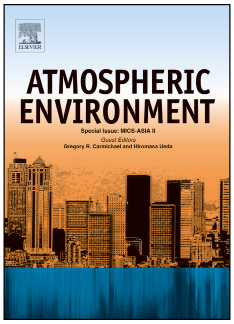

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Testing DayCent and DNDC model simulations of N_2O fluxes and assessing the impacts of climate change on the gas flux and biomass production from a humid pasture

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Key words: DayCent, DNDC, Nitrous Oxide, Pasture

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Testing DayCent and DNDC model simulations of N_2O fluxes and assessing the impacts of climate change on the gas flux and biomass production from a humid pasture

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Abstract

Simulation models are one of the approaches used to investigate greenhouse gas emissions and potential effects of global warming on terrestrial ecosystems. DayCent which is the daily time-step version of the CENTURY biogeochemical model, and DNDC (the DeNitrification-DeComposition model) were tested against observed nitrous oxide flux data from a field experiment on cut and extensively grazed pasture located at the Teagasc Oak Park Research Centre, Co. Carlow, Ireland. The soil was classified as a free draining sandy clay loam soil with a pH of 7.3 and a mean organic carbon and nitrogen content at 0-20 cm of 38 and 4.4 g kg^{-1} dry soil, respectively. The aims of this study were to validate DayCent and DNDC models for estimating N_2O emissions from fertilized humid pasture, and to investigate the impacts of future climate change on N_2O fluxes and biomass production. Measurements of N_2O flux were carried out from November 2003 to November 2004 using static chambers. Three climate scenarios, a baseline of measured climatic data from the weather station at Carlow, and high and low temperature sensitivity scenarios predicted by the Community Climate Change Consortium For Ireland (C4I) based on the Hadley Centre Global Climate Model (HadCM$_3$) and the Intergovernment Panel on Climate Change (IPCC) A1B emission scenario were investigated. DayCent predicted cumulative N_2O flux and biomass production under fertilized grass with relative deviations of +38% and (-23%) from the measured, respectively. However, DayCent performs poorly under the control plots, with flux relative deviation of (-57%) from the measured. Comparison between simulated and measured flux suggests that both DayCent model's response to N fertilizer and simulated background flux need to be adjusted. DNDC overestimated the measured flux with relative deviations of +132 and +258% due to overestimation of the effects of SOC. DayCent, though requiring some calibration for Irish conditions, simulated N_2O fluxes more consistently than did DNDC. We used DayCent to estimate future fluxes of N_2O from this field. No significant differences were found between cumulative N_2O flux under climate change and baseline conditions. However, above-ground grass biomass was significantly increased from the baseline of 33 t ha^{-1} to 45 (+34%) and 50 (+48%) t dry matter ha^{-1} for the low and high temperature sensitivity scenario respectively. The increase in above-ground grass biomass was mainly due to the overall effects of high precipitation, temperature and CO_2 concentration. Our results indicate that because of high N demand by the vigorously growing grass, cumulative N_2O flux is not projected to increase significantly under climate change, unless more N is applied. This was observed for both the high and low temperature sensitivity scenarios.

1. Introduction

Nitrous Oxide (N_2O), on a kg to kg basis, has a global warming potential of approximately 298-310 times that of carbon dioxide (CO_2) over a 100 year timescale (Watson et al., 1996; IPCC, 2007) with an atmospheric lifetime of approximately 120 years (Prather, 1998). The concentration of N_2O in the atmosphere has risen from a pre-industrial level of about 270 ppb to 319 ppb in 2005, and is estimated to be rising at a rate of 0.8 ppb per annum (IPCC, 2007). According to the IPCC (2001; 2007) N_2O is responsible for about 6% of the anthropogenic component of radiative forcing.

The complex interaction of microbiological processes and soil conditions, such as water content, carbon (C) and nitrogen (N) content, temperature and pH regulates N_2O dynamics in the soil profile, and determines how and when N_2O is released from the soil surface (Granli and Bockman, 1994). Management practices such as soil tillage, crop type, and the application of nitrogen fertilizers influence the physical and hydrological condition of the soil and the timing and distribution of nutrient inputs. This in turn affects the size, composition and activity of the soil microbial population, and therefore, the extent of N_2O production and emission from agricultural soils.

Worldwide, agricultural soils, particularly grazed pastures, are the major single source of N_2O emissions contributing approximately 46 to 52% of the global anthropogenic N_2O flux (Mosier et al., 1998; Olivier et al., 1998; Kroeze et al., 1999; IPCC, 2007). In Europe, grasslands are the major contributor to the exchange of greenhouse gases in the biosphere, with fluxes intimately linked to management practices. In Europe, about 40% of the agricultural area is covered by permanent grassland used for livestock farming (FAO, 2004). Grasslands range from intensively fertilized pure grass swards to extensively managed grass-legume mixtures and semi-natural grasslands, which are often found in mountainous areas or on moist lowland soils (FAO, 2004). In Ireland, about 80% of the agricultural area and 58% of the total land area is grassland (Teagasc, 2010; CSO Census of Agriculture, 2010). This includes grazed pasture, silage, hay meadows and rough grazing areas.

Changes in the exchange of greenhouse gases between grassland ecosystems and the atmosphere may significantly impact on global climate change. Consequently, the increase in global mean annual temperature, predicted to be 1.5-4.5 ^{o}C over the next 50-100 years, will dramatically affect terrestrial ecosystems (IPCC, 2007). Most biological and chemical soil processes are strongly dependent on temperature (Shaver et al., 2000) including decomposition (Shaw and Harte, 2001), N mineralization and nitrification (Stark and Firestone, 1996), nutrients uptake (BassiriRad, 2000), and consequently emissions of CO_2, N_2O and methane (CH_4) (Malhi et al., 1990; Raich and Schlesinger, 1992; Abdalla et al., 2009a) respond to temperature.

The DayCent (Daily Century) and DNDC (DeNitrification-DeComposition) models are two widely-used ecosystem biogeochemistry models used to estimate greenhouse gas emissions. The DayCent model is the daily time-step version of the CENTURY biogeochemical model (Parton et al., 1994). Comparison of model results and observed data have shown that DayCent reliably simulates crop yield, SOM levels, and trace-gas flux for various native and managed systems (Del Grosso et al., 2002; Del Grosso et al., 2009). The DNDC model was developed to assess N_2O, NO, N_2 and CO_2 emissions from agricultural soils (Li et al., 1992, Li 2000). The rainfall driven process-based model DNDC (Li et al., 1992) was originally developed for

USA conditions. It has been used for simulation at a regional scale for the United States (Li et al., 1996), China (Li et al., 2001), Canada (Smith et al., 2010) and Europe (Kesik et al., 2006). This study is part of an ongoing research programme to measure and model N_2O flux from Irish agriculture (Abdalla et al., 2009a, b and c). The aims of this study were to validate the DayCent and DNDC models for estimating N_2O emissions from fertilized humid grassland in the midlands of Ireland, and to investigate the effect of future climate change on N_2O fluxes and biomass production.

2. Materials and methods

2.1 Field experimental site

A detailed description of the study site can be found in Abdalla et al. (2009a, b). It is located at the Oak Park Research Centre in Carlow 52^o 86′ N and 6^o 54′ W, Ireland. The site area (≈ 7 ha) has an elevation of 56 m a.s.l, a mean annual rainfall of 824 mm and a mean annual air temperature of 9.4 ^{o}C. The soil is classified as a sandy clay loam with a pH of 7.3 and a mean organic carbon and nitrogen content at 0-20 cm of 38, and 4.4 g kg^{-1} dry soil, respectively. The pasture has been permanent grassland for at least the last 80 years, but was ploughed and reseeded in October 2001 with perennial ryegrass (*Lolium perenne L., cv Cashel*) at a density of 13.5 kg ha^{-1} and white clover (*Trifolium repens L., cv Aran*) at a density of 3.4 kg ha^{-1}.

