Publizierbarer Endbericht

gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
Kurztitel:	NitroAustria
Langtitel:	Nitrogen losses from Austrian agricultural soils – modelling to explore trade off-effects
Zitiervorschlag:	
Programm inkl. Jahr:	ACRP 7th Call 2014
Dauer:	01.05.2015 bis 31.10.2017
KoordinatorIn / ProjekteinreicherIn:	Universität für Bodenkultur Wien
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Projekt- und KooperationspartnerIn (inkl. Bundesland):	Austrian Agency for Health and Food Safety (AGES), Wien Umweltbundesamt GmbH (UBA), Wien Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft (BFW), Wien
Schlagwörter:	Lachgasemissionen, Minerungsmaßnahmen, Modellierung, Emissionsinventar, Klimawandel, Stickstoffeffizienz
Projektgesamtkosten:	357 191€
Fördersumme:	299 277 €
Klimafonds-Nr:	KR14AC7K11916
Erstellt am:	28.02.2018

B) Projektübersicht

1 Kurzfassung

Die Ergebnisse des Projektes „FarmClim", welches in der 4. ACRP-Ausschreibung gefördert wurde, zeigen, dass die nationale Berichterstattung für Lachgasemissionen lediglich auf den vom IPPC vorgegebenen Richtwerten beruht, und keine standort- oder regionalspezifischen Lachgasemissionen von landwirtschaftlichen Böden berücksichtigt werden. Der IPCC Standardwert basiert auf einer empirischen Regression zwischen ausgebrachter Düngermenge und Lachgasemissionen und nimmt an, dass landesweit 1% des ausgebrachten Stickstoffdüngers als Lachgas von den landwirtschaftlichen Böden emittiert werden. Regionale Unterschiede oder eine Ortung von Hotspots oder Hotmoments sind bei dieser Methode nicht möglich. Damit wird auch das Ergreifen gezielter Optimierungsmaßnahmen unmöglich. Hier können komplexe Modelle weit genauere Aussagen treffen.

Das prozessbasierte Modell LandscapeDNDC wurde innerhalb des Projekts „NitroAustria" verwendet um die Flüsse von Stickstoffverbindungen landwirtschaftlicher Acker- und Grünlandböden in sechs österreichischen Landwirtschaftsgebieten zu modellieren. In die Modellierung fließen umfangreiche Daten ein, die den jeweiligen Standort und seine Bewirtschaftung kennzeichnen. Die Ergebnisse der standort-angepassten Modellierung werden mit dem für ganz Österreich verwendeten Einheitsverfahren verglichen, welches für das Erstellen der nationalen Treibhausgasinventur verwendet wird.

Die regionale Schätzung der Emissionsfaktoren unter Berücksichtigung von Klima, Topografie, Nutzung, Fruchtfolgen und Bewirtschaftungsintensität machte es möglich, Hotspots und Hotmoments für Lachgas- und Nitratverluste zu identifizieren. Zusätzlich dazu wurden Stickstoff und Kohlenstoffbilanzen aufgestellt.

Um Regionen zu identifizieren, in denen eine Änderung des Klimas die Lachgasemissionsrate beeinflussen kann, wurden für alle sechs Regionen Klimaszenarien (Strauss et al (2012)) mit minimaler, durchschnittlicher und maximaler Erwärmung für die Periode 2030 bis 2040 verwendet.

Projektstruktur:

Das Projekt NitroAustria ist in sechs Arbeitspakete (AP) eingeteilt. AP 1 „Projektsteuerung und Veröffentlichungen" sichert den Projektfortschritt. AP 2 „Daten Erfassung und Anpassung", sammelt und harmonisiert die Daten zu Böden, landwirtschaftlicher Nutzung, Klima und N-Depositionen für AP 3 „Schätzung der N_2O-Emissionen landwirtschaftliche Böden". In diesem AP werden die regionalspezifischen Daten mit dem LandcapeDNDC-Modell modelliert und Stickstoff und Kohlenstoffbilanzen aufgestellt. AP 4 „Bereitstellung von landwirtschaftlichen Daten aus Österreich" stellt standortspezifische Daten von Versuchsstandorten, und regionale Daten von Landnutzung, Bewirtschaftung, Fruchtfolgen und Ernteerträgen für AP 2 und AP 5 „Anwendung der Ergebnisse und Nutzung für die nationale Treibhausgasinventur" bereit. AP 5 diskutiert außerdem Trade-offs zwischen den Klimagasemissionen und anderen Stickstoffverluste und vergleicht unterschiedliche Modelle mit dem

LandscapeDNDC Modell. Interessant ist hier der Vergleich von den Emissionsfaktoren zwischen den modellierten Regionen und den berechneten nationalen Schätzungen durch die IPCC-Methoden. In AP 6 „Klimawandelszenarien und statistische Analysen“ werden die möglichen Auswirkungen bei unterschiedlichen Klimaszenarien für die Periode 2030 – 2040 untersucht. In diesem AP werden auch die Hotspots und Hotmoments der Stickstoffverluste identifiziert.

