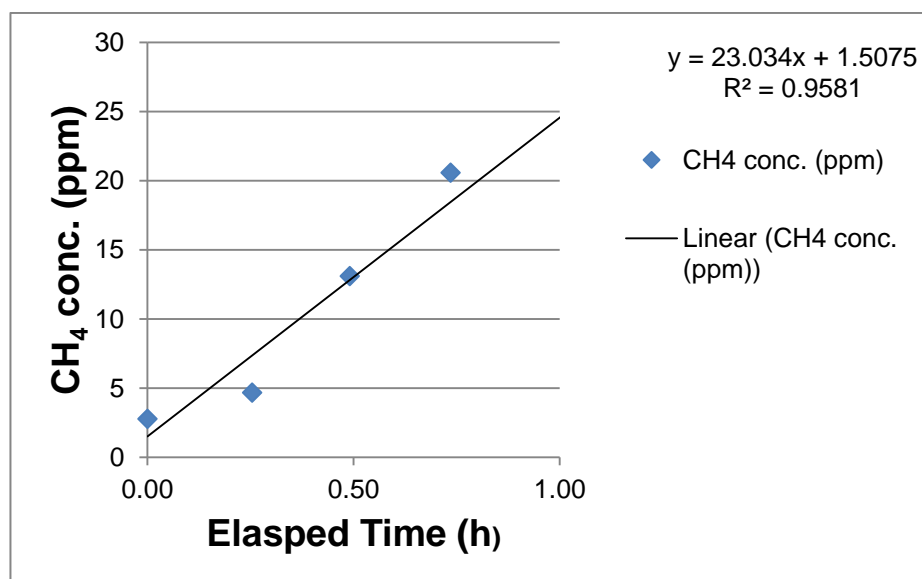


*Figure 5. Emission of methane as a function of time.*

Similarly, Figure 6 shows that the emission of $N_2O$ is also increasing linearly with time; however, it's rate of emission is low. In fact, it had the lowest rate of emission among the GHG's which is indicated by the small slope (0.3449).
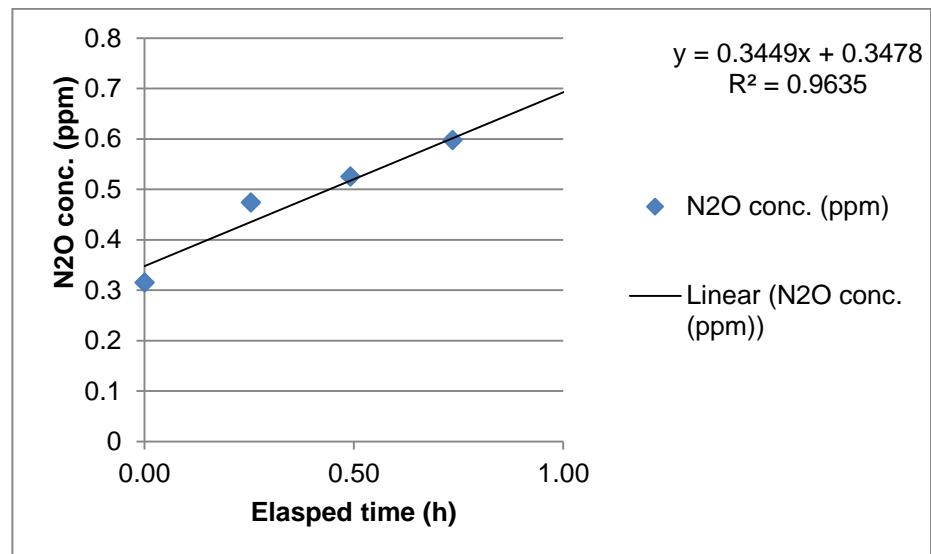


*Figure 6.Emission of $N_2O$ as a function of time.*

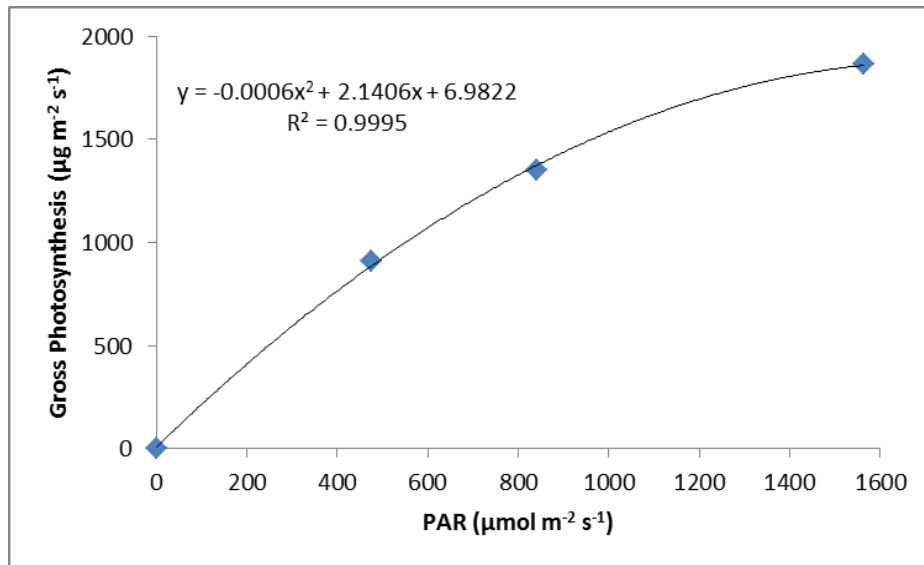## 8.3 Gross photosynthesis as a function of light response



