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EFFECTS OF ELEVATED SOIL TEMPERATURE AND ALTERED PRECIPITATION PATTERNS ON N-CYCLING AND PRODUCTION OF N_2O AND CO_2 IN AN AGRICULTURAL SOIL

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Declaration

I hereby declare that I have written this thesis entitled "Effects of Elevated Soil Temperature and Altered Precipitation Patterns on N-Cycling and Production of N_2O and CO_2 in an Agricultural Soil" as my original work independently as a portion of my dissertation at the Faculty of Agricultural Sciences, the University of Hohenheim. This thesis is an independent work and no sources but those which are listed in the references have been used.

Place, Date……. Signature…….

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Abbreviations

C	Carbon
CO_2	Carbon dioxide
C_{mic}	Microbial biomass cabon
CH_4	Methane
CO_2	Carbon dioxide
DWC	Dry-wet cycle
GHGs	Greenhouse gases
HoCC	Hohenheim climate change experiment
H_2O	Water
IPCC	Intergovernmental Panel on Climate Change
K_2SO_4	Potassium sulphate
N/N_2	Nitrogen/ Dinitrogen
nm	Nanometers
N_{mic}	Microbial biomass nitrogen
N_{min}	Soil available mineral nitrogen
NH_3	Ammonia
NH_4	Ammonium
NO	Nitric oxide
NO_2	Nitrogen dioxide
N_2O	Nitrous oxide
NO_2^-	Nitrite
NO_3^-	Nitrate
O_2	Oxygen
OC	Organic carbon

OM	Organic matter
Pg	Petagrams
ppb	Parts per billion (10^{-9})
ppm	Parts per million (10^{-6})
r.p.m	Revolutions per minute
Tg	Teragram (10^{12} g)
SOC	Soil organic carbon
SOM	Soil organic matter
µg	Microgram
VWC	Volumetric water content
WHC	Water holding capacity
Yr	Year

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Chapter 1: Introduction

1.1 Background

The global average surface temperature has increased by 0.6 – 0.9°C since the late 19th century (EIA, 2005). According to the predictions of the Intergovernmental Panel on Climate Change (IPCC, 2007), the global average surface temperature will be increased by an additional 0.6 – 2.5°C over the next 50 years and by 1.1–6.4°C by the end of the 21st century, though these values will change significantly by region.

Studies have indicated that the atmospheric concentration of greenhouse gases (GHGs), such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) have risen by 31%, 17% and, 151% respectively (Bouwman et al. 2000) within less than 150 years (IPCC, 2001). The atmospheric concentration of N_2O has gained from 270 ppb at the preindustrial time to 314 ppb. It has been found to be responsible for 5 – 6% of global warming (Lægreid et al. 1999; IPCC, 2001). The increase of N_2O emissions is attributed to the increased nitrogen (N) input into the biosphere (Mosier et al. 1998; IFA & FAO, 2001). Currently, there is no question that this change in atmospheric composition is mainly caused by human activities (Houghton, 1997).

With 379 ppm CO_2 in the atmosphere in 2005 (Forster et al. 2007) and 388 ppm in September 2011 (Conway and Tans, 2011), the CO_2 concentration has never reached a higher level in earth's history in the past 400,000 years, found by ice core analysis (Prentice et al. 2001). Woodwell et al. (1998) found a positive correlation of atmospheric CO_2 concentrations and temperature for the past 220,000 years. Anthropogenic production of GHGs, like CO_2, N_2O, CH_4, halocarbons, ozone, water vapour, and aerosols, are responsible for an average worldwide temperature rise of 0.76°C during the last 150 years (from 1850–1899 to 2001–2005) (IPCC, 2007).

The ecological consequences of global warming on soil microbial activities and nitrogen cycling have become a very important issue in global change research because a changing global climate is likely to alter these processes. Soils represent a very large sink of CO_2, holding more than three-fold the quantity of carbon (C) stored in aboveground biomass and

two-fold the quantity in the atmosphere (Eswaran et al. 1993). Any long-term changes in climate may have enormous influence of soil C cycling and C sequestration rates (Lal, 2004).

It is unclear if climate change will lead to high rates of CO_2 loss to the atmosphere or facilitate soil carbon sequestration due to uncertainties in climate forecasts, as well as the many complex interactions of climate on soil microbial activities. The results will likely vary between ecosystems, highlighting the need for more site- specific research (Landesman, 2009).

IPCC report (2007) states, that an anthropogenic influence on climate change is evident. It will have comprehensive effects on ecosystems worldwide, including agro-ecosystems. Agriculture is not only a source but also a sink for GHGs. The exchange of N and C between the atmosphere and the land has increased by intensification of land use. 37% of the earth's land surface is occupied by agricultural lands. Moreover, conversion of native vegetation to agricultural land is a major factor contributing to greenhouse GHGs emissions (Graham et al. 2011). German and American agriculture accounts for more than 13% (Hirschfeld et al. 2008) and 6-8% (Jhonson, 2009) of the total country-wise GHG emissions, respectively. The majority of agricultural N_2O emissions are produced from fertilizers, livestock waste and burning crop stubble. In fertilized soils, N_2-fixation by plants and microorganisms, denitrification of soil N in the form of N_2, N_2O, and gaseous ammonia (NH_3) are some examples for the change of N containing gases between the atmosphere and land surfaces. This changing pattern has been a crucial issue in agricultural and soil research for years (Algaidi et al. 2009).

The contribution of agricultural soils to N_2O emissions depends upon decomposition of organic residues (Diz-Munoz et al. 2010), mineral fertilizer addition (Moiser et al. 1998), soil moisture, and temperature (Ruser et al. 2006). Agriculture emits 10 to 12% of the total estimated CO_2 emissions (Niggli et al. 2009), which symbolizes between 17 and 32% of all global human-made GHGs emissions, including GHGs derived from land use changes (Bellarby et al. 2008). Immediate action will be needed for understanding the main factors determining the change of these GHGs between the atmosphere and the soil in order to develop effective mitigation technologies at different scales.

In Europe, temperature changes have increased by + 0.9°C from 1901–2005 (Jones and Moberg, 2003) and are expected to increase by 2.5 – 5.5°C (A2 scenario) or 1 – 4°C (B2 scenario) in the period from 2070 – 2099 (Alcamo et al. 2007). Jacob et al. (2008) predicted temperature increases of 2.5 – 3.5°C for Germany in the period from 1950–2100. Apart from temperature changes, precipitation patterns in Europe are expected to change as well (Alcamo et al. 2007). The entire amount of precipitation is expected to decrease in summer months and increase in winter. With climate change, global atmospheric circulation patterns and hydrological processes are expected to alter inter and intra-annual variability of precipitation regimes at global (Trenberth et al. 2007) and regional scales (Christensen et al. 2007). These changes in air temperature, altering seasonal soil temperature as well as leading to increased variability in intra-annual precipitation, can greatly affect the soil moisture variability, soil nitrogen (N) content and availability to plants, and, therefore, influence the response of crop production (Hlavinka et al. 2009). Climate change might increase crop yield by + 37% in the B2 scenario and + 101% in the A1Fl scenario by 2050 (Ewert et al. 2005). However, the overall yield increase comes with higher variability and more insecurity at harvest due to extreme weather events like drought and heavy rainfall, so that average yields could be reduced in the future (Alcamo et al. 2007).

Plant growth and nutrient uptake of plants have been reported to respond to small increases in soil temperature (Clarkson et al. 1992; Engels and Marschner 1992; Gavito et al. 2001). For example, elevated air and soil temperatures can decrease soil moisture availability and increase soil N content and N availability to plants, affecting the response of crop production to climate change (Patil et al. 2010). Warming and/or drought can change plant-N concentrations mainly by changing plant biomass production and soil N availability, thereby affecting plant C/N ratios as observed in temperate non-Mediterranean ecosystems (An et al. 2005) as well as in some arctic ecosystems (Tolvanen and Henry, 2001; Weintraub and Schimel, 2005). In comparison to these studies in natural ecosystems only a few experiments have been conducted to investigate the effects of climate warming on agricultural ecosystems for e.g. peanut (Awal & Ikeda 2002; Prasad et al. 2006) and maize crops (Stone et al. 1999). Enhanced root growth, higher biomass of leaves and stems, and lower N-concentrations in leaves and stems were observed for wheat under elevated temperature (Gavito et al. 2001).

The few field studies accomplished on soil warming in agriculture systems have looked at mainly crop response and productivity, like changes in plant growth, biomass accumulation and nutrient absorption rates (Clarkson et al. 1992; Engels and Marschner, 1992; Gavito et al. 2001) but how this is related to N-cycling in soils remains unclear. Ineson et al. (1998) found decreased N concentrations in soil solutions of an upland brown earth in lysimeter experiments under elevated soil temperature of 3°C above ambient temperature. Kamp et al. (1998) looked at soil-N availability and found higher NO_3^- and lower NH_4^+ contents in heated plots of both fallow and wheat fields. Similarly, Dijkstra et al. (2010) reported increasing inorganic N pools at elevated temperature in a grassland soil. Patil et al. (2010a; 2010b) evaluated the effects of increased soil temperature (+ 5°C above ambient temperature) on N cycling and plant growth of winter wheat in a lysimeter experiment in Denmark. They found accelerated plant development, increased biomass, and higher N-concentrations in plant tissues during vegetative stages under elevated temperature, which was related to increased nitrate (NO_3^-) availability in soil.

It is important to understand how soil microbial activity will respond to warming as most important biogeochemical processes in soil are microbially mediated. Increased soil temperature may result in a more favourable environment for microbial growth and activity, thereby increasing N availability and net primary production (Pendall et al. 2004). If temperature controls development processes, warming may directly affect the plants (Koerner and Larcher 1988), but also indirectly, because litter and soil organic matter decomposition and nutrient mineralization are probably accelerated by warming (Nadelhoffer et al. 1992, Robinson et al. 1997). Therefore, studying the effects of elevated soil temperature on soil N dynamics is important to evaluate the possible effects of climate change on agricultural management and food production (Wang et al, 2006).

The impacts of climate change on agriculture and food production make it critical to understand the underlying mechanisms. A lot of studies have been carried out in the last 15 years to assess the impacts of climate warming on various vegetation types. The main focus was on bogs, heathlands, forests, grasslands, and scrublands (Borekn et al 1999; Sardans et al 2006). Comparatively, only a few experiments have been carried out to analyze the effects of climate warming on agricultural crops and soils. Due to the important role of agricultural ecosystems too, we conducted our study at the Hohenheim Climate Change

(HoCC) experiment, which was established in a temperate agricultural ecosystem, where soil temperature and precipitation amount and frequency are manipulated (Poll et al. 2013).

1.2 Research objectives

The main aim of this dissertation is to determine the effects of elevated soil temperature and changing precipitation patterns on N cycling in a winter wheat cropping system and the emissions of GHGS such as N_2O and CO_2 which play a significant role in global warming.

The hypotheses for this thesis were, that

1. Elevated soil temperature changes N-cycling of an agricultural cropping system.
2. Changing precipitation patterns would alter N_2O and CO_2 emission patterns during dry periods in summer.
3. The magnitude of rewetting influences CO_2 production during drying-rewetting events.

To test these hypotheses, we had the following objectives.

1. Determination of the effects of elevated soil temperature on N cycling in a winter wheat cropping system,
2. Investigation of the short-term response of N_2O and CO_2 fluxes during rewetting of soils after extended dry periods in summer before and after following rain through rain simulation experiments, by using the field experiment which have experienced five years of environmental manipulation since 2008,
3. Determination of event-driven CO_2 emission peak in the use of soil cores from the HoCC experimental site that had been exposed to severe drought conditions of three months' duration for each of the last six years, by simulating drying-wetting events under laboratory conditions.

1.3 Outline of thesis

This thesis reports the results of a PhD project where the overall subject of the study was to determine the effects of elevated soil temperature and changing precipitation patterns on soil N cycling and CO_2 and N_2O emissions from agricultural soil. This thesis is divided into five chapters. The first chapter provides a general introduction. Chapter 2 presents a comprehensive literature review on the knowledge of N_2O and CO_2 formation and emissions

from agricultural soils, N cycling, and drying rewetting effects on gas fluxes. Chapter 3 focuses on the procedures and data analyses of all field and laboratory experiments conducted. Chapter 4 provides the results obtained from the methods in Chapter 3. A detailed discussion of results is provided in Chapter 5 followed by a general conclusion and summary.

Chapter 2: Literature Review

Most of the current global change research investigating the effects of climate warming on N cycling and trace gas fluxes such as N_2O and CO_2, has focused on grassland and forest ecosystems. Little has been done in agroecosystems, where both plants and soil microbes are believed to be more responsive to elevated temperature (Melillo et al. 1993). Agroecosystems are particularly important because they not only provide the majority of global food needs, but have been suggested to have an enormous potential to sequester more C (Lal, 2004; West & Post, 2002; Paustian et al. 1997).

2.1 Climate-related greenhouse gases (GHGs)

GHGs are a natural contribution to the atmosphere. The absorption and emission of GHGs within the thermal infrared range is known as the underlying cause of the greenhouse effect. The earth's atmosphere retains the amount of solar energy, called greenhouse effect and the gases that trap heat are called greenhouse gases (Ophardt, 2001; Rajput et al. 2014). Water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3) are the main GHGs in the Earth's atmosphere (EPA, 2010). The amount of GHGs in the atmosphere is increased by human activities such as burning fossil fuels for energy, land clearing, and agriculture (IPCC, 2007).

The global temperature is directly related to the amount of greenhouse gases in the atmosphere. Increased concentrations of GHGs will increase the atmospheric temperature, which will lead to the warming of the atmosphere and Earth's surface (Takle, 2008). CO_2 and N_2O are the long-lived greenhouse gases (Forster et al. 2007). They are chemically stable and exist in the atmosphere over decades and centuries or longer. They become well fluxed throughout the atmosphere much faster than they are moved out. Therefore, their emissions have become a long-term influence on the climate (IPCC, 2007).

2.1.1 N_2O emission

Agriculture accounts for approximately half of the anthropogenic N_2O emission in the EU (UNFCCC, 1998). On a global scale, 47% of N_2O emissions (IPCC, 2001) come from anthropogenic sources, particularly from the agricultural N cycle (Mosier et al. 1998). N_2O has great importance as a GHG because it has a mean atmospheric residence time of more

than 100 yr (Prather et al. 2001). N_2O, as part of the Earth's nitrogen cycle is normally present in the atmosphere. Although it has different kinds of natural sources, the amount of N_2O is increased by human actions such as agriculture, fossil fuel combustion, wastewater management (EPA, 2010). The N_2O emissions caused by human activities are mainly due to tillage (44%) and fertilization (22%) of agricultural soils, followed by the burning of biomass (9%) and fossil fuels (10%). High emissions from agricultural soils are primarily caused by the application of N fertilizer, which is transformed by nitrification and denitrification into N_2O (Algaidi et al. 2006).

N_2O is potentially agriculture's greatest contributor to the GHG Problem. It is a serious pollutant, implicated in virtually all current environmental problems (e.g. acid rain, GH effect, O_3 depletion). Global warming and stratospheric O_3 depletion are caused by N_2O emission (EPA, 2010). According to model calculations, atmospheric N_2O may become a value ranging from 354 to 460 ppb, compared with the present concentration of 316 ppb by 2100 (IPCC, 2001a).

N_2O is produced mainly from the microbial processes of nitrification and denitrification in the soil. In well-aerated conditions, N_2O emissions from the nitrification of ammonium based fertilizers can be substantial (Bremner and Blackmer, 1978; Duxbury and McConnaughey, 1986). Mineral N applications and organic matter amendments generally increase total denitrification and N_2O production. Other studies suggest that N_2O is a by-product of nitrification (Yoshida and Alexander, 1970) and may occur by denitrification of nitrite by nitrifying organisms under oxygen stress (Poth and Focht, 1985). N_2O production by autotrophic nitrification was considered to be negligible (Bateman and Baggs, 2005). However, under some conditions, nitrification might be the dominant source of N_2O at low soil carbon contents (Wan et al. 2009). Denitrification as compared to nitrification is often identified as the major source of N_2O (Hefting et al. 2003).These two natural processes are enhanced by anthropogenic activities.

2.1.2 CO_2 emissions

Due to human activity, the atmospheric CO_2 concentration has increased by approximately 33% in the last 150 years. The concentration is anticipated to rise by 0.4 % per year (Alley et al. 2007). When sufficient mineral nutrients are available, this increased CO_2 concentration

may stimulate plant biomass production as well as root growth (Ghannoum et al.2000; Curtis & Wang, 1998). Consequently, there is greater C input into the soil not only by higher rates of plant litter-fall, rhizodeposition and root turnover but also by changes in the chemical composition of plant tissues and root exudates, greater C inputs into the soil could be resulted (Denef et al. 2007).

CO_2 is normally present in the atmosphere as a part of the Earth's carbon cycle. Although CO_2 emissions derive from a variety of natural sources, human-related emissions are responsible for the increases to the atmosphere. The burning of fossil fuels (coal, oil and natural gas) for energy and transportation is the major human activities that emit CO_2 (EPA, 2010).

Organic matter decomposition and soil microbial respiration are also the sources of CO_2 emissions (IEA, 2012). Jenkinson et al. (1991) estimated that over the next 60 years, the extra release of CO_2 from soil organic matter will be 61 x 1015 g C. Irregular rainfall events, non-judicious use of inorganic and organic fertilizers and land management practices will enhance organic matter decomposition (Lal, 2008).

2.2 Effects of environmental change on soil processes

Environmental changes in local as well as global scales are likely to substantially affect the various components of terrestrial and aquatic ecosystems; however, very little is known about the nature of such changes and the magnitude how they will impact ecosystem processes and functioning (Stark and Richards, 2008). Environmental changes such as rising temperature (0.5 - 1°C by 2030) and CO_2 levels (up to 550 ppm), more variable precipitation patterns causing more severe droughts and floods, and accelerated rates of N deposition will have a growing impact on the productivity and functioning of agroecosystems worldwide by altering soil and growing conditions and plant productivity (IPCC 2007). Actual effects will vary regionally subject to site-specific interactions of the various climatic factors as well as soil and crop type and soil nutrient status, which strongly depend on local conditions (Stark and Richards, 2008).

The effects of climate change on soil microbial processes are less well understood especially for soil N dynamics (Zak et al. 2000). With temperature, water, C and N content being the

main drivers for biogeochemical processes in soils, environmental change will have direct and indirect consequences on soil nutrient turnover processes, including C cycling, ammonificaton, nitrification and denitrification, by modifying soil microbial communities, plant nutrient uptake and root exudation (Phillips et al. 2006; Chung et al. 2007; Dijkstra and Cheng, 2008).

Coupled with the expected rise in air temperature is an increase in soil temperature (Parton et al. 1987). It is predicted that the global average surface temperature will increase by between 1.4 and 5.8^{o}C until 2100 if the concentration of greenhouse gases continues to rise (IPCC, 2007). Elevated temperature levels and changing rainfall patterns are expected to stimulate microbial activity and increase microbial mediated soil processes. This could change relative N loss from soil systems by stimulating mineralization, which increases soil nitrate availability, or by promoting plant growth and N uptake as well as microbial N immobilization (Smith et al. 1997; Fuhrer 2003; Beier et al. 2004). Hart (2006) reported increases in active microbial biomass, net N mineralization and nitrification, and, net CO_2 efflux as a consequence of elevated temperature, while Barnard et al. (2005) concluded from a meta-analysis of published experimental data that elevated temperature had no significant effects on enzyme activities and net nitrification. Raising the soil temperature by 0.5^{o}C increased N mineralization, resulting in higher concentrations and subsequent losses of nitrate and dissolved organic N at a heathland site in the Netherlands (Schmidt et al. 2004).

2.3 Agriculture and nitrogen cycling

Koponnen (2007) described that “N-cycling is affected by human activities to a great extent. By the production of synthetic nitrogen fertilizers and the cultivation of N_2-fixing plants, Global N cycle is the regular increase in reactive nitrogen to the biosphere. Mitigation strategies that reduce the gaseous losses per applied unit of fixed nitrogen are needed to develop in order to cut-down a future run-away effect of anthropogenic climate forcing from agriculture. To achieve this goal, a thorough understanding of the soil processes involved in the formation and emission of N_2O is a necessity".

Nitrogen fertilizers (NH_4^+ and NO_3^-) can increase the emissions of N_2O immediately after addition (Mummey et al. 1994; Chang et al. 1998; Eichner, 1990). About half of applied N is

taken out from the field as harvest crop. The remainder of the N is incorporated into SOM or is lost to other parts of the environment. N can be lost from soil by nitrification, denitrification, ammonia volatilization, leaching, runoff, erosion, and vegetation (Mosier et al. 2004).

2.4 Nitrogen cycle

N, existing in both inorganic and organic forms, as well as many different oxidation states is a mobile element (Marschner, 1986). The principal forms of N in soil are ammonium (NH_4^+), nitrate (NO_3^-) and organic substances. N cycle as shown in Figure 1 describes the movement of N between the atmosphere, biosphere, and geosphere in different forms. N enters a farming system by atmospheric deposition, as fertilizer, by irrigation water, livestock production, feed, and manures and by N_2-fixation (Hatch et al. 2002). N can be utilized by crops in the form of ammonium (NH_4^+) or NO_3^-. It can be incorporated into OM and thus be subject to immobilization, released from an unusable organic form into an inorganic form via mineralization, transformed into inert gas and lost through volatilization, leached from the plant rooting zone or lost in surface runoff and soil erosion (Kanwar, 1972).

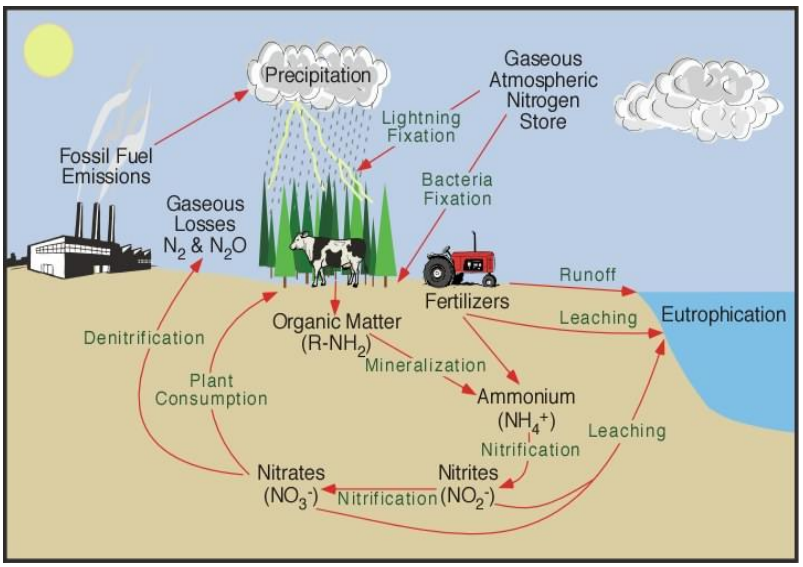

Figure 1 N cycle: Created by Michael Pidwirny, University of British Columbia Okanagan

N can be found in any terrestrial ecosystem. These entire N originally came from the atmosphere. Then, the substantial amounts come in to the soil through rainfall or the effects of lightning. However, most of the N is fixed by specified microorganisms like bacteria, actinomycetes, and cyanobacteria in the soil. Legume members and some other kinds of plants form mutually symbiotic relationships with N_2-fixing bacteria. According to

scientists' estimations, biological fixation globally contributes about 140 million metric tons of N to ecosystems yearly (Clark and Rosswall, 1981; www.eoearth.org).

N_2O is a by-product of the important microbiological N cycling processes in soils such as nitrification and denitrification (Butterbach-Bahl et al. 1997; Knowles, 2000; Rosenkranz et al. 2005). Atmosphere contains 78 % N_2 gas. However, plants cannot use this N directly for their growth. A number of microorganisms and chemical processes are involved in the conversion of organic N to inorganic N within the soil. Humans have also severely altered the nature of this nutrient cycle by making solid forms of N more available (Bouwman, 1998). Most plants can only take up N in two forms: NH_4^+ and NO_3^-. Therefore, N is often the most limiting nutrient for plant growth. Most plants obtain N as inorganic NO_3^- from the soil solution. NH_4^+ is extremely toxic in large concentrations so that plants use less NH_4^+ for uptake (Bouwman, 1998). In most ecosystems, N is mainly stored in living and dead OM. This organic N is then converted into inorganic forms via decomposition. N found in OM is chemically modified by decomposers found in the upper soil layer. This process is called mineralization and it is done by a variety of bacteria, actinomycetes, and fungi (Clark and Rosswall, 1981; www.eoearth.org). The process of biological oxidation from NH_4^+ to NO_3^- with NO_2 as an intermediate is called nitrification (Bremner, 1997). Nitrification is important for the N cycling in most agricultural and many natural soils. Denitrification is also common in anaerobic soils or anaerobic microhabitats within the soil profile. It is accomplished by heterotrophic bacteria. The process of metabolic reduction of NO_3^- into N_2 or N_2O gas is called denitrification. Both N_2 and N_2O gases then diffuse into the atmosphere (Bremner, 1997; www.eoearth.org).

2.5 Processes of N transformations

N_2O production and consumption in soils are mainly caused by microbial N turnover processes, including mineralization, nitrification, denitrification, and microbial immobilization (Conrad, 2002; Ambus et al. 2006). These processes are important in order to understand the microbial mediated biosphere-atmosphere exchange of trace gases.

2.5.1 Mineralization

It is capable of various chemical reactions that can change N to different organic or inorganic forms when N is fixed. Microorganisms convert organic N to inorganic forms via mineralization. There are two steps in mineralization. In the first step, complex proteins are broke down to simpler amino acids, amides, and amines by microorganisms (primarily heterotrophic) and this process is called aminization. The second step of mineralization in which amino (NH_2) groups are changed to ammonium, is known as ammonification. Microorganisms (primarily autotrophic) accomplish this action (Clark and Rosswall, 1981; Nemeth et al., 1996; Aulakh et al., 1991; Eichner, 1990).

2.5.2 Nitrification

Nitrification is the process of the conversion from NH_4^+ to NO_2^- and then NO_3^-. Nitrification is mainly accomplished by *Nitrosomonas*, *Nitrosospira* and *Nitrobacter* bacteria in agricultural soils (Hall and Matson, 1999). Soil water and O_2 content, as well as the macropores, OM and pH in the soil mainly influence the development rate of N_2O (Algaidi et al. 2006). Water content of 60 % is the optimum condition for the nitrification in soil. Nitrification is limited by O_2 when the water content is increased and vise versa. About 0.5 % of the N input is transformed into N_2O during the nitrification process (Veldkamp & Keller, 1997; Algaidi, 2009).

Hall & Matson (1999) defined the nitrification as the oxidation process of NH_4^+ to NO_2^- and NO_3^- by a specialized group of bacteria that attain energy from the NH_4+ oxidizing process. These bacteria gain C from CO_2 rather than from the consumption of organic compounds. Nitrifying bacteria may be limited by the availability of NH_4^+, which is controlled by several factors, mineralization; N uptake by microbiota (immobilization) or plants; retention of NH_4^+ by soil particles; factors governing diffusion, including temperature and water availability (Algaidi et al. 2006).

Production of N_2O by nitrification has often been reported (e.g. Bollmann & Conrad, 1997). Skopp et al. (1990) and Linn & Doran (1984) showed that the rate of nitrification can be relatively high when the moisture content of the soil is between 50 – 60 % WHC. Billore et al. (1996) found that fertilizer treated soil produced more emission than unfertilized soil at 50 – 60 % WHC and indicated that nitrification plays a major role in N_2O production. The

contribution of nitrification to the production of N_2O has been found to range between 61 – 98 % (Mummey et al. 1994) and 60–80 % (Parton et al. 1988b).

2.5.3 Denitrification

Firestone & Davidson (1989) defined denitrification as a group of processes during which NO_3^- or NO_2^- is reduced to the gaseous N species NO, N_2O, or N_2. Denitrification activity has been reported in dried soils and in desert soils (Peterjohn, 1991; Smith & Parsons, 1985), where it seems to depend on a complex interplay between soil moisture, C, N availability, pH, temperature, and O_2. Indeed, many soil denitrifying microorganisms have been found to be able to produce N_2O over a wide range of O_2 partial pressures (Davies et al. 1989; Lloyd et al. 1987; Robertson & Kuenen, 1990). Freney (1997) stated that N may be lost by NH_3 volatilization, by nitrification, by biological denitrification, and by chemo denitrification. As a result, emissions of NO, NO_2, N_2O and N_2 are produced. N emitted to the atmosphere as NH_3 may be returned to the biosphere and recycled, thus adding to the N_2O burden in the atmosphere (Patten et al. 1980; Huang et al. 2004).

Denitrification contributed 21 % to the production rate of N_2O in soil incubated at 50 % WHC (Yoshida & Alexander, 1970). Denitrification is an anaerobic process, and anaerobic conditions were limited in the incubations at 60 % WHC so the reduction of NO_3^- and the production rate of N_2O were small. Total N_2O emissions at 100% WHC was significantly larger than at 50% WHC (Yoshida & Alexander, 1970; Blackmer et al. 1980). The moisture regime of a soil is an important factor that influences N_2O emissions by regulating oxidation and reduction reactions (Kumar et al. 2000). Denitrification became the main process in the production of N_2O at 100 % WHC.