Ergebnisse und Schlußfolgerungen:

Das wichtigste Ziel von NitroAustria war die Identifizierung der Treiber von N_2O Emissionen. Dabei wurden verschiedene Bodenarten, klimatische Bedingungen und landwirtschaftliche Bewirtschaftungen berücksichtigt. Insgesamt wurden 34 Standorte in sechs verschiedenen Regionen in Österreich ausgewählt und standortspezifische N_2O Emissionen mit dem LandscapeDNDC Modell für den Zeitraum 2005 bis 2014 berechnet.

Innerhalb dieser zehn Jahre schwankten die kumulierten N_2O Emissionen zwischen 3 und 35 kg N_2O-N ha^{-1}. Generell waren die N_2O Emissionen vom Grünland höher als von den Ackerflächen. In den sogenannten ‚hot spot regions‘, trugen die Maximum-Emissionen zwischen 50% und 80% zu den Gesamtemissionen bei. Die Maximum-Emissionen korrelierten positiv mit dem verfügbaren Stickstoff und der Bodentemperatur und fanden hauptsächlich in der Vegetationsperiode statt.

Im Projekt NitroAustria wurde ebenfalls der Einfluss vom Klimawandel berücksichtigt. Ein Basis-Szenario (2005-2014), drei Temperatur-Szenarien und drei Niederschlags-Szenarien (2031-2040) wurden ausgewählt. Die Ergebnisse zeigen, dass weniger Niederschlag die NO3 Versickerung verringert und die Verfügbarkeit von Stickstoff erhöht. Da Maximum-Emissionen einen erheblichen Teil zu den Gesamtemissionen beitragen, werden sie auch zukünftig eine große Rolle spielen. Sie könnten durch die Wiederbefeuchtung nach Trockenheit höhere gasförmige N-Verluste auslösen bzw. verstärken.

Während der Projektdauer konnte das Modell LandscapeDNDC weiterentwickelt werden und hat zu einer verbesserten Version geführt. Weitere Entwicklungen sind notwendig um neue landwirtschaftliche Maßnahmen darstellen zu können.

2 Executive Summary

– *Initial situation / motivation of the project*

Results of the FarmClim project funded under ACRP 4th highlight that the IPCC default emission factor is not able to reflect region specific nitrous oxide (N_2O) emissions from Austrian arable soils. The methodology is limited in identifying hot spots nor can it indicate situations of hot moments of N_2O emissions. When estimations are based on default emission factors, no recommendations can be given on optimisation measures that would lead to a reduction of soil N_2O emissions. NitroAustria aimed at improving estimations of soil N_2O emissions by region specific modelling. It used the LandscapeDNDC model to update the N_2O emission factors for nitrogen (N) fertiliser and animal manures applied to soils. The derivation of suitable mitigation options by optimisation of common and evaluation of potential management practices for current and future climatic conditions is crucial to minimize threats to the environment while ensuring the long-term productivity and sustainability of agro-ecosystems.

– *Targets of the project*

NitroAustria analysed N_2O, NO and NO_3 leaching from arable and grassland soils in Austria with process based ecosystem modelling (LandscapeDNDC). Nitrogen and GHG budgets were produced. Hot spots, hot moments and management optimisation measures were assessed based on simulation calculations, and region specific emission factors were delivered. NitroAustria included Austrian specific data on agricultural management and integrated 9 climate change scenarios. Validated N_2O EFs for Austrian agricultural managed soils were evaluated to be integrated into the Austrian GHG emission inventory. Proposals for more targeted mitigation measures on arable land and grassland in Austria were derived based on the site specific and regional nitrous oxide (N_2O) EFs.

– *Project structure and methodology*

Nitro Austria was divided into six work packages. WP1 was responsible for the coordination and management of the project and for the dissemination of project results. WP2 “Data acquisition and harmonization” collected data and provided them to WP3 “Estimating N_2O emissions from arable soils” and WP6 “Climate change scenarios and statistical analysis of modelling results” where the data were used to model N_2O emissions and nitrate leaching from arable soils. WP3 performed process based modelling at site, regional and national scale. It delivered C and N budgets, region specific emission factors and potential mitigation options with improved agricultural management for current and future climatic conditions. Management according to good practice was displayed in the model. WP4 “Providing data on agricultural management in Austria” obtained at site scale arable management data from experimental data from AGES field trials or observations. At regional scale, such data were generated using region specific proxy data. WP4 provided crop rotation scenarios from arable regions and of agro-environmental measures. In WP5 ”Application of results and use for the GHG inventory”, the regional model results were compared with the National Greenhouse Gas Inventory approach based on the emission factors (EF) for nitrous oxide emissions. Trade-offs between the effects of agricultural measures on different GHG emissions, other N losses and soil organic carbon content in the soil were discussed. Furthermore measures for a policy framework towards climate friendly farming were derived. WP6 performed site/regional/national LandscapeDNDC simulations considering scenarios of climate change, assessed factors that influence N_2O emissions in various Austrian regions and suggested site/region specific mitigation measures.