Silage cutting took place once during the experimental period on 15th May 2004 and extensive cattle grazing was from July to November 2003, and then from July to November 2004 with a stocking rate of 2 cattle ha^{-1}. Nitrogen in the form of calcium ammonium nitrate (CAN) was applied at a rate of 200 kg N ha^{-1} y^{-1} in two applications of 128 and 72 kg N ha^{-1} on the 2nd of April and 27th of May 2004, respectively. Grazing and cutting took place on the whole field for both the control and the fertilized plots. Nitrous oxide fluxes were measured from four replicated chambers on the control plots and four replicated chambers on the fertilized plots.

2.2 Field N_2O fluxes and grass biomass

Measurements of N_2O flux were carried out from November 2003 to November 2004. Nitrous oxide fluxes were measured using the methodology of Smith et al. (1995). Large chambers were made from steel and painted with white paint on the outside and black paint on the inside to prevent interior heating. Chambers consisted of two parts: a 52 x 52 x 15 cm^3 square collar inserted permanently into the soil over which a 50 x 50 x 30 cm^3 lid with a plastic septum could be sealed in place for gas sample collection. To reduce spatial variation caused by excreta patches, we chose a part of the field which was deemed to be representative of the whole field, and used four replicated large static chambers that covered 0.25 m^2 at a distance of 100 m apart. Previous studies on grassland fields of similar size used 3–4 replicated chambers to measure N_2O fluxes (Flechard et al., 2007; Allard et al., 2007).

After the lids were in place an initial gas sample was taken and a second was taken at 60 minutes. Linearity was checked by sampling each half an hour for a closure period of 3 hours. In order to cover most of the year we sampled every week, and more intensively (twice a week) following fertilizer application. Previous studies of N_2O fluxes using static chambers have sampled at frequencies ranging from one hour to two weeks (Mogge et al., 1999; Choudhary et al., 2002; Simek et al., 2004; Flechard et al., 2007). Samples were taken in the morning between 9 and 11 am. Samples were taken using a 60 ml gas-tight syringe after flushing of the syringe 3-4 times in the chamber to ensure adequate mixing of air within the chamber. All 60 ml of the sample was then injected into a 3 ml gas-tight vial with a vent needle inserted into the top of the vial to allow the extra air flush out. N_2O concentrations were measured using a gas chromatograph (Shimadzu GC 14B, Kyoto, Japan) with electron capture detection (column and detector temperatures were 30 and 300 ^oC respectively). The nitrous oxide standard was a 1 +/- 0.02 ppm N_2O in synthetic air. A calibration series was made by proportional dilution of the standard with pure N_2. The daily flux rate for each chamber and the average daily flux rate for the four replicates were calculated using the closed flux chamber technique equation (Smith et al., 1995; Baggs et al., 2003). Aboveground biomass samples were harvested each 1-2 weeks from four circular rings of 50 cm diameter.

2.3. Models descriptions

The DayCent model is the daily time step version of the CENTURY (Parton et al., 1994) biogeochemical model. DayCent (DelGrosso et al., 2001; Parton et al., 1998) simulates fluxes of C and N between the atmosphere, vegetation, and soil. Plant growth is controlled by nutrient availability, water, and temperature. Nutrient supply is a function of soil organic matter (SOM) decomposition and external nutrient additions. Daily maximum/minimum temperature and precipitation, timing and description of management events and soil texture data are needed as model inputs. Key sub-models include plant production, SOM decomposition, soil water and temperature by layer, nitrification and denitrification, and CH_4 oxidation. Comparison of model results and plot data has shown that DayCent reliably simulates crop yield, SOM levels, and trace gases (Li et al., 2005; DelGrosso et al., 2009).

In this study the DNDC model (version 8.9; http://www.dndc.sr.unh.edu/) was applied. DNDC contains four main sub-models (Li et al., 1992; Li, 2000); the soil climate sub-model calculates hourly and daily soil temperature and moisture fluxes in one dimension, the crop growth sub-model simulates crop biomass accumulation and partitioning, the decomposition sub-model calculates decomposition, nitrification, NH_3 volatilization and CO_2 production, whilst the denitrification sub-model tracks the sequential biochemical reduction from nitrate (NO_3) to NO_2^-, NO, N_2O and N_2 based on soil redox potential and dissolved organic carbon.

Measured values of meteorological parameters and land management records were used as input variables to the DayCent and DNDC models (Abdalla et al., 2009a). Field N_2O flux data were used for DayCent and DNDC models validations by comparing measured and predicted N_2O fluxes. The models accuracies were evaluated by calculating the Root Mean Square Error (RMSE) and relative deviation (RD) between observed and DayCent/DNDC out puts.

$$\mathrm{RMSE} = (\Sigma(\text{modelled} - \text{observed})^2/N)^{1/2} \qquad (1)$$

$$\mathrm{RD} = (\text{modelled} - \text{observed})/\text{observed} \times 100 \qquad (2)$$

where N is the number of data series. Annual cumulative flux for models outputs were calculated as the sum of simulated daily fluxes (Cai et al., 2003). Soil properties and climate input data of both models are summarized in Table 1.

2.4. Climate scenarios

The future climate data used in this research were statistically downscaled by the Irish National Meteorological Service Research Group (C4I, 2008) based on the Hadley Centre Global Climate Model ($HadCM_3$) and the emission scenario (A1B) published by the Intergovernmental Panel on Climate Change (Nakicenovic and Swart, 2000; IPCC, 2001). Two different temperature sensitivity scenarios (high and low) were investigated to estimate the uncertainty in future climate (Collins et al., 2006). A regional climate model, known as RCA_3, was applied to the $HadCM_3$ data in a process which is known as dynamic downscaling. RCA_3 is based on a model initially developed by the Rossby Centre and further developed by the C4I project at Met Éireann. The resultant model data has a horizontal resolution of 25 km. A full description is given in the C4I (2008) report.

The baseline scenario is a measured daily climate data set (1961-1990) from a nearby weather station in Carlow. The two future climate scenarios (high and low temperature sensitivity) investigated in this study are of daily data and for a period of 30 years (2061-2090) from the $HadCM_4$. Weather input data are maximum and minimum air temperature and precipitation. CO_2 concentrations of 350 and 700 ppmv were suggested and used in the models for the baseline and future scenarios, respectively (IPCC, 1995).

2.5 Statistical analysis

Statistical analyses were carried out using the PRISM (GraphPad, San Diego, USA) and Data Desk (Data Description Inc. New York, USA) software packages. Flux data was checked for normal distribution and log transformed. Regression analysis and both 1- and 2-way analyses of variance (ANOVA) were applied to N_2O flux and biomass production.

3. Results and discussion

3.1 Model validations and results under baseline scenario

Temporal patterns of N_2O for the observed and DayCent modelled fluxes from the fertilized plots were generally similar for most of the measured period. However, DayCent overestimated the influence of added N fertilizer by producing two types of N_2O peaks; a smaller one at the time of N application and a higher one later in August, 2004 (Figure 1). This second higher peak was not observed for the control plots. Here, as both the fertilized and control plots were subjected to the same climate and extensively grazed, it was clear that N availability in the soil was the only difference between the two, suggesting that this later peak was due to residual effects of applied N fertilizer. The model suggests that applied fertilizer N is retained in the soil for long periods (up to September), where other environmental factors like rainfall and temperature are high (Figure 2), resulting in a second higher N_2O peak (Figure 1). Comparisons over many years showed that the height and time of this later peak depends on the combined effects of higher rainfall and temperature (Figure 2). Rainfall increases soil moisture and stimulates denitrification by temporarily reducing the oxygen diffusion into the soil (Dobbie and Smith, 2001) and increasing the solubility of organic carbon and nitrate in the soil (Bowden and Bormann 1986). High temperature increases both soil organic matter decomposition and microbial response to other perturbations, such as fertilization and rainfall (Stanford and Epstein 1974; Bramley and White, 1990; Antonopoulos, 1999; Wennman and Katterer, 2006). The model also overestimated the measured soil water filled pore space values (WFPS; Figure 3). This overestimation may result in significant flux discrepancies between the measured and modelled data since WFPS is a critical determinant of N_2O flux (Keller and Reiners, 1994; Ruser et al., 1998; Dobbie and Smith, 2001). This parameter is a key requirement for a reliable simulation of N_2O (Frolking et al., 1998), as increasing WFPS may reduce the contribution of nitrification, and increase denitrification (Li, 2000; Li et al., 2001).