2.6 Release of mineral N and its availability to plants

Microbes break down organic polymers and release N in the form of ammonium through mineralization which can be further taken up by the plants. NH^{4+} is an important source of N for plants. Nitrification is one process by which microbes utilize NH_4^+. NH_4^+ is used as an energy source by ammonia-oxidizing microbes to produce NO_2^- that is usually quickly converted to NO_3^- by the process of nitrification. As with NH_4^+, both plants and microbes take up NO_3^-, to meet their N demand through the process of N immobilization. When active

microbial populations are rapidly mineralizing N from labile SOM, and at the same time, plant roots are taking up NH_4^+ and NO_3^- at rapid rates, then there can be very effective and efficient transfer of soil N to plants, with little potential for N loss (Jackson et al. 2008; Schimel and Bennett, 2004).

2.7 Important factors controlling N_2O emissions

N_2O emissions from soil are mainly by soil microbial processes. Soil microbial processes are mainly responsible for soil N_2O emissions. Soil characteristics, cropping patterns, and climate and their interactions, impact nitrification and denitrification processes. As a consequence, the production and emissions of N_2O are affected (Algaidi, 2009; Beauchamp 1997). Hutchinson (1995) mentioned that most N_2O was produced by denitrifiers.

N_2O emissions into the atmosphere were measured in closed chambers at the soil surface (Reth et al. 2008). At the same time, soil temperature and soil water contents were recorded in order to quantify their effects on the fate of N_2O in the soil. The highest N_2O concentration was recorded after 'special events' like snowmelt, heavy rain, fertilization, and grubbing. The combination of fertilization and heavy rain led to an increase of up to 2,700 ppb in the subsoil. Colbourn & Dowdell (1984) measured between 0–20% and 0–7% N loss from field soils and grassland, respectively.

The amount of N_2O emissions are mainly influenced by the N fertilization (Granli & Bockman, 1994) as shown in studies of Schmidt & Bock (1998), who determined a strong correlation between N content in the soil and N_2O emissions. The positive correlation between increased N input and increased N emissions provides the basis for estimating the impact of agriculture on N_2O emissions on a global scale (Bouwman, 1990; Eichner, 1990).

Soil moisture, soil temperature and nutrient availability (environmental factors) control the biogeochemical processes (such as; mineralization, nitrification and denitrification) (Davidson, 1992; Conrad, 1996a,b; Smith et al. 2003). These processes normally cause the high variability of trace gas flux rates. The environmental factors vary in time and space so that site –specific estimates of annual trace gas exchange are probably to contain large uncertainties (Algaidi, 2009). Soil temperature and moisture were the most crucial factors influencing N_2O emissions. Microorganisms and their metabolism can be affected by those

parameters, and then consequently, the production and consumption of N trace gases in the soils can also be affected (Conrad, 1996a, b). The movement of the gases into the atmosphere and away from the atmosphere is controlled by the air-filled porosity. It also affects soil aeration, and therefore, indirectly controls the capability of the soil for making or depleting soil produced trace gases (Algaidi, 2009; Smith et al. 2003; Davidson et al. 2000; Kitzler et al. 2006).

2.8 C cycle

Carbon is stored on our planet as different forms; such as, organic molecules in living and dead organisms in the biosphere; CO_2 in the atmosphere; organic matter in soils; fossil fuels and sedimentary rock deposits such as limestone, dolomite and chalk in the lithosphere; and dissolved atmospheric CO_2 in the oceans and as calcium carbonate shells in marine organisms. The basic terrestrial carbon cycle of life is: (1) to change atmospheric CO_2 to carbohydrates by photosynthesis in plants; (2) to consume and oxidise these carbohydrates by animals, plants and microorganisms for production of CO_2 and other products; and (3) to bring back CO_2 to the atmosphere. (http://soilcarboncenter.k-state.edu/carbcycle.html)

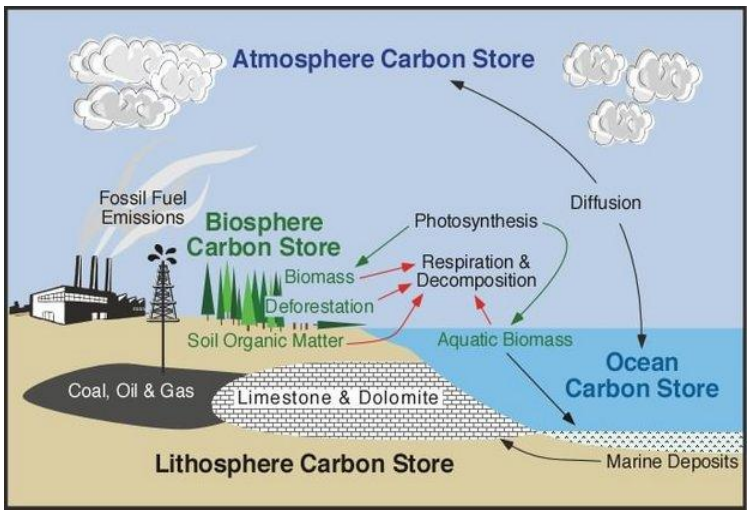

Figure 2 C cycle (Source: PhysicalGeography.net)

Soils play a central role in maintaining a balanced global C cycle. They contain approximately 75 % of the C pool on land, which is threefold more than the amount stored in living plants and animals (Batjes, 1996). Organic material is manufactured by the plants through photosynthesis using atmospheric CO_2 and water as raw materials. The soil fauna and flora

die and return to the soil, providing organic C to soil microorganisms, especially heterotrophs, their main energy source (Chan, 2008).

Plants sequester carbon from the atmosphere through growth. CO_2 is converted into plant tissue by photosynthesis. After a plant dies, the plant materials are decomposed principally by soil microorganisms. Carbon is released back into the atmosphere by respiration, or it is left behind as soil organic matter. Therefore, plants and microorganisms in the soil provide the connection between carbon in the atmosphere and how it can be fixed to biological matter in soils. The latter process is called soil carbon sequestration (Lal, 2004).

Carbon sequestration is one of the pathways to reduce GHGs in the atmosphere. European soils store 73 - 79 billion tons of C. About 45 % of European soils including some parts of Germany are low in OM (0-2 % OC) (Jones et al. 2012). Such loss is due to land use and climate change at a range equivalent to 10% of the amount of fossil fuel emissions for Europe (www.Europa.eu).

2.9 Factors influencing CO_2 emission

There may be a relationship between climate change phenomena and the rise in atmospheric CO_2 (Jolankai and Birkas, 2005). Carbon fluxes from plants to soil and from soil to the atmosphere are probably influenced by the increase in atmospheric CO_2 concentration and potential climatic changes (Algaidi, 2009). In most ecosystems, the parts of soil CO_2 efflux include respiration due to litter decomposition, rhizo-microbial respiration, root respiration, and microbial respiration (Cheng, 2009). Some researchers and planners (IPCC, 2000; Lal, 2004) indicate that land use and soil management technologies are feasible options for reducing the net rate of increase in CO_2 abundance. For example, Cox et al. (2000) observed that the biosphere will act as the overall C sink until approximately 2050, and will then become a source. Thereafter the ocean will become a bigger sink, sequestering about 5 Pg C yr^{-1}.

CO_2 concentration is currently enhanced at the rate of 1.9 ppm yr^{-1} or 0.47 % yr^{-1} (WMO, 2006) by land use conversion and deforestation, and fossil fuel combustion. The impact of land use conversion and agricultural activities on CO_2 abundance started approximately 10,000 years ago since the oncoming of located agriculture (Ruddiman, 2003). CO_2

emissions from land use conversion and deforestation stepped up with the clearance of Northern Hemisphere forests in the 19th century and emissions were aggravated by deforestation of tropical rainforests (TRF) during the 20th century. It is approximated that 350 Mha of TRF were deforested and another 500 Mha of secondary and primary tropical forests were degraded with substantial CO_2 emission to the atmosphere (Lamb et al. 2005).

In temperate regions and tropical climates, SOC pool has decreased by 30–50 % over 50–100 years and 50–75 % over 20–50 years, respectively, due to conversion of natural to agricultural ecosystems. The proposed global warming with an approximate increase in mean annual temperature of 4 – 6°C by 2100, may have a fundamental impact on the amount soil C pool and its dynamics. Because of increased biomass production and accretion into the soil, so called CO_2 fertilization effect, the SOC pool may increase, consequently, the production of the root biomass may also be enhanced. The quantity of C pool may also be increased by an increase in the weathering of silicates due to increased temperature, and the formation of secondary carbonates due to increased partial pressure of CO2 in soil air. However, in contrast, due to an increased rate of respiration and mineralization, water limitation and increased losses by soil erosion, the SOC pool might be decreased (Lal, 2004; Lal, 2008).

Currently, soil respiration has received considerable attention due to the release of large quantities of CO_2 from the soils to the atmosphere (Merino et al. 2004). Alternations in land use and soil management practices (such as; tillage, use of fertilizers, organic residues, pesticides) cause changes in SOC and are largely responsible for increases in atmospheric CO_2 from terrestrial ecosystems (Bouwman, 1990). Less intensive management improves biological properties (Emmerling et al. 2001) and the conversion of agricultural land to forest usually results in considerable gains in SOC and reductions in CO_2 fluxes (Paul et al. 2002, Merino et al. 2004).

2.10 Effects of climate warming on soil microbes

There is now much evidence to show that climate warming can affect an array of ecosystems, from polar terrestrial to topical marine environments, and influence a broad range of organisms, from microorganisms to plants to animals (Walther et al. 2002; Root et al. 2003; Davidson & Janssens 2006). There are two thoughts on the effects of climate

warming on soil microbes and associated processes. One thought maintains that current climate warming would stimulate soil microbial growth and activities, thus accelerating the rate of soil organic C decomposition (Cheng, 2010). A positive relationship between temperature and soil microbial respiration has been well illustrated (Lloyd & Taylor, 1994). Modeling and experimental evidence have documented a direct stimulation of higher temperature on soil microbial respiration (Jenkinson et al. 1991; Kirschbaum 1995; Melillo et al. 2002; Davidson & Janssens, 2006; Hartley et al. 2008, 2009). The respiration rate of organisms in the soil (mainly root and microbial respiration) would approximately double for every 10°C increase in temperature. Another argument, however, states that soil microbes may acclimate or adapt to climate warming, therefore weakening the positive effect of climate warming on soil respiration (Cheng, 2010). Some experimental studies provided supporting evidence to show that soil microbial biomass and respiration did not respond to experimental warming (Jonasson et al. 1999; Zhang et al. 2005; Giardina & Ryan 2000; Heinemeyer et al. 2006; Bradford et al. 2008). However, the underlying mechanisms by which soil microbes acclimate to warming are not well understood. It is likely that temperature might not be the most limiting factor in those warming experiments that have observed a temperature insensitivity of microbial decomposition (Bradford et al. 2008; Giardina & Ryan 2000). In other words, the effects of warming on microbial decomposition might be obscured by other hidden factors such as the quality of substrate in an incubation study (Giardina & Ryan 2000), or plant growth in a field experiment (Luo et al. 2001; Zhang et al. 2005; Cheng, 2010).

2.11 Mechanisms during drying of the soil

Soil drying is strongly influenced by air humidity, temperature, wind, and transpiration. It often only starts shortly after the rainfall as a result of the water shortage of air. The influences of soil drying on microbial activity are mostly restrained to elevated temperatures while the influence is rather small at low temperatures (Borken & Matzner, 2009).

2.11.1 Response to microorganisms

When soil is drying, both the matric potential and the osmotic potential become more negative in soil solution. Microorganisms may desiccate and decrease osmotic potential in the cell by aggregation of compatible solutes such as amino acids, carbohydrates and

inorganic solutes, in order to equilibrate with their environment (Harris, 1981; Halverson et al. 2000).

Osmotic regulation is constrained to a certain threshold and varies among microorganisms. When the threshold is exceeded, microorganisms further dehydrate and die (Sparling & Ross, 1988; Van Gestelet al. 1992, 1993) or survive the drought period by forming endospores, cysts or vegetative cells (Chen & Alexander, 1973). One-third of the microbial biomass in a Mediterranean grassland soil was killed by air-drying at 40°C over 24 h (Bottner, 1985). Likewise, Sparling et al. (1986) found that a decrease of 14 – 30% of microbial biomass following air-drying. In contrast, air-drying above 14 days reduced microbial biomass by only 10% in organic and mineral horizons of an aspen and pine forest. It was suggested that these microorganisms were well-adapted to water stress (Scheu & Parkinson, 1994; Borken & Matzner, 2009).

2.11.2 Diffusive limitations

Drying of soils reduces the accessibility of organic and inorganic soluble substrates and the mobility of extracellular enzymes. Both the disseminative transport of substrates and extracellular enzymes, and the active or passive mobility of microorganisms decelerate with decreasing water potential and abating thickness of the water film. Discontinuous water films inhibit the disseminative transport of solute substrates at very low matric potential (Borken & Matzner, 2009). Voroney (2007) found that a decrease in microbial activity can be attributed to osmotic regulation and limited diffusive transport.

2.12 Mechanisms during wetting of dry soils

Microbial activity is naturally increased by wetting of dry soils within minutes (Borken et al. 2003; Lee et al. 2004; Sponseller, 2007) and/ or hours (Pulleman & Tietema, 1999; Prieme & Christensen, 2001). This wetting pulse might be attributed to the restructuring for mineralization of soil organic matter and to the mineralization of formerly unavailable and easily decomposable organic substrates (van Gestel et al. 1991; Appel, 1998; Wu & Brookes, 2005). The latter may cause an additional short-term rise in microbial activity for a few days that surpasses the microbial activity of a permanently moist soil. This priming effect has recently been termed as the ‘Birch effect' to acknowledge Birch's pioneering work (Birch,

1958 a, b, 1964) on drying and wetting effects in soils (Jarvis et al. 2007). The organic substrates that cause this priming effect may come from different sources during the drying period. Wetting of a dry soil, however, may cause further mechanisms that increase the availability of organic substrates (Borken and Matzner, 2009).

2.12.1 Release of microbial biomass

Wetting of dry soils activates the hydration and lysis of dead microbial cells, which accumulate during drying periods. These substrates may subsequently be metabolized by surviving microorganisms. Surviving microorganisms, however, may experience even more stress than during the drying period and possibly die following wetting (Schimel et al. 2007). If microorganisms do not quickly equilibrate to abruptly changes in water potential, water will flow down to the cytoplasm and destroy the cell unless the cell wall protects the turgor pressure (Kieft et al. 1987). The equilibration to the water potential may include metabolic decay or polymerization of compatible solutes into osmotically less active compounds, as well as passive and active export from the cell into the soil solution (Halverson et al, 2000). Kieft et al. (1987) found that 17–70 % of total microbial biomass C was released by rapid wetting for grassland soils. The release of biomass C increased with the change in water potential and varied between two grassland soils. Active microorganisms are probably to be more susceptible to drying and wetting stress than dormant microorganisms. The decrease in microbial biomass was stronger in soil with high microbial activity compared with soil with low activity (Van Gestel et al. 1993 Borken & Matzner, 2009).

Borken and Matzner reported that the release of microbial substrates during wetting appears to be one significant C and N source in many soils. Its contribution to the wetting pulse will depend on the recycling of compatible solutes for microbial growth and on the change in water potential during drying and wetting. Quick response and recovery of microbial activity and biomass after wetting indicates that most of the microbial communities are well-adjusted to both drying and wetting stress even when a portion of the microbial population is killed during these extreme cases. The situation might be different in soils or soil horizons that do not regularly experience drying/ wetting cycles.

2.12.2 Hydrophobicity

Hydrophobicity of SOM considerably slows down the increase in water potential following wetting. After a drought period, most rainwater infiltrates on preferential flow routes into the soil or runs off on the soil surface in hilly and mountainous landscapes. Depending on the hydrophobicity of the soil, initial water potential, and the intensity and duration of precipitation, the moistening of top soils often continues over weeks or months. Preferential flow prevents the overcoming of hydrophobicity as parts of soil organic matter have little or even no contact with water during rainfall. A slow increasement of water potential gives microorganisms more time to equilibrate with their environment and to restore their metabolism including the re-assimilation of compatible solutes. Hence, the wetting of hydrophobic soil possibly means less stress for microorganisms (Borken and Matzner, 2009; Halverson et al. 2000; Schimel et al. 2007).

2.13 Microbial response to precipitation pulse

After the first rainfall following a prolonged drought, the abrupt increase in water availability produces an osmotic shock. With renewed water and resource availability, wetting-up make up both a physiological stress and a defined stimulus for microorganisms regaining from the extreme drought of summer (Placella et al. 2012).

Huxman et al. 2004 reported that "C balance of the system in various ways in most ecosystems is directly altered by a precipitation pulse into dry soil. Firstly, soil microbial activity during the former dry period and high concentrations of CO_2, built up from inorganic C sources are physically displaced because percolating water fills soil pore spaces. Secondly, precipitation pulses can release C held in large soil pools of inorganic carbonates. Thirdly, microbial activity, decomposition, and N mineralization can be quickly enhanced by soil rewetting through the increase assessment of substrate. Therefore, high respiration rates from biological processes can happen rapidly following a precipitation pulse leading to significant CO_2 release to the atmosphere. These CO_2 effluxes may together outweigh the subsequent photosynthetic CO_2 accumulation, and, therefore, the precipitation pulse might result in a net loss of C from an ecosystem".

2.14 Patterns of soil gas flux response to rewetting

Altered precipitation patterns may result in altered soil moisture patterns and, consequently, extended drought periods with more heavily rewetting may be resulted. Altered precipitation patterns may change the CO_2 production regime from a more or less continuous regime to a more pulse driven regime (Borken et al. 2003; Borken and Matzner 2009; Murh et al. 2008).

2.14.1 Carbon dioxide

Carbon dioxide is the most important GHG in the atmosphere. It is the soil gas that has received the third most attention for studying the effects of rewetting and thawing of soils (Kim et al. 2012).

In many terrestrial ecosystems and various land-use types, including croplands (Kessavalou et al. 1998; Beare et al. 2009), grazing pastures (Xu and Baldocchi 2004; Wu et al. 2010b), forests (Kim et al. 2010b), grasslands (Joos et al. 2010; Xiang et al. 2008), savannas (Castaldi et al. 2010), and deserts (Sponseller and Fisher, 2008), increases in CO_2 flux after rewetting of dry soils have been reported. For instance, in an upper Sonoran Desert ecosystem, CO_2 flux increased up to 30-fold directly following experimental rewetting, and within 48 h returned to the rate of gas flux before the event (Sponseller, 2007). Drying and rewetting treatments raised the annual CO_2 flux by 51% compared with a control plot in case of soil moisture manipulations in a Norway spruce plantation (Borken et al. 1999). The relative CO_2 flux increase following rewetting in the desert is higher than those of croplands, forests, grasslands, savannas, and wetlands. The hypothesis of "rewetting a variety of soil types might have substantial effects on the C balance of terrestrial ecosystems" is supported by these studies (Lee et al. 2004; Xu et al. 2004; Borken et al. 1999).

Some studies showed no responses or only a small increase in CO_2 fluxes following rewetting events and did not substantially affect annual flux rates (Coxson and Parkinson, 1987; Schimel and Clein, 1996; Neilsen et al. 2001). Other studies showed reduced CO_2 fluxes during dry periods. However, an abruptly increase in fluxes following rewetting then did not compensate for the reduction values during the drying period at the seasonal scale (Borken and Matzner, 2009; Joos et al. 2010).

2.14.2 Nitrous oxide

Field studies have observed that there were increased soil N_2O fluxes following wetting in croplands (Barton et al. 2008), tropical forests (Butterbach-Bahl et al. 2004), grasslands (Hao et al. 1988), grazed pastures (Kim et al. 2010a), savannahs (Martin et al. 2003), and fens (Goldberg et al. 2010a). Laboratory incubation experiments with croplands (Beare et al. 2009), forests (Dick et al. 2001), grasslands (Yao et al. 2010), and peatland soils (Dinsmore et al. 2009) have given similar results for increase in N_2O fluxes after rewetting. In tropical soils of Costa Rica, N_2O flux pulses started within 30 min and reached the peak no later than 8 h after rewetting. 25 g N_2O-N ha^{-1} was emitted after three simulated rain events above a 22-day period and one episodic N_2O production event driven by one moderate rain accounted for 15–90% of the entire weekly production (Nobre et al. 2001). These studies have discovered increased soil N_2O flux following rewetting in the short-term (12 h–15 d), and an increase of N_2O flux with respect to the background conditions. Increases in forest N_2O fluxes following rewetting are higher than those of cropland, grassland, and other ecosystems (Kim et al. 2012).

In contrast, some studies showed either only small increase of N_2O fluxes following rewetting that did not considerably affect annual flux rates (Garcia- Montiel et al. 2003; Neill et al. 2005; Borken and Matzner, 2009) or no responses. Some studies indicated reduced N_2O fluxes during drying periods. But rapidly increase in fluxes after rewetting did not compensate for the reduced rates of uptake during drying period at the seasonal scale (Borken and Matzner, 2009; Goldberg and Gebauer, 2009; Kim eat al. 2012). Therefore, there are still uncertainties and more research is needed to estimate the effect of altered precipitation on CO_2 and N_2O production.

2.15 Mechanisms for soil gas flux response to rewetting

There are two broad mechanisms responsible for changed soil gas flux following rewetting. These are (1) increased microbial metabolism by substrate supply and (2) physical mechanisms (Kim et al. 2012). First, microbial metabolism can be increased by the availability of accumulated substrates during soil drying that get available as solutes in water after the rewetting of soils. A large proportion of microorganisms, fine roots, and mycorrhiza die during drought conditions (Clein and Schimel, 1994; Teepe et al. 2001).

While rewetting, these dead cells become to have low C: N ratios and can be decomposable rapidly (Van Gestel et al. 1993; Kieft et al. 1987;). Microorganisms accumulate high concentrations of solutes to retain water inside the cell during drought conditions (Harris, 1981), which also decompose on rewetting (Schimel et al. 2007; Fierer and Schimel, 2003). Drying-wetting could break-up soil aggregates, exposing physically protected OM and increasing the accessibility of substrates that can be rapidly mineralized (Groffman and Tiedje, 1988; Appel, 1998; Pesaro et al. 2003; Grogan et al. 2004). Furthermore, root exudates from revived plants following rewetting could significantly affect soil surface fluxes (Curiel Yuste et al. 2007; Crow and Wieder, 2005). Second, physical mechanisms include reduced diffusivity, infiltration and gas displacement reaction in the soil (Jensen et al., 1996; Huxman et al., 2004; Kim et al. 2012).

Importantly, the relative contribution of autotrophic or heterotrophic activity to changes in CO_2 fluxes following rewetting is poorly understood. Also, the relative contribution of specific microbial processes (e.g., nitrification, denitrification and nitrifier denitrification) to changes in N_2O fluxes following rewetting is still poorly understood, although several studies have investigated that denitrification is a major contribution process in N_2O fluxes following rewetting (Kim et al. 2012; Groffman and Tiedje, 1988; Prieme and Christensen, 2001). There are also two possibilities of a reduction in GHG fluxes after rewetting due to: (1) increased accumulation of rain water in the soil pore space that causes reduction of soil CO_2 diffusivity rates (Rochette et al. 1991), and (2) limitation of the soil macro-porosity by rainfall that causes increased anaerobiosis, reduced soil air-filled pore space and reduced aerobic respiration (Kim et al. 2012; Linn and Doran, 1984; Ball et al. 1999; Davidson et al. 2000).

Chapter 3: Materials and methods

PART (A): Elevation of soil temperature might influence N-cycling of an agricultural cropping system

3.1 Experimental site description

The experiment was carried out at the site of the Hohenheim Climate Change (HoCC) experiment (Poll et al. 2013). The experiment is situated at the Heidfeldhof experimental field station (48°42'N, 9°11'E, 395 m a.s.l.) of the University of Hohenheim (Stuttgart, Germany) (Figure 3). The mean annual temperature and precipitation at the site are 8.7°C and 679 mm, respectively. The soil is a stagnic luvisol derived from loess with a silty loam soil texture, a pH of 7.0 and an organic carbon content of 12.1 g kg^{-1}. The HoCC experiment was established in 2008 and combines experimental soil warming, reductions in precipitation amount and reductions in precipitation frequency independent of the amount.

The experiment is laid out in four blocks with a split-plot design. The experimental setup is shown in Figure 4. This study was conducted from one subplot (1m x 1m) of each roof-control plot exposed to either ambient (Ta) or elevated (Te) soil temperature and ambient precipitation. Each plot is separated by PVC- barriers, to a depth of 50 cm, to avoid lateral water movement in soil from their surroundings. Soil temperature is manipulated according to the predicted temperature changes for Central Europe within the range from +2.5 - 5.5°C or +1 - 4°C for the IPCC A2 scenario or B2 scenario, respectively (Forster et al. 2007) and to scenarios of regional climate models for Germany (Umweltbundesamt 2006). The soil temperature was elevated by + 2.5°C to 4 cm depth using heating cables (RS 611-7918, RS Components GmbH) according to Ineson et al. (1998). Temperature probes at 4 cm depth are connected to two data loggers (DT85, UMS GmbH), which log soil temperature every minute and control the heating system.

Figure 3 Picture of the HoCC experiment showing the roofs and roof-control plots

3.2 Plant sampling and analyses

Winter wheat (*Triticum aestivum.* Toras) was sown in the plots in October 2011. 190 plants/sqm were planted in 7 rows and fertilized with calcium ammonium nitrate on March 23rd 2012 (67.5 kg N ha^{-1}), on April 27th 2012 (27 kg N ha^{-1}), and on May 31st 2012 (40.5 kg N ha^{-1}). Crop phenology was monitored during the main growth period from March to July 2012 using the BBCH scale for cereals (Lancashire et al. 1991). SPAD measurements were taken at every second leaf of the main stem, starting with leaf number 3, and ending at the youngest fully developed leaf present (leaf number 11 here). Plants were rated weekly for plant height, number of leaves and senescence. Above-ground plant biomass was sampled at five dates representing the following wheat phenological growth stages: tillering (BBCH 22, 16 March), stem elongation (BBCH 31, 17 April), booting (BBCH 49, 21 May), flowering (BBCH 65, 11 June) and ripening (BBCH 89, 16 July 2012). At each sampling date 5 representative plants were collected from each plot by cutting the plants at the soil surface. The plant samples were dried in an oven at 60 °C to constant weight, and dry matter biomass was determined. The representative sample from partitioned plant parts (leaves, stems, ears, grains) was ground to a fine powder with a ball mill and analyzed for C and N

content using the Vario MACRO CNS Elemental Analyzer (Elementar Analysensysteme GmbH, Hanau, Germany).

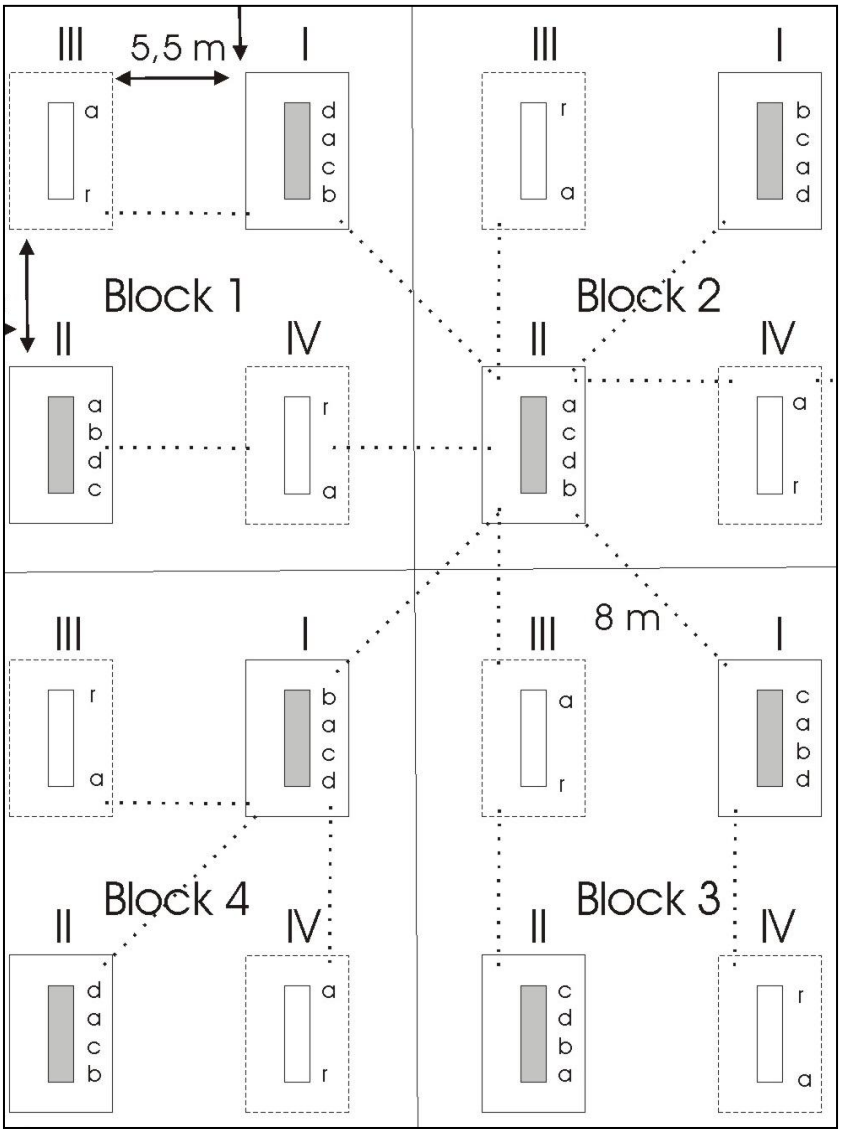

Figure 4 Experimental set up of the HoCC experiment

Treatments temperature:
I Roof, elevated temperature
II Roof, ambient temperature
III No roof, elevated temperature
Iv No roof, ambient temperature

Treatments precipitation:
a Ambient
b Low amount
c Low frequency
d Low amount + frequency
r Exclusion earthworms

3.3 Soil sampling and analyses

Soil samples were taken from 0-15 cm and 15-30 cm depth on the same sampling dates as for plant samples. After sieving at 2 mm, the field moist soil samples were homogenized and stored at -20 °C until further analyses. Soil water content was determined by drying at 105°C for 24 h. C and N concentrations in soil were measured with the Vario MACRO CNS Elemental Analyzer (Elementar Analysensysteme GmbH, Hanau, Germany).