– *Results and conclusions of the project*

WP1 successfully organised the project and produced publications. WP2 determined the required data for the model, and delivered these data to a database with input parameters for LandscapeDNDC. WP3 compiled a large consistent data set of model inputs and model drivers at site, regional and national scale and estimated N_2O emissions from six agricultural regions. WP4 generated scenarios for crop rotations in 4 different arable regions. WP5 evaluated the results of the regional specific LandscapeDNDC calculations with regard to the IPCC methodology and default value for the emission factor of direct soil nitrous emissions and compiled dedicated measures for an agri-environment-climate policy framework. WP6 assembled climate input data for LandscapeDNDC modelling and calculated N budgets of climate scenarios (2013-2040) for model regions.

– *Outlook and Summary*

The overall aim of NitroAustria was to identify drivers for N_2O emissions taking into account different soil types, climate conditions and agricultural management. Thirty-four sites in six agricultural production regions of Austria were selected, and site and region specific N_2O emissions from managed arable and grassland soils were calculated by the model LandscapeDNDC for the period 2005 to 2014. The cumulative N_2O emissions from the six regions over the ten-year period ranged from 3 to 35 kg N_2O-N ha^{-1} and were higher from intensively managed grasslands compared to arable fields. The N_2O emissions showed high inter-annual variations for many regions. In the hot spot regions, extreme peak emissions made up for 50 to 80% of annual N_2O emissions. Peak emissions correlated positively with available nitrogen and soil temperature and took place mainly in the vegetation period. Temperature increase and precipitation change will impact crop yields and N losses. NitroAustria also considered the impact of climate change. A baseline scenario (2005 to 2014), 3 temperature and 3 precipitation change scenarios (2031 to 2040) were chosen. The results indicate that lower precipitation decreases NO_3^- leaching and increases N availability in soil. Peak N_2O emissions are mainly responsible for high annual fluxes and these peaks may increase in future under lower precipitation due to drought-rewetting events triggering gaseous N-losses. Results were evaluated for integration into the national emission inventory. NitroAustria proposes measures for a policy framework towards climate friendly farming. Within the project we could help to improve the model significantly which led to an enhanced version of the LDNDC. Further developments are required to depict the influence if a range if novel agricultural management measures.

3 Hintergrund und Zielsetzung

– *Initial situation / motivation of the project*

Results of the FarmClim project funded under ACRP 4th highlight that the IPCC default emission factor is not able to reflect region specific nitrous oxide (N_2O) emissions from Austrian arable soils. The methodology is limited in identifying hot spots nor can it indicate situations of hot moments of N_2O emissions. When estimations are based on default emission factors, no recommendations can be given on optimisation measures that would lead to a reduction of soil N_2O emissions. NitroAustria aimed at improving estimations of soil N_2O emissions by region specific modelling. It used the LandscapeDNDC model to update the N_2O emission factors for nitrogen (N) fertiliser and animal manures applied to soils. The derivation of suitable mitigation options by optimisation of common and evaluation of potential management practices for current and future climatic conditions is crucial to minimize threats to the environment while ensuring the long-term productivity and sustainability of agro-ecosystems.

– *Targets of the project*

NitroAustria analysed N_2O, NO and NO_3 leaching from arable and grassland soils in Austria with process based ecosystem modelling (LandscapeDNDC). Nitrogen and GHG budgets were produced. Hot spots, hot moments and management optimisation measures were assessed based on simulation calculations, and region specific emission factors were delivered. NitroAustria included Austrian specific data on agricultural management and integrated 9 climate change scenarios. Validated N_2O EFs for Austrian agricultural managed soils were evaluated to be integrated into the Austrian GHG emission inventory. Proposals for more targeted mitigation measures on arable land and grassland in Austria were derived based on the site specific and regional nitrous oxide (N_2O) EFs.

4 Projektinhalt und Ergebnis(se)

2.2.1 Initial situation / motivation for the project

Results of the FarmClim project funded under ACRP 4th highlight that the IPCC default emission factor is not able to reflect region specific N_2O emissions from Austrian arable soils. The methodology is limited in identifying hot spots and hot moments of N_2O emissions. When estimations are based on default emission factors no recommendations can be given on optimisation measures that would lead to a reduction of soil N_2O emissions.

