Comparison of N_2O Fluxes as Affected by Land Use Systems and Climate in the Haean Catchment in South Korea

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Abstract: Global change is a challenge for mankind, especially to mitigate the negative effects. One important aspect of global change is the increasing release of infrared absorbing trace gases into the atmosphere, since they contribute significantly to global warming. Agricultural land covers a large part of the earths' surface, and agricultural management is becoming more intensive in order to meet food demands of the continuously growing population on earth. In addition to intensified nitrogen fertilization of crops, plastic mulching is an often used weed control method in East Asia. Until now, little information exists about the effect of plastic mulching on N_2O emissions. This work aims to elucidate such soil processes behind the trace gas emissions in dry land fields. Besides the work in agricultural ecosystems we also focus on natural ecosystems. We investigate the effect of the South Korean early summer drought followed by heavy monsoon rains on N_2O fluxes of deciduous forests. All of the research was conducted in the Haean Basin, South Korea, which as a super study site has both natural forest and intensively used agricultural land use systems.

Keywords: *N_2O emission, N_2O consumption, plastic mulching, nitrogen fertilization, soil moisture*

1. Introduction

The earths' population is growing and with it global issues - such as intensification of crop growing by introducing new agricultural practices – as well as problems - like an increasing release of greenhouse gases causing global warming - certainly having severe effects on ecosystem functions (Millennium Ecosystem Assessment 2005). Regarding the changing environment questions of how to deal with the global change and its' side effects come up.

Nitrous oxide (N_2O) is regarded as the third important greenhouse gas following CO_2 and CH_4 because of its long lifespan in the atmosphere of 114 years (IPCC 2007) and the resulting global warming potential of 6% (WOM 2006) and its involvement in the stratospheric ozone depletion (Cicerone 1987). Soils and specifically cultivated soils act as the main sources for atmospheric N_2O. It is of great interest to better understand processes leading to N_2O emissions from soils in order to mitigate N_2O emissions. The research question and assumption of this work are addressed to N_2O emissions in both natural and agricultural ecosystems.

In large parts of China, Japan and South Korea plastic mulching gets established as a more and more common method in agriculture (Kyrikou & Briassoulis 2007) because it results in increased yields, earlier harvests, less reliance on herbicides and pesticides, better protection of food products and more efficient water conservation and it can improve product quality and yield by mitigating extreme weather changes, optimizing growth conditions, extending the growing season and reducing plant diseases. Besides the disposal problem hardly any disadvantages of the plastic mulching are known so far (Kyrikou & Briassoulis 2007, www.plasticulture.com). No research on whether the plastic mulching increases greenhouse gas emissions has been conducted, yet. The first part of this work is dealing with the question whether plastic mulching increases N_2O emissions or not. Therefore, comparative N_2O flux measurements between rows covered with the plastic cover and uncovered walkways have been taken in 2010 in a radish field. In 2011 there are measurements ongoing in a bean field where covered and uncovered rows and walkways are being compared with respect to their N_2O release to the atmosphere.

The second research question is dealing with a natural ecosystem: the forest. As Goldberg & Gebauer (2009a, b) showed, experimentally induced drought turned the soil of a Norway spruce forest in the Fichtelgebirge in

Germany from an N_2O source into a transient N_2O sink. Large parts of the Haean basin are covered with forest, especially the steep mountainsides, and since Korea is very dry during the early summer and receives heavy monsoon rain in July and August (Ding et al. 2005) the research question came up how these extreme weather events may influence the forest soils in South Korea with respect to their N_2O emission behavior. Would there be consumption during the drought period and emission during the wet season as observed in the experiment in the Fichtelgebirge? To answer that question N_2O flux measurements in three different forest sites were taken in 2010.