3.3.1 Mineral nitrogen content

For extraction of mineral N (N_{min}) in the forms of NH_4^+ and NO_3^-, 10 g of soil was mixed with 40 ml 1 M potassium chloride and shaken on a horizontal shaker for 30 min at 250 r.p.m. The suspension was then centrifuged at 4400 g for 30 minutes to separate the soil particles from the solution. NH_4^+ and NO_3^- concentrations in the supernatant were measured with a continuous flow auto analyzer (Auto analyzer 3, Bran & Luebbe, Norderstedt, Germany).

3.3.2 Microbial biomass C and N (C_{mic} and N_{mic})

Microbial biomass carbon (C_{mic}) and nitrogen (N_{mic}) in the soil were measured by using the chloroform fumigation extraction (CFE) method (Vance et al. 1987). 10 g of soil was fumigated with ethanol-free chloroform and extracted with 40 ml of 0.5 M K_2SO_4 on a horizontal shaker for 30 min at 250 r.p.m. Then the suspension was centrifuged at 4400 g for 30 min and the supernatant was diluted 1:4 with $H_2O_{dest.}$ to avoid a high salt concentration for the subsequent analysis. Soil extractable organic C and total N in the diluted extracts before (non-fumigated control) and after fumigation were analysed using a TOC/TN analyzer (Multi N/C 2100S, Analytik Jena, Germany). The released C and N were converted to C_{mic} and N_{mic} using a k_{EC} factor of 0.45 (Joergensen 1996) and a K_{EN} factor of 0.54 (Brookes *et al*. 1985), respectively.

3.3.3 Soil enzyme activities

The potential nitrification activity was determined by aerobic incubation of soil following a modified method of Kandeler (1996). Twenty ml of 1 mM ammonium sulfate and 0.1 ml of 1.5 M sodium chlorate solution were added to 5 g of field- moist soil and incubated at 25 °C for 5 h. Nitrite (NO_2^-) released during incubation was extracted with potassium chloride and

determined photometrically at 520 nm. Potential nitrification was expressed as the amount of NO_2-N released per gram soil in 5 h.

Protease activity was determined according to a modified protocol of Kandeler (1996). The method involves the estimation of tyrosine released after a 2 h incubation period at 50°C with a buffer casein solution. 5 ml of substrate solution (casein solution, 2% w/v) and 5 ml of Tris (Tris-hydroxymethyl-aminomethane) buffer (0.05 M, pH 8.1) were added to 1 g of field-moist soil and incubated for 2 h at 50°C. Then, the aromatic amino acids produced were extracted with trichloracetic acid (0.92 M) and measured photometrically after adding Folin-Ciocalteau-reagent and expressed as tyrosine equivalents per gram dry soil in 2 h.

The activities of N-acetyl glucosaminidase, tyrosine-, leucine- and alanine-aminopeptidase were determined using fluorogenic substrates (Marx et al. 2001). The substrates contained the fluorescent compounds 4-methylumbelliferon (4-MUF) and 7-amino-4-methylcoumarin (7-AMC). Buffers and substrates were prepared according to Poll *et al*. (2006). Fifty ml of autoclaved water was added to 1 g of soil to make 50 ml of soil suspension and dispersed by ultrasonication for 2 min. The suspensions were continuously stirred using a magnetic stir plate while 50 µl aliquots were dispensed into 96-well microplate (PPF black 96 well; Greiner Bioone GmbH, Frickenhausen, Germany). Then 50 µl of appropriate autoclaved buffer (MES or TRISMA buffer) and 100 µl of substrate solution were added. Standard wells (0, 10, 20, 50, 80, 120 µl) received 50 µl of soil suspension, standard solution (MUF or AMC) and filled with the appropriate buffer to the final reaction volume of 200 µl. After 0, 30, 60, 120 and 180 min, the plates were pre-incubated at 30 °C and then were measured in a microplate fluorescence reader (FLX 800, Bio-Tek Instruments Inc., Germany) at 360/460 nm wavelength. The enzyme activity was expressed as nmol MUF/AMC g^{-1} soil h^{-1}. All analytical results were related to the basis of the oven dried (105°C) soil.

3.4 Data analysis

A linear mixed-effects model (LME) was used to test for differences of the means of all variables among treatments and sampling dates. Block and plot were included as random effects to account for the block-design of the experiment and for repeated measurements. LMEs with block as random effect were used to test the effect of warming at each sampling date. Prior to analyses data were tested for normality (Shapiro-Wilk test) and homogeneity

of variances (Bartlett's test). Data were log-transformed to meet the ANOVA assumptions of normality and homogeneity of variance if it is necessary. Significant differences were accepted at the $P < 0.05$ level of probability. All statistical tests were performed using R version 2.15.2 (R Core Team 2014) and the nlme package with lme function (Pinheiro et al. 2014).

PART (B): Impacts of rainfall manipulations on CO_2 and N_2O fluxes after rewetting in an agricultural soil

3.5 Experimental design

The simulated changes are based on climate change predictions for Germany (regional climate models, Umweltbundesamt, 2006). In the HoCC experiment, the soil is subjected to a factorial combination of warming and manipulations of precipitation amount and frequency during summer (June 1st to August 31st). Data for average daily temperature and precipitation pattern from this period were drawn from the Hohenheim weather station of the Landwirtschaftliches Technologiezentrum Augustenberg (LTZ 2013, Figure 5). Soil temperature at a 4 cm depth is increased by 2.5°C, precipitation amount is reduced by 25% and precipitation frequency is reduced by measuring cumulative rainfall of two precipitation events and delivering that amount after the second precipitation event. The treatments were established in quadruplicate in a split-plot design with a total of 8 plots. Each plot has a size of 4 x 1 m² and is seperated into 4 subplots. This study was conducted at four subplot (1m x 1m) of each roofed plot exposed to either ambient (Ta) or elevated (Te) soil temperatures and four precipitation manipulations (ambient plot, reduced precipitation amount, reduced precipitation frequency, and reduced precipitation amount and frequency) (without plants). To avoid lateral water movement, each subplot is surrounded by a PVC barrier to a depth of 0.5 m between subplots and the surrounding soil.

The plots are warmed by the use of heating cables (RS 611-7918, RS Components GmbH) placed on the soil surface according to Ineson et al. (1998) and are covered by roofs, which are closed with a greenhouse film (transmission 90% of PAR) from June 1st until August 31st. Rainfall was collected in storage tanks and the water is applied manually to the four subplots according to the four precipitation manipulation treatments. The amount of water added to the four treatments is shown in Table 1. Soil temperature and moisture were

detected by temperature probes (Th2-fs, UMS GmbH) and TDR probes (CS630/CS635, Campbell Scientific Ltd.), respectively. Soil moisture contents for the four precipitation treatments at ambient and elevated plots after the 1st and 2nd dry periods are shown in Table 2.

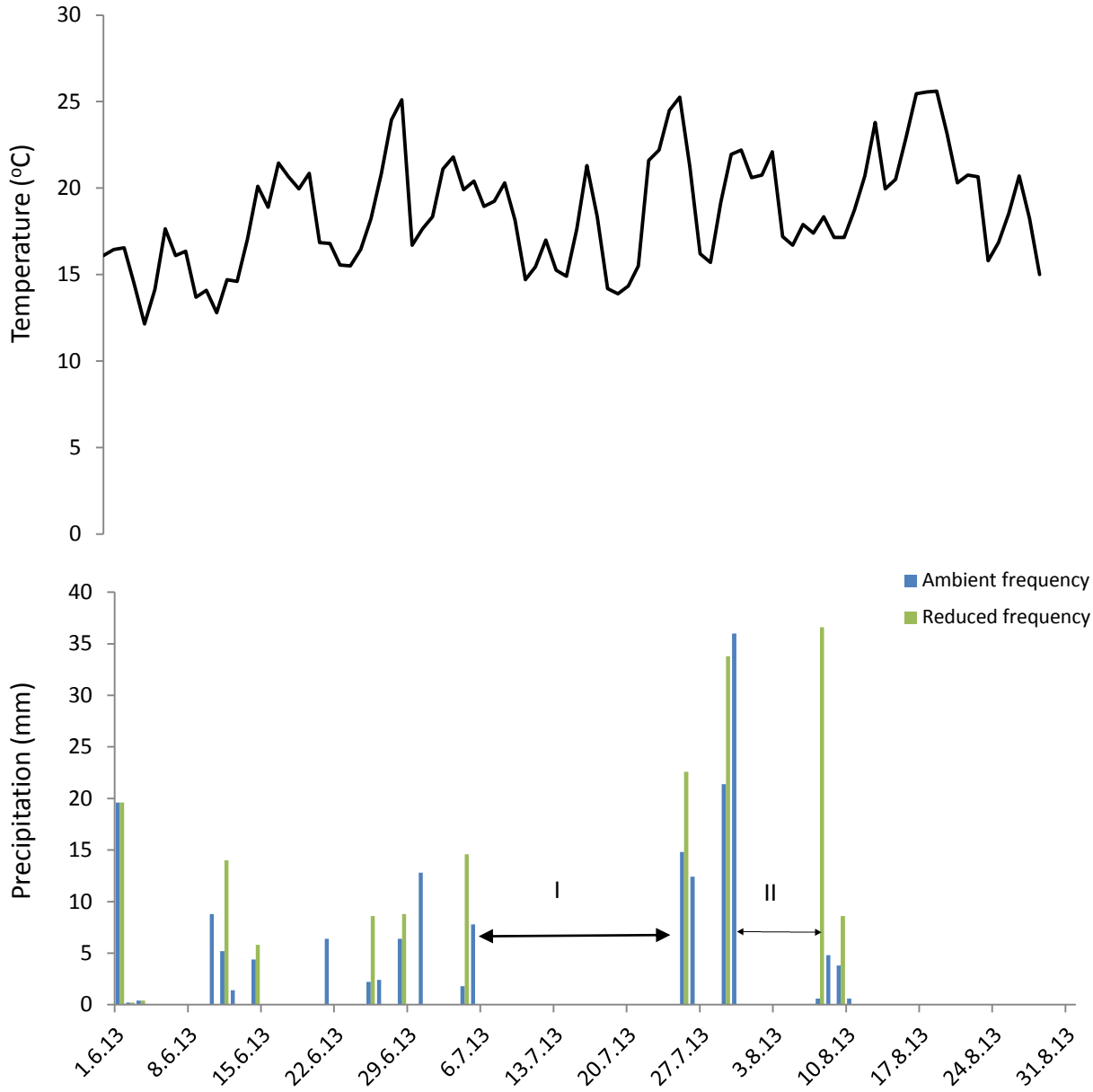

Figure 5 Average daily air temperature and precipitation pattern from June 1st to August 31st, 2013 for ambient and reduced precipitation frequency without reduction in precipitation amount (I, 1st dry period; II, 2nd dry period)

Table 1 Water addition (mm) for four precipitation treatments after the 1st and 2nd dry periods

Dry period	Treatment	Water addition (mm)
Dry period I	AaFa	14.8
	ArFa	11.1
	AaFr	22.6
	ArFr	17.0
Dry period II	AaFa	0.6
	ArFa	0.5
	AaFr	36.6
	ArFr	27.5

(AaFa, ambient precipitation; ArFa, reduced precipitation amount; AaFr , reduced precipitation frequency; ArFr, reduced precipitation amount + reduced precipitation frequency)

Table 2 Moisture content for four precipitation treatments at ambient and elevated plots after the 1st and 2nd dry periods

Dry period	Treatment	Moisture content	
		Ambient	Elevated
Dry period I	AaFa	0.197	0.080
	ArFa	0.146	0.096
	AaFr	0.163	0.107
	ArFr	0.184	0.103
Dry period II	AaFa	0.277	0.165
	ArFa	0.200	0.183
	AaFr	0.280	0.195
	ArFr	0.231	0.173

(AaFa, ambient precipitation; ArFa, reduced precipitation amount; AaFr , reduced precipitation frequency; ArFr, reduced precipitation amount + reduced precipitation frequency)

3.6 CO_2 and N_2O flux measurements

After the 1st and 2nd dry periods (19 days and 7 days, respectively), CO_2 and N_2O fluxes were measured from each roofed plot on July 25th and August 7th, 2013. We used closed chambers (Hutchinson & Mosier, 1981) with a volume of 4850 cm^3 covering an area of 270 cm^2. The bases of the chambers were permanently installed to avoid soil disturbance prior to each measurement and with a vent for pressure connection. A channel on top of the base was filled with water prior to each measurement to ensure airtight closure between the lower and upper parts of the closed chamber. At 0, 15 and 30 minutes after chamber closure, 25 ml of the gas inside the closed chamber was sampled with a gastight syringe and filled in pre-evacuated exetainers (12 ml, Labco Ltd.).

CO_2 and N_2O concentration in gas samples were measured using a gas chromatograph (Agilent 7890 equipped with a methanizer, ECD and FID). The instrumental conditions were as follow: ECD operation temperature 330°C, FID operation temperature 250°C, oven temperature 60°C, carrier gas N_2 and make-up gas ECD Ar/CH4 (95%/5%). Three standard gases with known CO_2 and N_2O concentrations were used for calibration. Gas flow rates of CO_2 and N_2O were calculated by measuring the change of gas concentration in the headspace using linear regression (Livingston & Hutchinson, 1995). Then cumulative emission was calculated by linear interpolation. Measurements were made at 6 time steps (before irrigation and 0, 1, 2.5, 4.5 and 24 h after irrigation).

3.7 Data analysis

The datasets for the production of CO_2, N_2O and the cumulative production of CO_2 and N_2O were analyzed as a three factorial ANOVA with rainfall manipulation treatment (amount and frequency) and temperature as the three factors. Prior to analyses, data were tested for normality (Shapiro-Wilk test) and homogeneity of variances (Bartlett's test). When necessary, data were log-transformed to meet the ANOVA assumptions of normality and homogeneity of variance. Significant differences were accepted at the $P < 0.05$ level of probability. All statistical tests were performed using R version 2.15.2 (R Core Team 2014) and the nlme package with lme function (Pinheiro et al. 2014).

PART (C): Effects of the intensity of rewetting of dry soils on soil CO_2 production in a microcosm experiment

3.8 Sample collection and preparation

In total, 30 soil cores were taken at a soil depth of 5–10 cm. The soil cores were taken beside the roofed plots of the HoCC. These areas did not receive water during the roofed period (from June 1st until August 31st) and, therefore, dried out severely. The HoCC experimental site, from which we took our soil cores, had been exposed to severe drought conditions of three months' duration for each of the last six years. 4 cm soil cores were cut in half to approximately 2 cm. Then, the cores were dried in the oven at 30°C before analyses.

3.9 Wetting experiment

The experimental setup included 6 treatments with 5 replicates each. The treatments consisted of: 5%, 15%, 25%, 35%, 45% volumetric water content (VWC), and control (no water added). The samples were then wetted with 1.25 ml, 3.75 ml, 6,25 ml, 8.75 ml and 11.25 ml of water to the top and bottom of each 2 cm soil core to adjust the moisture content to 5%, 15%, 25%, 35% and 45% of VWC, respectively.

3.10 Microcosm setup

After wetting, soil cores were placed into microcosms (19 cm height, 10 cm diameter) at room temperature (18°C) for 24 hours to determine CO_2 emission (Figure 6). The microcosms were sealed with plastic lids containing rubber septa. Measurements of CO_2 production were started after 0, 1, 2, 3, 4, 5, 6, 7 and 24 hours of incubation by using the closed chamber method. For measuring CO_2 flux, the microcosms were tightly closed and a rubber septum was fixed on the lid with a 2-way Luer-Lock valve. Gas sampling was done at 0, 30 and 60 minutes time intervals by connecting the microcosm atmosphere to evacuated exetainers (5.9 ml) with a mounted septum and, using a syringe (Smith et al. 1995). Gas fluxes were calculated from the linear increase or decrease in the gas concentrations in the chamber headspace.

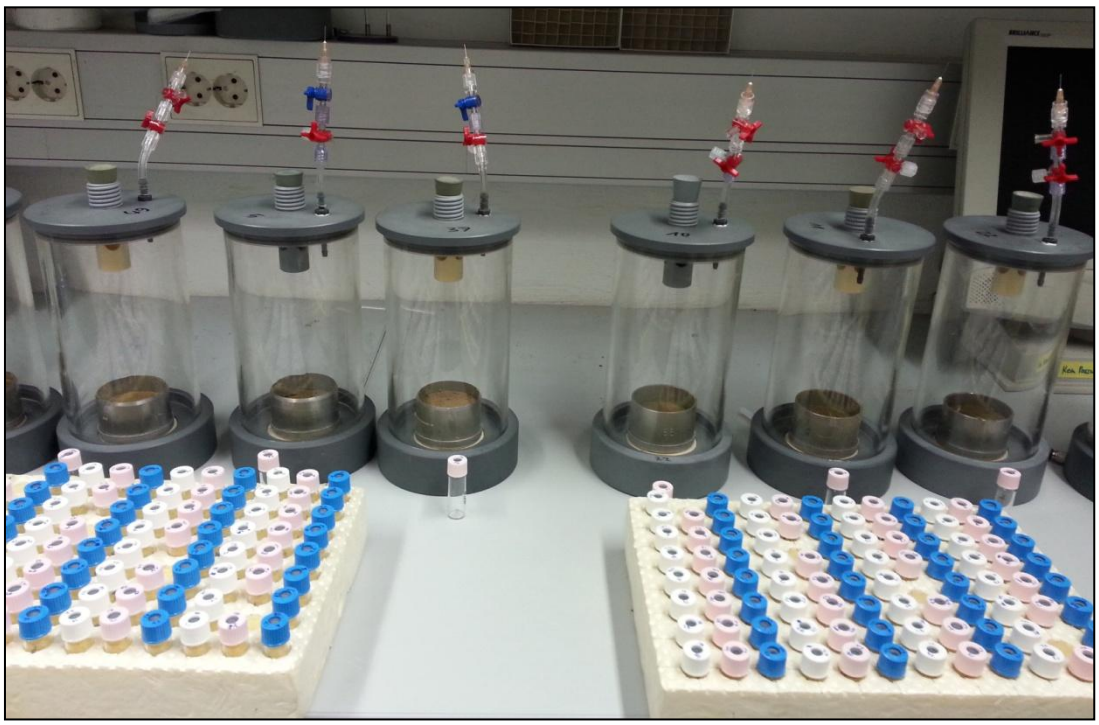

Figure 6 Set up of microcosms

3.11 Rates of CO_2 production

CO_2 concentration in gas samples were analysed using a gas chromatograph (Agilent 7890 equipped with a methanizer and FID). The instrumental conditions and calculation of the gas flow rates were the same as described in the section 3.6. Calibration was done with three standard gases with known CO_2. Both cumulative CO_2 production and the immediate CO_2 production rate over each time interval were calculated. To estimate cumulative CO_2 fluxes over the whole measuring period, cumulative emission rates were calculated by multiplying mean fluxes at two consecutive sampling dates with the corresponding period and summarizing these time-weighted means.

3.12 Data analysis

Data on CO_2 production per sampling hours was analyzed as a two-way factorial ANOVA with VWC treatment and sampling hours as the two factors. Tukey's HSD was used for comparison of means. A Spearman correlation analysis was used to check for correlation of VWC and CO_2 production. Prior to analyses, data were tested for normality (Shapiro-Wilk

test) and homogeneity of variances (Bartlett's test). When necessary, data were log-transformed to meet the ANOVA assumptions of normality and homogeneity of variance. Significant differences were accepted at the $P < 0.05$ level of probability. All statistical tests were performed using R version 2.15.2 (R Core Team 2014) and the nlme package with lme function (Pinheiro et al. 2014).

Chapter 4: Results

PART (A): Elevation of soil temperature might influence N-cycling of an agricultural cropping system

4.1 Plant analyses

4.1.1 Plant rating

Generally, soil warming did not significantly affect phenological plant development during the investigated period. However, at some dates the mean values of plant height (Figure 7), number of leaves (Figure 8) , and SPAD values (data not shown) tended to be higher in warmed than in control plots, but the differences were not significant.

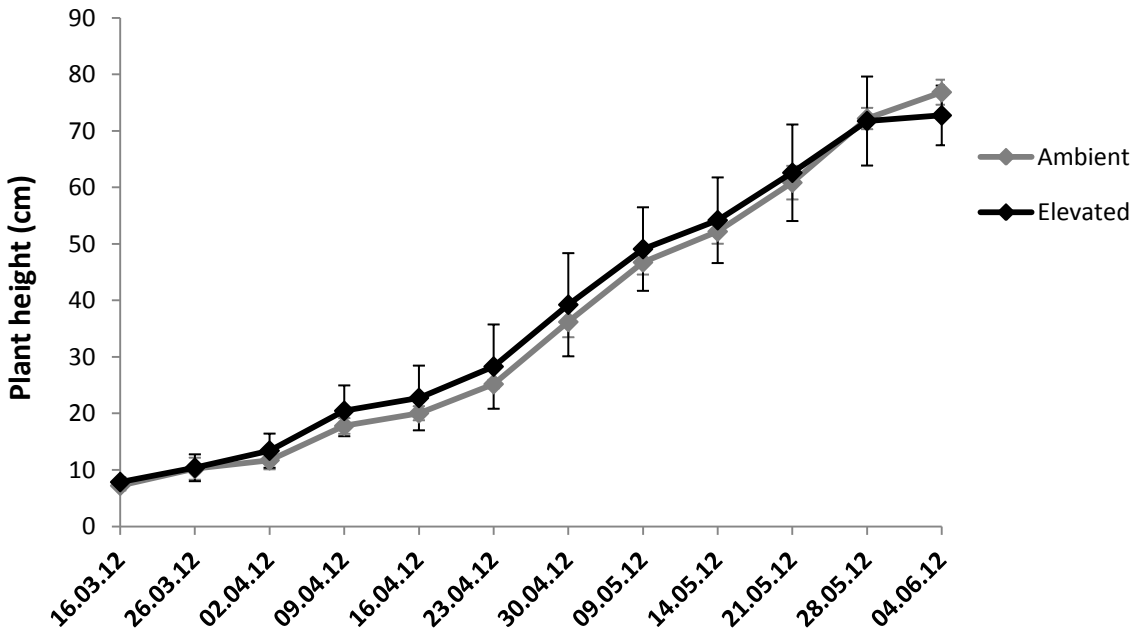

Figure 7 Plant heights from 12 rating events in warmed and control plots

Values are means ± SD with the sample size n=4.

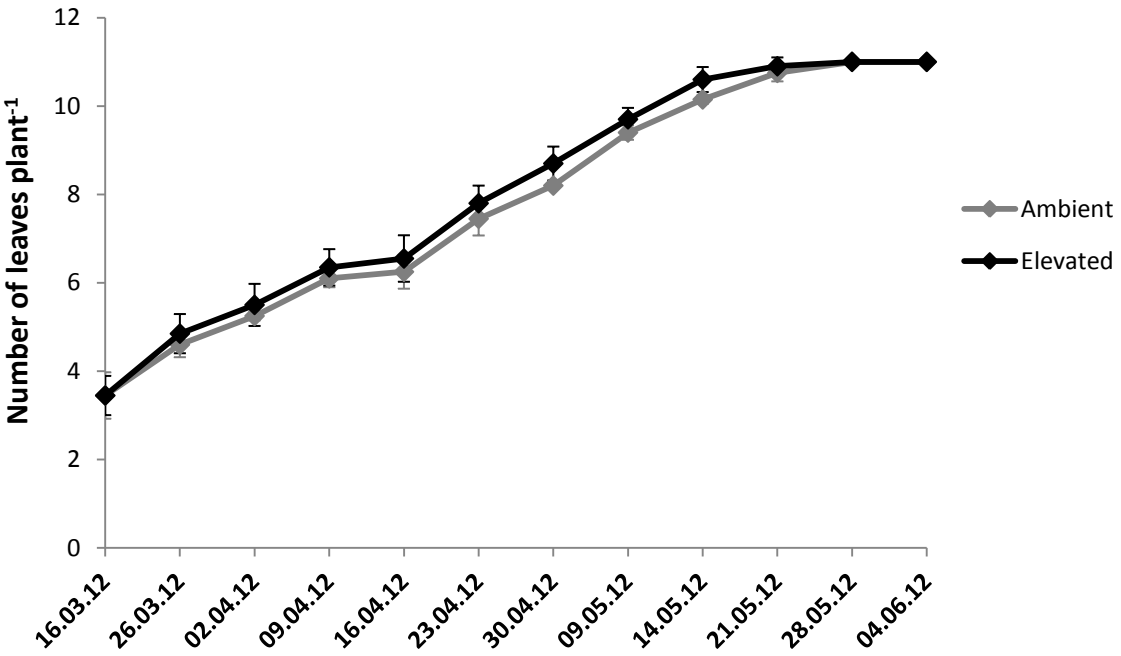

Figure 8 Number of leaves per plant from 12 rating events in warmed and control plots

Values are means ± SD with the sample size n=4.

4.1.2 Plant biomass and C and N concentration

At all sampling dates, plant biomass in soil warming and ambient plots did not differ statistically although the mean values were sometimes lower in warmed than in control plots (Table 3).

N concentrations in ears and grains did not differ between treatments (Table 4), whereas the effect of warming on N concentrations in leaves (P=0.047) and stems (0.056) was dependent on the sampling date (temperature x sampling date). In May, leaf and stem N concentrations tended to be lower in warmed plots, which resulted in higher C: N ratios of leaves and stems in May (Table 4). At harvest, C: N ratios of leaves and stems were considerably higher in warmed plots, although this was not significant.

Table 3 Biomass in g kg^{-1} dry matter

Sampling date	Elevated Mean		SD	Ambient Mean		SD	*P*
16.3.2012	0.638	±	0.421	0.737	±	0.176	n. s.
17.4.2012	3.011	±	1.038	3.010	±	0.637	n. s.
21.5.2012	24.44	±	6.113	25.64	±	8.633	n. s.
11.6.2012	42.72	±	8.920	41.08	±	3.944	n. s.
16.7.2012	42.03	±	6.548	45.37	±	10.357	n. s.

Mean ± SD, n=4; *P*-values for significant differences between treatments at each sampling date

Table 4 C and N in g kg^{-1} dry matter, and C: N-ratio in plant parts

Sampling date	Elevated Mean		SD	Ambient Mean		SD	*P*	Elevated Mean		SD	Ambient Mean		SD	*P*
	N leaves							*C leaves*						
16.3.2012	42.59	±	2.70	45.19	±	2.66	n. s.	390.39	±	10.28	380.64	±	10.75	n. s.
17.4.2012	46.07	±	4.52	43.45	±	3.72	n. s.	400.33	±	3.42	404.99	±	7.82	n. s.
21.5.2012	31.90	±	2.99	38.63	±	4.10	0.077	423.25	±	5.44	426.39	±	10.70	n. s.
11.6.2012	29.91	±	3.35	31.20	±	5.61	n. s.	417.91	±	4.70	417.10	±	7.51	n. s.
16.7.2012	7.83	±	3.09	11.37	±	6.83	n. s.	400.98	±	11.88	405.44	±	12.71	n. s.
	N stems							*C stems*						
21.5.2012	7.73	±	0.46	9.45	±	1.22	0.100	423.30	±	3.51	423.02	±	3.46	n. s.
11.6.2012	6.03	±	0.88	6.36	±	0.89	n. s.	430.51	±	5.04	427.98	±	4.73	n. s.
16.7.2012	2.51	±	1.65	2.49	±	0.79	n. s.	430.46	±	3.90	428.94	±	3.53	n. s.
	N ears							*C ears*						
11.6.2012	18.45	±	1.35	17.88	±	0.98	n. s.	441.28	±	13.46	440.90	±	11.32	n. s.
	N grains							*C grains*						
16.7.2012	19.53	±	2.15	17.68	±	1.32	n. s.	411.98	±	3.48	411.68	±	0.88	n. s.
	C:N-ratio		***leaves***					***C:N-ratio***		***stems***				
16.3.12	9.18	±	0.53	8.45	±	0.68	n. s.							
17.4.12	8.75	±	0.94	9.36	±	0.73	n. s.							
21.5.12	13.34	±	1.08	11.12	±	1.10	0.060	54.68	±	2.90	45.41	±	6.57	0.092
11.6.12	14.06	±	1.48	13.68	±	2.40	n. s.	72.65	±	11.54	68.17	±	9.38	n. s.
16.7.12	55.79	±	16.00	45.24	±	22.09	n. s.	256.70	±	22.36	187.03	±	65.85	n. s.

Mean ± SD, *P*-values for significant differences between treatments at each sampling date

4.2 Soil analyses

4.2.1 C and N in soil

Warming did not show any significant treatment effects on C or N contents at either soil depths. Analyses of the total concentrations of C and N in the soil samples are showed in Table 5. Mean values of C and N contents from control plots were below those of the warmed plots in all sampling dates but this difference was not statistically significant. The interaction between treatment and sampling date was also not significant for both C and N.