NitroAustria aimed at improving estimations of soil N_2O emissions by region specific modelling. It used the LandscapeDNDC model to update the N_2O emission factors for nitrogen (N) fertiliser and animal manures applied to soils. The derivation of suitable mitigation options by optimisation of common and evaluation of potential management practices for current and future climatic conditions is crucial to minimize threats to the environment while ensuring the long-term productivity and sustainability of agro-ecosystems.

NitroAustria analysed N_2O, NOx, N_2, NH_3, and CO_2 emissions and NO_3 leaching from arable and grassland soils in Austria with process based ecosystem modelling (LandscapeDNDC). Nitrogen and GHG budgets were produced. Hot spots, hot moments and management optimisation measures were assessed based on simulation calculations, and region specific emission factors were delivered.

NitroAustria included Austrian specific data on agricultural management and integrated climate change scenarios. Validated N_2O EFs for Austrian agricultural managed soils were evaluated to be integrated in the Austrian GHG emission inventory calculations. Proposals for more targeted mitigation measures on arable land and grassland in Austria were derived based on the site specific and regional nitrous oxide EFs.

2.2.2 Targets of the project

WP1 “Coordination and Dissemination” was responsible for the coordination and management of the project and for the dissemination of project results. The project management structure was successfully set up and maintained at a highly productive level throughout the project duration. A total of ten project meetings proofs the highly intensive collaboration and commitment of all project partners. Major outcomes have successfully been shared with the agricultural and scientific community.

WP 2 “Data acquisition and harmonization” collected data and provided them to WP 3 and WP 6. Milestones and deliverables were the determination and harmonization of the required data for the LandscapeDNDC modelling at national, regional and spatial scale.

Within WP3 “Estimating N_2O emissions from arable soils” more accurate N_2O model calculation for all six regions was carried out. Milestones and deliverables were the compilation of a large consistent data set of model inputs and model drivers and running the LandscapeDNDC. Additionally, C and N budgets including N_2O emissions and NO_3^- leaching potential from different typical agricultural regions were calculated.

WP4 “Providing data on agricultural management in Austria” provided crop rotation scenarios from arable regions according to crop statistics from the period 2005-2014. Current agro-environmental measures such as cultivation of cover crops were included. WP4 determined the required management data for the model and generating of scenarios for crop rotations in 4 different arable regions. For Styria, the proposed crop rotation comprised a 75% share in corn (incl. for ensilage). Meanwhile, restrictions entered into force as from 2017 the maximum share is fixed at 67% (Stmk. Maiswurzelbohrer-Verordnung 2015[1]). Therefore,

[1] Verordnung der Steiermärkischen Landesregierung vom 12. März 2015 betreffend die Bekämpfung des Maiswurzelbohrers (Stammfassung LGBl. Nr.22/2015, Änderung LGBl. Nr. 32/2015) Quelle: https://www.ris.bka.gv.at

the calculated results characterise a worst case scenario as much less nitrogen demanding crops such as soya and oil pumpkin corn will substitute corn. For the Marchfeld, scenarios of agro-environmental measures were generated and the results were summarised.

WP 5 ”Application of results and use for the GHG inventory” compared calculations in the framework of the GHG inventory according to the 2006 IPCC Guidelines with the LandscapeDNDC model results. Further milestones and deliverables were the discussion of different N_2O modelling approaches and of trade-off effects of agricultural measures to reduce N_2O emissions. Measures for a policy framework towards climate friendly farming from the point of view of minimizing nitrous emissions were developed.

WP 6 “Climate change scenarios and statistical analysis of modelling results” examined impacts of elevated temperature and changed precipitation regimes on N_2O fluxes in 6 Austrian agricultural regions and 6 different soil types. Simulation runs were performed with the LandscapeDNDC model considering scenarios of climate change. The scenarios were taken from Strauss et al., 2012[2]. These scenarios were derived from the statistical climate model ACLiReM which include daily weather data on minimum and maximum temperatures, solar radiation, precipitation, relative humidity and wind speed for Austria at 1 km² grid resolution and the period 1975-2040. The simulation results determine annual N losses under various climate change scenarios from 2031-2040. The output was compared with the actual N losses that were calculated for the years 2005-2014 (WP2). In a further step regions were identified were gaseous N losses will increase or decrease in future.

2.2.3 Activities performed within the framework of the project, including methods employed

WP1: Regular internal meetings were seen as the key element of efficient communication within the project. Throughout the project and even after its formal end, about every three months plenary meetings were held, at which all project partners were represented. Meetings were organised to allow for bilateral or group discussions at the end, for which ample time was foreseen. Discussion sparked further interaction between participating partners and WPs and further bilateral meetings. Detailed meeting protocols allowed the respective agreements to be traced and maintained. To facilitate document and file management an online data repository (based on Nextcloud) was prepared. Data was collected in document libraries (description of milestones, deliverables, presentations, protocols, articles, reports) and provided a general accessible form for all project partners. Dissemination activities were taken care of as planned – see section “description of dissemination and publication measures”.