The second simulated peak resulted in a higher cumulative N_2O flux of 3.6 kg ha^{-1} compared with the measured flux of 2.6 kg ha^{-1}, which corresponds to a relative deviation of +38% from the measured flux (Table 2). The regression between observed and modelled fluxes ($y = 0.41x + 0.57$) accounted for 32% of the variation in the data (RMSE = 2) (Figure 4). However, by excluding this peak, the model gave approximately similar cumulative N_2O flux to that observed, with a deviation of only +1%. This is not the case for the control plots where, although this second peak was not observed, the model performed poorly compared to observed data with a relative deviation of (-57%) RMSE = 0.5 (Table 2 and Figure 1). In contrast to Del Grosso et al. (2008), DayCent underestimated the flux at zero N fertilizer with a cumulative flux of 0.5 kg ha^{-1} compared with a cumulative measured flux of 1 kg ha^{-1}. The comparison with field data suggests that, for applications on unfertilised Irish grasslands, DayCent could be improved by increasing the background emissions of N_2O (Del Grosso et al., 2008).

The pattern of simulated grass biomass by the DayCent-model agreed well with the measured results and the model underestimated observed biomass by (-23%).

The relationship between the weekly simulated above-ground grass biomass and the weekly field observed biomass is illustrated in Figure 5. Here, the regression (y = 0.47x + 0.5) accounted for 38% of the variation in the data (RMSE = 0.15). Comparable results using DayCent were also reported for wheat, rice, maize and soybean (Stehfest et al., 2007; Del Grosso et al., 2008). Simulated soil temperature by DayCent and DNDC compared favourably with measurements (Figure 6); for DayCent $r^2 = 0.64$ and RMSE = 0.57 whilst for DNDC $r^2 = 0.88$ and RMSE = 0.44.

Simulated emissions of N_2O flux by the DNDC model showed similar patterns as the field measured flux for most of the measured period. However, DNDC predicted a significantly higher peak, from both the fertilized and control plots in February. This higher peak resulted in an annual cumulative N_2O flux of 6.04 and 3.58 kg N_2O-N ha^{-1}, with annual differences between the measured and modelled flux of 3.44 and 2.58 kg N_2O-N ha^{-1}, for fertilized and control plots respectively (Table 2 and Figure 1). Due to this peak, estimation of annual emissions was very poor with relative deviations of +132% (RMSE = 5.2; for fertilized plots) and +258% (RMSE = 4; for the control plots) from the measured flux. DNDC also significantly underestimated the observed above-ground biomass by 75% (RMSE = 0.22) (Figure 5). The model (DNDC) is very sensitive to soil organic carbon content (SOC; Li et al., 1996, 2001; Beheydt et al., 2007; Abdalla et al., 2009a); a 20% increase in SOC corresponds to a 58% increase in N_2O flux (Abdalla et al., 2009a). Similar over-estimates of the effects of initial SOC by DNDC have also been reported by Li et al. (1992), Brown et al. (2002) and Hsieh et al. (2005). DNDC also significantly overestimates observed WFPS (Figure 3), leading to a higher than observed predicted flux (Beheydt et al., 2007; Abdalla et al., 2009a).

Although the Daycent model needs to be better parameterised for application in Irish grasslands, both cumulative total N_2O emission, and the general pattern of emissions agree quite well with measured data, and were better than equivalent estimates from the DNDC model, which significantly overestimated the observed flux and underestimated the observed biomass. Improving the parameterisation of DayCent for Irish grasslands will make the model a useful tool for testing different mitigation scenarios, and will enhance the quality of the reporting to the United Nations Framework Convention on Climate Change (UNFCCC) through use of an

IPCC tier 3 methodology (IPCC, 2006). In this study, depending on the results of model validations, we considered that using DayCent for estimating the magnitude and seasonal trends of N_2O fluxes and above ground biomass was more suitable than DNDC.

3.2 Model results under climate change scenarios

Because the DNDC model significantly overestimated observed N_2O fluxes and significantly underestimated observed above ground biomass, the impacts of future climate change were investigated using the DayCent model only. Two climate scenarios from the C4I, low and high temperature sensitivity, to provide the highest and lowest impacts of climate change, were investigated. For each scenario, the DayCent model was run for a period of 30 years. Simulated patterns of N_2O fluxes, under both scenarios, were similar to that at the baseline scenario during most of the year (Table 3; Figure 7). Here, average height of the first peak at baseline was approximately similar to that of 2004 but, under climate change scenarios, DayCent predicted a significant increase for this peak. The reason was the higher temperature and rainfall, expected due to climate change during fertilizer application, compared with the baseline. The average height for the second peak at baseline was decreased because time for this peak was different from one year to another. However, under climate change, the second peak disappeared, mainly due to the decrease in available N later in the season. No statistically significant difference ($p>0.05$) between the annual cumulative fluxes for the three scenarios was found. Under climate change, the high temperature sensitivity scenario produced slightly higher cumulative nitrous oxide fluxes (4.4 kg ha^{-1}) whilst the low temperature sensitivity scenario produced slightly lower cumulative nitrous oxide fluxes (4.1 kg ha^{-1}) compared with the baseline fluxes (4.2 kg ha^{-1}). This is different from the significant increases in N_2O flux predicted for a nearby cropland field, using DNDC, where climate change was projected to increase the flux by 55-88% depending on the N fertilizer application rate. However, in the cropland field, most of the fluxes took place during the post crop harvesting period, where straw was incorporated and no crops were present (Abdalla et al., 2009c).

For both future scenarios, predicted biomass production was significantly higher ($p<0.05$) than in the baseline (Figure 8). This increase was due to the overall effect of increasing rainfall, temperature and CO_2 concentration. Under baseline conditions, annual above-ground grass biomass (dry matter) was about 33 t ha^{-1} whilst under climate change this value was increased to 45 (+34%) and 50 (+48%) t ha^{-1} for the low and high temperature sensitivity scenario. An increase in grass dry matter production in Ireland due to climate change was also predicted by Fitzgerald et al. (2009). Here, changes in precipitation (Rosenzweig and Tubiello, 1997; Izaurralde et al., 2003; Mearns et al., 2003) and temperature (Fiscus et al., 1997) can affect crop productivity. Higher temperatures may increase plant carboxilation and stimulate higher photosynthesis, respiration, and transpiration rates. Plant growth and development would continue to increase, because of enhanced metabolic rates at higher temperatures, combined with increased carbon availability (Reddy et al., 2000). Changing atmospheric carbon dioxide concentrations could also have positive effects on plants (Mitchell et al., 1993; Curtis and Wang, 1998; Anwar et al., 2007). Several factors may be responsible for this effect (i) increasing CO_2 has a direct effect on C availability by stimulating photosynthesis and reducing photorespiration (Akita and Moss, 1973) (ii) increasing CO_2 concentrations decrease stomatal conductance (Moss et al., 1961; Akita and Moss, 1973; Wong, 1979; Rogers et al., 1983; Morrison and Gifford, 1984) which reduces the transpiration rate per unit leaf area. Reduced transpiration will also increase the leaf temperature which can further increase photosynthesis (Acock, 1990). Both an increase in photosynthesis and a decrease in transpiration result in an increase in the grass water use efficiency. (iii) increases in CO_2 decrease the crop N concentration (Schmitt and Edwards, 1981; Hocking and Meyer, 1991).