2. Materials and Methods

2.1 Site Description

The Haean basin is located in the North of the Kangwon province in South Korea between the longitude 128° 5' to 128°11' E and latitude 38° 13' to 38° 20' N. It ranges in altitude from ca. 400 m to 1100 m and it is directly bordering on the DMZ which divides the Korean Peninsula. The mean annual air temperature is about.10.5°C at valley sites and ca. 7.5°C on the mountaintops. The precipitation is estimated at 1200 mm per year with 50% falling during the summer monsoon. The dominant crops in the cropland area are rice (25%), radish (20%), potato and cabbage (15%) and bean (5%). The mountainsides are steep slopes, covered with a deciduous forest dominated by three oak species *Quercus mongolica*, *Q. dentata* and *Q. serrata*. (Lee et al. 2010).

2.2 Methods

• *N_2O fluxes* were determined two times per week using the closed chamber method in conjunction with a photoacoustic infrared trace gas analyzer (Multigas Monitor 1312, INNOVA, Denmark) (Yamulki & Jarvis, 1999). In each study site there were five chambers and every 10 minutes the N_2O concentration in the chambers was determined. An increase of N_2O in the chambers meant an N_2O flux from soil to atmosphere; in return, decreasing N_2O concentration in the chambers was regarded as N_2O flux from the atmosphere into the soil. From the concentration increase or decrease in the chambers as well as the chamber area, headspace volume and sampling interval the gas fluxes were calculated (for further details see Goldberg & Gebauer 2009a).

In order to calculate the *cumulative N_2O fluxes* the mean emission rates of two consecutive N_2O flux rates were summed up over the measuring period. These were multiplied by corresponding time period. Finally, these time weighed means were summarized (Goldberg & Gebauer 2009b).

• To determine the *N-deposition* at the forest sites soil and leaf samples were collected in three forest sites. The roots were taken out of the soil samples; leaves and soil were dried at 75°C for two days. Afterwards the leaf and soil material was ground in a ball mill (Retsch Schwingmühle MM2, Haan, Germany) and stored in a desiccator before further analysis. Relative N isotope abundance was measured with an elemental analyzer (Carlo Erba 1108, Milano, Italy) linked to a Finnigan MAT delta S isotope ratio mass spectrometer via a Finnigan MAT ConFlo III Interface. From the derived $\delta^{15}N$ values the ^{15}N enrichment factor was calculated and using a regression by Emmet et al. (1997) – giving the relation between ^{15}N enrichment factor and N deposition – the N deposition at the Haean forest sites was estimated.

• ECH2O probes were installed at each site to log soil temperature and soil moisture continuously, every 30 minutes in 10 cm soil depth.

2.3 Experimental design

2.3.1 Radish Field Study Site

In the radish field study site (see Figure 1) five different amounts of N-fertilizer were applied: 50, 150, 200, 250 and 350 kg N-fertilizer per ha. Except for the amount of 200 kg N/ha – which was applied in one plot only ("Sinas Plot") – each amount of N-fertilizer was applied on four plots which were 7x7m. Between the plots walkways were installed which were 0.7m to 0.6 m wide in the vertical and horizontal direction.

On all of the plots (except the four plots in the upper row and "Sinas Plot") one chamber for N_2O flux measurements was installed on a row with plants covered with a black plastic cover (plastic mulching) and on a walkway, without plastic mulching. In "Sinas Plot" three chambers were installed on the walkways (no plastic mulching) as well as on the rows (plastic mulching).

N_2O flux measurements were taken every 5 days in the 50, 150, 250 and 350 kg N/ha plots and every two to three days in the 200 kg N/ha plot.

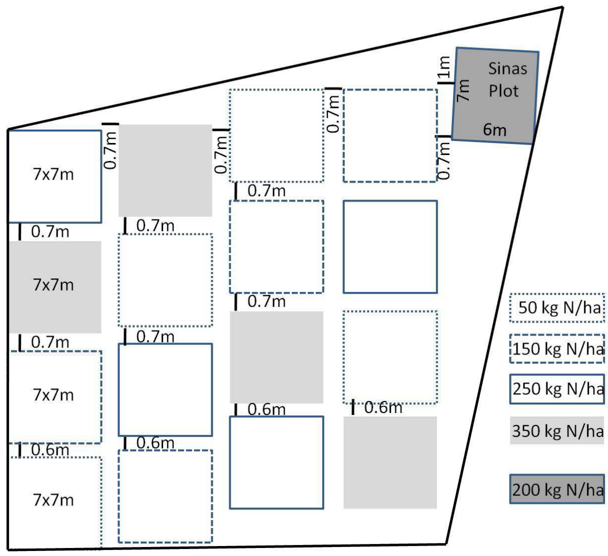

Figure 1: Experimental design of the radish field study site.