Table 5 C and N concentration in g kg^{-1} dry matter soil

Soil Depth	Sampling date	Elevated Mean g N kg^{-1}		SD	Ambient Mean		SD	*P*	Elevated Mean g C kg^{-1}		SD	Ambient Mean		SD	*P*
0-15cm	16.3.2012	1.268	±	0.080	1.227	±	0.106	n. s.	11.180	±	1.074	10.840	±	0.737	n. s.
	17.4.2012	1.338	±	0.045	1.289	±	0.092	n. s.	10.971	±	0.812	10.873	±	0.910	n. s.
	21.5.2012	1.168	±	0.074	1.145	±	0.098	n. s.	10.134	±	1.042	9.589	±	0.929	n. s.
	11.6.2012	1.327	±	0.079	1.313	±	0.098	n. s.	12.001	±	1.256	11.463	±	1.001	n. s.
	16.7.2012	1.254	±	0.070	1.217	±	0.115	n. s.	11.141	±	1.129	10.597	±	1.190	n. s.
15-30 cm	16.3.2012	1.209	±	0.069	1.162	±	0.142	n. s.	10.529	±	1.087	10.082	±	1.197	n. s.
	17.4.2012	1.227	±	0.102	1.164	±	0.097	n. s.	10.464	±	1.335	9.725	±	1.159	n. s.
	21.5.2012	1.187	±	0.643	1.154	±	0.094	n. s.	9.921	±	1.074	9.503	±	0.854	n. s.
	11.6.2012	1.237	±	0.053	1.186	±	0.107	n. s.	10.673	±	0.831	10.030	±	0.917	n. s.
	16.7.2012	1.114	±	0.090	1.077	±	0.092	n. s.	9.901	±	1.313	9.220	±	0.776	n. s.

Mean ± SD, *P*-values for significant differences between treatments at each sampling date

4.2.2 Mineral nitrogen content

Over the sampling period, extractable amount of NH_4^+ was not significantly influenced by soil warming at the 0 - 15 cm soil depth whereas at the 15 - 30 cm soil depth, NH_4^+ was significantly higher in warmed plots in July (Figure 9). In comparison to NH_4^+, higher amount of NO_3^- was extractable from soils at both soil depths (Figure 9). Soil warming increased NO_3^- significantly at the 0 - 15 cm soil depth only in April (Treatment x sampling date; $P < 0.001$) while at the other dates, no treatment effect was detectable.

4.2.3 Microbial biomass C and N (C_{mic} and N_{mic})

Soil microbial biomass and mineral nitrogen forms were generally higher at the upper (0 – 15 cm) than at the lower soil depth (15 – 30 cm) (Fig. 9). Across the growing season, C_{mic} at the 0 – 15 cm depth tended to be increased by soil warming (P = 0.05), which was most pronounced in March and June. At 15 – 30 cm soil depth C_{mic} was significantly increased by warming only in April but not at the other sampling dates (treatment × sampling date; P < 0.01). Similar to C_{mic}, N_{mic} tended to be increased by soil warming at the 0 – 15 cm (P = 0.07) and 15 – 30 cm (P = 0.1) depths with greatest effects of warming in March and June (0 – 15 cm) and May (15 – 30 cm).

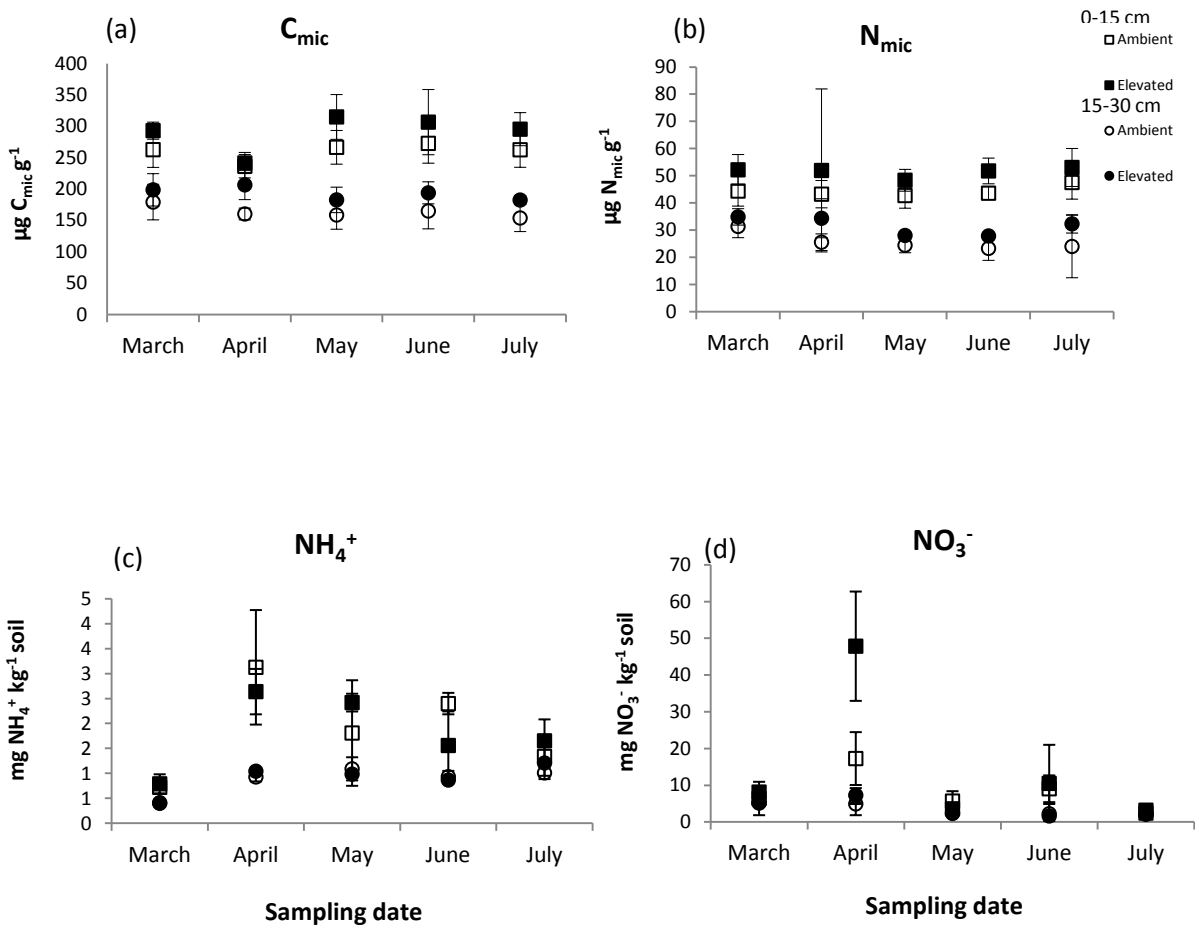

Figure 9 Effects of elevated soil temperature on (a) microbial biomass C, (b) microbial biomass N, (c) NH_4^+, and (d) NO_3^- at 0-15 and 15-30 cm soil depths from five sampling dates

Mean ± SD, Values are given as means of four replicates.

4.2.4 Soil enzyme activities

Similar to the depth distribution of soil microorganisms, soil enzyme activities were generally higher at 0 – 15 cm than at 15 – 30 cm soil depth (Figure 10). Protease activity was significantly increased by elevated soil temperatures in June and July and tended to be higher also in March at the 0 – 15 cm depth, whereas in April and May no effect was detectable (Treatment × sampling date; $P = 0.06$; Fig. 10, Table 6). At the 15 - 30 cm depth, the increase in protease activity by warming was most pronounced in April and July (Treatment × sampling date; $P = 0.06$, Table 7).

Potential nitrification was not affected by elevated soil temperature at the 0 – 15 cm layer, whereas at 15 – 30 cm depth soil warming enhanced potential nitrification significantly in March and tended to decrease it in May (Treatment × sampling date; $P = 0.05$, Table 7).
Tyrosine aminopeptidase and leucine aminopeptidase (Figure 10) showed a tendency towards higher activity at 0-15 cm soil depth in warmed plots across the growing season ($P = 0.08$ and $P = 0.09$, respectively), whereas at 15-30 cm depth no effects of warming were detectable. Alanine aminopeptidase and N-acetyl-glucosaminidase showed no significant treatment effects at 0-15 cm; while at 15-30 cm N-acetyl-glucosaminidase was significantly increased by soil warming in May and July (treatment x sampling date; $P<0.01$).

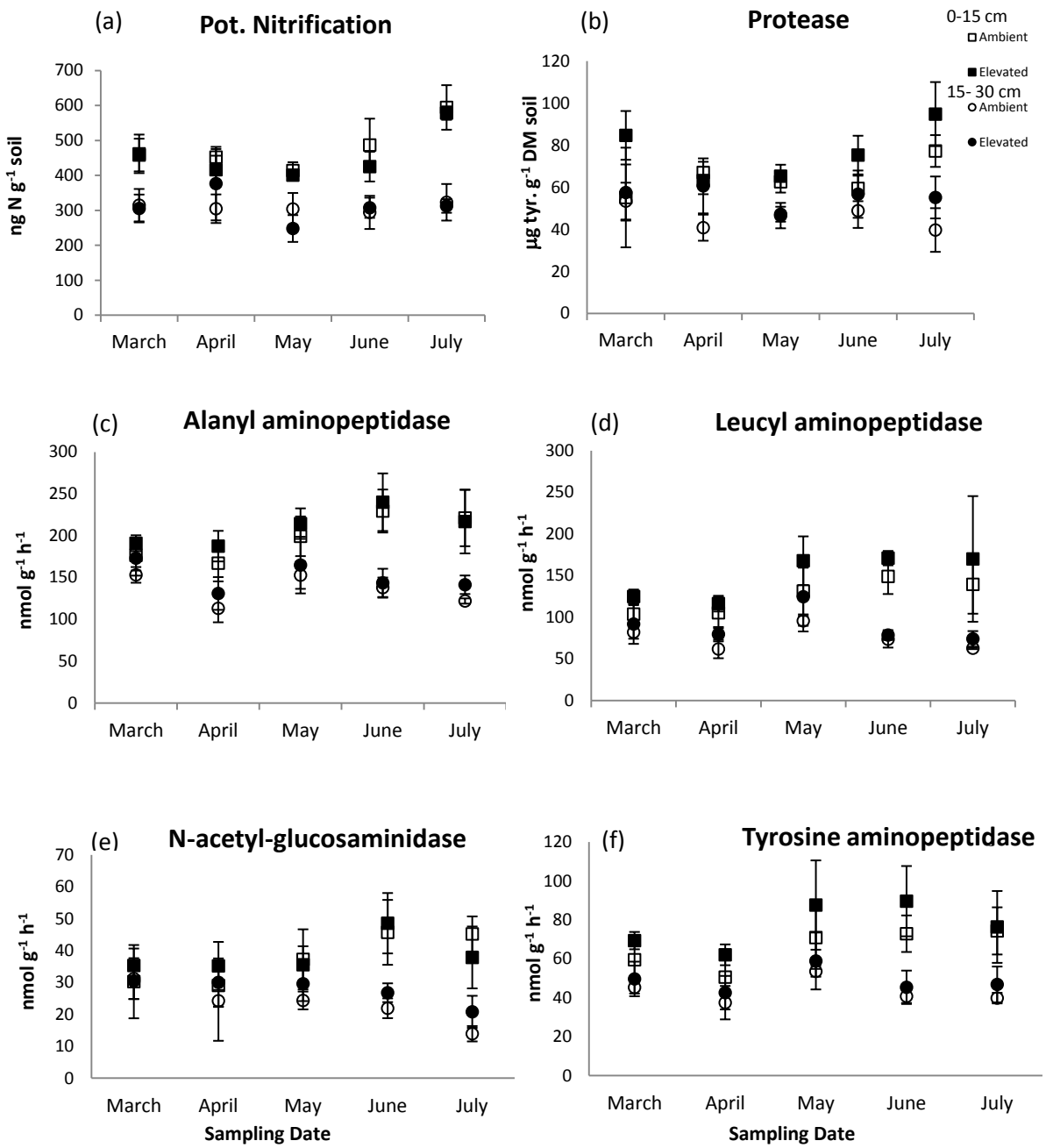

Figure 10 Effects of elevated soil temperature on (a) potential nitrification, (b) protease, (c) Alanyl-aminopeptidase, (d) Leucyl-aminopeptidase, (e) N-acetyl-glucosaminidase and (f) Tyrosine aminopeptidase activities at 0-15 and 15-30 soil depths from five sampling dates Mean ± SD, Values are given as means of four replicates.

Table 6 ANOVA results for the response of soil analyses to elevated soil temperature and sampling date at 0-15 cm soil depth.

Significance (in bold) is considered at $P < 0.05$ and trend (in bracket) is considered at $P < 0.1$, respectively.

Factor	C_{mic}	N_{mic}	C	N	NH_4^+	NO_3^-	Pot. Nit.	Prot	Tyro	Leu	Ala	N-ac
Temperature	(0.051)	(0.068)	0.591	0.609	0.498	0.206	0.278	**0.036**	(0.081)	(0.091)	0.228	0.474
Date	**0.010**	**0.021**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0002**	**0.006**	**0.007**	**0.0002**	**0.0007**
Temperature x Date	0.682	0.131	0.599	0.763	0.643	**0.037**	0.599	(0.060)	0.822	0.938	0.866	0.155

Pot. Nit., potential nitrification; Prot, protease; Tyro, tyrosine; Leu, leucine aminopeptidase; Ala, alanine aminopeptidase; N-ac, N-acetyl-glucosaminidase.

Table 7 ANOVA results for the response of soil analyses to elevated soil temperature and sampling date at 15-30 cm soil depth

Significance (in bold) is considered at $P < 0.05$ and trend (in bracket) is considered at $P < 0.1$, respectively.

Factor	C_{mic}	N_{mic}	C	N	NH_4^+	NO_3^-	Pot. Nit.	Prot	Tyro	Leu	Ala	N-ac
Temperature	0.137	(0.097)	0.455	0.469	0.623	0.862	0.909	0.133	0.339	0.177	0.219	0.131
Date	**0.011**	**<0.0001**	**0.015**	**0.0008**	**<0.0001**	**<0.0001**	**0.039**	(0.096)	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Temperature x Date	**0.001**	0.304	0.957	0.982	0.269	**0.024**	(0.052)	(0.055)	0.986	0.455	0.763	0.117

Pot. Nit., potential nitrification; Prot, protease; Tyro, tyrosine; Leu, leucine aminopeptidase; Ala, alanine aminopeptidase; N-ac, N-acetyl-glucosaminidase.

PART (B): Impacts of rainfall manipulations on CO_2 and N_2O fluxes in an agricultural soil

4.3 CO_2 emission during precipitation manipulation

The response of CO_2 emissions to rewetting of dry soils from plots, which are exposed to different precipitation and temperature regimes, is shown in Table 8.

In general, CO_2 emissions were lower at the end of the 2nd dry period compared to the first dry period. There was a significant effect of temperature on the amount of emitted CO_2-C ($P < 0.05$) after the 2nd dry period. However, there was no statistically significant effect of

precipitation on CO_2 emissions for both dry periods. A significant effect of frequency treatment on CO_2 % was found after the 1st dry period ($P < 0.01$, Figure 11).

Table 8 Mean fluxes of CO_2-C mg m^{-2} h^{-1} (± SD) in elevated and ambient plots after the 1st dry period (July 6 – July 25) and the 2nd dry period (July 31 – August 7) under different rainfall manipulations

Dry Period	Treatment	Elevated (Sampling hours)						Ambient (Sampling hours)					
		-1	0	1	2.5	4.5	24	-1	0	1	2.5	4.5	24
Dry period I	AaFa	69 ± 11.22	111.34± 34.76	112.05 ± 12.41,*	112.66 ± 12.64	123.76 ± 8.07,*	140.41 ± 3.99	61.69 ± 10.03	64.42 ± 23.17	76.23 ± 21.08,*	79.53 ± 26.69	87.98 ± 25.38,*	112.58 ± 18.98
	ArFa	79.13 ± 40.44	94.70± 31.17	124.22 ± 22.01	117.83 ± 23.56	114.61 ± 24.61	135.17 ± 26.87	63.14 ± 19.09	60.52 ± 8.94	98.78 ± 14.69	101.62 ± 17.96	100.06 ± 25.59	100.52 ± 34.63
	AaFr	68.14 ± 32.88	108.88 ± 18.84	100.67 ± 29.96	101.07 ± 19.44,*	131.65 ± 27.09	117.38 ± 11.32	55.86 ± 11.50	64.76 ± 23.23	90.57 ± 26.92	53.46 ± 14.32,*	80.28 ± 30.98	88.38 ± 28.27
	ArFr	53.94 ± 20.96	99.59 ± 8.81	143.70 ± 63.56	102.90 ± 25.36	120.22 ± 52.39	91.90 ± 42.26	54.46 ± 7.81	84.02 ± 39.16	91.97 ± 35.97	58.82 ± 15.11	93.92 ± 37.32	94.50 ± 8.05
Dry period II	AaFa	52.51± 9.98	71.00± 20.80	75.68 ± 17.11	64.93 ± 13.56	46.67 ± 3.75	66.84 ± 26.19	47.84 ± 10.22	59.48± 15.04	60.38 ± 20.43	41.37 ± 8.18	38.90 ± 5.43	79.72 ± 5.92
	ArFa	50.47± 17.22	79.92 ± 9.70,*	102.48 ± 37.70	90.31 ± 17.11,*	47.81 ± 15.97	101.98 ± 13.21,*	53.53 ± 16.38	51.87 ± 12.30,*	72.45 ± 29.40	51.87 ± 20.81,*	26.89 ± 4.42	68.69 ± 2.23,*
	AaFr	53.12± 8.71	58.71 ± 16.06	59.39 ± 15.12	65.43 ± 18.90	45.38 ± 6.22	74.34 ± 21.65	51.91 ± 12.92	34.71 ± 8.81	46.15 ± 19.70	38.08 ± 0	18.08 ± 12.05	54.56 ± 11.08
	ArFr	41.18 ± 3.05	66.10 ± 22.83	62.33 ± 22.83	70.74 ± 13.36	44.07 ± 15.82	86.13 ± 31.15	50.24 ± 1.32	35.03 ± 14.78	46.65 ± 2.40	48.01 ± 6.31	24.55 ± 6.45	59.54 ± 9.23

* Indicates significant effect of temperature between each sampling hour

(AaFa, ambient precipitation; ArFa, reduced precipitation amount; AaFr, reduced precipitation frequency; ArFr, reduced precipitation amount + reduced precipitation frequency; -1, 1 hour before rewetting)

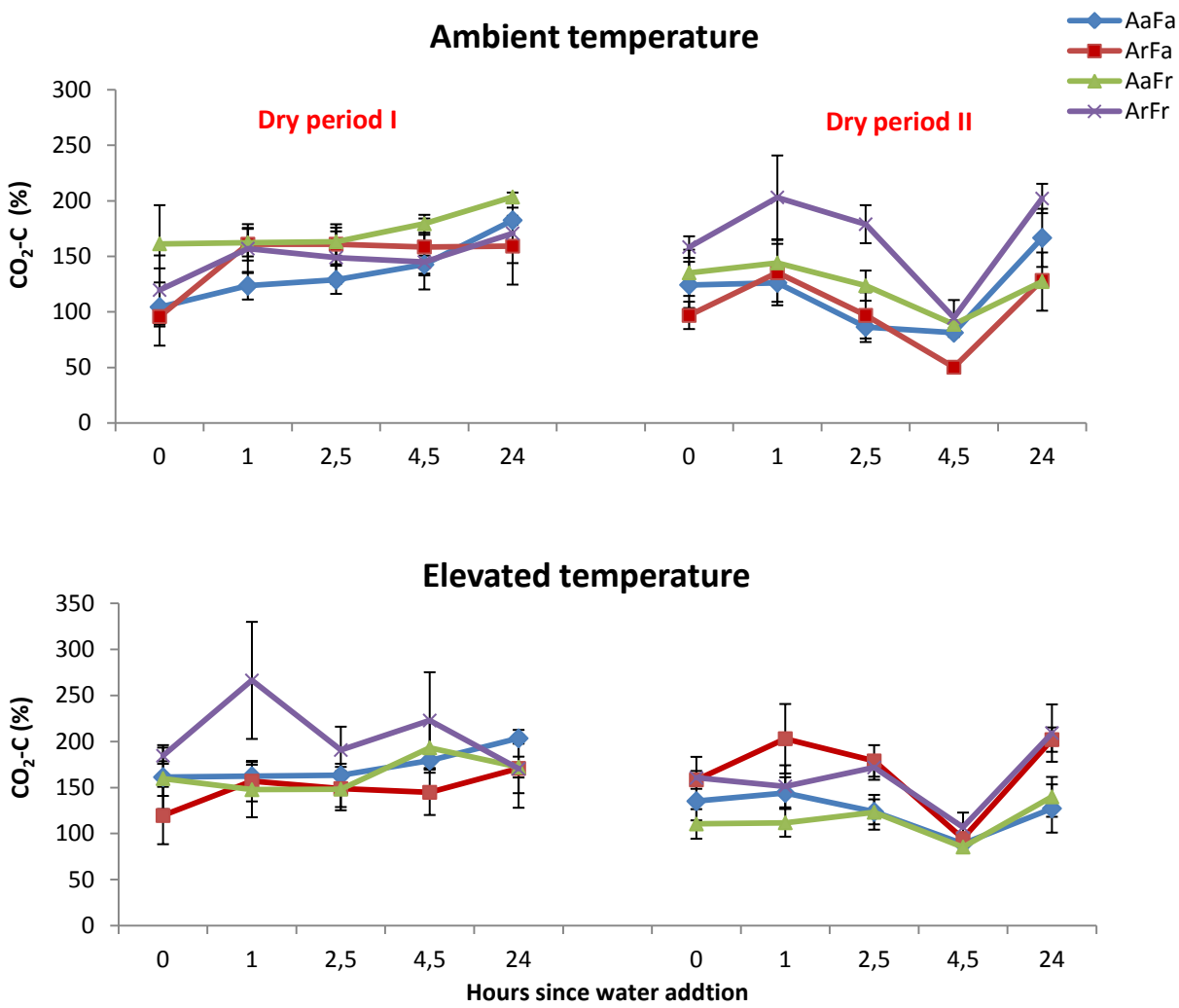

Figure 11 Percentage increase in CO_2 emission (Mean ± SD) from (a) ambient and (b) warmed plots after the 1st dry period (July 6 – July 25) and the 2nd dry period (July 31 – August 7). CO_2 emissions were related to the rate measured directly before the plots were rewetted.

(AaFa, ambient precipitation; ArFa, reduced precipitation amount; AaFr, reduced precipitation frequency; ArFr, reduced precipitation amount + reduced precipitation frequency)

4.4 N_2O emission during precipitation manipulation

The response of N_2O emissions to rewetting of dry soils from plots, which are exposed to different precipitation and temperature regimes, is shown in Table 9. There were no statistically significant effects of temperature and rainfall manipulation treatments on N_2O emissions for both dry periods. A significant effect of frequency treatment on N_2O % was found after the 2nd dry period ($P < 0.01$, Figure 12).

Table 9 Mean fluxes of N_2O-N mg m^{-2} h^{-1} (± SD) in elevated and ambient plots after ambient plots after the 1st dry period (July 6 – July 25) and the 2nd dry period (July 31 – August 7)

Dry Period	Treatment	**Elevated** (Sampling hours)						**Ambient** (Sampling hours)					
		-1	0	1	2.5	4.5	24	-1	0	1	2.5	4.5	24
Dry period I	AaFa	7.12 ± 3.29	10.57 ± 3.98	6.87 ± 1.89	7.15 ± 3.56	7.55 ± 2.47	5.99 ± 2.45	3.93 ± 4.53	4.56 ± 2.19	7.08 ± 3.04	7.65 ± 6.65	15.42 ± 15.14	4.54 ± 4.09
	ArFa	2.28 ± 1.33	8.75 ± 1.89	8.13 ± 5.16	9.01 ± 2.28	8.99 ± 2.61	5.32 ± 4.44	5.67 ± 0.52	4.24 ± 0.68	4.18 ± 2.73	4.70 ± 4.08	5.82 ± 2.86	2.70 ± 1.97
	AaFr	3.37 ± 1.55	7.07 ± 0.87,*	16.25 ± 14.60	14.03 ± 15.09	17.08 ± 14.87	4.93 ± 1.39	1.49 ± 2.08	1.89 ± 1.45,*	5.06 ± 3.03	11.16 ± 3.61	32.23 ± 24.10	4.19 ± 5.05
	ArFr	0.00 ± 0.00	6.91 ± 4.12	20.55 ± 9.11	7.41 ± 1.13	8.35 ± 4.83	1.72 ± 1.01	0.91 ± 0.13	2.77 ± 1.91	6.48 ± 0.84	15.02 ± 16.53	4.41 ± 32.10	3.61 ± 2.33
Dry period II	AaFa	4.92 ± 1.14	5.84 ± 2.39	5.45 ± 3.14	4.53 ± 2.63	7.20 ± 2.44	6.02 ± 2.09	1.63 ± 0.23	2.20 ± 0.85	2.28 ± 2.61	1.15 ± 0.59	4.24 ± 0.17	9.64 ± 0.40
	ArFa	4.45 ± 4.53	3.24 ± 2.63	2.50 ± 2.88	4.40 ± 3.79	4.71 ± 2.50	8.90 ± 5.51	2.32 ± 1.48	4.04 ± 3.37	4.14 ± 2.37	2.38 ± 0.36	3.07 ± 0.59	7.10 ± 3.28
	AaFr	4.40 ± 1.33	4.35 ± 1.81	3.96 ± 2.67	8.09 ± 5.19	9.57 ± 4.56	5.25 ± 3.53	2.78 ± 0.17	4.11 ± 1.60	4.41 ± 0.94	4.43 ± 0.00	7.36 ± 5.63	6.63 ± 2.49
	ArFr	2.47 ± 1.16	6.66 ± 5.74	8.97 ± 8.01	9.85 ± 4.30,*	14.04 ± 9.71	8.69 ± 7.25	1.34 ± 0.25	2.37 ± 2.10	3.22 ± 0.71	7.47 ± 3.24,*	7.96 ± 3.11	5.83 ± 2.78

* Indicates significant effect of temperature between each sampling hour

(AaFa, ambient precipitation; ArFa, reduced precipitation amount; AaFr, reduced precipitation frequency; ArFr, reduced precipitation amount + reduced precipitation frequency; -1, 1 hour before rewetting)

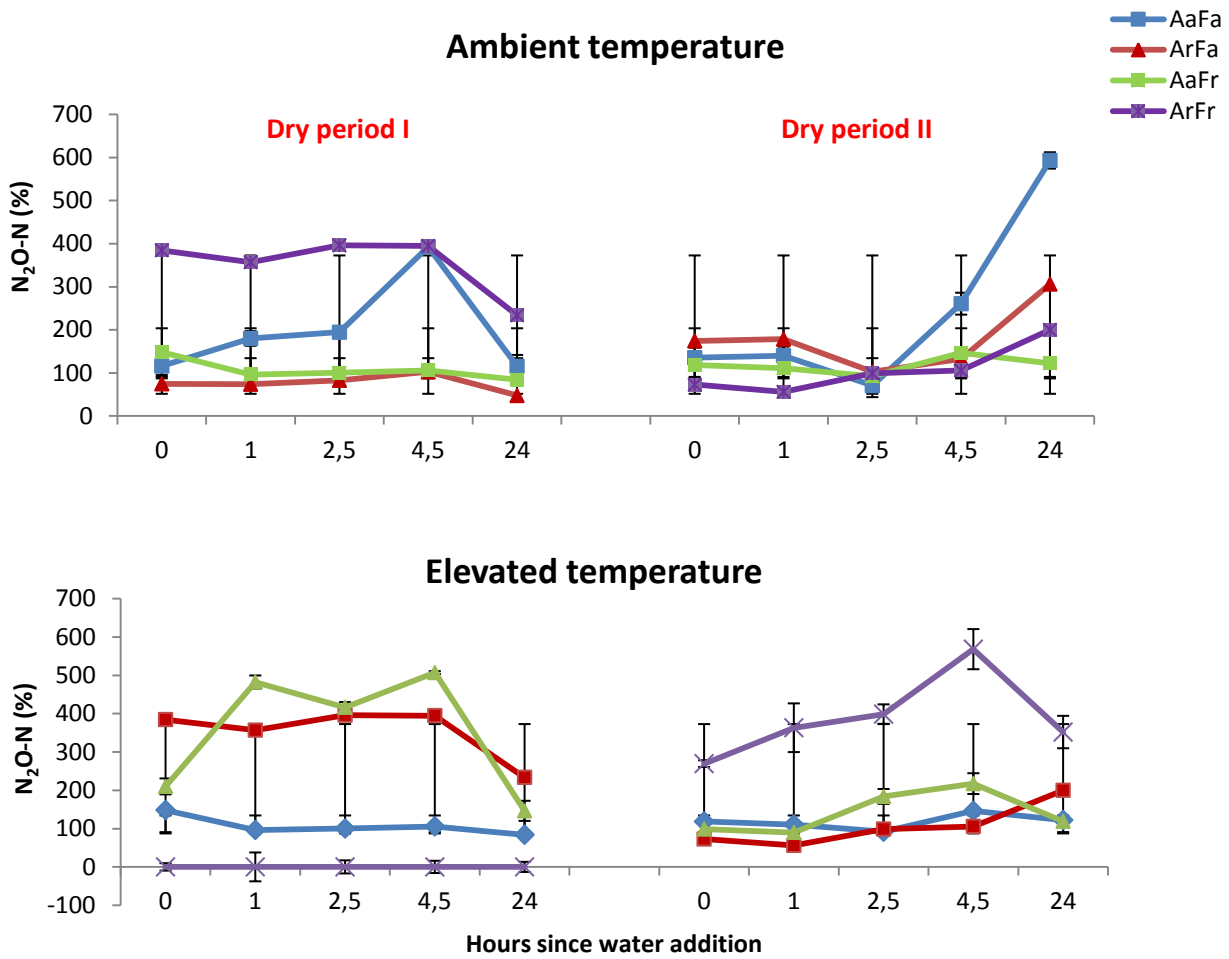

Figure 12 Percentage increase in N_2O emission (Mean ± SD) from (a) ambient and (b) elevated plots after the 1st dry period (July 6 – July 25) and the 2nd dry period (July 31 – August 7). N_2O emissions were related to the rate measured directly before the plots were rewetted.

