Modeling the Impacts of Different Agricultural Practices on Nitrogen Losses from Agricultural Soils in Haean Catchment

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Abstract: Agriculture practices such as crop rotation, tillage and fertilization have significant impact on ecosystem nutrient turnover and losses with potential harm to the atmosphere (greenhouse gas emissions - GHG) and hydrosphere (leaching). The Landscape-DNDC model, originated and further developed from the DNDC model, is capable of predicting soil carbon and nitrogen turnover and associated losses of greenhouse gases and nutrient leaching from terrestrial ecosystems. The study region is located in the Haean Catchment, northeast of Yanggu County, Korea. Highland agriculture is the dominant agricultural practice in this region. The Landscape-DNDC model was applied to estimate nitrogen turnover rates and N_2O emissions as well as NO_3^- leaching rates of forest and various agricultural sites experiencing different management practices of Haean Catchment. Field measurements of TERRECO such as N_2O emissions, inorganic soil nitrogen stocks (NH_4^+-N and NO_3^--N) as well as NO_3 concentration in soil water from upland fields and rice paddies, were used for comparison with the model simulations. In particular, simulation results were compared to the measured N_2O emissions from a radish field with different fertilization regimes. The underestimated simulation results indicate the need for improvements in the model, considering various agricultural practices such as heavy fertilizer use, soil dressing, and mulching and application of plastic ground covers, which were previously never considered in the model. In addition, detailed information for nitrogen fertilizer additions is required to achieve better simulation results. Simulated annual losses of nitrate in seepage (40-50 kg N) were one order of magnitude higher than N_2O emissions (1.5-3.5 kg N), which indicates that eutrophication is probably an even greater concern than GHG emissions from the agricultural system in the Haean Catchment.

Keywords: *Landscape-DNDC model, agriculture practices, agricultural soils, N_2O emission, inorganic nitrogen stocks, nitrate leaching*

1. Introduction

Agricultural soils can act as a source or a sink for the three greenhouse gases, nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) (Giltrap et al., 2010). In Korea, agricultural soils are the major sources of N_2O emission and account for about 47% of national N_2O emissions. The agricultural sector has been known to be the largest anthropogenic source of CH_4, approximately 46% of total CH_4 emissions, and significant amounts of CH_4 are released from rice paddies (about 26%) (KEEI, 2010).

In view of the rising world population and increasing demand of food and fiber, modern agricultural practices are strongly linked to fertilizer application for maintaining or even increasing yields. Intensification of agricultural practices can have significant impacts on ecosystem N turnover and possibly accelerate associated harmful losses into the atmosphere (greenhouse gas emissions) and hydrosphere (nitrate leaching) (Li et al., 2006). Thereby, nutrient turnover and losses are the result of the complex interaction of ecosystem nutrient input and processes such as nutrient uptake by plants and soil microbial processes (e.g. mineralization, nitrification, denitrification, methanogenesis and methane oxidation) which vary greatly in space and over time. Process-oriented biogeochemical models provide a useful instrument for integrating our knowledge of these processes and driving variables. As field measurements will always be limited in space and time, such models are also a promising tool for development of mitigation options and for up-scaling of GHG emissions and nutrient leaching to landscape and regional scales.

The Landscape-DNDC model used in this study originated from parts of different DNDC models, i.e. DNDC for agricultural simulations (crop growth, management; Li et al., 2001) and Forest DNDC (forest growth and soil biogeochemical processes; Stange et al., 2000, Kesik et al., 2005, Kiese et al., 2011), and is now capable to simulate C and N turnover of forest, arable and grassland ecosystem in the same model framework. In the recent past, the model was tested against a various number of field datasets with good success (e.g. Chirinda, et al. 2011; Kiese et al., 2011). However, so far, little or no research has been carried out on simulating trace gas fluxes and nutrient leaching from arable fields in Korea. This study is the first attempt to apply the Landscape-DNDC to examine the carbon and nitrogen turnover and associated losses in agricultural soils of Korea. The main aim of this study is to simulate and evaluate (in comparison with field measurements in the TERRECO project) N_2O emission and nitrate leaching, considering different upland crops and management practices at site scale. In a second step within a GIS framework, upscaling to the whole Haean Catchment will be undertaken. It is a challenge to adapt DNDC to regional scale, taking into account the special features of agricultural practices in Korea, such as soil dressing, mulching and application of plastic covering, and the overuse of chemical fertilizers.