2.3.1 Forest Study Sites

Three different forest sites were chosen along an altitudinal gradient. The first one ("C") was located in the middle of the Haean catchment at an altitude of 450 m a.s.l., north east exposed. It was surrounded by cropland (rice, grapes, radish, potato). The second forest site ("B") was installed at intermediate altitude (640 m a.s.l.) with a southern exposition. It bordered the cropland area. The third one ("D") was located on 970 m a.s.l., north exposed, next to a military camp, which resulted in a higher degree of disturbance. The vegetation of the three sites was dominated by *Quercus mongolica* and *Q. dentata*.

3. Results

3.1 Radish Field

After fertilizer application the N_2O emission started in each treatment, peaked after the first rain event and decreased until mid of July - 38 days after the fertilizer application - no emission was detectable anymore. Except for the lowest N fertilizer application, on all treatment plots covered rows (plastic mulching) showed a higher N_2O emission than the uncovered walkways. N_2O emission increased continuously with increasing N fertilizer application. The rows of the 50 kg N/ha plots showed the least emission, the plots fertilized with 350 kg N/ha the most.

3.2 Forests

The N-deposition results (see Figure 3) suggest that forest C (450 m a.s.l.) – the one surrounded by fields in the cropland area – receives the highest N-load (53 kg ha^{-1} yr^{-1}); the forest at 970 m a.s.l. is exposed to the least atmospheric N-deposition (24 kg ha^{-1} yr^{-1}) and the forest site "B" (located at 640 m a.s.l), which bordered on the cropland area, receives about 32 kg ha^{-1} yr^{-1}).
As the graphs 4-1 to 4-3 show, a soil N_2O sink function occurred in all three forest sites during the early summer drought period. In July, when the monsoon rains started and the soil got moister, the N_2O consumption turned into emission, but in September when the soil got drier again, slightly negative N_2O fluxes could be detected again. There is a significant relation between soil moisture content and N_2O flux.

The cumulative N_2O emissions reveal that forest site C (4-4) and D (4-6) have a positive N_2O emission balance during the measurement period but forest site B's (4-5) N_2O emission balance remains negative.