(AaFa, ambient precipitation; ArFa, low precipitation amount; AaFr, reduced precipitation frequency; ArFr, reduced precipitation amount + reduced precipitation frequency)

4.5 Cumulative CO_2

Cumulative CO_2 emission did not depend on precipitation treatments, but instead depended on temperature. Cumulative CO_2 emissions were significantly increased in plots with elevated temperature compared to plots with ambient temperature ($P<0.05$) (Figure 13). We found that the temperature effects were 31 % and 53 % (1st dry period) and 11 % and 56 % (2nd dry period) for ambient frequency treatment and reduced frequency treatment,

respectively. Therefore, reducing the frequency increased the effect of the temperature for both dry periods.

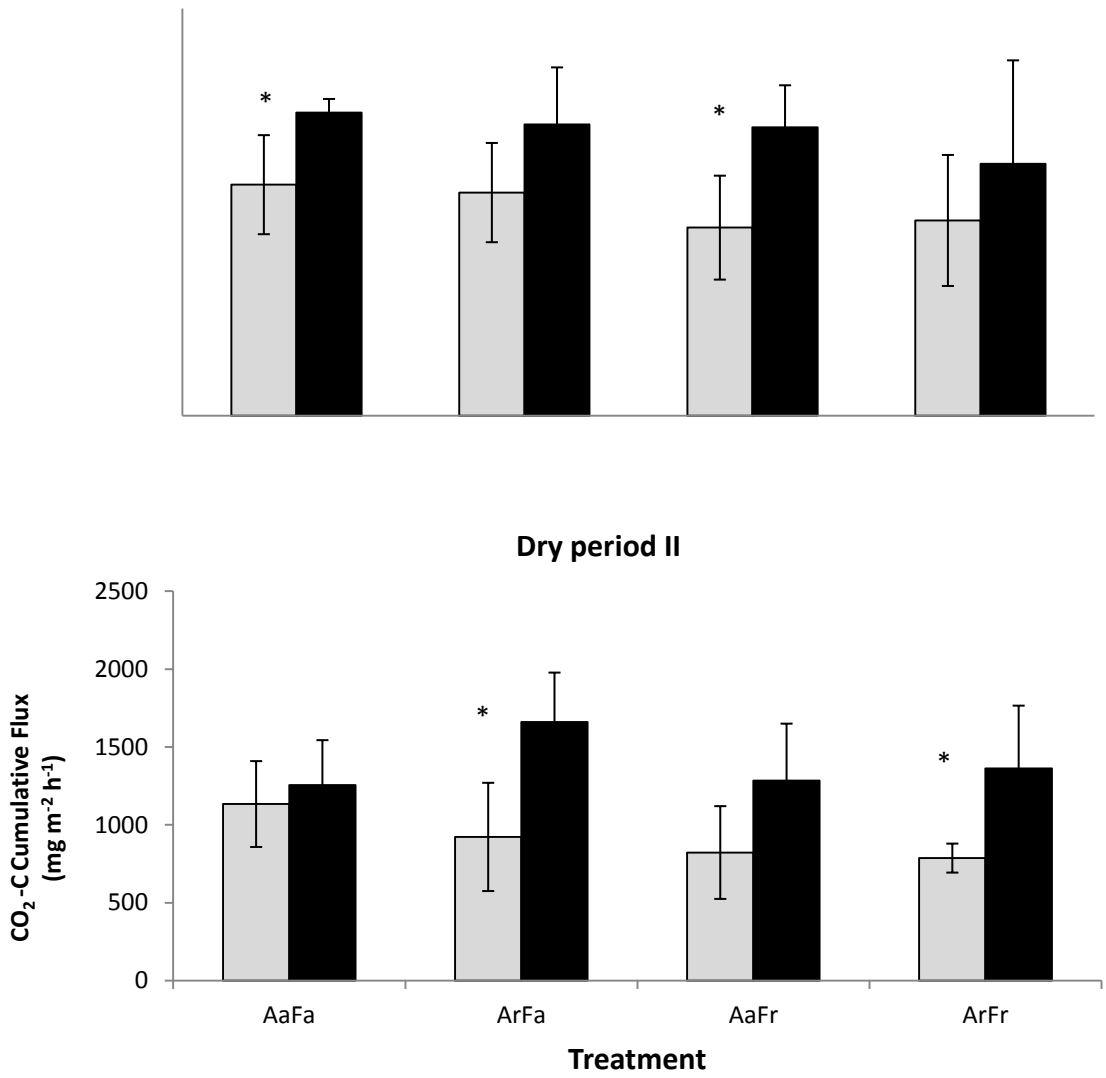

Figure 13 Mean cumulative fluxes of CO_2-C (mg m^{-2} h^{-1}) in elevated and ambient plots under different rainfall manipulations

Means of four replicates per treatment with standard deviation
(AaFa, ambient precipitation; ArFa, reduced precipitation amount; AaFr, reduced precipitation frequency; ArFr, reduced precipitation amount + reduced precipitation frequency)

* indicates significant differences between elevated and ambient plots

4.6 Cumulative N_2O

The rainfall simulation pattern artificially created in our study did not affect cumulative N_2O emissions. Despite different emission patterns (Figure 14), cumulative N_2O emissions did not differ significantly between the precipitation treatments (Figure 13). There was also no significant effect of temperature on the cumulative flux of N_2O for either the 1st or 2nd dry period.

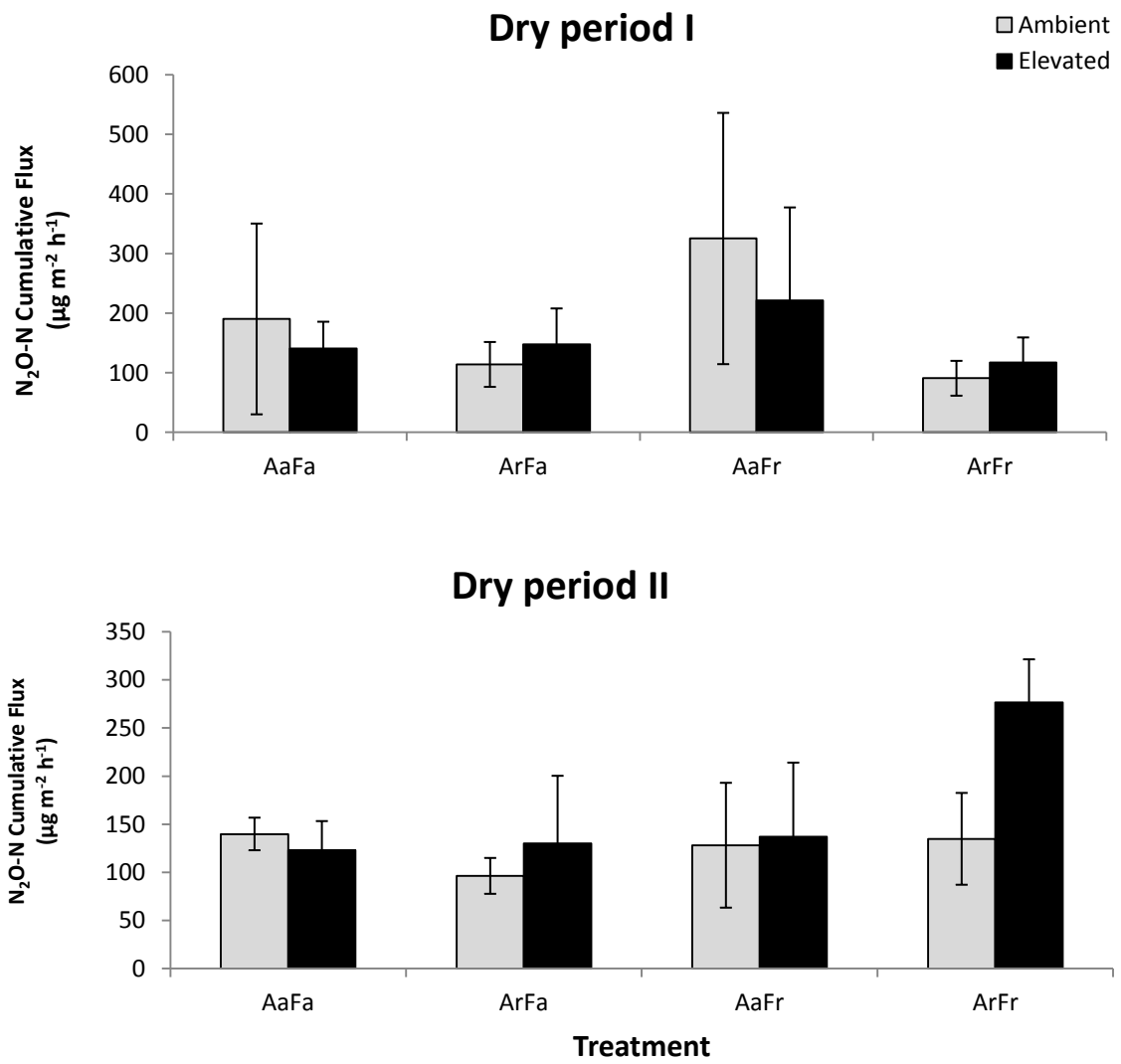

Figure 14 Mean cumulative fluxes of N_2O-N (µg m^{-2} h^{-1}) in elevated and ambient plots under different rainfall manipulation

Means of four replicates per treatment with standard deviation
(AaFa, ambient precipitation; ArFa, reduced precipitation amount; AaFr, reduced precipitation frequency; ArFr, reduced precipitation amount + reduced precipitation frequency)

PART (C): Effects of drying-rewetting event on CO_2 production from soil in a microcosm experiment

4.7 CO_2 production rate

CO_2 production from soil cores within 24 hours after rewetting with different amounts of water is shown in Figure 15. CO_2 production was strongly affected by the amount of water added and increased with increasing water content ($P < 0.001$). It was found that by increasing VWC, the rate of CO_2 production throughout the incubation time intervals increased.

The temporal pattern of CO_2 emission was affected by the amount of water that was added. The control treatment did not show CO_2 peak. The number of CO_2 peaks increased up to 3 peaks with increasing water addition. Most treatments showed their highest peak directly after water addition (0.78 mg C g^{-2} h^{-1}, 1.79 mg C g^{-2} h^{-1}, 2.21 mg C g^{-2} h^{-1} and 2.53 mg C g^{-2} h^{-1} for 5%, 15%, 25% and 35% VWC, respectively, Table 10). Then, for 15 and 25% VWC there is a second peak after 7 and 6 h, respectively. For 35% VWC, there was a second peak after 4 and 5 h and CO_2 production remained rather stable until the end of the incubation. Finally, for 45 % VWC the first peak was delayed and was lower than that observed under 15 – 35 %. The second peak was comparable to the second peak under 35% VWC, the highest peak came after 24h.

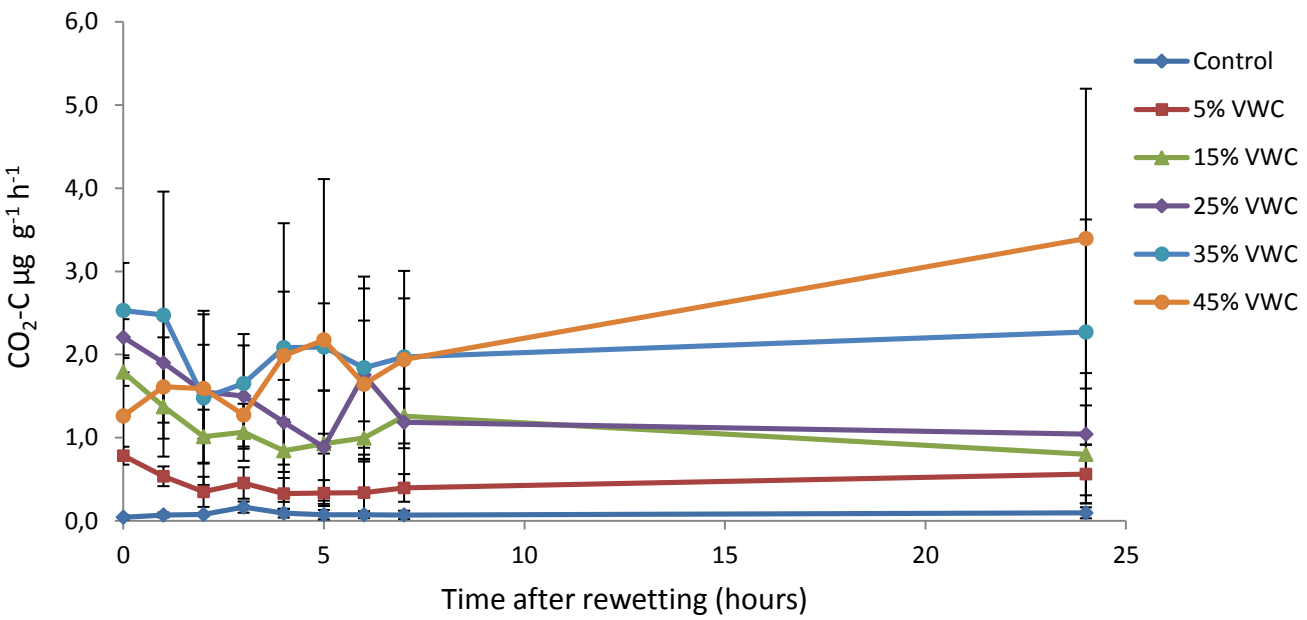

Figure 15 Mean CO_2 production from soil cores during 24 hours after rewetting by adding different amounts of water

Table 10 CO_2 production from soil cores at different time points by adding different amounts of water

VWC (%)	CO_2 – C emission (µg CO_2-C g^{-2} h^{-1})									*P*
	Time after rewetting (hours)									
	0	1	2	3	4	5	6	7	24	
0	0.04±0.11	0.07±0.12	0.00±0.18	0.17±0.19	0.09±0.19	0.08±0.16	0.07±0.40	0.07±0.17	0.10±0.35	n.s.
5	0.78±0.17	0.54±0.19	0.35±0.32	0.46±0.34	0.33±0.62	0.34±0.12	0.34±0.20	0.40±0.33	0.56±0.59	n.s.
15	1.79±0.22	1.37±0.31	1.01±0.56	1.07±0.61	0.84±0.51	0.93±0.68	0.99±1.04	1.26±0.77	0.80±0.73	0.036
25	2.21±0.57	1.90±1.49	1.55±1.05	1.50±0.59	1.19±1.50	0.89±0.53	1.75± 1.10	1.19±0.71	1.04±1.35	n.s.
35	2.53±0.52	2.47±0.84	1.48±0.89	1.65±0.41	2.08±0.77	2.09±1.93	1.84±0.76	1.97±1.07	2.27±1.80	n.s.
45	1.26±0.03	1.61±0.03	1.59±0.02	1.27±0.07	1.99±0.05	2.18±0.06	1.64±0.04	1.94±0.05	3.39±0.07	0.003

Mean ± SD, *P*-values for significant differences between volumetric water content and sampling hours

4.8 Cumulative CO_2 production

Cumulative production of CO_2-C differed significantly between the wetting treatments ($P < 0.001$). Figure 15 shows the relationship between VWC and cumulative CO_2 production in soil cores by adding different water during the 24 hour experiment. Cumulative CO_2 productions were positively correlated with VWC ($R^2 = 0.989$, $P < 0.001$).

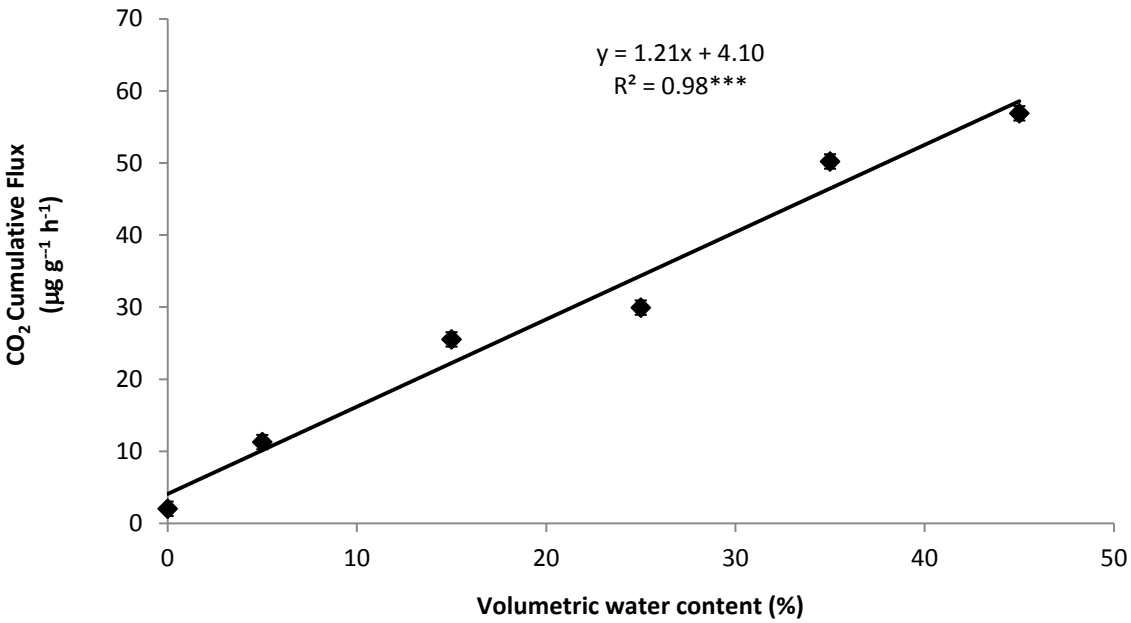

Figure 16 Relationship between cumulative CO_2 fluxes and volumetric water content

*** $P<0.001$.

Chapter 5: Discussion

5.1 Effects of elevated soil temperature on plant development

Various warming facilities have been used in field experiments, such as open-top chambers, greenhouses, soil-heating cables, and infrared heaters, in order to study the projected effects of future climate warming on terrestrial ecosystems (Yin et al. 2012). Our soil warming plots have utilized buried soil-heating-cables and buried method to manipulate soil temperature and to study its effects on wheat crop growth, C and N concentration in biomass and soil N availability.

In our study, plants from warmed plots seemed to grow faster and had more leaves than plants in the ambient temperature treatment even though the differences were not significant. However, during the last two weeks before harvest leaf numbers converge between the two treatments resulting in almost equal numbers at harvest. Similarly, the effect of warming on plant height changed during the last two weeks with slightly higher plants at ambient temperature. These observations indicate that wheat plants showed a faster vegetative growth but also a faster senescence under elevated temperature. Interestingly, these effects did not result in a consistent effect of soil warming on above-ground biomass. Our results are in agreement to Patil et al. (2010a), who found advanced crop growth and development during vegetative stages under elevated soil temperature of 5°C.

Leaf and stem N concentrations started to decrease in May with a faster decrease in the warmed plots. Lower leaf N concentrations due to warming have also been observed in different temperate-type non-Mediterranean ecosystems (Tolvanen & Henry, 2001; An et al., 2005). However, the more advanced phenological development may explain lower plant N concentrations in warmed plots by decreased N uptake of fertilizer N during advanced development stages (Holmes 1980) or by increased internal N allocation to grains. Interestingly, there was more N in grains in warmed plots which may support the hypothesis of a faster internal allocation of N into grains. The only effect of warming on plant N concentrations was that the faster plant development resulted in a faster senescence and therefore an advanced decrease in N concentration, However, this is probably not affected by the effects of warming on the soil N cycle, because there were no differences in mineral

N contents in soil in the second half of the vegetation period. Lower N concentration in wheat plant fractions due to elevated soil temperatures was also reported by Gavito et al. (2001).

5.2 Effects of elevated soil temperature on N cycling in soil

Temperature is an important factor that regulates microbial activity and therefore N turnover and N-mineralization. Microbes play critical roles in C and nutrient transformation in soils, and even slight changes in the microbial biomass or community structure may affect soil C and N cycling (Xu et al. 2010). Therefore, soil microbial properties have been proposed to be potential indicators for impacts of global warming on soils. In our study, microbial biomass C and N showed a tendency towards higher biomass under elevated soil temperature. This tendency of microbial biomass under elevated temperature was not associated with changes in plant biomass, suggesting that the soil microbial biomass responded directly to temperature, rather than indirectly to a change in plant productivity (Bardgett et al. 1999). Similar to our results, an increase in microbial biomass under elevated temperature was also found in several other studies (Kandeler et al. 1998, Bardgett et al. 1999) and Liu et al. (2011) reported that warming significantly increased microbial biomass C and N in rhizosphere soils of spruce seedlings. However, the effects of warming on soil microbial biomass varied among studies. For example, Yin et al. (2012) observed that microbial biomass C and N were not sensitive to warming irrespective of tree species and sampling date. The lack of a remarkable warming effect on soil microbial biomass was also found in studies conducted in arctic tundra, tallgrass prairie and subalpine forest (Zhang et al., 2005; Biasi et al., 2008; Xu et al., 2010). The variability of these results may reflect the diversity of ecosystems, soils and plant species.

Previous studies have shown that soil N availability increases with soil warming (Rustad et al., 2001; Patil et al. 2010a, Sardans et al., 2008). However, across the vegetation period our results did not show a persistent effect of soil warming on soil mineral N content. This insensitivity of mineral N to temperature changes was also described by Beier et al. (2008). At none of the sampling dates in the present study the concentration of NH_4^+ was significantly influenced by soil warming (with the exception of higher values at the last sampling in July in the deeper layer), which may indicate that ammonification was not

affected by warming. On the other hand, the rather low NH_4^+ concentrations may be explained by an almost complete uptake of N by the growing wheat plants, by higher losses in the form of gases due to denitrification or by fast ammonia oxidation during nitrification or by faster uptake and immobilization by soil microorganisms. Warming probably will affect the ratio of $NH_4^+$and NO_3^-. Soil warming increased the nitrification potential in March and April but only in the deeper soil layer. This increased production potential for NO_3^- by nitrification in combination with high NH_4^+ availability after fertilization in spring could be the reason for the observed significantly increased NO_3^- concentrations in April in the elevated temperature treatment. The increased NO_3^-content increases the vulnerability of agricultural soils to N losses by leaching or by gaseous N-form (N_2O and N_2) via denitrification (Dobbie and Smith, 2001; Abdalla et al, 2010)

The N-cycling enzymes showed different responses to elevated temperature. In our experiment, protease activity increased significantly in the warmed plots (Figure 10). This might show a higher turnover of microorganisms and roots and could further suggest that protein input from dead roots was enhanced under elevated temperature treatment (Sardans and Penuelas, 2005). Protease activity was enhanced in March, when plant residues from the previous year may have been left and in June and July when dying roots may provide new substrates. However, in April and May, the time of most pronounced plant growth, warming did not affect the activity of this N releasing enzyme, which may indicate decoupling of plant N demand and N recycling in soil. Another possible reason might be that there was sufficient N available in April and May because fertilization took place after the first sampling and probably there was no need for microbes to produce protease to ensure their N-supply. The stimulation of N cycling under elevated soil temperature was also evident from our results of tyrosine aminopeptidase and leucine aminopeptidase showing higher trends under elevated temperature treatment. Alanine aminopeptidase and N-acetyl-glucosaminidase showed no significant response to elevated soil temperature. This is in accordance to previous studies, which observed a stimulative, suppressive or no effect of warming on the activity of different enzymes in a range of ecosystems (Butler et al. 2012, Bardgett et al. 1999; Patil et al. 2010a,b; Sardans et al. 2008c). This variation in the response of enzymes to soil warming might be partly the consequence of differences in microbial community composition (Agnelli et al., 2004).

Under elevated temperature of 5°C, Patil et al. (2010a, 2010b) found accelerated plant development, higher biomass, and higher N concentrations of plant tissues during vegetative stages of wheat. Hartley et al. (1999) also found that soil warming by 5°C stimulates soil N cycling, shrub growth and development. In our study, we found only a small N cycling response to elevated soil temperature at 2.5°C during plant growth stages. One possible reason for these weak responses might be low soil temperature enhancement, since the increase in soil temperature was only by 2.5°C, while other studies with similar systems have increased soil temperature considerably higher (e.g Hartley et al. 1999; Patil et al. 2010a, 2010b). It might be a possible explanation that a 5°C warming appeared to be sufficient to stimulate N mineralizing microbes, in contrast to other field experiments that raised soil temperatures by only 1-2°C, but did not promote N mineralization (Robinson et al. 1995). Our results may confirm the hypothesis of Tinker and Ineson (1990) that the temperature optima for soil organisms are sufficiently broad to buffer them against relatively small changes in temperature.

5.3 Impacts of rainfall manipulations on CO_2 and N_2O fluxes after rewetting in an agricultural soil

Studies analyzing the respiration responses after rewetting at a high time resolution (measurements every few hours or shorter) usually report highest respiration rates within an hour (Borken et al. 2003; Lovieno and Bååth, 2008; Unger et al. 2010; Kim et al. 2012; Placella et al. 2012; Lee et al. 2004; Sponseller, 2007) followed by decreasing rates.

Drying releases biomass-C from dead soil biota, and rewetting releases new substrates from previously inaccessible aggregates (Bottner, 1985). The result of the increase in available, readily decomposable substrates is microbial growth that induces the observed rapid release of CO_2 (Jager & Bruins, 1975; Scheu & Parkinson, 1994). Other authors attributed that this increase in mineralization increases microbial activity (Denef et al., 2001; Smith et al., 2003). In contrast, some authors have found no response to drying and wetting events. For example, Rovira & Vallejo (1997) incubated soils of three forest species at several depths in the field in a Mediterranean climate and found no stimulation of mineralization. In our study, CO_2 emissions generally increased within 1 h of rewetting dry soils, an observation similar to others made in a variety of ecosystems (e.g. Davidson et al. 1993; Borken et al.

2003; Austin et al., 2004). The increase in respiration and short-lived pulses can be taken as evidence of reactivation of microbial activities by water addition (Huxman et al. 2004).

Following a wetting event, C and N availability is often high (Birch, 1958; Smith and Parson, 1985). Soon after moistening a dry soil, the newly-developed microbial community is more active than later on (Griffith and Birch, 1961). The enhanced mineralization following the wetting of dried soil results partly from the death of microbial biomass (Groffman and Tiedje, 1988). Several studies (Smith and Parsons, 1985; Cates and Keeney, 1987; Rudaz et al. 1991) observed short -term N_2O pulses after rewetting dry soil and other studies (Rudaz et al. 1991; Scholes et al. 1997; Joergensen eta l. 1998) also observed a steep increase in the N_2O emission rate within the first hours after wetting.

Koponen (2007) explained that during the first dry-wet cycle (DWC), drying-wetting events induce a flush of microbial C and N, but the ability of microbial communities to decompose SOM declines after the cycle repeats. And during the first DWC, most of the organic and inorganic substrates are released; the amount of available substrates decreases cycle by cycle, leading to lower CO_2 and N_2O emissions. Generally, soils that are seldom exposed to natural drying and rewetting cycles will show a larger CO_2 pulse on rewetting than soils that are often dried and rewet (Fierer and Schimel, 2003). In our study, the CO_2 and N_2O emissions were higher after the 1st dry period than after the 2nd dry period in most treatments, that is in accordance with Fierer and Schimel et al. (2002). The authors pointed out that the more rewetting events, the less CO_2 released after a rapid rewetting. There could be two possible explanations. The first explanation is that there may be simply less OM available for release following drying-rewetting events, reducing the size of the CO_2 pulse if drying-rewetting releases physically protected SOM. The second explanation is that the microbial community may adjust to the water potential shock that occurred while rewetting after some drying-rewetting events. This adjustment would decrease the mortality rate and reduce the size of the flush of labile substrate available for mineralization by surviving microbes.

The duration of the dry period also influences the population of soil microorganisms during drying and wetting (Schimel et al. 1999). In our study, the soil was drier at the end of the 1st dry period than after the 2nd dry period (Table 2) and the duration of the 1st drying period is

longer (19 days) than that of the 2nd dry periodd (7 days), exposing soil microbes to a greater water and rewetting stress during the 1st dry period. CO_2 flush in our study seemed to be partly a stress reaction and, therefore, the larger the stress, the larger the stress response is produced, by observing higher CO_2 emissions after the 1st dry period than after the 2nd dry period.

In our study, CO_2 emissions were positively correlated with soil temperature showing the significant higher amount of emitted CO_2-C from elevated plots compared to ambient plots. The positive relationship with soil temperature is not surprising, as some indicators of soil microbial activity, such as respiration, are positively related to temperature (Curiel Yuste et al. 2004; Chen et al. 2000; Franzluebbers et al. 2002). Soils might be much drier at the end of a dry period as warming dries out the soil. If the soil is then rewetted, the effect of rewetting might be larger in the warmed plots due to either higher microbial activity of microbes at higher temperatures or a stronger effect of all the processes, which may induce a CO_2 flush after rewetting. The lack of significant effects of rewetting on CO_2 and N_2O emissions among precipitation treatments was surprising. It meant that the responses of these gas emissions are not dependent on precipitation treatment.