2. Materials and Methods

2.1 Study Site

The study was conducted at the site of Haean Catchment (38°29´84.29˝N, 128°14´27.65˝E, 451 m a.s.l), located in the northeast of Yanggu County, South Korea. Annual average air temperature of the basin is ca. 8.4°C and average precipitation is about 1,100 mm. More than half of the area in Haean Catchment is covered by forest, approximately 58.6% of the total area, followed by upland agriculture (27.4%) and rice paddy fields (8.8%). As its topographical characteristics, upland agriculture is the dominant agricultural practice and soil dressing, plastic film ground covers and heavy fertilizer use are very common in this region. According to the annual statistics of Yanggu County, radish, soybean, potato, Chinese cabbage and European cabbage (which are often grown in rotations) were shown to be the major upland crops, comprising about 52% of total upland crops in Haean during 2009.

2.2 Field Measurements

Inorganic soil nitrogen stocks (Nmin)

For determination of the initial nutrient status of the soils, NH_4^+ and NO_3^- concentrations where measured in spring 2011 at 20 field sites covering five different crop types i.e. rice, radish, bean, potato, Chinese cabbage and European cabbage. Soil samples at 0-30 cm were taken before and after planting, fertilization and other field management operations (ploughing, formation of rows and interrows) in three replicates. The nitrogen fertilizer was applied to all fields one week just before planting, except in the bean fields which did not receive any fertilizer treatment. Further soil sampling was conducted also later during the crop growing season, and after harvest considering row and interrow positions (data not yet analyze).

All collected soil samples were kept in a refrigerator (0°C) until analyzed in the laboratory of Kangwon National University. The soil samples were extracted with 2M KCl, filtered (Whatman No.2 filter paper) after 1 hour shaking and analyzed by Kjeldahl-N (UDK 129 Distillation Unit) for ammonium-N (NH_4^+-N) and nitrate-N (NO_3^- -N) concentration. NH_4^+-N and NO_3^--N concentration were determined by following equation (Keeney and Nelson, 1982). In this study 0.01N HCl was used for titration instead of H_2SO_4.

$$\text{N (ppm)} = \frac{[\text{Volume (ml) of acid consumed\_Blank}]\ (14.01)\ (100)\ (A)\ (R)\ (10^4)}{[\text{Weight of the soil (g)}]\ (10^3)}$$

Where A = Normality of H_2SO_4; and R = Dilution factor

Inorganic soil nitrogen stocks were finally calculated by multiplying NH_4-N and NO_3-N soil concentration with the mean bulk density (provided by soil team) of 0-30 cm soil depth.

N_2O flux measurements

The N_2O flux measurements used in this study for model testing were carried out at row and interrow positions in one radish field by infrared photoacoustic gas analyzer in 2010 (Berger et al. in this proceedings). To examine the influence of N fertilizer application rates on the magnitude of N_2O emissions, field measurements were made with different rates of nitrogen fertilizer application (50 kg, 150 kg, 250 kg and 350 kg, plus 187 kg N ha^{-1} pre treatment). Furthermore, important environmental conditions such as soil moisture and temperature in 15 and 30 cm soil depth were recorded by an echo logger at daily time interval.

2.3 Landscape-DNDC Model Description

In recent years IMK-IFU developed the Landscape-DNDC model (Haas et al., 2011; Figure 1), which integrates former DNDC models (i.e., arable and grassland from DNDC, Li et al., 2001; forest from Forest-DNDC, Stange et al., 2000, Kesik et al., 2005, Kiese et al., 2011) into one model framework. The Landscape-DNDC belongs to the process-based biogeochemical models which simulate ecosystem C and N cycling, and the associated biosphere–atmosphere exchange of greenhouse gases (N_2O, CO_2 and CH_4) on the basis of plant physiological, microbial and physicochemical processes. The model is running on (sub-) daily time step and uses daily data (max. and min. air temperature, precipitation, radiation, wind speed) as meteorological drivers. Further input data is needed to reflect agricultural management practices, e.g., planting/harvesting, tillage, fertilizer application, irrigation and information on soil and vegetation properties (SOC, bulk density, texture, pH, crop types) for site characterization and model initialization. Based on this input and driving data via the sub-modules soil climate, mineralisation and plant growth, Landscape-DNDC predicts soil environmental factors such as substrate availability (C and N), pH, soil temperature and moisture and shares of anaerobic/ aerobic micro sites for all user defined soil layers, which are finally driving microbial N turnover processes of nitrification and denitrification and associated losses of N_2O and NO_3^- (Figure 1).