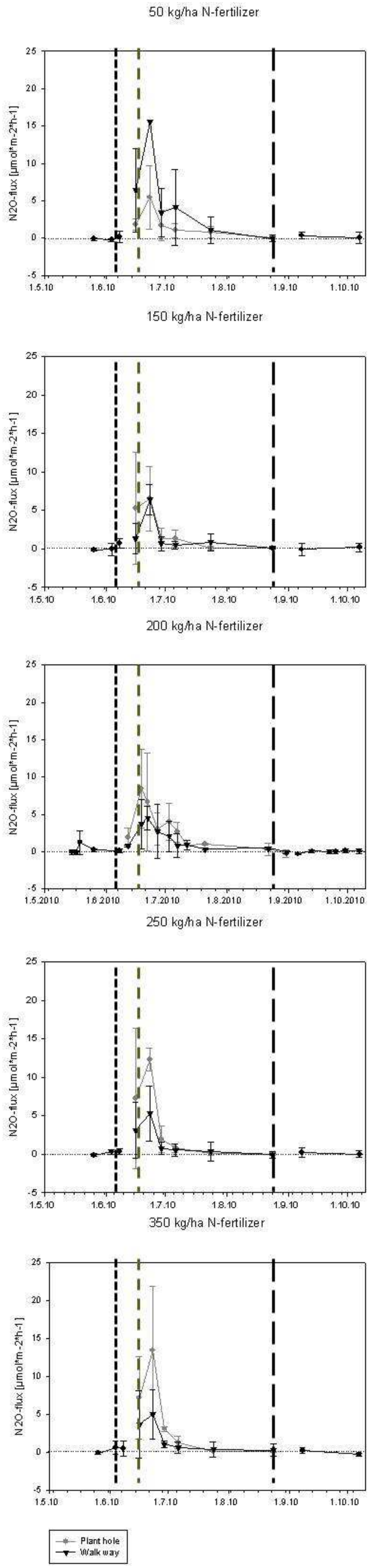

Figure 2. N_2O fluxes ± 1SD in the radish field from May to October 2010 in dependence on the amount of fertilizer applied. The black line indicates the N_2O emission of the rows, covered with the plastic cover (plastic mulching. The grey line gives the N_2O emission of the uncovered walkways. The vertical black narrowly dashed line shows the fertilizer application time, the gray dashed line indicates the planting date of the radish, the black widely dashed line the day of harvest of the radish.

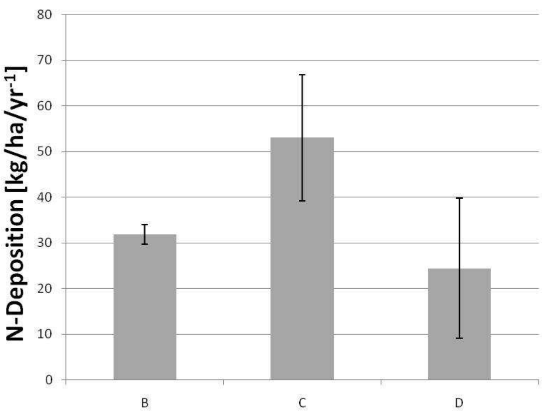

Figure 3. Nitrogen-deposition of the three forest sites ("C", "B", "D").