Climate feedback could have significant impacts on N_2O fluxes from soil. Soil nitrogen increases due to increasing mineralisation with changing temperature and precipitation (Waksman and Gerretsen, 1931; Kirschbaum, 1995; Wennman and Katterer, 2006; Abdalla et al., 2009c). However, in this simulation, climate change showed no significant effect on N_2O flux from the soil. In our simulations, there was a considerably greater demand for N from enhanced grass growth under climate change (Figure 8). The amount of available soil N, in excess of the N requirement of the grass decreased, resulting in low N_2O flux. Here, N_2O flux has a threshold response to N, and the amount of N lost to atmosphere depends on the amount of N taken by the crop (McSwiney and Robertson, 2005; Abdalla et al., 2010). Soil mineral nitrogen and N mineralization are the main sources of N_2O production (Bouwman 1990; Granli and Bockman 1994; Abdalla et al., 2010). Nitrogen has a direct influence on N_2O production by provision of N for both nitrification and denitrification (Baggs and Blum, 2004). This is in agreement with many other studies over a range of different soils and crop systems (McSwiney and Robertson, 2005-arable; Abassi and Adams, 2000; Maddock et al. 2001; Ball et al., 2002 and Maljanen et al., 2002-forest and grasslands). However, the soil type under investigation is a sandy loam that has relatively low mineralization. Soil characteristics and environmental conditions affect mineralisation (Schoenau and Campbel, 1996), and the extensive grazing had no significant effect on N_2O flux. Compared to the baseline, a significant decrease ($p<0.05$) was observed for the daily soil ammonium at 15cm depth, from 35 to 14 and 19 mg kg^{-1} for the high and low temperature sensitivity scenarios, respectively (Table 3). Therefore, future N_2O flux from this field will not be significantly affected by climate change, unless more N fertilizer is applied.

Considering that the grass area in Ireland is about 4 M ha (CSO, 2010), sandy loam soil make up > 30% of Irish soil types and the nitrogen fertilizer application rates used by the farmers at the time of this work were 200 kg ha^{-1} N, DayCent predicted large increase in above-ground grass biomass due to climate change. Under climate change, for the high and low temperature sensitivity scenarios, above-ground grass biomass could increase by approximately 68 and 48 Mt dry matter, respectively. However, the increase in N_2O flux due to climate change under this low N input grass is negligible, suggesting that future climate change will favour Irish low N input grasslands, with more biomass but no significant change in N_2O flux.

DayCent model was run assuming that the current field management will remain the same in the future. However, the predicted future higher above ground biomass production by DayCent would encourage farmers to increase grazing intensity. This would increase emissions of methane (CH_4) and excretal N deposition from grazing animals. Alternatively, farmers could apply less N fertilizer to the pasture to achieve the current amount of above ground biomass production without making significant change on N_2O or CH_4 fluxes.

4. Conclusions

Although further improvement is possible, the DayCent model effectively estimates the N_2O fluxes and biomass production from the Irish grasslands compared with DNDC model. DNDC significantly overestimates the measured N_2O flux, with relative deviations of +132% (RMSE = 5.2) and 258% (RMSE = 4) for the fertilized and control plots. DayCent predicted N_2O flux and biomass production from fertilized grass with relative deviations of +38% (RMSE = 2) and (-23%) (RMSE = 0.15) compared with the observed values, respectively. DayCent predicts a significantly higher peak coinciding with higher temperature and rainfall in August - September, associated with fertiliser N still held in the soil later in the season. The model fit under control plots was not good with a relative deviation of (-57%) (RMSE = 0.5). Under climate change, grass biomass was projected to increase from the baseline value of 33 t ha^{-1} to 45 (+34%) and 50 (+48%) t ha^{-1} for the low and high temperature sensitivity scenarios, respectively. Our results suggest, that due to significant grass growth and higher N demand by the grass, climate change is not expected to significantly affect N_2O fluxes from this low N input pasture, unless more N is applied in the future. This was projected for both the high and low temperature sensitivity scenarios. Our results suggest that future climate change will favour the Irish, low N input grasslands with more biomass but with no significant change in N_2O flux.

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Table

Table 1: DayCent/DNDC models input data for the pasture field

Climate data	
Latitude (degree)	52°86′ N
Yearly maximum of average daily temperature (°C)	13.3 (baseline), 15.2 (high scenario) and 12 (low scenario
Yearly minimum of average daily temperature (°C)	5.4 (baseline), 10.3 (high scenario) and 7 (low scenario)
Yearly accumulated precipitation (mm).	794 (baseline), 1472 (high scenario) and 1407 (low scenario)
N concentration in rainfall (mg Nl^{-1})	0.001*
Atmospheric CO_2 concentrations (ppm)	350* (baseline) and 700* (future scenarios)
Soil properties (0-10 cm depth)	
Vegetation type	Moist pasture
Soil texture	Sandy clay loam
Bulk density (g cm^{-3})	1.0
Clay fraction	0.34*
Soil pH	7.3
Initial organic C content at surface soil (kg Ckg^{-1}).	0.038
Harvest	Grazing/ cutting
WFPS at field capacity	0.87
WFPS at wilting point	0.09
Depth of water-retention layer (cm)	100*
Slope (%)	0.0

*Default values

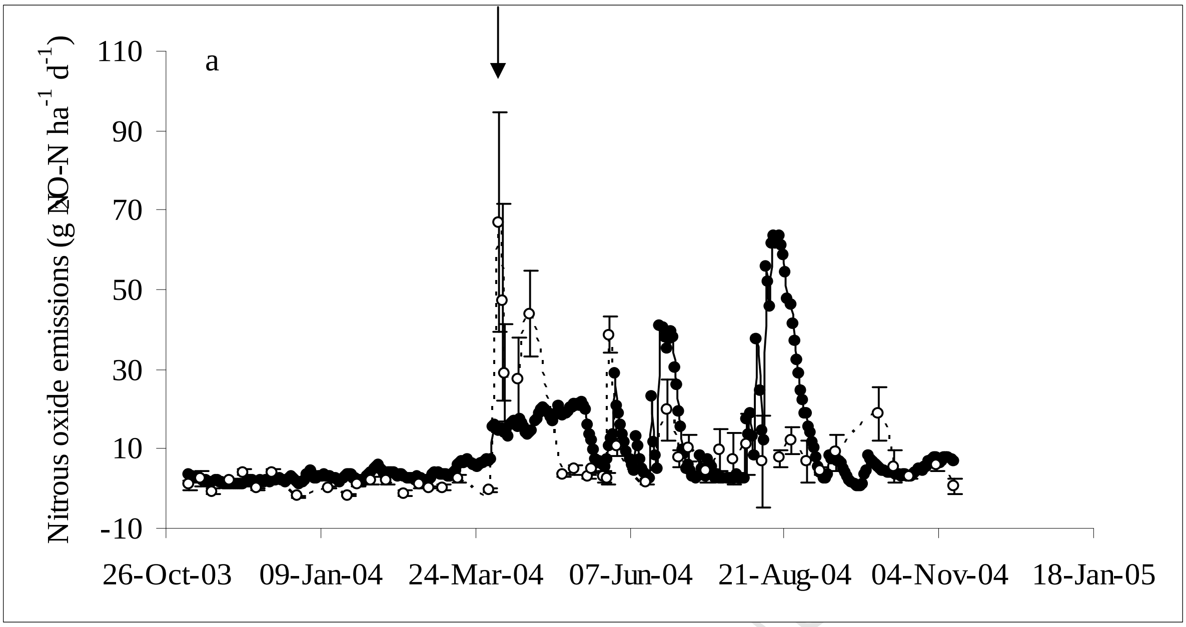
Table 2: Annual measured flux, DayCent predicted flux, DNDC predicted flux and differences between predicted and measured fluxes of N_2O (kg N_2O-N ha^{-1}).