As a process-based model, Landscape-DNDC is a useful tool both for modeling the environmental impacts of agricultural management systems and for improving our understanding of the underlying processes (Giltrap et al., 2010). In this study, the Landscape-DNDC model was mainly applied to quantify N_2O emission and nitrate leaching from agricultural soils with different application rates of nitrogen fertilizer and manure. Datasets for the model input, with regard to agricultural practices include crop rotation, planting and harvesting date, tillage and amounts of fertilizer and manure applied, were prepared from interviews with local farmers and by use of annual fertilizer and crop statistics. Daily climate data used for simulations was collected from automatic weather station located next to the radish field.

3. Results and Discussion

Results of investigation of the initial soil nitrogen stocks in spring 2011 before and after fertilization are summarized in Figure 2a (NH_4) and 2b (NO_3). In general, our measurements show very high initial soil nitrogen stocks in spring 2011. NH_4 soil stocks across different fields averaged 83.4 kg N ha^{-1}, and variation between fields was low. In contrast, NO_3^- soil stocks varied significantly across fields with the lowest value for rice (9.8 kg N ha^{-1} and highest value for bean (201.5 kg N ha^{-1}). The mean NO_3^- soil stock of 112.7 kg N ha^{-1} was slightly higher than for soil NH_4-N, which is somehow surprising since the capacity for fixing NH_4^+ as a cation is much higher than for the anion NO_3^-. Mean total inorganic soil N stocks in spring before fertilization across all fields was 186.1 kg N ha^{-1} and, thus, ca. ½ of the fertilization rate indicated by the farmers in interviews.

Since information of fertilizer application rates provided by the farmers are quite uncertain, we aimed to estimate fertilization rates by comparing measurements of inorganic N stocks before and after fertilization. In general, our measurements show higher inorganic nitrogen stocks after fertilization, except for the bean field which was not fertilized. Measured fertilization rates resulted in 117, 53, 294, 89 kg N ha^{-1} for the cabbage, potato, radish and rice fields, respectively. Except the radish field, measured fertilization rates were very much less than farmers' estimates, which were usually higher than 300 kg N ha^{-1}. Reasons for the difference could relate to uncertainty in farmers' estimates, but also uncertainty in spatial representativeness of the sampling procedure.

Figure 3 shows the comparison of mean simulated and measured N_2O emissions in the radish field for different application rates of nitrogen fertilizer (50, 150, 250, 350 plus 187 kg N ha^{-1} pre-treatment), taking only into account simulated values at the times that measurements were available. Simulated N_2O emissions were always lower than measured values, but in both cases increases occurred with increasing N fertilization rates.