[2] Strauss, F. (2012): Modeling climate change and impacts on crop production in Austria. Dissertation, Universität für Bodenkultur, Institut für Nachhaltige Wirtschaftsentwicklung.

WP2: The determination of required data (M1) was based on the experience from former projects. Six representative regions covering the different heterogenic climatic and agricultural conditions in Austria were chosen. These six regions were KPG Marchfeld; KPG Mühlviertel, KPG Grieskirchen, KPG Oststeirisches Hügelland, KPG Ennstal and KPG Rheintal (For figure see map in Annex). The model used in this project (LandscapeDNDC 1.9.3) is well described in Haas et al. (2013)[3]. For running the model, LandscapeDNDC required input data including measured data for daily weather, geographical and soil parameters, land use and management practices. Furthermore, mean regional crops, yields and fertilization and calculated data of mean regional nitrogen (N) deposition are considered. Required information exists on different scales.

Spatial information on land use and soil properties was taken from eBod[4] instead of BORIS. eBOD is a digital soil map, containing all site characteristic from all mapped arable and grassland soils in Austria and was perfectly suitable for this study. Hectare and yields of crops and grassland categories (2005 – 2014), number of cattle and pigs or poultry in the regions (2007 – 2014) was held from the Statistics Austria and the INVEKOS database. Statistics Austria carries through the Farm Structure Surveys (FSSs), where regional and national information on agricultural land is collected (e.g. Statistics Austria 2014[5]), furthermore they undertake the annually harvest surveys (Statistics Austria 2009[6]). INVEKOS data are derived from the annual multiple applications forms of the farmers by Agrarmarkt Austria for the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW). Additionally, we included crop yields from the research stations of Austrian Agency for Health and Food Safety Ltd. (AGES), whereby a correction for the influence of top-sites was regarded (- 10% of registered yield) (M2).

N deposition, climate and management are generated on municipality level, whereas soil parameters used for modelling are site specific. In detail, the following data were collected (M3): *Site parameters*: latitude, longitude, annual precipitation, slope, elevation etc.; *Soil data*: humus type, soil type, texture, stone fraction, bulk density, C_{org}, N_{org}, pH, soil moisture, wilting point, WHC, etc.; *N-Deposition*: regional annual wet and dry N deposition from EMEP-modelling, downscaled to 1x1 km; *Climate data*: all available meteorological data was gathered from regional ZAMG stations; air temperature (mean, min, max), precipitation, air humidity, wind speed, global radiation; at a daily time resolution from 2005 till 2014; *Vegetation characteristics; Management:* regional crop rotation and cut intensities; regional yield; *area (ha)* of arable and

[3] Haas, E., Klatt, S., Froehlich, A., Kraft, P., Werner, C., Kiese, R., Grote, R., Breuer, L., Butterbach-Bahl, K., 2013. LandscapeDNDC: a process model for simulation of biosphere-atmosphere-hydrosphere exchange processes at site and regional scale. Landscape Ecology, pp. 615-636.

[4] BMLFUW 2007: eBod, https://bfw.ac.at/rz/bfwcms2.web?dok=7066

[5] Statistics Austria (2014): Agrarstrukturerhebung 2013. Schnellbericht 1.17. Wien.:

[6] Statistics Austria (2009): Harvest Survey. Standard documentation: Meta information (definitions, explanations, methods, quality) on the Harvest Survey. valid as of/for the period under review/survey date: 2003. Status: March 2009.

grassland sites of the different soil types in the regions. All information required were successfully gathered and harmonized. We were able to collect measured or estimated values for each parameter needed except for soil bulk density. Bulk density was calculated on the basis of the available C_{org} content using the pedotransfer function of Manrique & Jones (1991).

A database was created for the LandscapeDNDC model (D1). Each region included several sites, representing main soil types and land use management. In Ennstal, we had 5 sites, in Marchfeld, Mühlviertel and Oststeirisches Hügelland we had six sites, in Rheintal seven sites and in Grieskirchen nine sites represented the region. In total, the chosen sites cover more than 70% of the agricultural land and crops within the land use category for each region.

WP3: Landscape DNDC was fed with 297 input files (D1) compiled from the large dataset of model inputs and model drivers for the six regions at site/regional/national scale (M1, e.g. see Table 1 in "WP 3 deliverables for annex"). Yearly reported yields from several local surveys published by Statistic Austria were used for the calibration of the regional modelled biomass growth. Certain plant physiological parameters in LandscapeDNDC were in each region minor adjusted in order to fit the regional modelled yields with the reported ones (M2, D2, see Figure 1 in "WP 3 deliverables for annex").