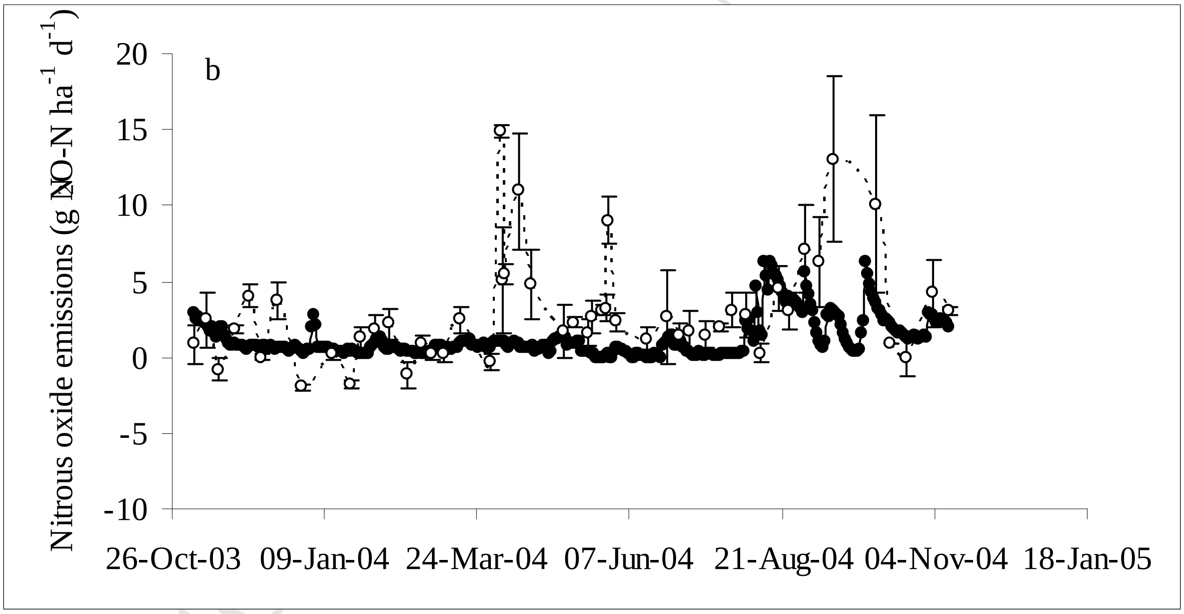
Treatment	Measured flux	DayCent	DNDC	Flux difference (DayCent-measured)	Flux difference (DNDC-measured)
Control	1.0	0.5	3.58	-0.5	+2.58
fertilized	2.6	3.6	4.06	+1.0	+3.44

Table 3: DayCent simulated soil ammonium, nitrate, annual above ground biomass and cumulative N_2O fluxes at different climate scenarios. Values with different letters for the same column are significantly different from each other ($P<0.05$).

Climate scenario	Average soil ammonium (g kg^{-1})	Average soil nitrate (g kg^{-1})	Average biomass (t ha^{-1} y^{-1})	Cumulative flux (kg N_2O-N $ha^{-1}y^{-1}$)
Baseline	35a	3a	33a	4.2a
High sensetive	14b	2a	50b	4.4a
Low sensetive	19c	2a	45c	4.1a

Figures


a
Nitrous oxide emissions (g N_2O-N ha^{-1} d^{-1})
110
90
70
50
30
10
-10
26-Oct-03
09-Jan-04
24-Mar-04
07-Jun-04
21-Aug-04
04-Nov-04
18-Jan-05


b
Nitrous oxide emissions (g N_2O-N ha^{-1} d^{-1})
20
15
10
5
0
-5
-10
26-Oct-03
09-Jan-04
24-Mar-04
07-Jun-04
21-Aug-04
04-Nov-04
18-Jan-05

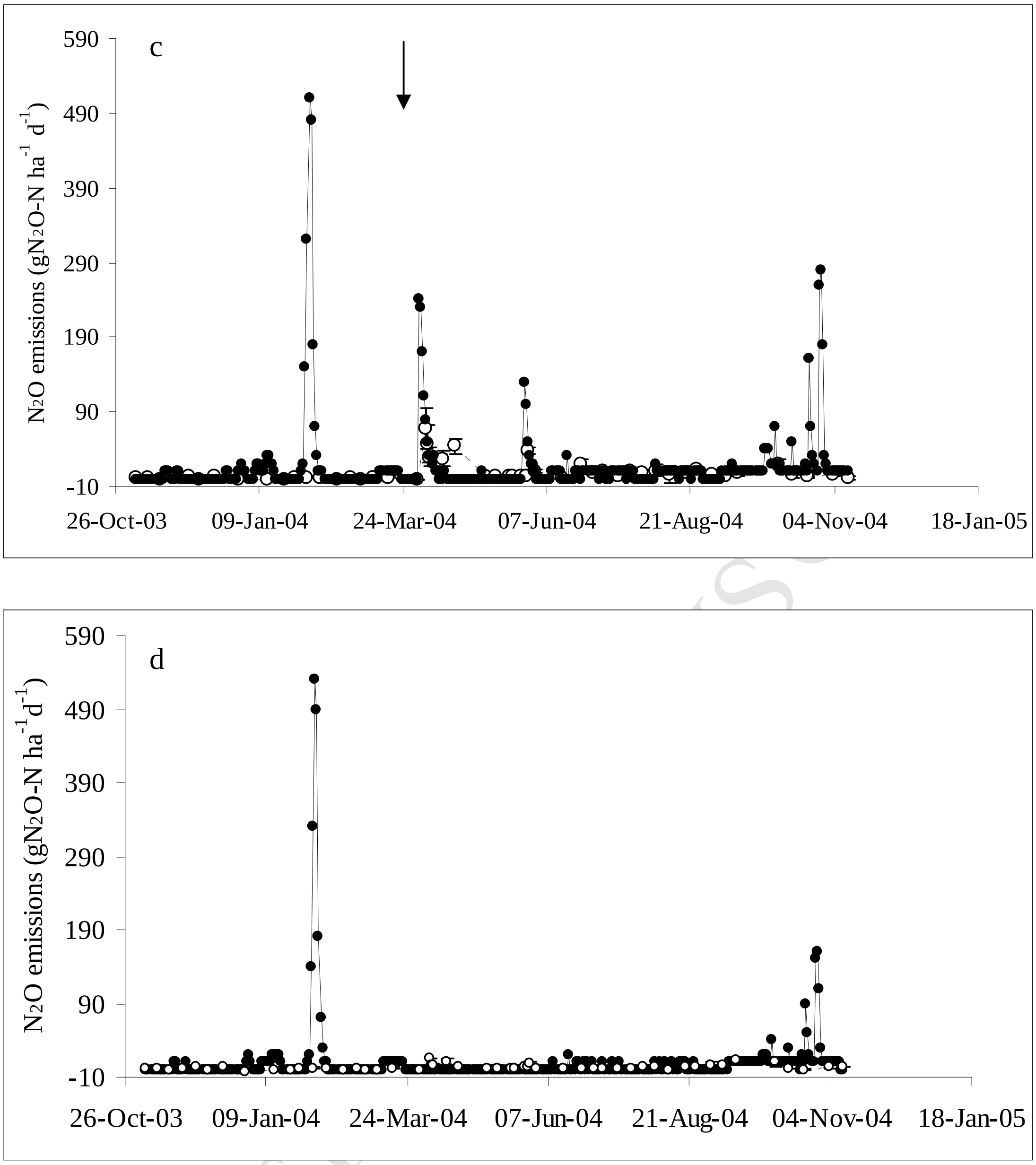


Figure 1: Comparisons of DayCent (a and b) and DNDC (c and d) model-simulated (●) and field measured (o) N_2O fluxes from the fertilized (a and c) and control (b and d) pasture treatments in 2003/2004. (Error bars for measured values are ± standard error). Arrow show time of fertilizer application.