We did not find significant effects of precipitation treatments on CO_2 and N_2O fluxes for neither ambient nor warmed plots after the 1st and 2nd dry periods. Placella et al. (2012) found that the pulse of CO_2 from the first rainfall after the dry summer is prominent in Mediterranean ecosystem. Their soil might have been much drier than our soil because our soil was frequently wetted due to a high number of precipitation events during summer (from June 1st until August 31st). In Mediterranean soils, the dry period is much longer and, therefore, the soils dry out to a larger degree than in our region. Consequently, the response to rewetting is much more pronounced in such soils. Soil microorganisms from Mediterranean climate may be adapted to response to favorable water circumstances and endure in this water pulse-driven ecosystem (Placella et al. 2012). The soil in our study could adjust to changed climate conditions because the environmental manipulation in the HoCC field site started five years ago and soil microorganisms might be adapted to a water pulse-driven system like in Mediterrenean soils. It also could be that the differences in soil moisture between precipitation treatments were too small to make any changes in the response to rewetting.

Precipitation pattern also had no effect on cumulative CO_2 and N_2O emissions. We only found that the temperature effect was higher in reduced precipitation frequency treatments than in ambient frequency treatments. This meant that reducing the frequency increased the effect of the temperature. This might be that we added larger amounts of water in the reduced precipitation treatments after the dry periods by summing up two precipitation events.

These field studies were supported by laboratory studies on soils from arable land, grassland, forest, and other systems, which indicated no systematic difference in cumulative CO_2 fluxes after drying and wetting. About 50% of these studies revealed an increase in cumulative CO_2 fluxes following drying and wetting, whereas the other studies showed no change or decrease in cumulative CO_2 fluxes relative to a moist control soil (Borken and Matzner, 2009). In our study, cumulative CO_2 fluxes were increased only by the temperature effect. It seemed that only temperature treatment affected the results, not by precipitation treatment.

5.4 Rates of CO_2 production from laboratory incubation

Due to the death of microorganisms or exposure of easily decomposable C to drying, the CO_2 pulse following the rewetting of dried soil has been associated to the amount of easily decomposable C (Borken et al, 1888; van Gestel et al. 1991). CO_2 emission rates increased with increasing soil water contents have been described from laboratory and field studies (Rey et al. 2005). In our study, we found a similar trend that, CO_2 production increased with an increase in soil water content by rewetting to 5%, 15%, 25%, 35% and 45% VWC (Figure 15).

Our results suggested that sudden increases in soil water after rewetting can considerably increase soil CO_2 efflux, most likely because of increased soil heterotrophic respiration as a result of stimulation of microbial activity (Jarvis et al. 2007). The specific mechanisms of the release of C following a rewetting event are not well-understood. The first of these explanations, the metabolic hypothesis, involves that metabolism of osmolytes used by the microorganisms to protest desiccation during the dry conditions provides respiration pulses (Fierer and Schimel, 2003; Xiang et al. 2008; Williams and Xia, 2009). The other explanation, the physical hypothesis, involves that fluctuations in soil moisture can break up

microstructures in the soil, presenting the microbial community with previously inaccessible substrates that are then respired (Denef et al. 2001a,b; Six et al. 2004).

Short-term rewetting (24-hours in our experiment) induced the first CO_2 peak immediately upon rewetting. We found that respiration rates increased to higher levels immediately upon rewetting dry soils, compared to the control soil. Different temporal patterns of CO_2 emission were observed with differing amounts of added water. With increasing water additions, more peaks in CO_2 production were detected. One possible explanation is that with greater water additions, successively larger pore sizes were filled with water and, therefore, new bacterial groups may have contributed to CO_2 production. C mineralization differs between pore size classes, and different microbial groups located in different pore sizes response in a succession to rewetting (Strong et al. 2004). Resuscitation of microorganisms after wet-up is responsible for an environmentally important CO_2 pulse (Xu and Baldocchi, 2004). Placella et al. (2012) found that a succession of specific phylogenetic group was active after rewetting of dry soil. The authors described that soil bacteria were classified as rapid responders, intermediate responders or delayed responders. These three groups may be located in different pore size classes, and this might result in a different temporal pattern after rewetting.

Strong et al. (2004) pointed out that there may be two reasons why carbon may accumulate in different pore size classes at different rates. The first reason may be that certain soil biological functions might be location specific and are being restricted to the pore classes in which the responsible organisms reside, since different organisms perform different functions. Therefore, decomposable microorganisms can only reach pores that can receive them. The second reason may be that pore-size distribution determines where water resides in the pore system. Therefore, water location has an important influence on the biological activity in different pore classes since the microflora and fauna depend on this water for motility. In our experiment, we added different amounts of water, and different microbial groups located in different pore size classes, respired CO_2 differently. Both Killham et al. (1993), and Strong et al. (2004) have shown that the rate of decomposition of organic C is dependent on the location in the soil pore network. Yoo et al. (2006) found that with an increasing proportion of large pores, C mineralization increased. The result obtained in our study was in agreement with this: CO_2 production increased when larger pores were filled

with water, which was achieved by adding larger amounts of water. It has been observed that sandy soils decompose organic matter more rapidly than clayey soils (Gregorich et al. 1991; Amato & Ladd, 1992). The reason for this difference between soils of different texture has been attributed to the ability of small pores to protect organic matter, including biomass, or adsorption onto mineral surfaces (Ladd et al. 1993).

It is well-known that microbial activity is very low in air-dried soil and a positive correlation between microbial activity, as reflected by respiration rate, and water content is generally found (Franzluebbers, 1999; Schimel et al. 1999; O'Connell, 1990; Borken et al., 2003; Hicks et al., 2003). In our study, we also found a positive correlation between cumulative CO_2 production and VWC.

5.5 Conclusion

An understanding of soil N cycling under elevated soil temperature is important in predicting changes in ecosystem N availability. There have been only a few efforts to place the effects of elevated soil temperature on the processes of N-cycling on ecosystem scale. Our objective was to determine how elevated soil temperature alters the soil N cycle of an arable field planted with winter wheat (*Triticum aestivum*). According to the results, an increase in soil temperature by 2.5^{o}C did not show a persistent effect on mineral N content and the activity of potential nitrification within the soil. Plant growth development also did not response to increased soil temperature. However microbial biomass C and N, and some enzymes involved in N cycle, like Tyrosine aminopeptidase, Leucine aminopeptidase, tended to increase with elevated soil temperature. Overall, the results of this field study suggested that soil warming by 2.5^{o}C slightly stimulates soil N cycling without altering plant growth. One possible reason for this can be linked to the relatively low levels of temperature elevation compared to other studies. However, conditions used in this experiment are fairly realistic in agricultural soils in Europe, thus they can provide new information on belowground processes for predicted climate changes.

In agricultural soils, the duration of drying as well as soil water content are important in determining the emissions of N_2O and CO_2 during rewetting. Field measurements did not show large differences, but under laboratory conditions, higher differences in CO_2 emissions were found. Possible reasons for this are the variability of the soil and the differences in soil

water content between the precipitation treatments in the field, which were relatively small as compared to the laboratory study. It could be that the differences in soil moisture between precipitation treatments were too small to make any changes in the response to rewetting. Furthermore, the soil could adjust to changed climate conditions because the environmental manipulation in the HoCC field site started five years ago and soil organisms might be adapted to a water pulse-driven system like in Mediterranean soils. Our results indicated that a simulation of altered precipitation patterns had no influence on N_2O and CO_2 emissions as we expected. Further, work is needed to clarify the ongoing processes in dry soils during rewetting to better understand the dynamic of N_2O and CO_2 emissions during these events.

In contrast to the field study, the laboratory-incubation experiment was set up under well-defined conditions. The experiment indicated that there was a treatment effect on CO_2 peaks and on the temporal pattern of CO_2 emissions after rewetting by adding different amounts of water to the soil cores. The different temporal pattern in respiration following rewetting seemed to be due to different bacterial groups located in different pore sizes. These bacterial groups respire differently, and as a consequence, different temporal patterns were found. Our results suggested that microbial respiration after rewetting dry soils can be affected by adding different amounts of water.

In conclusion, this study presents how the predicted climate change affects the soil N cycling; N_2O and CO_2 trace gas fluxes through an arable field and the laboratory-incubation experiment. It has been shown that soil temperature elevated by 2.5^{o}C slightly stimulates soil N cycling, showing the responses of microbial biomass and some enzyme activities. Changing precipitation patterns had no response on N_2O and CO_2 emissions during dry periods in summer. However, the pulses in microbial respiration following rewetting dry soil in the laboratory incubations did show enhanced CO_2 production by adding different amounts of water. Further research is needed in order to understand possible changes in N_2O and CO_2 emission regimes under predicted conditions of climate change scenarios. In order to understand the overall responses of altered temperature and precipitation conditions caused by the predicted climate change, long-term ecosystem specific research is needed, especially in agro-ecosystems.

Summary

Both temperature and precipitation regimes are expected to change with climate change and are, at the same time, major environmental factors regulating biogeochemical cycles in terrestrial ecosystems. Therefore, crop water availability, soil nitrogen transformations, losses, and uptake by plants as well as CO_2 emissions from soil are likely to be changed by climate change. Agriculture is known to be one of the most important human activities for releasing significant amounts of N_2O and CO_2 to the atmosphere. Due to global concern about the changing climate, there has been a great interest in reducing emissions of N_2O and CO_2 from agricultural soils. CO_2 and N_2O are produced in soil primarily by microbial processes. Their production and emissions from the soil are controlled by a number of environmental variables including inorganic N availability, soil temperature and water content. Agricultural management practices, such as irrigation, affect these environmental variables and thus have the potential to dramatically alter N_2O and CO_2 emissions from the soil.

The present study is titled "Effects of elevated soil temperature and altered precipitation patterns on N cycling and production of N_2O and CO_2 in an agricultural soil". The objectives of this study were: to determine the effects of elevated soil temperature on N cycling in a winter wheat cropping system, to investigate the short-term response of N_2O and CO_2 fluxes during rewetting of soils after extended dry periods in summer, and to determine the effects of different degrees of rewetting on the CO_2 emission peaks after rewetting in laboratory incubations.

In the 1st experiment, we used the Hohenheim Climate Change (HoCC) experiment in Stuttgart, Germany, to test the hypothesis that elevated soil temperature will increase microbial N cycling, plant N uptake and wheat growth. In the HoCC experiment, soil temperature is elevated by 2.5°C at 4 cm depth. This experiment was conducted at non-roofed plots (1m x 1m) with ambient (Ta) and elevated (Te) soil temperature and with ambient precipitation. In 2012, winter wheat (*Triticum aestivum*) was planted. C and N concentrations in soil and aboveground plant fractions, soil microbial biomass C and N (C_{mic} and N_{mic}), mineral N content (NH_4^+ - N and NO_3^- - N), potential nitrification and enzymes involved in nitrogen cycling were analyzed at soil depths of 0-15 and 15-30 cm at five

sampling dates. The plants were rated weekly for their phenological development and senescence behavior. We found that an increase in soil temperature by 2.5^{o}C did not have a persistent effect on mineral N content and the activity of potential nitrification within the soil. Plant growth development also did not respond to increased soil temperature. However microbial biomass C and N, and some enzyme activities involved in N-cycling, tended to increase under elevated soil temperature. Overall, the results of this study suggested that soil warming by 2.5^{o}C slightly stimulates soil N cycling but does not alter plant growth development.

In the 2nd experiment, in 2013, the effects of a change in the amount and frequency of precipitation patterns on N_2O and CO_2 emissions were studied after the two dry periods in summer in the HoCC experiment. N_2O and CO_2 gas samples were taken from four subplots (1m x 1m) of each roofed plot exposed to ambient (Ta) or elevated (Te) soil temperature and four precipitation manipulations (ambient plot, reduced precipitation amount, reduced precipitation frequency, and reduced precipitation amount and frequency). We found that CO_2 emissions were affected only by temperature, but not by precipitation pattern. It can be said that N_2O and CO_2 emissions after rewetting of dry soil were not altered by changing precipitation patterns during dry periods in summer.

In the year 2014, using laboratory incubations, we also measured the short-term response of CO_2 production to a rewetting of dry soil to different volumetric water contents for 24 hours. This study was conducted by manipulating microcosms with agricultural soil from the HoCC experimental site, which had been exposed to severe drought conditions of three months' duration for each of the last six years. The results showed that CO_2 production increased with increases in the water content of soils by rewetting at 5%, 15%, 25%, 35% and 45% VWC. With increasing water additions more peaks in CO_2 production were detected and different temporal patterns of CO_2 emission were affected by adding different amounts of water. It might be due to the fact that with greater water additions successively larger pore sizes were water filled and therefore different bacterial groups located in different pore size classes might have contributed to CO_2 production.

In summary, the results from field study suggested that climate warming will affect N cycling in soils in an agricultural cropping system. The results from both field and microcosm

rewetting experiments contribute to a better understanding of C and N dynamics in soil by investigating the effect of varying soil water content on the emission of N_2O and CO_2.

Zusammenfassung

Im Zuge des Klimawandels wird angenommen, dass sich wichtige Klimafaktoren wie Temperatur und Niederschlagsereignisse, die maßgeblich an der Regulierung von Stoffkreisläufen in terrestrischen Ökosystemen beteiligt sind, verändern werden.

Daher ist es wahrscheinlich, dass der Klimawandel zu Veränderungen in der Wasserverfügbarkeit, den CO_2 Emissionen aus dem Boden sowie dem Stickstoffhaushalt und damit der Transformation sowie dem Verlust und der Aufnahme des Bodenstickstoffs durch Pflanzen führt. Ein erheblicher Anteil der klimarelevanten Gase CO_2 und N_2O wird durch die Landwirtschaft freigesetzt. Hauptsächlich werden diese Gase durch mikrobiologische Prozesse in Böden gebildet, wobei ihre Produktion von zahlreichen Umweltfaktoren, wie der Temperatur, dem Wassergehalt und der mineralischen Stickstoffverfügbarkeit abhängt. Landwirtschaftliche Bewirtschaftungsweisen, beispielsweise Bewässerung, können diese Umweltfaktoren beeinflussen und haben somit das Potenzial bodenbürtige N_2O und CO_2-Emissionen zu verändern. Eine Reduktion klimarelevanter Gase bedingt durch landwirtschaftliche Aktivitäten ist somit von weltweitem Interesse.

Die Ziele der gegenwärtigen Studie „Auswirkungen von erhöhter Bodentemperatur und veränderter Niederschlagsverteilung auf den Stickstoffkreislauf und die Produktion von N_2O und CO_2 in landwirtschaftlich genutzten Böden“ waren: 1) die Auswirkung von erhöhter Bodentemperatur auf den Stickstoffkreislauf in einem Feldexperiment mit Winterweizenbestand zu bestimmen, 2) die kurzfristige Reaktion von N_2O- und CO_2-Flüssen auf die Beregnung eines Ackerböden nach längeren Trockenperioden im Sommer zu untersuchen und 3) in Laborexperimenten den Einfluss unterschiedlicher Wiederbefeuchtungsszenarien auf die CO_2-Emissionskurven eines Ackerbodens nach längeren Trockenperioden im Sommer zu bestimmen.

Zur Untersuchung der ersten Hypothese, dass eine Temperaturerhöhung zur Förderung des Pflanzenwachstums, des mikrobiellen Stickstoffumsatzes, sowie der pflanzlichen Stickstoffaufnahme aus dem Boden beiträgt, wurde im Jahr 2102 ein Feldversuch auf den etablierten Versuchsflächen des Hohenheimer Climate Change (HoCC) Experimentes in Stuttgart-Hohenheim angelegt. Für das Feldexperiment wurden nicht überdachte Flächen in

einer Größe von 1 m x 1 m gewählt. Zur Untersuchung wurden Flächen herangezogen, bei denen die Bodentemperatur in 4 cm Tiefe um 2,5 °C erhöht (Te) und unbeeinflusst (Ta) waren. Die Bewässerung fand ausschließlich über die natürlichen Niederschlagsereignisse statt. Im Versuchsjahr 2012 wurde Winterweizen (*Triticum aestivum*) angebaut. Es erfolgte zu fünf Zeitpunkten eine Bodenprobenentnahme in den Tiefen 0–15 cm und 15–30 cm. Bestimmt wurden die Kohlenstoff- und Stickstoffgehalte im Boden und der oberirdischen Vegetation, sowie im Boden C- und N-Gehalte der mikrobiellen Biomasse (C_{mik} und N_{mik}), der mineralische N-Gehalt (NH_4^+-N und NO_3^--N), die potenzielle Nitrifikation und charakteristische Enzyme des Stickstoffkreislaufes. Eine Bonitur der Vegetation hinsichtlich der phänologischen Entwicklung und des Seneszenzverhaltens wurde wöchentlich durchgeführt. Die Ergebnisse unserer Feldstudie zeigen, dass eine erhöhte Bodentemperatur um 2,5 °C keinen Einfluss auf das Pflanzenwachstum sowie den mineralischen Bodenstickstoffgehalt und die potenzielle Nitrifikation hat. Jedoch zeigte sich mit Erhöhung der Temperatur ein tendenzieller Anstieg der mikrobielle Biomasse (C_{mik} und N_{mik}) und einiger Enzymaktivitäten des N-Kreislaufs. Insgesamt zeigt die Studie, dass eine Erhöhung der Bodentemperatur um 2,5 °C zwar zu einer leichten Stimulierung des Stickstoffkreislaufes beiträgt, dies jedoch keinen Einfluss auf die Entwicklung des Pflanzenwachstums hat.

Im zweiten Feldexperiment wurde im Jahr 2013 die Auswirkung einer veränderten Niederschlagsverteilung (Menge und Frequenz) auf die CO_2- und N_2O-Emission eines von Trockenheit beeinflussten Ackerbodens untersucht. Hierzu wurden die überdachten Versuchsflächen (1 m x 1 m) mit 2,5 °C erhöhter (Te) und unveränderter Temperatur (Ta) des HoCC-Experimentes genutzt. Bewässert wurde insgesamt zwei Mal nach einer längeren Trockenperiode im Sommer mit folgender Niederschlagsverteilung: standortentsprechendem Niederschlag, reduzierte Niederschlagsmenge, reduzierte Niederschlagshäufigkeit sowie reduzierte Niederschlagsmenge und -häufigkeit. Im Anschluss daran wurden von vier Teilflächen N_2O- und CO_2-Gasproben entnommen. Es zeigte sich, dass die CO_2-Emissionen ausschließlich vom Faktor Temperatur nicht aber durch die Niederschlagsverteilung (Menge und Häufigkeit) beeinflusst wurden. Die Ergebnisse zeigen, dass sich N_2O- und CO_2- Emissionen nach der Bewässerung von trockenen Böden nicht

ändern, auch wenn es zu veränderten Niederschlagsverteilungen in trockenen Sommerperioden kommt.

Im Jahr 2014 haben wir in Mikrokosmenexperimenten unter Laborbedingungen die kurzfristige Reaktion der CO_2-Produktion von Böden auf eine Wiederbefeuchtung nach längeren Trockenperioden untersucht. Hierzu wurden Mikrokosmen mit Ackerboden aus dem HoCC-Experiment befüllt, welcher über sechs Jahre jährlich dreimonatigen Trockenperioden ausgesetzt war. Dieser Boden wurde bis zur Erreichung unterschiedlicher volumetrischer Wassergehalte von 5 %, 15 %, 25 %, 35 % und 45 % beregnet. Anschließend wurden CO_2-Gasproben über einen Zeitraum von 24 Stunden entnommen. Die Ergebnisse zeigen, dass die CO_2-Produktion mit steigendem volumetrischem Bodenwassergehalt zunimmt und sich die zeitlichen Verläufe der CO_2-Emissionen je nach zugegebener Wassermenge verändern. Dies könnte mit der Tatsache zusammenhängen, dass mit zunehmendem Bodenwassergehalt auch Poren größeren Durchmessers wassergefüllt waren und darin befindliche, zusätzliche Bakteriengruppen an der CO_2-Produktion beteiligt waren.

Zusammenfassend zeigen die Ergebnisse der Feldstudien, dass eine Klimaerwärmung den Stickstoffkreislauf in landwirtschaftlich genutzten Böden beeinflusst. Zudem konnten die Ergebnisse sowohl der Feldstudien als auch des Mikrokosmenexperimentes, durch die Untersuchung der Wirkung unterschiedlicher Bodenwassergehalte auf die N_2O- und CO_2-Emissionen, zu einem besseren Verständnis der C- und N-Dynamik in Böden beitragen.

Curriculum Vitae

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2nd- 6th	July 2006	Workshop on Solving Soil Problems found in crop production; Agro-ecological Zone of Myanmar (Soil, Plant and Atmosphere Relationship) Central Agricultural Research and Training Center (CARTC), Hlegu, Myanmar
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13th	August 2003	Nutriment Management CARTC, Hlegu, Myanmar
3rd – 5th	March 2003	Seed Quallity Training CARTC, Hlegu, Myanmar
6th – 8th	September 2002	Breeder Seed Production Department of Agricultural Research (DAR) Yezin, Myanmar
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Awards and Achievements

September 2011 – July 2015	Scholarship for PhD Food Security Center (FSC), part of DAAD (German Academic Exchange Service)
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Publication

Yadana Khin LATT, Aung Kyaw MYINT, Takeo YAMAKAWA and Kazuo OGATA (2009) The effects of green manure (Sesbania rostrata) on the growth and yield of rice. Fac. Agri., Kyushu Univ., 54 (2): 313-319.

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References

Abdalla, M., Jones, M., Williams, M., 2010. Simulation ofN2O fluxes from Irish arable soils: effect of climate change and management. Biol. Fertil. Soils 46, 247–260.

Agnelli, A., Ascher, J., Corti, G., Ceccherini, M.T., Nannipieri, P., Pietramellara, G. (2004) Distribution of microbial communities in forest soil profile investigated by microbial biomass, soil respiration and DGGE of total and extracellular DNA. Soil Biol. Biochem, 36: 59–868.

Alcamo, J., Moreno, J. M. (2007) Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Europe. Climate Change, Cambridge, UK: 541-580.

Algaidi, A. A., Kristóf, K., Kampfl, G. Y., Hamid, Y.S., Bayoumi Hamuda,H. E. A. F., Nótás Erika, Issa, I. A., Heltai, G. Y. (2006) Predicting N_2O and CO_2emission from agricultural soil amended with different C:N ratios. Proceedings of VI. National Scientific Conference with International Participation. Ecology & Health, Plovdiv, Bulgaria. pp: 268-272.

Algaidi, A. A. (2009) Predicting NO, N_2O and CO_2 emission from agricultural soil through related environmental parameters. PhD thesis.

Amato, M. & Ladd, J. N. (1992) Decomposition of ^{14}C-labelled glucose and legume material in soils: Properties influencing the accumulation of organic residue C and microbial biomass C. Soil Biology and Biochemistry, 24: 455–464.

Ambus, P., Zechmeister-Boltenstern, S., Butterbach-Bahl, K. (2006) Biogeosciences Sources of nitrous oxide emitted from European forest soils. Biogeosciences, 3: 135–145.

An, Y.,Wan, S., Zhou, X., Luo, Y. (2005) Plant nitrogen concentration, use efficiency, and contents in a tallgrass prairie ecosystem under experimental warming. Global Change Biology, 11: 1733-1744.

Anderson, J. P., Domsch, K. H., (1973) Quantification of bacterial and fungal contributions to soil respiration. Archiv für Mikrobiologie 93: 113-127.

Anderson, J. P. E., Domsch, K. H., (1978) Physiological method for quantitative measurement of microbial biomass in soils. Soil Biology & Biochemistry, 10: 215-221.

Appel, T. (1998) Non-biomass soil organic N – the substrate for N mineralization flushes following soil drying-rewetting and for organic N rendered $CaCl_2$-extractable upon soil drying, Soil Biol. Biochem., 30: 1445–1456.

Aulakh, M. S., Doran, J. W., Walter, D. T., Mosier, A. R., Francis, D. D. (1991) Crop residue type and placement effects on denitrification and mineralization. Soil Sci. Soc. Am. J., 55: 1020–1025.

Austin, A. T., Yahdjian, M. L., Stark, J. M., Belnap, J., Porporato, A., Norton, U., Ravetta, D. A., Schaeffer, S. M. (2004) Water pulses and biogeochemical cycles in arid and semiarid ecosystems. Oecologia. DOI 10.1007/s00442-004-1519-1.

Awal, M. A. & Ikeda, T. (2002) Effects of changes in soil temperature on seedling emergence and phenological development in field-grown stands of peanut (*Arachis hypoagea*). Environmental and Experimental Botany, 47: 101-113.

Ball, B. C., Scott, A., and Parker, J. P. (1999) Field N_2O, CO_2 and CH_4 fluxes in relation to tillage, compaction and soil quality in Scotland, Soil Till. Res., 53: 29-39.

Bardgett, R. D., Kandeler, E., Tscherko, D., Hobbs, P. J., Bezemer, T. M., Jones, T. H., Thompson, L. J. (1999) Below-ground microbial community development in a high temperature world. Nordic Society Oikos, 85(2): 193-203.

Barnard, R., Leadley, P. W., Hungate, B. A. (2005) Global change, nitrification, and denitrification: A review. Global Biogeochemical Cycles, 19: 1-13.

Bateman, E. J., Baggs, E. M. (2005) Contributions of nitrification and denitrification to N_2O emission from soils at different water-filled pore space. Biol Ferti Soils, 41: 379-388.

Batjes, N. H. (1996) Total carbon and nitrogen in soils of the world. European Soil Sci, 47: 151-163.

Beare, M. H., Gregorich, E. G., and St-Georges, P. (2009) Compaction effects on CO_2 and N_2O production during drying and rewetting of soil, Soil Biol. Biochem., 41: 611–621, doi:10.1016/j.soilbio.2008.12.024.

Beauchamp, E. G. (1997) Nitrous oxide emission from agricultural soils. Can. J. Soil Sci., 77: 113–12.

Beier, C., Schmidt, I. K., Kristensen, H. L. (2004) Effects of climate and ecosystem disturbances on biogeochemical cycling in a semi-natural terrestrial ecosystem. Water, Air, and Soil Pollution: Focus, 4: 191-206.

Bellarby, J., Foereid, B., Hastings, A., Smith, P. (2008) Green peace International 5, Amsterdam. School of Biological Sciences, University of Aberdeen, Cruickshank Building, St Machar Drive, Aberdeen, AB24 3UU.

Billore, S. K., Numata, M., Minami, K. (1996) Nitrous oxide emission from grassland and forest soils through nitrification. Curr. Sci., 70:1010-1012.

Birch, H. F. (1958a) The effect of soil drying on humus decomposition and nitrogen availability.Plant and Soil, 10: 9-31.

Birch, H. F. (1958b) Further aspects of humus decomposition. Nature, 182, 1172.

Birch, H. F. (1964) Mineralisation of plant nitrogen following alternate wet and dry conditions.Plant and Soil, 24: 333-339.

Blackmer, A. M., Bremner, J. M., Schmidt, E. L. (1980) Production of nitrous oxide by ammoniaoxidizing chemoautotrophic microorganisms in soil. Appl. Environ. Microbiol., 40: 1060-1066.

Bollmann, A., Conrad, R. (1997) Recovery of nitrification and production of NO and N_2O after exposure of soil to acetylene. Biol. Fertil Soils, 25: 41-46.

Borken, W., Xu, Y. J., Brumme, R., and Lamersdorf, N. (1999) A climate change scenario for carbon dioxide and dissolved organic carbon fluxes from a temperate forest soil: Drought and rewetting effects, Soil Sci. Soc. Am. J., 63: 1848-1855.

Borken, W., Davidson, E. A., Savage, K., Gaudinski, J., Trumbore, S. E (2003) Drying and wetting effects on CO_2 release from organic horizons. Soil Science Society of America Journal, 67: 1888-1897.

Borken, W. and Matzner, E. (2009) Reappraisal of drying and wetting effects on C and N mineralization and fluxes in soils, Global Change Biol., 15: 808-824.

Bottner, P. (1985) Response of microbial biomass to alternate moist and dry conditions in a soil incubated with ^{14}Cand ^{15}N-labelled plant material. Soil Biology & Biochemistry, 17: 329-337.

Bouwman, A. F. (1990) Exchange of greenhouse gases between terrestrial ecosystems and the atmosphere. In: Soils and the Greenhouse Effect. (ed.: Bouwman, A. F.) 100-120. Wiley, Chichester.

Bouwman, A. F. (1996) Direct emissions of nitrous oxide from agricultural soils. Nutr. Cycl. Agroecosyst., 46: 53-70.

Bouwman, A. F. (1998) Nitrogen oxides and tropical agriculture. Nature, 392: 866-867.

Bouwman, A. F., Taylor, J. A., Kroeze, C. (2000) Testing hypothesis on global emissions of nitrous oxide using atmospheric models. Glob.Change Sci., 2: 475-492.

Bottner, P. (1985) Response of microbial biomass to alternate moist and dry conditions in a soil incubated with ^{14}C and ^{15}N labeled plant material. Soil Biology and Biochemistry, 17: 329-337.

Bradford, M. A., Davies, C. A., Frey, S. D., Maddox, T. R., Melillo, J. M., Mohan, J. E. (2008) Thermal adaptation of soil microbial respiration to elevated temperature. Ecol. Lett., 11: 1316-1327.

Bremner, J. M. (1997) Sources of nitrous oxide in soils. Nutr. Cycl. Agroecosyst. 49:7-16.