WP4: Experimental management data (date of soil cultivation, seed, fertilizing and manuring, irrigation) and yield results of the selected crops were summarised from the AGES sites at the relevant arable areas. These field experiments for the official cultivar registration are conducted according to good agricultural practice on sites with medium to high soil quality conditions. Due to different weather conditions during the period 2005 – 2014, the recorded yields and qualities of the crops were influenced clearly, thereon the model could be improved and calibrated for calculating climate effects on dry matter production and yields.

WP5: Comparison of different N_2O modelling approaches and discussion of trade-off-effects of agricultural measures able to reduce N_2O emissions were carried through based on a literature review. The results of these surveys were distributed and discussed within the project team during the project meetings and via written comments based on draft findings. Comparison of the LandscapeDNDC model results with the Austrian GHG inventory was carried out by developing an excel-tool which calculated weighted, adjusted emission factors for the 6 regions. This enabled direct comparison of model assumptions and results with the greenhouse gas inventory methodology. Finally, proposals for a policy framework were derived based on regional model results and literature findings, which were also discussed and reflected among the project partners.

WP6: The assembly of climate input data for the LandscapeDNDC modelling was done to create a database of climate scenarios for all model regions. Within WP6, we simulated the years 2031-2040. Overall, 9 climate change scenarios were provided by Strauss et al. (2012)[7]. 3 temperature scenarios (maximum, minimum and average temperature) combined with 3 different precipitation scenarios were used (-20%, average and +20% precipitation). The Table in the annex shows mean annual temperature and mean precipitation for each scenario. For the baseline simulation runs, we used climate data from the nearby climate station provided by ZAMG (see WP2 and 3). For the appropriate use of comparable climate clusters (Figure and Table in the annex) as provided by Strauss et al. (2012), we compared ZAMG data from the years 2005-2007 with the "past" climate data of Strauss et al. (2012) which was used for clustering. Precipitation and air temperature were tested for non-significant differences between ZAMG data and "past" data. Only clusters with non-significant differences were taken. For the simulation runs in WP6, input parameters for LDNDC were kept constant as for the baseline runs (2005-2014), only climate input data was changed.

2.2.4 Description of the results and project milestones

WP1 Coordination and dissemination coordinated the work, organised meetings, and arranged project reports. WP1 coordinated contacts to the funding agency and maintained the overview on milestones and deliverables. A platform for communication and data management was established with "owncloud". It allowed interaction between and common understanding of the project participants. Ten internal meetings were held. The dissemination activities during the first reporting period are listed under chapter 2.3. The interim (D1) and the final report (D2) were produced including an overview on dissemination activities throughout the project (D3, D4).

WP2 Data acquisition and harmonization compiled all relevant spatial input data, generated a large data pool and delivered it to WP3 as input parameters on relevant spatial scale (site, regional, national) (M1, M2, M3 and D1 in "WP 2 deliverables for annex").

WP3 Estimating N_2O emissions from arable soils adapted the LandscapeDNDC model according to climate, soil conditions and management practices in Austria.Regional specific C and N soil budgets including N_2O emissions and nitrate leaching and maps of N_2O emissions from the modelled regions were generated (D3). Factors influencing N_2O emissions were determined by statistical means and mitigation potentials assessed (D5).

M3 Application of LandscapeDNDC on regional scale.

Between 2005 and 2014 mean annual emissions from arable soils ranged from 0.3 ±0 kg N_2O-N ha^{-1} in Muehlviertel to 1.2 kg N_2O-N ha^{-1} in Grieskirchen (Table 1). Mean annual N_2O-N emissions from intensive managed grassland were generally higher and ranged from 1.9 kg N_2O-N ha^{-1} in Muehlviertel to 3.4 kg

[7] Strauss, F. (2012): Modeling climate change and impacts on crop production in Austria. Dissertation, Universität für Bodenkultur, Institut für Nachhaltige Wirtschaftsentwicklung.

N_2O-N ha^{-1} in Rheintal. Emissions from extensive managed grassland thereby were similar to arable fields, ranging from 0.7 kg N_2O-N ha^{-1} in Ennstal up to 1.1 kg N2O-N ha^{-1} in Muehlviertel.

Annual and daily N_2O fluxes from arable and intensive managed grassland, depending on year, crop and crop rotation, ranged from 0.1 to 10.2 kg N_2O-N ha^{-1} and from 0 to 2.1 kg N_2O-N ha^{-1}, respectively (Table 1). Mean annual N-Input in form of mineral fertilizer and manure spans from 68 kg N ha^{-1} at arable sites in Muehlviertel and 206 kg N ha^{-1} at intensive grassland managed meadows in Grieskirchen. Comparing annual regional N_2O-N emissions, it is obvious that N-input alone does not reflect N-fluxes.