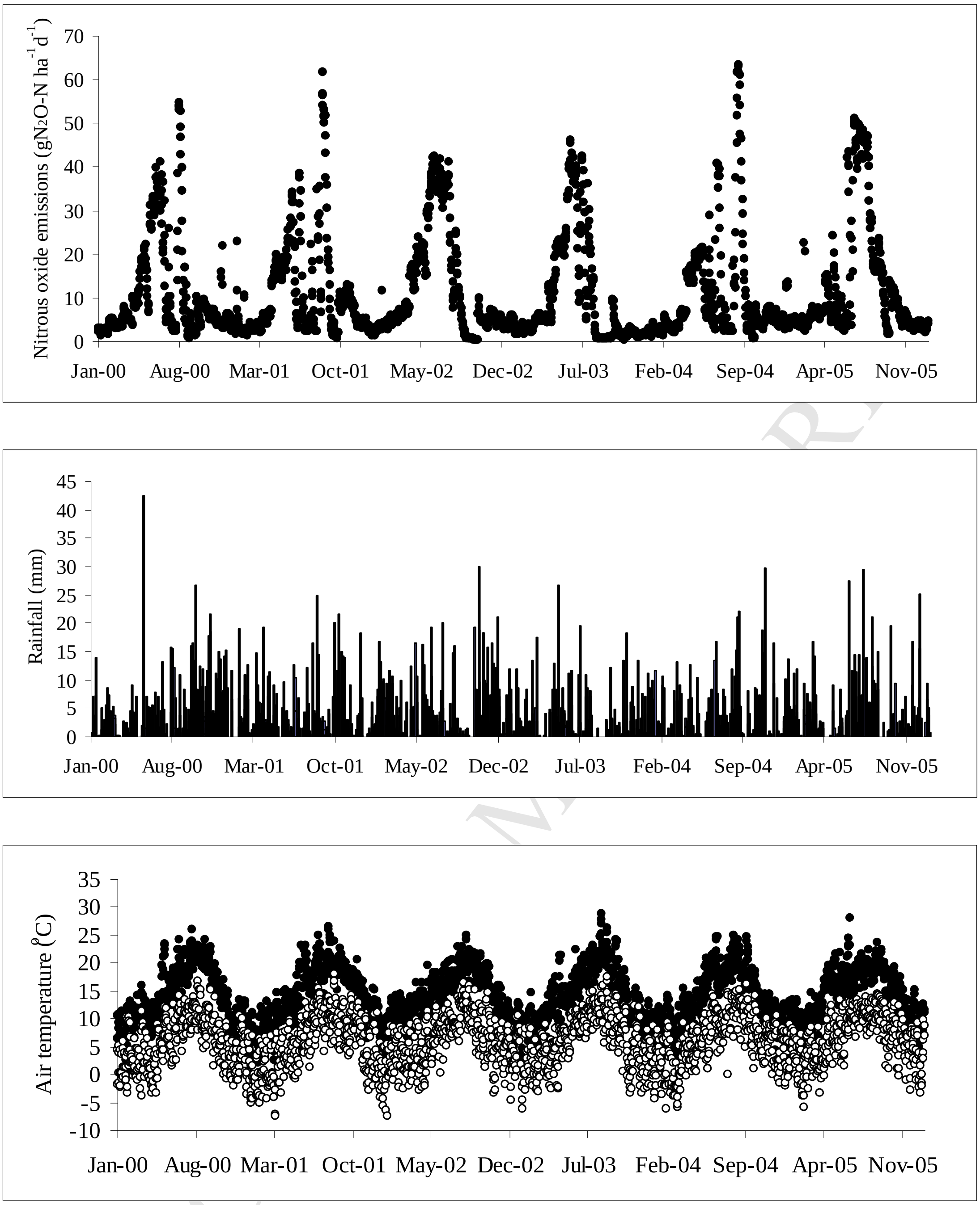


Figure 2: Simulated nitrous oxide fluxes (a), measured precipitation (b) and maximum (●) and minimum (o) temperature (c) during 2000-2005.

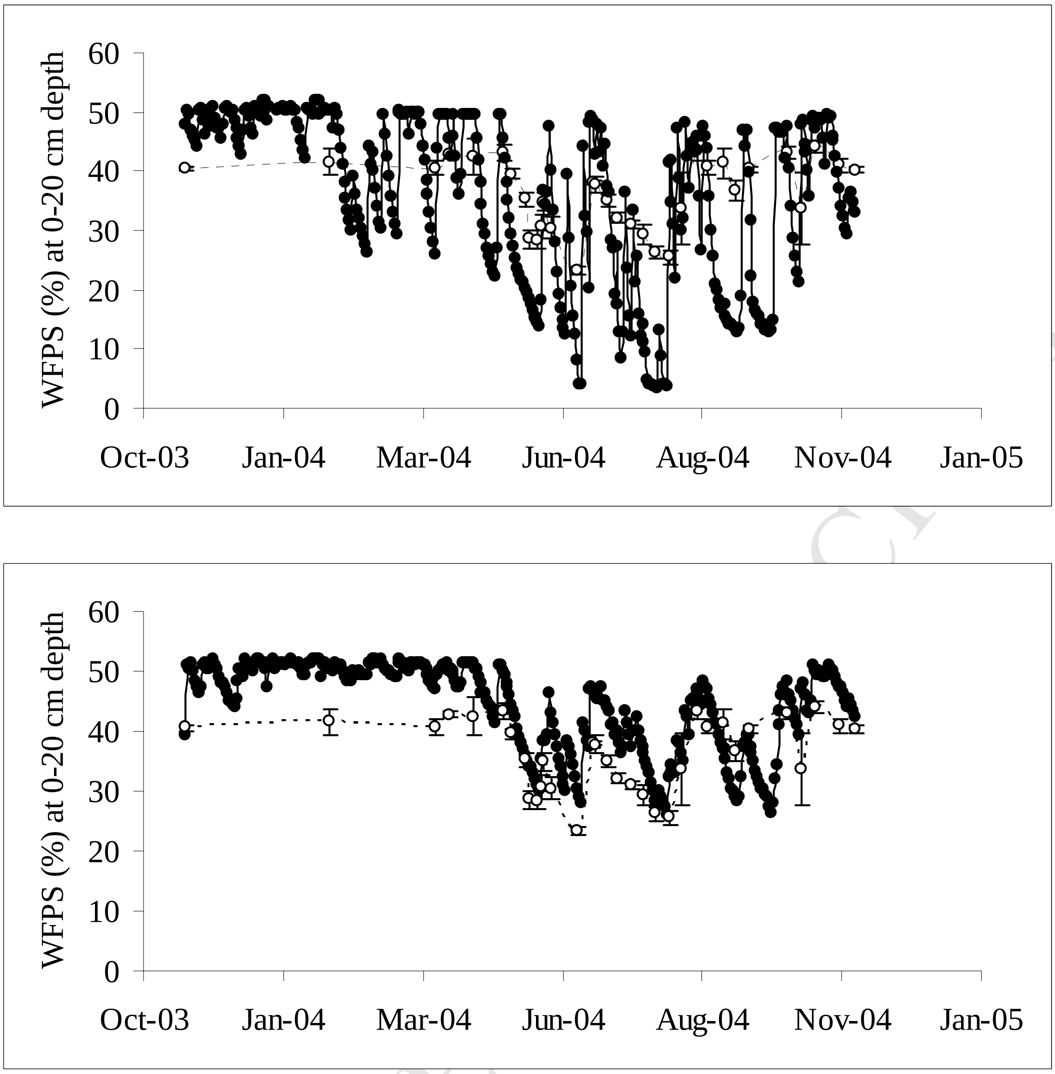


Figure 3: Comparisons between the simulated (●) and field measured (o) WFPS from the cut and grazed pasture for DayCent (a) and DNDC (b) models in 2003/04. (Error bars for measured values are ± standard error).