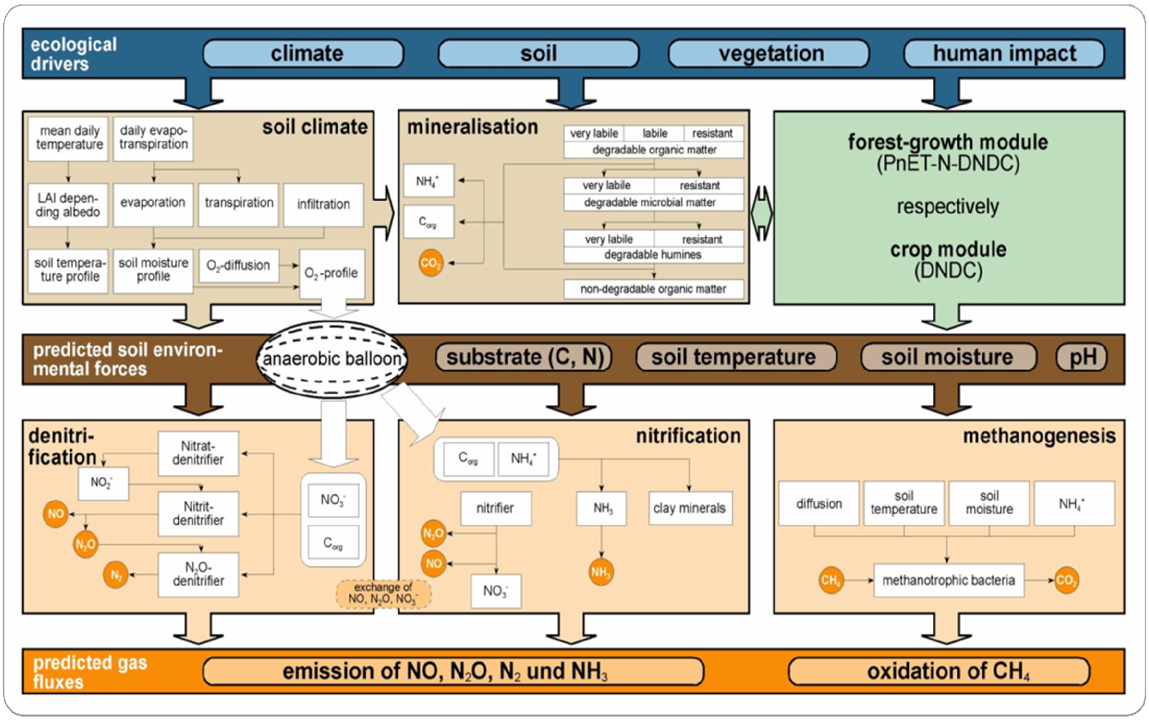

Figure 1. Landscape-DNDC model structure

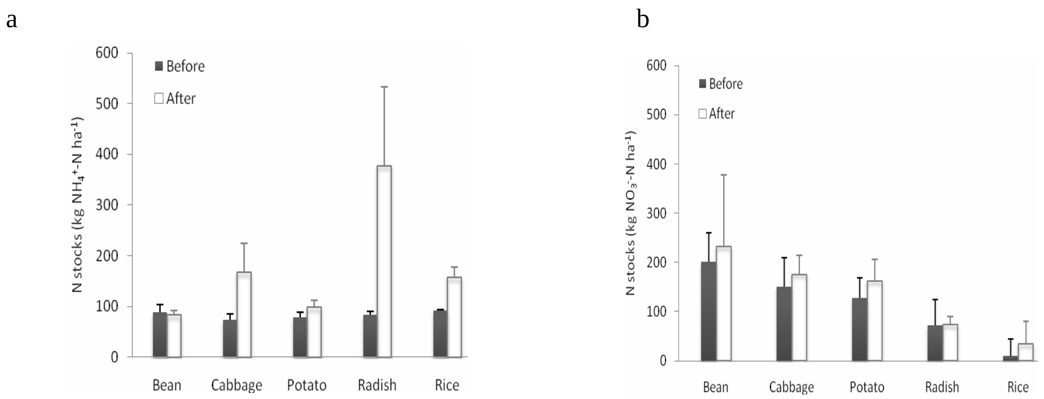

Figure 2. N stocks in the top soil (30 cm depth) of agricultural fields in Haean Catchment. Graphs show the mean NH_4^+-N (a) and NO_3^--N (b) stocks before and after nitrogen fertilizer application in five different crop fields. The fertilizer was applied to all crop fields, except bean fields, before planting. Bars indicate standard error (n = 3 for all fields except bean fields (n = 2)).

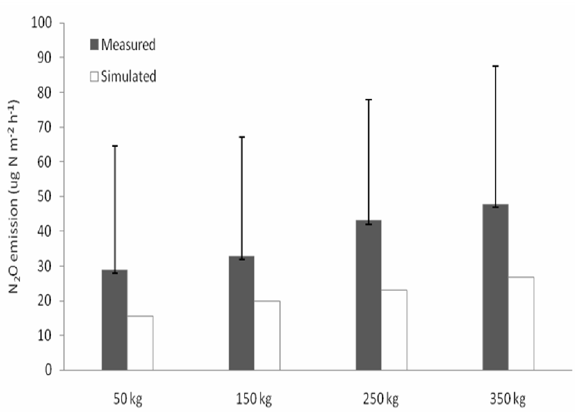

Figure 3. Effects of different application rates of nitrogen fertilizer on N_2O emission from the radish field as simulated by the Landscape-DNDC and compared with measured values.

Figure 4 shows the development of measured and simulated N_2O emissions over a full year for the 50 and 350 kg N treatment. The dynamics of N_2O emissions of measured as well as simulated values were mainly driven by the fertilizer application around day of year (DOY) 150, and a rainfall event around DOY 250. However, as mentioned before simulations tend to underestimate measured fluxes, in particular at the fertilization peak.