Example of soil type specific N_2O emissions from A) arable and B) grassland regions:

A) As shown in Figure 1, mean annual N_2O emissions of Marchfeld vary significantly among all three soil types. Loamy silty soils (lZ) are largest in area and emit in average 1.5 ± 1.3 kg ha^{-1} a^{-1}. Furthermore, several crops result in significantly higher mean annual N_2O emissions. Depending on year and crop, as much as 60 to 80% of the sum of annual emission is emitted during a short period of one to two weeks (hot moments).

B) Because of its climatic and geographical conditions, Ennstal in Steiermark is suitable to represent grassland soils and different grassland management types in Austrian mountainous areas. Figure 2 shows the spatial emissions from intensive managed meadows in Ennstal. The highest mean annual emissions in the period 2005 – 2014 were calculated for silty soils with 2.8 kg N_2O-N ha^{-1}. Loamy sandy soils (lS) emitted 2.0 and 2.4 kg N_2O-N ha^{-1} depending on climate, whereas the climate impact made no difference in N_2O emissions from sandy silty soil with mean annual emissions of 1.6 kg N_2O-N ha^{-1}.

Table 1: Modelled annual N_2O-N emissions [kg ha^{-1}], N_2O-N fluxes and mean amount of N fertilizer between 2005 and 2014 of Grieskirchen (GK), Marchfeld (MF), Mühlviertel (MV), Oststeirisches Hügelland (OH), Ennstal (ET) and Rheintal (RT) with arable (A) and intensive grassland (G) land use.

		Total annual N_2O-N emissions					Mineral and organic N fertilizer
		mean*	sd*	median*	range of N_2O-N fluxes		
Region	Land use	[kg ha^{-1} a^{-1}]		[kg ha^{-1} a^{-1}]	[kg ha^{-1} d^{-1}]	[kg ha^{-1} a^{-1}]	[kg ha^{-1} a^{-1}]
GK	A	1.2	± 0.4	0.9	0.000 - 0.3	0.2 - 7.5	137
	G	2.1	± 0.4	2.0	0.000 - 0.2	1.1 - 4.1	206
MF	A	1.0	± 0.3	0.5	0.000 - 0.4	0.1 - 6.7	116
MV	A	0.3	± 0	0.3	0.000 - 0.1	0.1 - 1.3	68
	G	1.9	± 0.3	1.9	0.000 - 0.5	1.4 - 3.8	178
OH	A	0.6	± 0.3	0.5	0.000 - 0.1	0.3 - 3.5	141
	G	3.1	± 0.5	2.9	0.000 - 0.3	2.2 - 5.9	192
ET	G	2.1	± 0.7	2.0	0.000 – 0.4	1.2 – 4.7	177
RT	G	3.4	± 3.0	2.9	0.000 – 2.1	1.6 – 10.2	198

A Spearman correlation analysis between mean annual N_2O emissions (2005 – 2014) from arable and intensive managed grassland and selected climatic and soil parameters and management from all regions is displayed in Table 2. Our results show that several parameters are influencing N_2O fluxes. Without regard to regional climatic and geographical factors of management mean annual temperature (r_s=0.27***), soil water content (r_s =0.38***) and content of soil organic C (r_s = 0.28***) together with N fertilization (r_s =0.41***) have the highest influence on N_2O emissions.