Bremner, J. M. and Blackrner, A. M. (1978) Nitrous oxide emissions from soil during nitrification of fertilizer nitrogen. Science 199: 295-296.

Breuer, L., Papen, H., Butterbach-Bahl, K. (2000) N_2O emission from tropical forest soils of Australia. J. Geophys. Res. Atmos., 105: 26353-26367.

Brookes, P. C., Kragt, J. F., Powlson, D. S., Jenkinson, D. S. (1985) Chloroform fumigation and the release of soil nitrogen: The effects of fumigation time and temperature. Soil Biology and Biochemistry, 17(6): 831-835.

Butler, S. M., Melillo, J. M., Johnson, J. E., Mohan, J., Steudler, P. A., Lux, H., Burrows, E., Smith, R. M., Vario, C. L., Scott, L., Hill, T. D., Aponte, N. and Bowles, F. (2012) Soil warming alters nitrogen cycling in a New England forest: implications for ecosystem function and structure. Ecosystem Ecology, 168: 819-828.

Butterbach-Bahl, K., Gasche, R., Breuer, L., Papen, H. (1997) Fluxes of NO and N_2O from temperate forest soils: Impact of forest type, N deposition and of liming on the NO and N_2O emissions. Nutr. Cycl. Agroecosyst., 48: 79-90.

Butterbach-Bahl, K., Kock, M., Willibald, G., Hewett, B., Buhagiar, S., Papen, H., and Kiese, R. (2004) Temporal variations of fluxes of NO, NO_2, N_2O, CO_2, and CH_4 in a tropical rain forest ecosystem, Global Biogeochem. Cy., 18, GB3012, doi:10.1029/2004GB002243.

Castaldi, S., de Grandcourt, A., Rasile, A., Skiba, U., and Valentini, R. (2010) CO_2 , CH_4 and N_2O fluxes from soil of a burned grassland in Central Africa, Biogeosciences, 7: 3459–3471, doi:10.5194/bg-7-3459-2010.

Cates, R. L., Keeney, D. R. (1987) Nitrous oxide production throughout the year from fertilized and manured maize fields. Journal of Environmental Quality 4: 443-447.

Chan, Y. (2008) Increasing soil organic carbon of agricultural land. NSW DPI, PRIMEFACT 735.

Chang, C., Cho, C. M., Janzen, H. H. (1998) Nitrous oxide emissions from long term manured soils. Soil Science Society of America Journal 62: 677-682.

Chen, M., Alexander, M. (1973) Survival of soil bacteria during prolonged desiccation. Soil Biology & Biochemistry, 5: 213-221.

Chen, H. M., Harmon, M. E., Griffiths, R. P., Hicks, W. (2000) Effects of temperature and moisture on carbon respired from decomposing woody roots. Forest Ecol. Manag., 138: 51-64.

Chen, S. K., Edwards, C. A., Subler, S. (2003) The influence of two agricultural bio-stimulants on nitrogen transformations, microbial activity, and plant growth in soil microcosms. Soil Biology & Biochemistry, 35: 9-19.

Cheng, W. (1999) Rhizosphere feedbacks in elevated CO2. Physiol., 19: 313-320.

Cheng, L. (2010) Soil microbial responses to climate change factors: Impacts on soil carbon and nitrogen dynamics, PhD thesis.

Christensen, J. H., Hewitson, B., Busuloc, A., Chen, A., Gao, X., Heid, I., Jones, R., Kolli, R. K., Kown, W. T., Laprise, R., Rueda, V. M., Mearns, L., Mene´ndez, C. G., Ra¨isa¨nen, J., Rinke, A., Sarr,A. & Whetton,P. (2007) Regional climate projections. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Eds S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tigor & H. L. Miller), pp. 847-940. Cambridge, UK and New York, NY: Cambridge University Press.

Chung, H., Zak, D. R., Reich, P. B., Ellsworth, D. S. (2007) Plant species richness, elevated CO_2 and atmospheric nitrogen deposition alter soil microbial community composition and function. Global Change Biology, 13: 980-989.

Clark, F. E. and Rosswall, T. (Eds) (1981) Terrestrial nitrogen cycles. Ecol. Bull. (Stockholm) 33.

Clarkson, D. T., Jones, L. H. P. & Purves, J. V. (1992) Absorption of nitrate and ammonium ions by Lolium perenne from flowing solution cultures at low root temperatures. Plant, Cell and Environment, 15: 99-106.

Clein, J. S. and Schimel, J. P. (1994) Reduction in microbial activity in birch litter due to drying and rewetting events, Soil Biol. Biochem., 26: 403-406.

Crow, S. E. and Wieder, R. K. (2005) Sources of CO_2 emission from a northern peatland: root respiration, exudation, and decomposition, Ecology, 86: 1825-1834.

Colbourn, P., Dowdell, R. J. (1984) Denitrification in field soils. Plant and Soil, 76: 213-226.

Conrad, R. (1996a) Soil microorganisms as controllers of atmospheric trace gases (H_2, CO, CH_4, N_2O, and NO). Microbiol. Rev., 60: 609-640.

Conrad, R. (1996b) Metabolism of nitric oxide in soil and soil microorganisms and regulation of flux into the atmosphere. In: Microbiology of Atmospheric Trace Gases: Sources, Sinks, and Global Change Processes. (ed.: Kelly, D.P.) 167-203. Springer, Berling Heidlberg, New York.

Conrad, R. (2002) Microbiological and biochemical background of production and consumption of NO and N_2O in soil. In: Trace Gas Exchange in Forest Ecosystems (eds.: Gasche, R., Papen, H., Rennenberg, H.) 3-33. Kluwer Academic Publishers, Dordrecht, Netherlands.

Conway, T., Tans, P. (2011) Trends in Atmospheric Carbon Dioxide - Global CO_2. U.S. Department of Commerce, National Oceanic & Atmospheric Administration -NOAA/ESRL Retrieved 29.11.2011, from http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html.

Cox, R. M., Betts, R. A., Jones, C. D., Spall, S. A., Totterdell, I. J. (2000) Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. Nature, 408: 184-187.

Coxson, D. and Parkinson, D. (1987) Winter respiratory activity in aspen woodland forest floor litter and soils, Soil Biol. Biochem., 19: 49-59.

Curiel Yuste, J., Janssens, I. A., Carrara, A., Ceulemans, R. (2004) Annual Q_{10} of soil respiration reflects plant phenological patterns as well as temperature sensitivity. Glob. Change Biol., 10: 161-169.

Curiel Yuste, J., Baldocchi, D. D., Gershenson, A., Goldstein, A., Misson, L., and Wong, S. (2007) Microbial soil respiration and its dependency on carbon inputs, soil temperature and moisture, Global Change Biol., 13: 2018-2035, doi:10.1111/j.1365-2486.2007.01415.x, 2007.

Davidson, E. A. (1992) Sources of nitric oxide and nitrous oxide following wetting of dry soil. Soil Sci. Soc. Am. J., 56: 95-102.

Davidson, E. A. & Janssens, I. A. (2006) Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature, 440: 165-173.

Davidson, E. A., Keller, M., Erickson, H. E., Verchot, L. V., Veldkamp, E. (2000) Testing a conceptual model of soil emissions of nitrous and nitric oxides. BioScience, 50: 667-680.

Davies, K. J. P., Lloyd, D., Boddy, L. (1989) The effect of oxygen on denitrification in *Paracoccus denitrificans* and *Pseudomonas aeruginosa*. J. Gen. Microbiol., 136: 2945-2951.

Denef, K., Six, J., Bossuyt, H., Frey, S. D., Elliott, E. T., Merckx, R., Paustian, K. (2001a) Influence of dry-wet cycles on the interrelationship between aggregate, particulate organic matter, and microbial community dynamics. Soil Biology & Biochemistry 33: 1599-1611.

Denef, K., Six, J., Paustian, K., Merckx, R. (2001b) Importance of macroaggregate dynamics in controlling soil carbon stabilization: short-term effects of physical disturbance induced by dry-wet cycles. Soil Biology & Biochemistry 33: 2145-2153.

Dick, J., Skiba, U., and Wilson, J. (2001) The effect of rainfall on NO and N_2O emissions from Ugandan agroforest soils, Phyton, 41: 73-80.

Dijkstra, F., Cheng, W. (2008) Increased soil moisture content increases plant nitrogen uptake and the abundance of ^{15}N in plant biomass. Plant and Soil, 302: 263-271.

Dijkstra, F. A., Blumenthal, D., Morgan, J. A., Pendall, E., Carrillo, Y., Follett, R. F. (2010) Contrasting effects of elevated CO_2 and warming on nitrogen cycling in a semiarid grassland. New Phytologist, 187(2): 426-437.

Dinsmore, K., Skiba, U., Billett, M., and Rees, R. (2009) Effect of water table on greenhouse gas emissions from peatland mesocosms, Plant Soil, 318: 229-242.

Diz-Munoz, C., Paulino, L., Monreal, C., Zagal, E. (2010) Greenhouse gas (CO_2 and N_2O) emissions from soil. A review, Chilean Agric Res, 70: 485-497.

Dobbie, K.E., Smith, K.A., 2001. The effects of temperature, water-filled pore space and land use on N2O emissions from an imperfectly drained gleysol. Eur. J. Soil Sci. 52, 667–673.

Duxbury, J. M. and McConnaughey, P. K. (1986) Effect of fertilizer source on denitrification and nitrous oxide emission in a maize field. Soil Sci Soc Am, 50: 644-648.

Eichner, M. J. (1990) Nitrous oxide emissions from fertilized soils: a summary of available data. Journal of Environmental Quality, 19: 272-208.

Emmerich, W. E. (2003) Carbon dioxide fluxes in a semiarid environment with high carbonate soils. Agric For Meteorol, 116: 91-102.

Emmerling, C., Edelhoven, T., Schröder, D. (2001) Response of soil microbial biomass and activity to agricultural de-intensification over a 10 year period. Soil Biol. Biochem., 33: 2105-2114.

Engles, C. & Marschner, H. (1992) Root to shoot translocation of macronutrients in relation to shoot demand in maize (*Zea mays* L.) grown at different root zone temperatures. Zeitschrift fuer Pflanzenernahrung und Bodenkunde, 155: 121-128.

EIA (2005) Energy Information Adminstration. Emissions of greenhouse gases in the United States

EPA (2010) Methane and nitrous oxide emissions from natural sources (PDF). Environmental Protection Agency, Washington, DC, USA.

Eswaran, H., Van Den Berg, E., Reich, P. (1993) Organic carbon in soils of the world. Soil Science Society of America Journal 57: 192-194.

Ewert, F., Rounsevell, M. D. A., Reginster, I., Metzger, M. J., Leemans, R. (2005) Future scenarios of European agricultural land use: I. Estimating changes in crop productivity. Agriculture, Ecosystems and Environment, 107(2-3): 101-116.

Fierer, N. and Schimel, J. P. (2002) A proposed mechanism for the pulse in carbon dioxide production commonly observed following the rapid rewetting of a dry soil, Soil Sci. Soc. Am. J., 67: 798–805.

Fierer, N., Schimel, J. P., Holden, P. A. (2003) Variations in microbial community composition through two soil depth profiles. Soil Biol. Biochem, 35: 167-176.

Firestone, M. K., Davidson, E. A. (1989) Microbiological basis of NO and N_2O production and consumption in soil. In: Exchange of trace gases between terrestrial ecosystems and the atmosphere (eds.: Andreae, M.O., Schimel, D.S.) 7-21. John Wiley & Sons, New York.

Forster, P., Ramaswamy, V. (2007) Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: 135-137.

Frank, A. B., Dugas, W. A. (2001) Carbon dioxide fluxes over a northern, semiarid mixed-grass prairie. Agric For Meteorol, 108: 317-326.

Franzluebbers, A. J. (1999) Microbial activity in response to water filled pore space of variably eroded southern Piedmont soils. Appl Soil Ecol, 11: 91-101.

Franzluebbers, K., Franzluebbers, A. J., Jawson, M. D. (2002) Environmental controls on soil and whole-ecosystem respiration from a tallgrass prairie. Soil Sci. Soc. Am. J., 66: 254-262.

Frenck, G., Van Der Linden, L., Mikkelsen, T. N., Brix, H., JØrgensen, R. B. (2011) Increased CO_2 does not compensate for negative effects on yield caused by higher temperature and O_3 in *Brassica napus* L. European Journal of Agronomy, 35(3): 127-134.

Freney, J. R., Denmead, T. O., Simpson, J. R. (1979) Nitrous oxide emission from soils at low moisture content. Soil Biology and Biochemistry, 11: 167-173.

Freney, J. R. (1997) Strategies to reduce gaseous emission of nitrogen from irrigated agriculture. Nutr. Cycl. Agroecosyst., 48: 155-160.

Fuhrer, J. (2003) Agroecosystem responses to combinations of elevated CO_2, ozone, and global climate change. Agriculture, Ecosystems and Environment, 97: 1-20.

Galloway, J. N., Schlesinger, W. H., Levy, H. I., Michaels, A., Schnoor, J. L. (1995) Nitrogen fixation: anthropogenic enhancement - environmental response. Global Biogeochemical cycles, 9: 235-252.

Garcia-Montiel, D. C., Steudler, P. A., Piccolo, M., Neill, C., Melillo, J., and Cerri, C. C. (2003) Nitrogen oxide emissions following wetting of dry soils in forest and pastures in Rondonia, Brazil, Biogeochemistry, 64: 319-336.

Gavito, M. E., Curtis, P. S., Mikkelsen, T. N., Jakobsen, I. (2001) Interactive effects of soil temperature, atmospheric carbon dioxide and soil N on root development, biomass and nutrient uptake of winter wheat during vegetative growth. Journal of Experimental Botany, 52(362): 1913-1923.

Giardina, C. P. & Ryan, M. G. (2000) Evidence that decomposition rates of organic carbon in mineral soil do not vary with temperature. Nature, 404: 858-861.

Goeransson, H., Godbold, D. L., Jones, D. L., Rousk, J. (2013) Bacterial growth and respiration responses upon rewetting dry forest soils: Impact of drought-legacy. Soil Biology and Biochemistry. 57: 477-486.

Goldberg, S. D. and Gebauer, G. (2009) Drought turns a Central European Norway spruce forest soil from an N_2O source to a transient N_2O sink, Global Change Biol., 15: 850-860, doi:10.1111/j.1365-2486.2008.01752.x, 2009.

Goldberg, S. D., Knorr, K. H., Blodau, C., Lischeid, G., and Gebauer, G. (2010a) Impact of altering the water table height of an acidic fen on N_2O and NO fluxes and soil concentrations, Global Change Biol., 16: 220-233.

Goldhammer, T. and Blodau, C. (2008) Desiccation and product accumulation constrain heterotrophic anaerobic respiration in peats of an ombrotrophic temperate bog, Soil Biol. Biochem., 40: 2007-2015, doi:10.1016/j.soilbio.2008.03.005.

Goulding, K. W. T., Poulton, P. R., Webster, C. P., Howe, M. T. (2000) Nitrate leaching from the Broadbalk Wheat Experiment, Rothamsted, UK, as influenced by fertilizer and manure inputs and the weather. Soil Use Manage, 16: 244-250.

Graham, A., Layzell, D. B., Scott, N. A., Cen, Y., Kyser, T. K. (2011) Carbon sequestration in soybean crop soils: the role of hydrogen-coupled CO_2 fixation. American Geophysical Union, Fall Meeting, abstract No. B11 A-0466.

Granli, T., Bøckmann, O. C. (1994) Nitrous oxide from agriculture. Norw. J. Agric. Sci. Suppl. 12: 48-53.

Gregorich, E.G., V oroney, R. P. & Kachanoski, R. G. (1991) Turnover of carbon through the microbial biomass in soils with different textures. Soil Biology and Biochemistry, 23: 799-805.

Griffith, E., Birch, H. F. (1961) Microbial changes in freshly moistened soil. Nature 178: 500-501.

Groffman, P. M. and Tiedje, J. M. (1988) Denitrification hysteresis during wetting and drying cycles in soil, Soil Sci. Soc. Am. J., 52: 1626-1629.

Grogan, P., Michelsen, A., Ambus, P., and Jonasson, S. (2004) Freezethaw regime effects on carbon and nitrogen dynamics in subarctic heath tundra mesocosms, Soil Biol. Biochem., 36: 641-654.

Hall, S. J., Matson, P. A. (1999) Nitrogen oxide emissions after nitrogen additions in tropical forests. Nature, 400: 152-155.

Halverson, L. J., Jones, T. M., Firestone, M. K. (2000) Release of intracellular solutes by four soil bacteria exposed to dilution stress. Soil Science Society of America Journal, 64: 1630-1637.

Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D. W. & Medina-Elizade, M. (2006) Global temperature change. Proc. Natl. Acad. Sci. U. S. A., 103: 14288-14293.

Hao, W. M., Scharffe, D., Crutzen, P. J., and Sanhueza, E. (1988) Production of N_2O, CH_4, and CO_2 from soils in the tropical savanna during the dry season, J. Atmos. Chem., 7: 93-105.

Harris, R. (1981) Effect of water potential on microbial growth and activity, in: Water potential relations in soil microbiology, edited by: Parr, J., Gardner, W., and Elliott, L., Soil Science Society of America, Madison, WI, USA, 23-97.

Hart, S. C. (2006) Potential impacts of climate change on nitrogen transformations and greenhouse gas fluxes in forests: a soil transfer study. Global Change Biology, 12: 1032-1046.

Hartley, I. P., Hopkins, D. W., Garnett, M. H., Sommerkorn, M. & Wookey, P. A. (2008) Soil microbial respiration in arctic soil does not acclimate to temperature. Ecol. Lett., 11: 1092-1100.

Hartley, I. P., Hopkins, D. W., Garnett, M. H., Sommerkorn, M. & Wookey, P. A. (2009) No evidence for compensatory thermal adaptation of soil microbial respiration in the study of Bradford et al. (2008). Ecol. Lett., 12: E12-E14.

Hatch, D., Goulding, K., Murphy, D. (2002) Nitrogen. In: Agriculture, Hydrology, and Water Quality (eds.: Haygarth, P.M., Jarvis, S.C.) 7-28. CABI Publishing, New York, NY.

Hefting, M. M., Bobbink, R., de Caluwe, H. (2003) Nitrous oxide emission and denitrification in chronically nitrate-loaded riparian buffer zones. Environ Qual, 32: 1194-1203.

Hentschel, K., Borken, W., Matzner, E. (2007) Leaching losses of inorganic N and DOC following repeated drying and wetting of a spruce forest soil. Plant and Soil, 300: 21-34.

Hicks, W. T., Harmon, M. E. & Griffiths, R. P. (2003) Abiotic controls on nitrogen fixation and respiration in selected woody debris from the Pacific Northwest, USA. Ecosc ience, 10: 66-73.

Hirschfeld, J., Weiss, J., Preidl, M., Korbun, T. (2008) The impact of German agriculture on the climate. Institute for Ecological Economy Research, Berlin.

Hlavinka, P., Trnka, P., Semeradova, D., Dubrosky,M., Zalud, Z. & Mozny, M. (2009) Effect of drought on yield variability of key crops in Czech Republic. Agricultural and Forest Meteorology, 149: 431-442.

Holmes, W. R. J. (1980) Nutrition of the oilseed rape crop. London, Applied Sciences Publishers LTD.

Houghton, J. (1997) Global Warming: the Complete Briefing, 2nd Edn. Cambridge University Press, Cambridge, UK.

Hutchinson, G. L., Mosier, A. R. (1981) Improved soil cover method for field measurement of nitrous oxide fluxes. Soil Sci. Soc. Am. J., **45**: 311-316.

Hutchinson, G. L. (1995) Biosphere-atmosphere exchange of gaseous N oxides. In: Soils and Global Change. (eds.: Lal, R., Kimble, J., Levine, E., Stewart, B.A.) 219-236. CRC Press, Inc., Boca Raton, FL.

Huxman, T. E., Snyder, K. A., Tissue, D., Leffler, A. J., Ogle, K., Pockman, W. T., Sandquist, D. R., Potts, D. L., and Schwinning, S. (2004a) Precipitation pulses and carbon fluxes in semiarid and arid ecosystems, Oecologia, 141: 254-268, doi:10.1007/s00442-004-1682-4.

Huxman, T. E., Cable, J. M., Ignace, D. D., Eilts, J. A., English, N. B., Weltzin, J., Williams, D. G. (2004b) Response of net ecosystem gas exchange to a simulated precipitation pulse in a semiarid grassland: the role of native versus non-native grasses and soil texture. Oecologia.

IEA (2012) International Energy Egency, CO_2 emissions from fuel combustion. IEA/OECD

Ineson, P., Benham, D. G., Poskitt, J., Harrison, A. F., Taylor, K., Woods, C. (1998) Effects of climate change on nitrogen dynamics in upland soils. 2. A soil warming study. Global Change Biology, 4: 153-161.

IPCC (1997) Intergovernmental panel on climate change guidelines for national greenhouse gas inventories chapter 4: agriculture: nitrous oxide from agricultural soils and manure management. OECD, Paris.

IPCC (2000a) Land use, land use change and forestry IPCC. Pp 377, Cambridge University Press, UK.

IPCC (2000b) Special report on emissions scenarios. Cambridge University Press, Cambridge, UK.

IPCC (2007) Summary for Policymakers of Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Isermann, K. (1994) Agriculture's share in the emissions of trace gases affecting the climate and some cause-oriented proposals for sufficiently reducing this share. Environmental Pollution, 83: 95-111.

Jackson, L. E., Burger, M. and Cavagnaro, T. R. (2008) Roots, nitrogen transformations, and ecosystem services. Annual Review of Plant Biology, 59: 341-363.

Jackson, L. (2010) Soil microbial nitrogen cycling for organic farms

Jacob, D., Goettel, H., Kotlarski, S., Lorenz, P., Sieck, K. (2008) Klimaauswirkungen und Anpassung in Deutschland – Phase 1: Erstellung regionaler Klimaszenarien für Deutschland. Max-Planck-Institut für Meteorologie (MPI-M), Hamburg, Dessau: pp 41.

Jager, G. & Bruins, E. H. (1975) Effect of repeated drying at different temperatures on soil organic matter decomposition and characteristics, and on soil microflora. Soil Biology and Biochemistry, 7: 153-159.

Jarvis, P., Rey, A., Petsikos, C. (2007) Drying and wetting of Mediterranean soils stimulates decomposition and carbon dioxide emission: the ‘‘Birch effect’’. Tree Physiology, 27: 929-940.

Jenkinson, D. S., Adams, D. E. & Wild, A. (1991) Model estimates of CO_2 emissions from soil in response to global warming. Nature, 351: 304-306.

Jensen, L. S., Mueller, T., Tate, K. R., Ross, D. J., Magid, J., and Nielsen, N. E. (1996) Soil surface CO_2 flux as an index of soil respiration in situ: A comparison of two chamber methods, Soil Biol. Biochem., 28: 1297-1306, doi:10.1016/S0038-0717(96)00136-8.

Jhonson, R. (2009) Climate change: The role of the U.S. agriculture sector. Congressional Research Service, 7-5700.

Joergensen, R. G. (1996) The fumigation-extraction method to estimate soil microbial biomass: Calibration of the kEC value. Soil Biology and Biochemistry, 28(1): 25-31.

Joergensen, R. N., Joergensen, B. J., Nielsen, N. E. (1998) N_2O emission immediately after rainfall in a dry stubble field. Soil Biology and Biochemistry, 30: 545-546.

Jolánkai, M., Birkás, M. (2005) Carbon Sequestration of Crops Influenced by Nitrogen Fertilization. Proceedings. 43rd Croatian and 3rd International Symposium on Agriculture. Opatija. Croatia. pp.: 540-543.

Jonasson, S., Michelsen, A., Schmidt, I.K. & Nielsen, E.V. (1999) Responses in microbes and plants to changed temperature, nutrient, and light regimes in the arctic. Ecology, 80: 1828-1843.

Jones, P. D., Moberg, A. (2003) Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. Journal of Climate 16(2): 206-223.

Jones, A., Panageos, P., Barcelo, S., Bouraoui, F., Bosco, C., Dewitte, O., Gardi, C., Hervas, J., Hiederer, R., Jeffery, S., Montanarella, L., Penigek, V., Toth, G., Van Den Eeckhaut, M., Liedekerke, M. V., Verheijen, F., Yigini, Y. (2012) The state of soil in Europe. Reference Report by the Joint Research Commission, Report Eur 25186 EN.

Joos, O., Hagedorn, F., Heim, A., Gilgen, A. K., Schmidt, M. W. I., Siegwolf, R. T. W., and Buchmann, N. (2010) Summer drought reduces total and litter-derived soil CO_2 effluxes in temperate grassland – clues from a ^{13}C litter addition experiment, Biogeosciences, 7: 1031-1041, doi:10.5194/bg-7-1031-2010.

Kamp, T., Steindl, H., Hantschel, R.E., Beese, F., Munch, J.C. (1998) Nitrous oxide emissions from a fallow and wheat field as affected by increased soil temperatures. Biol. Fertil. Soils, 27: 307-314.

Kandeler, E. (1996) Potential Nitrification and Protease Activity. Methods in Soil Biology (Schinner, F., O¨ hlinger R., Kandeler, E. & Margesin, R., eds). Springer, Berlin, Germany, pp. 176-179.

Kandeler, E., Tscherko, D., Bardgett, R. D., Hobbs, P. J., Kampichler, C., Jones, T. H. (1998) The response of soil microorganisms and roots to elevated CO_2 and temperature in a terrestrial model ecosystem. Plant and Soil, 202(2): 251-262.

Kanwar, J.S. (1972) Fertil. News., 17: 17.

Kessavalou, A., Doran, J. W., Mosier, A. R., and Drijber, R. A. (1998) Greenhouse gas fluxes following tillage and wetting in a wheat fallow cropping system, J. Environ. Qual., 27: 1105-1116.

Kieft, T. L., Soroker, E., and Firestone, M. K. (1987) Microbial biomass response to a rapid increase in water potential when dry soil is wetted, Soil Biol. Biochem., 19: 119-126.

Kiese, R., Hewett, B., Graham, A., Butterbach-Bahl, K. (2003) Seasonal variability of N_2O emissions and CH_4 uptake by tropical rainforest soils of Queensland, Australia. Glob. Biogeochem. Cycl., 17: 1043. doi:10.1029/2002GB002014.

Kiese, R., Li, C., Hilbert, D., Papen, H, Butterbach-Bahl, K. (2005) Regional application of PnET-N-DNDC for estimating the N2O source strength of tropical rainforests in the Wet Tropics of Australia. Glob. Change Biol., 11: 128-144.

Killham, K., Amato, M., Ladd, J. (1993) Effect of substrate location in soil and soil pore water regime on carbon turnover. Soil Biology and Biochemistry, 25: 57-62.

Kim, D. G., Mishurov, M., and Kiely, G. (2010a) Effect of increased N use and dry periods on N_2O emission from a fertilized grassland. Nutr. Cycl. Agroecosys., 88: 397-410.

Kim, D. G., Mu, S., Kang, S., and Lee, D. (2010b) Factors controlling soil CO_2 effluxes and the effects of rewetting on effluxes in adjacent deciduous, coniferous, and mixed forests in Korea. Soil Biol. Biochem., 42: 576-585.

Kim, D. G., Vargas, R., Bond-Lamberty, B., Turetsky, M. R. (2012) Effects of soil rewetting and thawing on soil gas fluxes: a review of current literature and suggestions for future research. Biogeosciences, 9: 2459-2483.

Kirschbaum, M. U. F. (1995) The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage. Soil Biol. Biochem., 27: 753-760.

Kitzler, B., Zechmeister-Boltenstern, S., Holtermann, C., Skiba, U., Butterbach-Bahl, K. (2006) Biogeosciences Controls over N2O, NO and CO2 fluxes in a calcareous mountain forest soil. Biogeosciences, 3: 383 – 395.

Knowles, R. (2000) Nitrogen cycle. In: Encyclopedia of Microbiology. vol. 3. 2nd ed (ed.: Lederberg, J.) 379-391. Academic, San Diego, CA.

Koerner, C., and Larcher, W. (1988) Plant life in cold climates. Pages 25-57in S. F. Long and F. I. Woodward, editors. Plant and temperature. Symposium of the Society for Experimental Biology. Volume 42. The Company of Biologists, Cambridge, UK.

Koponen, H. (2007) Productin of Nitrous oxide (N2O) and Nitric oxide (NO) in boreal agricultural soils at low temperature. PhD thesis.

Kroeze, C., Mosier,A., Bouwman, L. (1999) Closing the global N_2O budget: a retrospective analysis 1500-1994. Global Biogeochemical Cycles 13: 1-8.

Kumar, U., Jain, M. C., Kumar, S., Majumdar, D. (2000) Role of nitrification inhibitors on nitrous oxide emissions in a fertilized alluvial clay loam under different moisture regimes. Curr. Sci., 79: 224-228.

Ladd, J. N., Foster, R. C. & Skjemstad, J. O. (1993) Soil structure: carbon and nitrogen metabolism. Geoderma, 56: 401-434.

Lægreid, M., Bøckman, O. C., Kaarstad, O. (1999a) Global challenge – to feed the people. *In*: Agriculture, Fertilizer and the Environment. 25-75. Norsk hydro ASA, Porsgrunn, Norway. No 12.

Lal, R. (2004) Soil carbon sequestration impacts on global climate change and food security. Science 304: 1623-1627.

Lal, R. (2008) Soil carbon stocks under present and future climate with specific reference to European ecoregions. Nutr. Cycl. Agroecosyst., 81: 113-127.