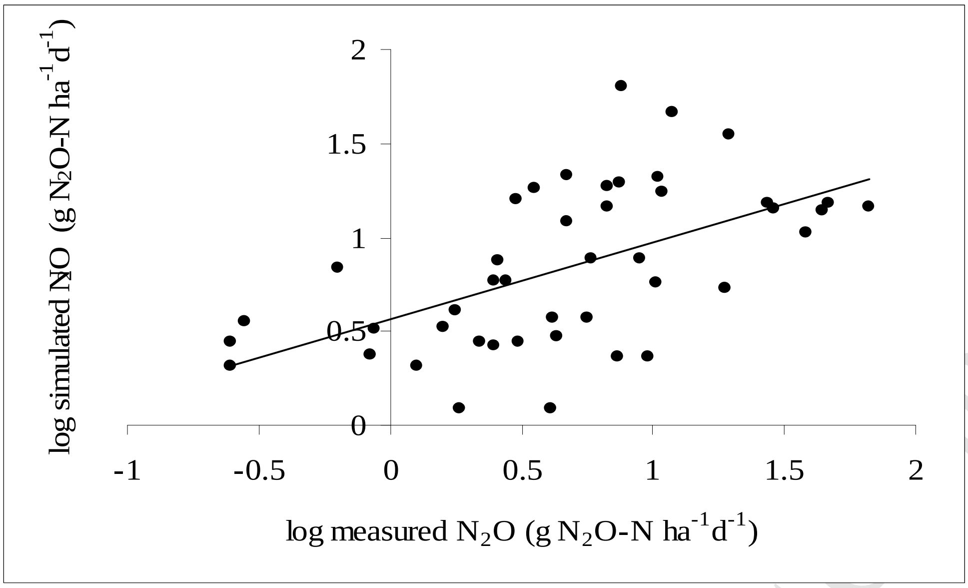


Figure 4: Correlation between the DayCent model-simulated and field measured N_2O fluxes for the grass field. y = 0.41x + 0.57 (r^2 = 0.32).

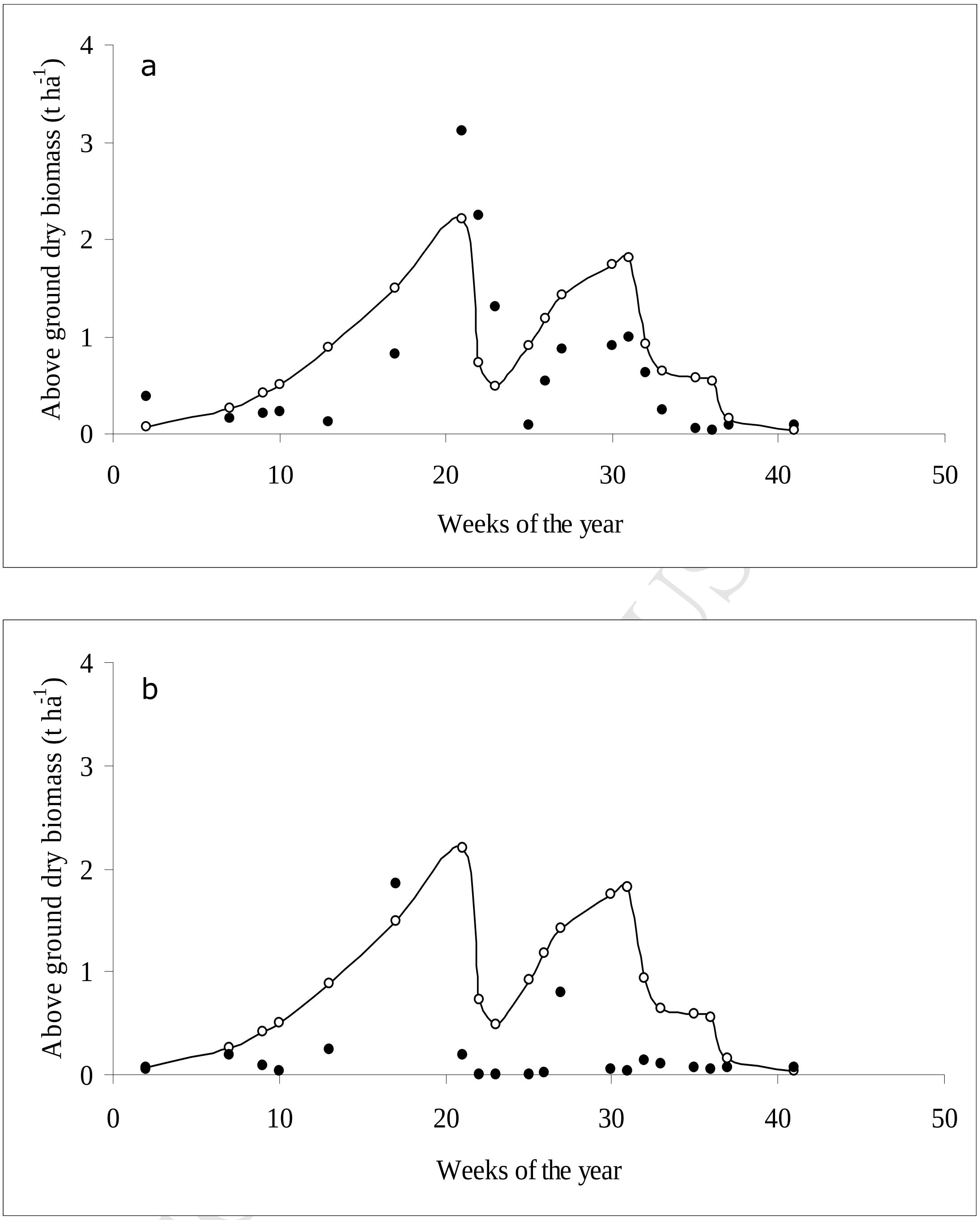


Figure 5: Weekly DayCent (a) and DNDC (b) simulated (●) and field measured (o) grass biomass in 2004.