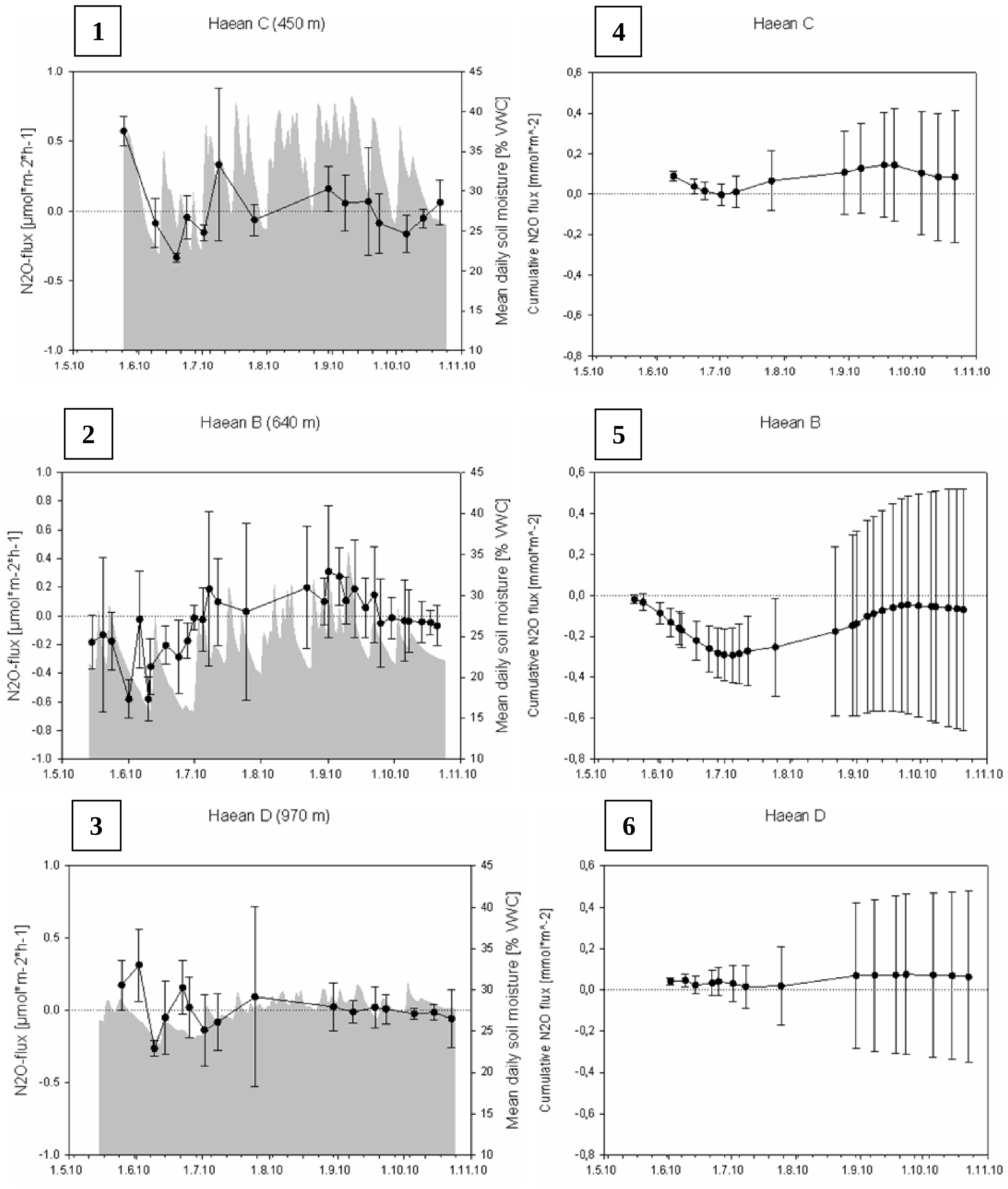

*Figure 4. Graphs **1-3** show the N_2O fluxes of the forest sites "B", "C" and "D" ± 1SD and the soil moisture from May until October 2010. The graphs **4-6** give these forest sites cumulative N_2O emissions ± 1SD.*

4. Discussion and Outlook

The aim of the N_2O flux measurements in the radish field was to investigate the effect of nitrogen fertilizer application and plastic mulching on soil N_2O fluxes. Our preliminary finding is that the covered radish rows emitted more nitrous oxide than the uncovered walkways and that this difference was enhanced with increasing nitrogen fertilizer application. Further investigations in 2011 will compare N_2O emissions from walkways, rows covered with plastic cover (plastic mulching) and uncovered rows and underlying reasons in order to deepen our knowledge on the effect of plastic mulching on soil N_2O emission. If the effect of plastic mulching on N_2O emissions is confirmed, this needs to be taken into account for global trace gas emission budgets especially since in almost 80 % of agriculturally used areas in South Korea, Japan and China plastic mulching is a common method for growing dry crops (Espi et al., 2006).

The temporary N_2O sink function of the South Korean deciduous oak forest soils under natural summer drought conditions in 2010 confirms experimental findings in a Norway spruce forest in Germany (Goldberg & Gebauer 2009a, b). Though this N_2O sink function of forest soils under drought conditions is tiny and transient, it should be considered in regional and global budgets due to the huge cover of forests on earth’s surface (Billings 2008).

One of the three most important crops in the world is rice (http://faostat.fao.org/). Paddy rice fields are known to provide an environment for the production of the two important greenhouse gases, CH_4 and N_2O, because of variations in soil characteristics, moisture content, and microbial activity during the cropping season (Hou et al. 2000). Alternate anaerobic and aerobic cycling considerably increases N_2O emission (Smith & Patrick 1983). However, as Yagi et al. (1996) figured out in a Japanese rice paddy, water management with very short anaerobic–aerobic cycling may cause a very low emission of N_2O.

Preliminary results of N_2O flux measurements in rice paddies in Haean in 2010 suggest that there is almost no N_2O emission even though longer periods with no flooding have been observed. The question is: why is that? To approach that question in 2011 N_2O and CH_4 flux measurements in rice paddies are being taken again. In addition, various other soil parameters are being determined, such as N_2O and CH_4 concentration and isotope signature along soil profiles to figure out what happens to the nitrous oxide in the rice paddy soils leading to no emissions at all. Furthermore nitrate and ammonium concentration along soil profiles are being determined. As substrate for nitrous oxide production the presence or absence of NO_3^- and NH_4^+ should reveal ongoing production and consumption processes in the soil. Oxygen probes are being installed as well to indicate the redox potential of the rice paddy soils.

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