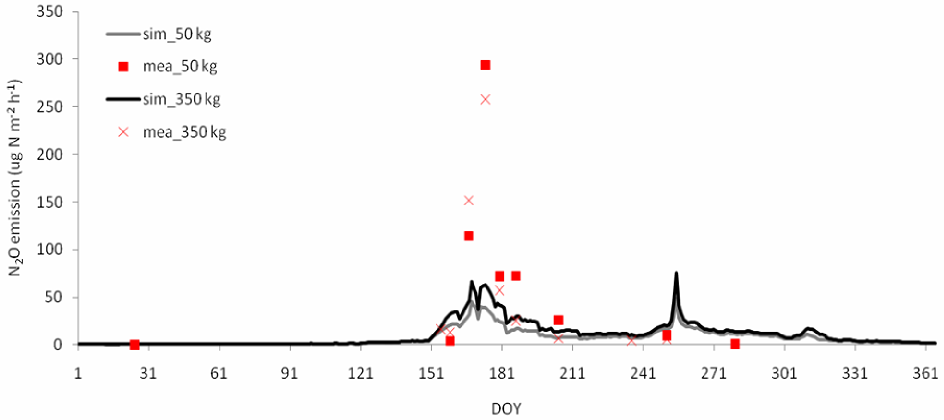

Figure 4. Simulated and measured N_2O emissions for the 50 and 350 kg N ha^{-1} treatment of the radish field covering a full year

Figure 5 compares annual losses of N_2O and nitrate leaching (at 30 cm soil depth) for the different fertilizer treatments of the radish field. As shown before for N_2O emissions, also NO_3 leaching rates increased with increasing fertilization rates. Simulated loss rates of nitrate with 40-50 kg N ha^{-1} yr^{-1} are one order of magnitude higher than N_2O emissions which varied between 0.6 and 1.0 kg N ha^{-1} yr^{-1}. This finding indicates that in Haean Catchment nitrogen losses via seepage water into groundwater and/ or rivers may be much higher than N_2O emissions into the atmosphere. Furthermore, indirect N_2O emissions, stemming from conversion of exported nitrate into N_2O emissions at other places than in the radish field, e.g. riparian zones, might be of significant importance.

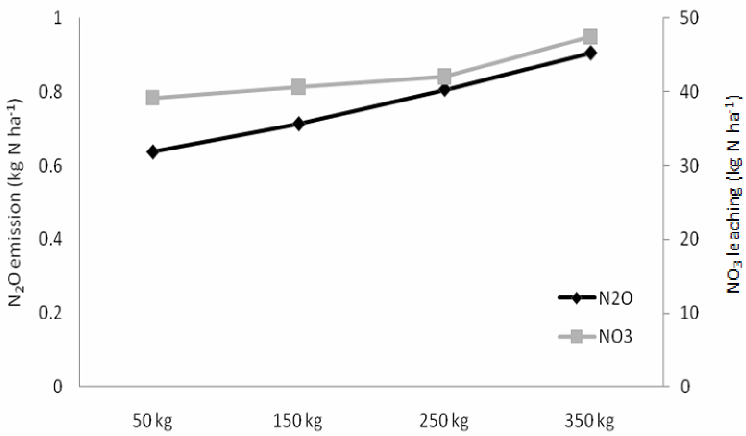

Figure 5. Annual rates of N_2O emission and nitrate leaching of different fertilizer treatments of the radish field

4. Conclusions

This study was the first attempt to use the Landscape-DNDC model to examine the nitrogen turnover and associated losses of N_2O and NO_3^- in agricultural soils of Korea. So far the simulation results were compared to measured N_2O emissions with reasonable agreement. Further work will concentrate on refinement of input data considering various agricultural practices, for example, soil dressing, mulching and use of plastic ground covers which have only been partly considered in the model before. On the other hand, simulations will be evaluated in much more detail taking into account more TERRECO data such as soil moisture, temperature, yields, inorganic soil N concentrations, etc. However, the often limited information provided by farmers on agricultural management - in particular fertilizer application rates - makes it difficult to understand the field system in more detail, which causes uncertainties when applying the model to more TERRECO field sites beyond the radish field discussed here. Our findings on inorganic N soil stocks provide some information to help solve this problem, but require also a further quality check of the laboratory analysis methods.

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