Lamb, D., Erskine, P. D., Parrota, J. A. (2005) Restoration of degraded tropical forest landscapes. Science, 310: 1628-1632.

Lancashire, P. D., Bleiholder, H., Langeluddecke, P., Stauss, R., Den Boom, T., Weber, E., Witzen-Berger, A. (1991) A uniform decimal code for growth stages of crops and weeds. Ann. Appl. Biol, 119: 561-601.

Law, B. E., Falge, E., Gu, L. (2002) Environmental controls over carbon dioxide and water vapor exchange of terrestrial vegetation. Agric For Meteorol 113: 97-120.

Lee, X., Wu, H. J., Sigler, J., Oishi, C., and Siccama, T. (2004) Rapid and transient response of soil respiration to rain, Global Change Biol., 10: 1017-1026.

Linn, D. M., Doran, J. W. (1984) Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and nontilled soils. Soil Sci. Soc. Am. J., 48: 1667-1672.

Liu, Q., Yin, H. J., Chen, J. S., Zhao, C. Z., Cheng, X. Y., Wei, Y. Y., Lin, B. (2011) Belowground responses of *Picea asperata* seedlings to warming and nitrogen fertilization in the eastern Tibetan Plateau. Ecological Research, 36: 37-648.

Livingston, G. P. & Hutchinson, G. L. (1995) Enclosure-based measurement of trace gas exchange: applications and sources of error. In: Matson P. A. Harrison R. C. (Eds.), Biogenic trace gases: Measuring emissions from soil and water. Blackwell Science Ltd., Oxford.

Lloyd, D., Boddy, L., Davies, K. J. P. (1987) Presistence of bacterial denitrification capacity under aerobic conditions: the rule rather than the exception. FEMS Microbiol. Ecol., 45: 185-190.

Lloyd, J. & Taylor, J. A. (1994) On the temperature dependence of soil respiration. Funct. Ecol., 8: 315-323.

Iovieno, P., Bååth, E. (2008) Effect of drying and rewetting on bacterial growth rates in soil. FEMS Microbiology Ecology 65: 400-407.

Lundquist, E. J., Scow, K. M., Jackson, L. E., Uesugi, S. L., Johnson, C. R. (1999) Rapid response of soil microbial communities from conventional, low input, and organic farming systems to a wet/dry cycle.Soil Biology & Biochemistry, 31: 1661-1675.

Luo, Y. Q., Wan, S. Q., Hui, D. F. & Wallace, L. L. (2001) Acclimatization of soil respiration to warming in a tall grass prairie. Nature, 413: 622-625.

Luomala, E. M., Laitinen, K., Kellomaeki, S., Vapaavouri, E. (2003) Variable photosynthetic acclimation in consecutive cohorts of Scots pine needles during 3 years of growth at elevated CO2 and elevated temperature. Plant, Cell and Environment, 26: 645-660.

Marschner, H. (1986) Mineral Nutrition of Higher Plants. 2nd edition. Academic Press, 889 pp.

Martin, R. E., Asner, G. P., Ansley, R. J., and Mosier, A. R. (2003) Effects of woody vegetation encroachment on soil nitrogen oxide emissions in a temperate savanna, Ecol. Appl., 13: 897-910.

Marx, M. C., Wood, M., Jarvis, S. C. (2001) A microplate fluorimetric assay for the study of enzyme diversity in soils. Soil Biol. Biochem, 33: 1633-1640.

Melillo, J. M., McGuire, A. D., Kicklighter, D. W., Moore, B., Vorosmarty, C. J. & Schloss, A. L. (1993) Global climate change and terrestrial net primary production. Nature, 363: 234-240.

Melillo, J. M., Steudler, P. A., Aber, J. D., Newkirk, K., Lux, H., Bowles, F. P. (2002) Soil warming and carbon-cycle feedbacks to the climate system. Science, 298: 2173-2176.

Merino, A., Pérez-Batallón, P., Macías, F. (2004) Responses of soil organic matter and greenhouse gas fluxes to soil management and land use changes in a humid temperate region of southern Europe. Soil Biol. Biochem., 36: 917-925.

Minami, K. (1997) Atmospheric methane and nitrous oxide: sources, sinks and strategies for reducing agricultural emissions. Nutrient Cycling in Agroecosystems, 49: 203-211.

Monger, H. C., Gallegos, R. A. (2000) Biotic and abiotic processes and rates of pedogenic carbonate accumulation in the southwestern United States—relationship to atmospheric CO2sequestration. In: Lal R, Kimbel JM, Eswaran H, Stewart BA (eds) Global climate change and pedogenic carbonates. CRC, Boca Raton, Fla., pp 273-289.

Mosier, A. R., Kroeze, C. (1998) A new approach to estimate emissions of nitrous oxide from agriculture and its implications for the global N2O budget. IGBP Newsletter, 34: 8-13.

Muhr, J., Stefanie, D. G., Borken, W., and Gebauer, G. (2008) Repeated drying-rewetting cycles and their effects on the emission of CO_2, N_2O, NO, and CH_4 in a forest soil. Plant Nutr. Soil Sci., 171: 719-728.

Mummey, D. L., Smith, J. L., Bolron Jr, H. (1994) Nitrous oxide flux from shrub steppe ecosystem: Sources and regulation. Soil Biology & Biochemistry 26: 279-286.

Nadelhoffer K. J., Giblin, A. E., Shaver, G. R. and Linkins, A. E. (1992) Microbial processes and plant nutrient availability in arctic soils. Pages 281-300in F. S. Chapin, III, R. L. Jefferies, J. F.

Reynolds, G. R. Shaver, and J. Svoboda, editors. Arctic ecosystems in a changing climate. An ecophysiological perspective. Academic Press, San Diego, California, USA.

Neill, C., Steudler, P. A., Garcia-Montiel, D. C., Melillo, J. M., Feigl, B. J., Piccolo, M. C., and Cerri, C. C. (2005) Rates and controls of nitrous oxide and nitric oxide emissions following conversion of forest to pasture in Rondonia, Nutr. Cycl. Agroecosys., 71: 1-15, doi:10.1007/s10705-004-0378-9.

Neilsen, C. B. G., Groffman, P. M., Hamburg, S. P., and Driscoll, C. T. (2001) Freezing effects on carbon and nitrogen cycling in northern hardwood forest soils, Soil Sci. Soc. Am. J., 65: 1723-1730.

Németh, T., AbdEl-Galil, A., Radimszky, L., Baczó, G.Y. (1996) Effect of plant residues on ammonium and nitrate content of soils during incubation. In: Progress in Nitrogen Cycling Studies (eds.: Van Cleemput, O., Hofman, G., Vermoesen, A.), 109-114. Kluwer, London.

Niggli, U., Fliessbach, A., Hepperly, P., Scialabba, N. (2009) Low Greenhouse Gas Agriculture Mitigation and Adaptation Potential of Sustainable Farming Systems. Food and Agriculture Organization of the United Nations, Rome, Italy.

Nobre, A. D., Keller, M., Crill, P. M., and Harriss, R. C. (2001) Short-term nitrous oxide profile dynamics and emissions response to water, nitrogen and carbon additions in two tropical soils, Biol. Fert. Soils, 34: 363-373.

O'Connell, A. M. (1990) Microbial decomposition (respiration) of litter in eucalypt forests of south-western Australia: an empirical model based on laboratory incubations. Soil Biol Biochem, 22: 153-160.

Ophardt, C. (2001) Absorption of solar radiation greenhouse effect. CHM 110. Chemistry and issues in the environment. Home Laboratory No.3. Elmhurst College, Elmhurst, USA.

Parton, W. J., Schimel, D. S., Cole, C. V., Ojima, D. S. (1987) Analysis of factors controlling soil organic matter levels in Great Plain grasslands. Soil Science Society of America Journal, 51: 1173-1179.

Parton, W. J., Mosier, A. R., Schimel, D. S., (1988b) Rates and pathways of nitrous oxide production in a shortgrass steppe. Biogeochem., 6: 45-58.

Patil, R. H., Laegdsmand, M., Olesen, J. E., Porter, J. R. (2010a) Effect of soil warming and rainfall patterns on soil N cycling in Northern Europe. Agriculture, Ecosystems and Environment, 139(1-2): 195-205.

Patil, R. H., Laegdsmand, M., Olesen, J. E., Porter, J. R. (2010b) Growth and yield response of winter wheat to soil warming and rainfall patterns. Journal of Agricultural Sciences, 148: 553-566.

Patten, D. K., Bremner, J. M., Blackmer, A. M. (1980) Effects of drying and air-dry storage of soils on their capacity for denitrification of nitrate. Soil Sci. Soc. Am. J., 44: 67-70.

Paul, K. I., Polglase, P. J., Nyakuengama, J. G., Khanna, P. K. (2002) Change in soil carbon following afforestation. Forest Ecol. Manag., 168: 241-257.

Paustian, K., Andren, O., Janzen, H. H., Lal, R., Smith, P., Tian, G. (1997) Agricultural soils as a sink to mitigate CO_2 emissions. Soil Use Manage, 13: 230-244.

Pendall, E., Bridgham, S., Hanson, P. J., Hungate, B., Kicklighter, D. W., Johnson, D. W., Law, B. E., Luo, Y., Megonigal, J. P., Olsrud, M., Ryan, M. G., Wan, S. (2004) Below-ground process responses to elevated CO_2 and temperature: a discussion of observations, measurement methods, and models. New Phyotologist, 162: 311-322.

Pesaro, M., Widmer, F., Nicollier, G., and Zeyer, J. (2003) Effects of freeze-thaw stress during soil storage on microbial communities and methidathion degradation, Soil Biol. Biochem., 35: 1049-1061.

Peterjohn, W. T. (1991) Denitrification: enzyme content and activity in desert soils. Soil Biol. Biochem., 23: 845-855.

Phillips, D. A., Fox, T. C., Six, J. (2006) Root exudation (net efflux of amino acids) may increase rhizodeposition under elevated CO_2. Global Change Biology, 12: 561-567.

Pinheiro, J., Bates, D., Debroy, S., Sarkar, D. and R Core Team (2014) _nlme: Linear and Nonlinear Mixed Effects Models_. R package version 3.1-117, URL:http://CRAN.R-project.org/package=nlme.

Placella, S. A., Brodie, E. L., Firestone, M. K. (2012) Rainfall-induced carbon dioxide pulses result from sequential resuscitation of phylogenetically clustered microbial groups. Proceedings of the National Academy of Sciences 109: 10931-10936.

Poll, C., Ingwersen, J., Stemmer, J. M., Gerzabek, M. H., Kandeler, E. (2006) Mechanisms of solute transport affect small-scale abundance and function of soil microorganisms in the detritusphere. Eur. J. Soil Sci, 57: 583-595.

Poll, C., Marhan, S., Back, F., Kandeler, E. (2013) Field scale manipulation of temperature and precipitation change soil CO_2 flux in a temperate agricultural ecosystem Agriculture, Ecosystems and Environment, 165: 88-97.

Prasad, P. V. V., Boote, K. J., Thomas, J. M. G., Allen, L. H. Jr & Gorbet, D. W. (2006) Influence of soil temperature on seedling emergence and early growth of peanut cultivars in field conditions. Journal of Agronomy and Crop Science, 192: 168-177.

Prentice, I. C., Farquhar, G. D. (2001) The carbon cycle and atmospheric carbon dioxide. Cambridge, UK: 183-237.

Prieme, A. and Christensen, S. (2001) Natural perturbations, drying-wetting and freezing-thawing cycles, and the emission of nitrous oxide, carbon dioxide and methane from farmed organic soils, Soil Biol. Biochem., 33: 2083-2091.

Poth, M. and Focht, D. D. (1985) 15^N kinetic analysis of N_20 production by Nitrosomas europea: an examination of nitrifier denitrification. Applied Env Microbiol, 49: 1134-1141.

Pulleman, M., Tietema, A. (1999) Microbial C and N transformation during drying and rewetting of coniferous forest floor material.Soil Biology & Biochemistry, 31: 275-285.

Qaderi, M. M., Basraon, N. K., Chinnappa, C. C., Reid, D. M. (2010) Combined effects of temperature, ultraviolet-b radiation, and watering regime on growth and physiological processes in canola (*Brassica napus*) seedlings. International Journal of Plant Sciences, 171(5): 466-481.

Renault, P., Sierra, J., (1994) Modelling oxygen diffusion in aggregated soils. 2. Anaerobiosis in topsoil layers. Soil Sci. Soc. Am. J., 58: 1023-1030.

Reth, S., Graf, W., Gefke, O., Schilling, R., Seidlitz, H. K., Munch, J. C. (2008) Whole-year-round Observation of N_2O Profiles in Soil: A Lysimeter Study. Water, Air, Soil Pollut., 8: 129-137.

Rey, A., Petsikos, C., Jarvis, P. G. & Grace, J. (2005) Effect of temperature and moisture on rates of carbon mineralization in a Mediterranean oak forest soil under controlled and field conditions. Eur J Soil Sci, 56: 589-599.

Rice, C. W., Smith, M. S. (1982) Denitrification on no-tilled and plowed soils. Soil Science Society of America Journal.,46: 1168-1173.

Robertson, L. A., Kuenen, J. G. (1990) Physiological and ecological aspects of aerobic denitrification, a link with heterotrophic nitrification? In: Denitrification in Soils and Sediments (eds.: Revsbech, N.P., Sørensen, J.) 91-104. Plenum Press, New York.

Robinson, C. H., Wookey, P. A., Parsons, A. N., Potter, J. A., Callaghan, T. V., Lee, J. A., Press, M. C. and Welker, J. M. (1995) Responses of plant litter decomposition and nitrogen mineralization to simulated environmental change in a high arctic polar semi-desert and a subarctic dwarf shrub heath. Nordic Society Oikos, 74: 503-512.

Robinson, C. H., Michelsen, A., Lee, J. A., Whitehead, S. J., Callaghan, T. V., Press, M. C. and Jonasson, S. (1997) Elevated atmospheric CO_2 affects decomposition of *Festuca vivipara*(L.) Sm. litter and roots in experiments simulating environmental change in two contrasting arctic ecosystems. Global Change Biology,3: 37-49.

Rochette, P., Desjardins, R. L., and Pattey, E. (1991) Spatial and temporal variability of soil respiration in agricultural fields, Can. J. Soil Sci., 71: 189-196.

Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C. & Pounds, J. A. (2003) Fingerprints of global warming on wild animals and plants. Nature, 421: 57-60.

Rovira, P. & Vallejo, V. R. (1997) Organic carbon and nitrogen mineralization under Mediterranean climatic conditions: the effects of incubation depth. Soil Biology and Biochemistry, 29: 1509-1520.

Rudaz, A. O., Davidson, E. A., Firestone, M. K., (1991) Sources of nitrous oxide production following wetting of dry soil. Federation of European Microbiological Societies, Microbiological Ecology 85: 117-124.

Ruddiman, W. F. (2003) The anthropogenic greenhouse erabegan thousands of years ago. Climatic Change, 61: 292-292.

Ruser, R., Flessa, H., Russow, R., Schmidt, G., Buegger, F., Munch, J. C. (2006) Emission of N_2O, N_2 and CO_2 from legumes. Nutr Cyc Agroecosys, 73: 171-179.

Russow, R., Sich, I., Neue, H. U. (2000) The formation of the trace gases NO and N_2O in soils by the coupled processes of nitrification and denitrification: results of kinetic 15^N tracer investigations. Chemosphere, 2: 359366.

Rustad, L. E., Campbell, J. L., Marion, G. M., Norby, R. J., Mitchell, M. J., Hartley, A. E., Cornelissen, J. H. C., Gurevitch, J. (2001) A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. Oecologia, 126: 543-562.

Sardans, J., Penuelas, J. (2005) Drought decreases soil enzyme activity in a Mediterranean *Quercus ilex* L. forest. Soil Biology and Biochemistry, 37: 455-461.

Sardans, J., Penuelas, J., Estiarte, M., Prieto, P. (2008) Warming and drought alter C and N concentration, allocation and accumulation in a Mediterranean shrubland. Global Change Biology, 14(10): 2304-2316.

Sardans, J., Penuelas, J., Estiarte, M. (2008c) Changes in soil enzymes related to C and N cycle and in soil C and N content under prolonged warming and drought in a Mediterranean shrubland. Applied Soil Ecology, 39: 223-235.

Scheu, S., Parkinson, D. (1994) Changes in bacterial and fungal biomass-C, bacterial and fungal biovolume and ergosterol content after drying, remoistening and incubation of different layers of cool temperate forest soils. Soil Biology & Biochemistry, 26: 1515-1525.

Schimel, J. P., Gulledge, J. M., Clein-Curley, J. S., Lindstrom, J .E., Braddock, J. S. (1999) Moisture effects on microbial activity and community structure in decomposing birch litter in the Alaskan taiga. Soil Biology & Biochemistry, 31: 831-838.

Schimel, J. P., and J. Bennett. 2004. Nitrogen mineralization: Challenges of a changing paradigm. Ecology 85: 591-602.

Schimel, J. P., Balser, T. C., and Wallenstein, M. (2007) Microbial stressresponse physiology and its implications for ecosystem function, Ecology, 88: 1386-1394.

Schimel, J. P. and Clein, J. S. (1996) Microbial response to freeze-thaw cycles in tundra and taiga soils, Soil Biol. Biochem., 28: 1061-1066.

Schimel, J., Boot, C., Roux-Michollet, D., Parker, S., Schaeffer, S., Treseder, K. (2010) Enzyme activity and adaptation in dry soil. Proceedings of the World Congressof Soil Science, 19: 17-20.

Schlesinger, W. H. (1985) The formation of caliche in soils of the Mojave Desert, California. Geochim Comochim Acta, 49: 57-66.

Schmidt, I., Bock, E. (1998) Anaerobic ammonia oxidation by cell-free extracts of Nitrosomonas eutropha. Antonie Leeuwenhoek, 73: 271-278.

Schmidt, M. S., Parsons, L. L. (1985) Persistence of denitrifying enzyme activity in dried soils. Applied and Environmental Microbiology, 49: 316-320.

Schmidt, I. K., Tietema, A., Williams, D., Gundersen, P., Beier, C., Emmett, B. A., Estiarte, M. (2004) Soil solution chemistry and element fluxes in three European heath lands and their responses to warming and drought. Ecosystems, 7: 638-649.

Scholes, M. C., Martin, R., Scholes, R. J., Parsons, D., Winstead, E. (1997) NO and N_2O emissions from savanna soils following the first stimulated rains of the season. Nutrient Cycling in Agroecosystems, 48: 115-122.

Scott, R. L., Edwards, E. A., Shuttleworth, W. J., Huxman, T. E., Watts, C., Goodrich, D. C. (2004) Interannual and seasonal variation in fluxes of water and CO_2 from a riparian woodland ecosystem. Agric For Meteorol, 122: 65-84.

Serca, D., Delmas, R., Jambert, C., Labroue, L. (1994) Emissions of nitrogen-oxides from equatorial rainforests in Central-Africa—Origin and regulation of NO emissions from soils. Tellus, 46: 243-254.

Six, J., Bossuyt, H., Degryze, S., Denef, K., (2004) A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. Soil & Tillage Research, 79: 7-31.

Skopp, J., Jawson, M. D., Doran, J. W. (1990) Steady-state aerobic microbial activity as a function of soil water content. Soil Sci. Soc. Am. J., 54: 1619-1625.

Smith, K. A., Clayton, H., McTaggart, I. P., Thomas, P. E., Arah, J. R. M., Scott, A. (1995) The measurement of nitrous oxide emission from soil by using chambers. Phil T rans Roy Soc London Ser A, 351: 327-338.

Smith, M. S., Parsons, L. L. (1985) Persistence of denitrifying enzyme activity in dried soils. Appl. Environ. Microbiol., 49: 316-320.

Smith, K. A., McTaggart, I. P., Tsuruta, H. (1997) Emissions of N_2O and NO associated with nitrogen fertilization in intensive agriculture, and the potential for mitigation. Soil Use and Management, 13: 296-304.

Smith, K. A., Ball, T., Conen, F., Dobbie, K. E., Massheder, J., Rey, A. (2003) Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes. Eur. J. Soil Sci., 54: 779-791.

Soussana, J. F., Casella, E., Loiseau, P. (1996) Long term effects of CO_2 enrichment and temperature increase on a temperate grassland sward. II. Plant nitrogen budgets and root fraction. Plant and Soil, 183: 110-114.

Sparling, G. P., Speir, T. W., Whale, K. N. (1986) Changes in microbial biomass-C, ATP content, soil phospho-monosterase and phospho-diesterase activity following air-drying of soils.Soil Biology & Biochemistry, 18: 363-370.

Sparling, G. P., Ross, D. J. (1988) Microbial contributions to the increased nitrogen mineralization after air-drying of soils. Plant and Soil, 105: 163-167.

Sponseller, R. A. (2007) Precipitation pulses and soil CO_2 flux in a Sonoran Desert ecosystem, Global Change Biol., 13: 426-436.

Sponseller, R. A. and Fisher, S. G. (2008) The influence of drainage networks on patterns of soil respiration in a desert catchment, Ecology, 89: 1089-1100.

Stark, C. H., Richards, K. G. (2008) The continuing challenge of agricultural nitrogen loss to the environment in the context of global change and advancing research. Dynamic Soil, Dynamic Plant, Global Science Books.

Stone, P. J., Sorensen, I. B. & Jamieson, P. D. (1999) Effect of soil temperature on phenology, canopy development, biomass and yield of maize in a cool-temperate climate. Field Crops Research, 63: 169-178.

Strong, D. T., Wever, H. D., Merckx, R., Recous, S. (2004) Spatial location of carbon decomposition in the soil pore system. European Journal of Soil Science 55: 739-750.

Takle, E. (2008) Global warming: agriculture's impact on greenhouse gas emission AgDM newsletter article.

Tang, J., Baldocchi, D. D., Qi, Y., Xu, L. (2003) Assessing soil CO_2 efflux using continuous measurements of CO_2 profiles in soils with small solid-state sensors. Agric For Meteorol, 118: 207-220.

Teepe, R., Brumme, R., and Beese, F. (2001) Nitrous oxide emissions from soil during freezing and thawing periods, Soil Biol. Biochem., 33: 1269-1275.

Tinker, P. B. and Ineson, P. (1990) Soil organic matter and biology in relation to climate change. - In: Scharpenseel, H. W., Schomaker, M. and Ayoub, A. (eds), Soils on a warmer earth. - Dev. Soil Sci, 20: 71-88.

Tolvanen, A., Henry, G. H. R. (2001) Responses of carbon and nitrogen concentration in high artic plants to experimental warming. Canadian Journal of Botany, 79,: 711-718.

Trenberth, K. E., Jones, P. D., Amenje, P. G., Bojariu, R., Easterling, D. R., Kleintank, A. M. G., Parker, D. E., Rahimzadeh, F., Renwick, J. A., Rusticucci, M. M., Soden,B.J. & Zhai, P. M. (2007) Observations: surface and atmospheric climate change. In Chapter 3 of Climate Change 2007. The Science of Climate Change. Contribution of WG 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Eds S. Solomon, D. Qin & M. Manning), pp. 237-336. Cambridge, UK: Cambridge University Press.

Umweltbundesamt (2006) Künftige Klimaänderungen in Deutschland- Regionale.

Unger, S., Maguas, C., Pereira, J.S., David, T.S., Werner, C. (2010) The influence of precipitation pulses on soil respiration e assessing the “birch effect” by stable carbon isotopes. Soil Biology & Biochemistry 42: 1800-1810.

UNFCCC. (1998) Review of the implementation of commitment and of other provisions of the convention. Review of information communicated under Article 12. National Communication from parties included in the annex 1 to the convention. Summary compilation of annual greenhouse gas emissions inventory data from Annex I Parties. Note by the secretariat. United Nations Framework Convention on Climate Change. Conference of the Parties. http://unfccc.de.

Van Gestel, M., Ladd, J. N., Amato, M. (1991) Carbon and nitrogen mineralization from two soils of contrasting texture and micro-aggregate stability: influence of sequential fumigation, drying and storage. Soil Biology & Biochemistry, 23: 313-322.

Van Gestel, M., Ladd, J. N., Amato, M. (1992) Microbial biomass responses to seasonal change and imposed drying regimes at increasing depths of undisturbed topsoil profiles. Soil Biology & Biochemistry, 24: 103-111.

Van Gestel, M., Merckx, R., and Vlassak, K. (1993) Microbial biomass responses to soil drying and rewetting: The fate of fast- and slowgrowing microorganisms in soils from different climates, Soil Biol. Biochem., 25: 109-123.

Vance, E. D., Brookes, P. C., Jenkinson, D. S. (1987) An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry,19(6): 703-707.

Veldkamp, E., Keller, M. (1997) Fertilizer-induced nitric oxide emissions from agricultural soils. Nutr. Cycl. Agroecosyst., 48: 69-77.

Vitousek, P., Aber, J. D., Howarth, R. W., Likens, G. E, Matson, P. A., Schindler, D. W., Schlesinger, W. H., Tilman, D. G. (1997) Human alteration of the global nitrogen cycle: sources and consequences. Ecological Applications 7: 737-750.

Voroney, R. P. (2007) The soil habitat. In: Soil Microbiology, Ecology, and Biochemistry(ed. Paul EA), pp. 25-49. Elsevier, Oxford, UK.

Walther, G. R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J. C. (2002) Ecological responses to recent climate change. Nature, 416: 389-395.

Wan, Y., Ju, X., Ingwersen, J., Schwarz, U., Stange, C. F., Zhang, F., Streck, T. (2009) Gross nitrogen transformations and related nitrous oxide emissions in an intensive used calcareous soil. Soil Sci Soc Am, 73: 102-112.

Wang, C., Wan, S., Xing, X., Zhang, L., Han, X. (2006) Temperature and soil moisture interactively affected soil net N mineralization in temperate grassland in Northern China. Soil Biol. Biochem, 38: 1101-1110.

Weintraub, M. N., Schimel, J. P. (2005) Nitrogen cycling and the spread of shrubs control changes in the carbon balance of artic tundra ecosystems. Bioscience, 55: 408-415.

West, T. O. & Post, W. M. (2002) Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Sci. Soc. Am. J., 66: 1930-1946.

Williams, M. A., Xia, K. (2009) Characterization of the water soluble soil organic pool following the rewetting of dry soil in a drought-prone tall grass prairie. Soil Biology & Biochemistry, 41: 21-28.

Woodwell, G. M., Mackenzie, F. T., Houghton, R. A., Apps, M., Gorham, E., Davidson, E. (1998) Biotic feedbacks in the warming of the earth. Climatic Change, 40(3-4): 495-518.

Wrage, N., Velthof, G. L., Laanbroek H. J., Oenema, O. (2004) Nitrous oxide production in grassland soils: assessing the contribuation of nitrifier denitrification. Soil Biol. Biochem., 36: 229-236.

Wu, J., Brookes, P. C. (2005) The proportional mineralisation of microbial biomass and organic matter caused by air-drying and rewetting of a grassland soil. Soil Biology & Biochemistry, 37: 507-515.

Wu, X., Yao, Z., Breuggemann, N., Shen, Z. Y., Wolf, B., Dannenmann, M., Zheng, X., and Butterbach-Bahl, K. (2010b) Effects of soil moisture and temperature on CO_2 and CH_4 soil-atmosphere exchange of various land use/cover types in a semi-arid grassland in Inner Mongolia, China, Soil Biol. Biochem., 42: 773-787.

Xiang, S. R., Doyle, A., Holden, P. A., and Schimel, J. P. (2008) Drying and rewetting effects on C and N mineralization and microbial activity in surface and subsurface California grassland soils, Soil Biol. Biochem., 40: 2281-2289.

Xu, L. K., Baldocchi, D. D., and Tang, J. W. (2004) How soil moisture, rain pulses, and growth alter the response of ecosystem respiration to temperature, Global Biogeochem. Cy., 18, GB4002, doi:10.1029/2004GB002281.

Yao, Z., Wu, X., Wolf, B., Dannenmann, M., Butterbach-Bahl, K., Breuggemann, N., Chen, W., and Zheng, X. (2010) Soil-atmosphere exchange potential of NO and N_2O in different land use types of Inner Mongolia as affected by soil temperature, soil moisture, freeze-thaw, and drying-wetting events, J. Geophys. Res., 115, D17116, doi:10.1029/2009jd013528.

Yin, H., Chen, Z., Liu, Q. (2012) Effects of experimental warming on soil N transformations of two coniferous species, Eastern Tibetan Plateau, China. Soil Biology and Biochemistry, 50: 77-84.

Yoo, G., Spomer, L. A., Wander, M. M., (2006) Regulation of carbon mineralization rates by soil structure and water in an agricultural field and a prairie-like soil. Geo-derma, 135: 16-25.

Yoshida, T., Alexander, M. (1970) Nitrous oxide formation by *Nitrosomonas europaea* and heteretrophic microorganisms. Soil Sci. Soc. Am. Proc., 34: 880-882.

Zak, D. R., Pregitzer, K. Z., King, J. S. Holmes, W. E. (2000) Elevated atmospheric CO_2, fine roots and the response of soil microorganisms: a review and hypothesis. New Pyotologist, 147: 201-222.

Zhang, W., Parker, K. M., Luo, Y., Wan, S., Wallace, L. L. & Hu, S. (2005) Soil microbial responses to experimental warming and clipping in a tall grass prairie. Glob. Change Biol., 11: 266-277.

Appendices

Appendix 1 Experimental place, 2nd sampling date

Appendix 2 Experimental place, 3rd sampling date

Appendix 3 Experimental place, 4th sampling date

Appendix 4 Experimental place, 5th sampling date

Appendix 5 Taking N_2O and CO_2 gas samples at the HoCC experimental site