*Figure 7.Effect of light intensity (PAR) on gross photosynthesis.*

It is clear from the graph that gross photosynthesis or net $CO_2$ uptake increases exponentially with increasing intensity of falling light and becomes saturated at certain light intensity. Here, at the light intensity of 0 µmol/m²/s (PAR) gross photosynthesis is 0 µg/m²/s and maximum at 1600 µmol/m²/s with gross photosynthesis of about 1750 µg/m²/s.

## 9 Discussion

This experiment investigated the effect of flooding in a peatland on greenhouse gas emission by comparing it with the emission from the wet and the dry plots. Unlike $CO_2$, emissions of $CH_4$ and $N_2O$ was higher from wet parts than from the dry one, which is compatible with the previous findings. However, a large spatial variation in the emissions of nitrous oxide and methane were observed especially

within wet parts (Figure 1). There might be many possible reasons associated with it. One of the reasons might be the cultivation of RCG, which have a complex effect on the biogeochemical properties of the soil and may have contributed to higher emissions of $CH_4$ as fresh carbon in it's root exudates is more easily converted into $CH_4$ than the old carbon in the peat. In addition, the sudden large spike in the emission of $N_2O$ from the wet plots might be due to the application of the prior to the conduction of the experiment which triggered the denitrification process after the area had been flooded, resulting in the euphoric emission of $N_2O$. However, in one of the plot, emission of $N_2O$ was higher from the dry part (Figure 1.), which might be because of the increase in the growth of vegetation in the adjacent wet part that consumed more nitrate leaving less for the denitrification process.

## 10 Conclusion

From this experiment, following conclusions could be drawn based on the results and repetitive observations.

1) In all the four experimental plots, the dry part contributed more in emission of $CO_2$ than  wet part. The dry part released almost 32% more $CO_2$ in average than the wet part. (Figure 2)

2) The emission of methane was predominant from marshy and wet areas. The wet part was responsible for 97% of the methane emission. However, it does not mean that wet part is a dominant force of GHG emission. (Figure 2)

3) Similarly, the wet part emitted more $N_2O$ than the dry part. In total, the Wet part released 81% more nitrous oxide than the dry part. (Figure 2)

4) Figure 3 is quite misleading; especially in the case of methane and nitrous oxide where one may easily think that the wet areas are emitting more GHG and should be more responsible for global warming and climate change. This holds true only for the individual emission scenario; In fact, in comparison to the total emission, dry area released 45% more GHG's than the wet area. (Figure 3)

These findings suggest that the draining of fen peatland cultivated with RCG can particularly lead to the higher emission of Carbon dioxide while rewetting results in lower emission of $CO_2$ but higher emissions of $CH_4$ and $N_2O$. The high emission of $CH_4$ and $N_2O$ is counterbalanced by a low emission of $CO_2$ providing good overall GHG benefit. As the emission of $CO_2$ lowers, more and more carbon sinks into the soil. Thus, the natural property of the peatland is restored in rewetting whereas drainage destroys the peatland.

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## Appendices

### Appendix 1.             Glimpse of the experimental field



The picture above shows the experimental field which is a peatland near river valley


### Appendix 2.             Cultivation of reed canary grass



The above picture shows the cultivation of Reed canary grass in the peatland prior to the conduction of the experiment.

**Appendix 3.**       **Results of flux calculation**

| Plot | Treatment | Frame | $CO_2$ (g day-1) | $CH_4$ (mg day-1) | $N_2O$ (mg day-1) |
|---|---|---|---|---|---|
| 3 | Dry | 1 | 9.13 | 6.42 | 0.24 |
| 3 | Dry | 2 | 9.09 | 8.65 | 0.25 |
| 9 | Dry | 1 | 14.58 | 7.62 | 7.87 |
| 9 | Dry | 2 | 21.56 | 16.83 | 4.55 |
| 12 | Dry | 1 | 17.19 | -0.98 | 0.22 |
| 12 | Dry | 2 | 16.00 | 3.54 | -0.68 |
| 15 | Dry | 1 | 17.98 | 0.37 | 5.00 |
| 15 | Dry | 2 | 18.75 | 0.22 | -0.09 |
| 3 | Wet | 1 | 4.93 | 206.41 | 12.71 |
| 3 | Wet | 2 | 6.51 | 26.55 | 1.94 |
| 9 | Wet | 1 | 8.26 | 90.24 | 12.29 |
| 9 | Wet | 2 | 9.74 | 230.82 | 37.16 |
| 12 | Wet | 1 | 10.93 | 1071.24 | -0.31 |
| 12 | Wet | 2 | 14.71 | 926.62 | 0.96 |
| 15 | Wet | 1 | 16.37 | 16.49 | 0.59 |
| 15 | Wet | 2 | 18.65 | 57.07 | 1.83 |