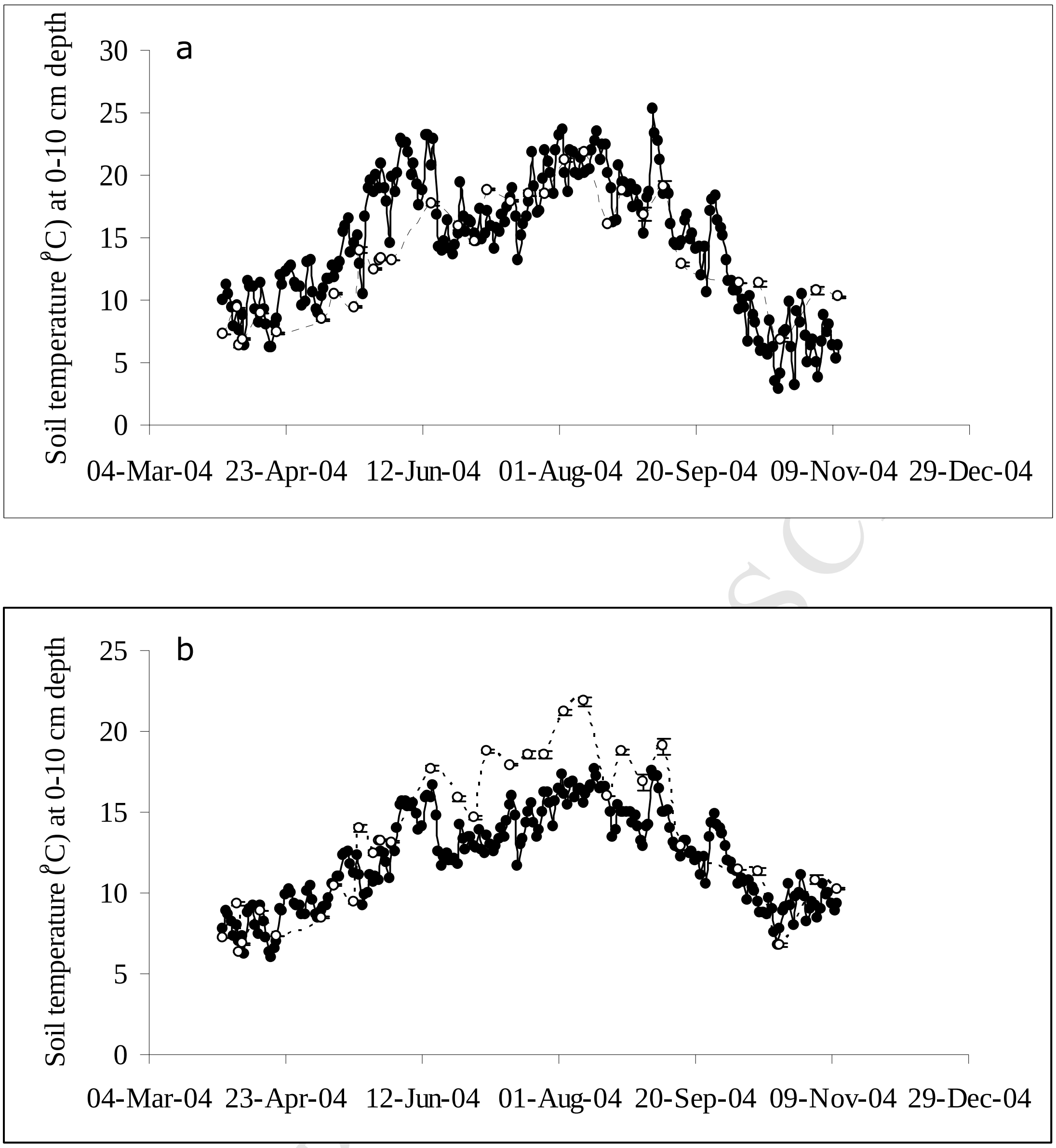


Figure 6: Comparison between the DayCent (a; r^2 = 0.64; RMSE = 0.57) and DNDC (b; r^2 = 0.88; RMSE = 0.44) simulated (●) and field measured (o) soil temperature (0-10 cm depth) from the cut and grazed pasture in 2004. (Error bars for measured values are ± standard error).

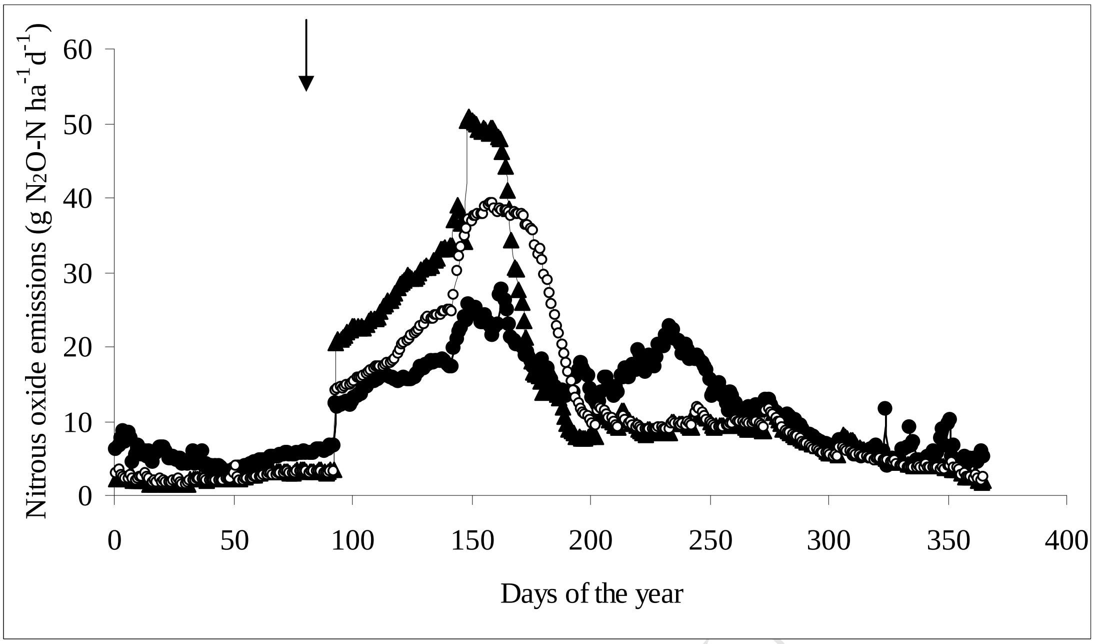


Figure 7: Effects of climate change on N_2O emissions from the grass field for the high (▲) and low (o) temperature sensitive climate data compared with measured baseline climate (●). Arrow show time of fertilizer application.

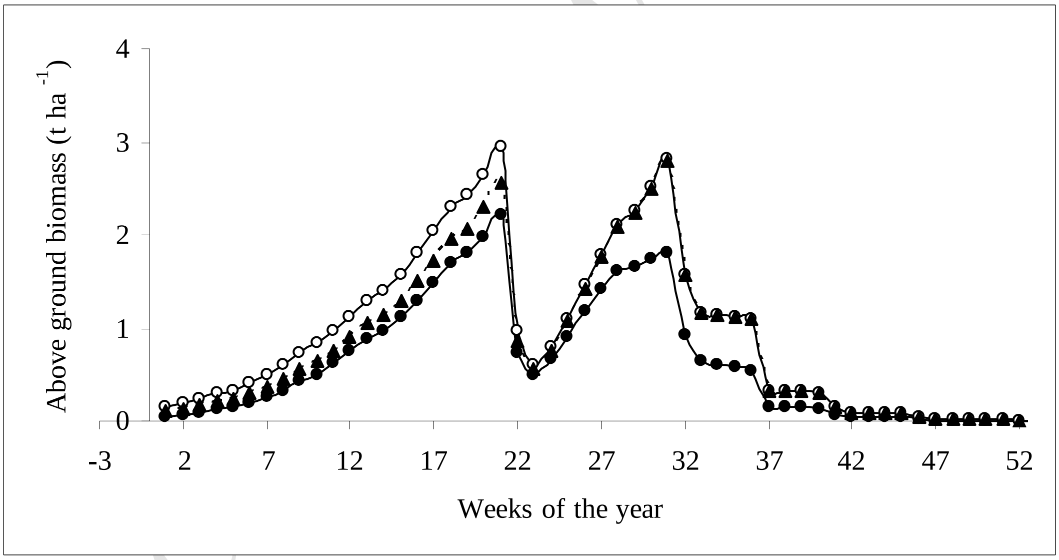


Figure 8: Effects of climate change on above ground grass biomass production for the high (o) and low (▲) temperature sensitive climate scenarios compared with measured baseline climate (●).