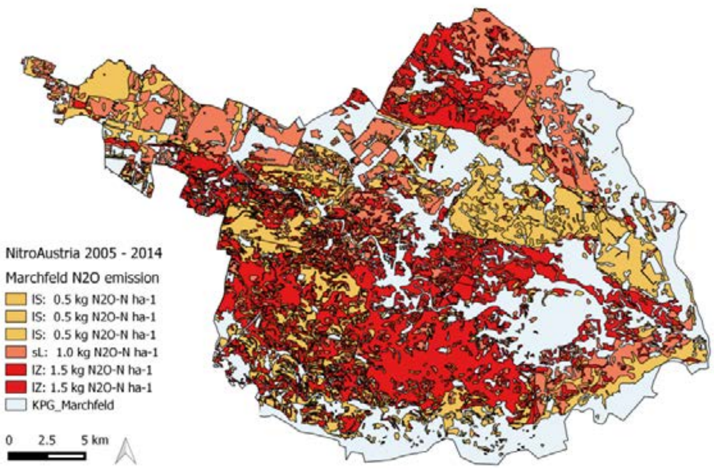

Figure 1 Mean annual N_2O emissions (kg ha^{-1}) in Marchfeld from 2005 to 2014

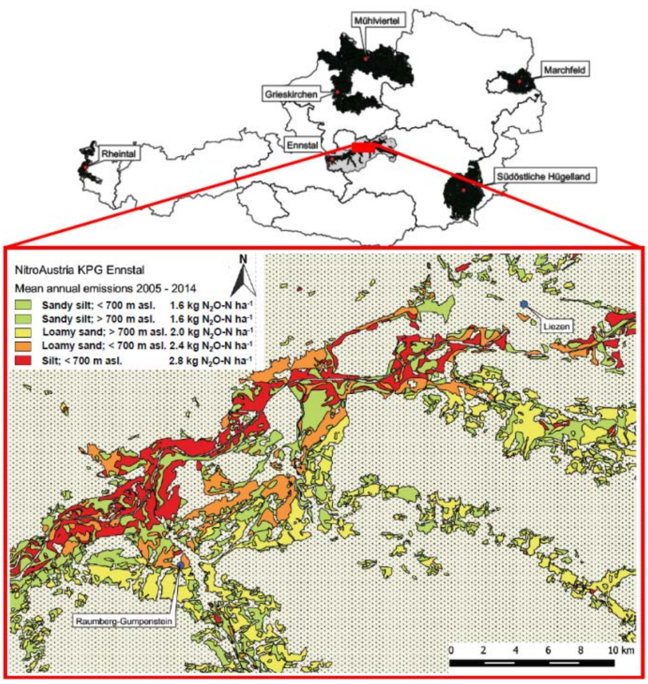

Figure 2 Spatial soil type heterogeneity in Ennstal; mean N_2O-N emissions from intensively managed grassland from 2005 – 2014.

Table 2: Spearman correlation between mean annual N_2O emissions and different soil-, climate- and management parameters. All regions; both land uses.

Parameters	Mean annual temperatur	Mean annual precipitatio	pH- value	Clay content	C_{org} content [kg ha^{-1}]	Soil temperatur e^1	Soil water content^1	Fertilizer^2 [kg ha^{-1}]
All	0.27***	0.15***	0.07**	0.06**	0.28***	0.13***	0.38***	0.41***
Ennstal grassland	0.47***	$-0.08^{n.s.}$	$0.13^{n.s.}$	$0.13^{n.s.}$	0.36*·	$0.27^{n.s.}$	0.52***	0.28*
Grieskirchen arable	0.22***	$-0.03^{n.s.}$	0.16***	0.12**	$-0.03^{n.s}$.	0.23***	$0.03^{n.s}$.	0.51***
Grieskirchen grassland	$0.22^{n.s.}$	$-0.29^{n.s}$.	$-0.11^{n.s}$.	0.17n.s.	0.44**	0.25n.s.	$0.07^{n.s}$	0.52***
Marchfeld arable	0.15***	$0.08^{n.s.}$	0.32***	-0.12*	0.61*	0.17***	0.50***	0.15***
Muehlviertel arable	0.20**	$0.06^{n.s}$	-0.50***	$0.10^{n.s}$	0.47***	0.24**	-0.50***	$-0.02^{n.s}$.
Muehlviertel grassland	$0.03^{n.s}$	$-0.02^{n.s}$	-0.50**	$0.25^{n.s}$.	-0.39*	$0.26^{n.s}$	$0.04^{n.s}$	$0.05^{n.s}$
Oststeirisches Huegelland arable	0.49***	0.52***	$0.12^{n.s}$	$-0.12^{n.s}$	$0.09^{n.s}$	0.53***	$0.08^{n.s}$	0.16*
Oststeirisches Huegelland grassland	0.62***	$0.31^{n.s}$	$-0.01^{n.s}$	$-0.20^{n.s}$	0.04n.s.	0.61***	$0.01^{n.s}$	$-0.33^{n.s}$
Rheintal grassland	$0.22^{n.s.}$	$0.03^{n.s.}$	$0.14^{n.s.}$	$-0.02^{n.s.}$	$0.16^{n.s.}$	0.27*	$0.14^{n.s.}$	$-0.23^{n.s.}$

*1 = at 10 cm soil depth, 2= mineral and organic fertilizer; * p<0.05; ** p<0.01; ***p<0.001; n.s.= not significant*

In Ennstal, air temperature (r_s =0.47***) and soil water content (r_s =0.52***) were the most important factors increasing soil N_2O emissions. At arable sites in Grieskirchen, N input by mineral and organic fertilizer had the highest impact (r_s =0.51***). At grassland sites additional to fertilizer input (r_s =0.52***) also the content of soil organic C (r_s =0.44**) was important. In Marchfeld soil parameters like content of organic C (r_s =0.61*) and soil water (r_s =0.50***) are important drivers for the emissions. At arable sites in Muehlviertel, low pH-value (r_s =-0.50***) and low water content (r_s =-0.50***) in combination with high soil organic C content (r_s =0.47***) increased N_2O emissions, whereas from grassland soils, higher emissions occurs at sites with low pH-value (r_s =-0.50**) and lower soil organic C content (r_s =-0.39*). At arable and grassland sites in Oststeirisches Huegelland, climatic parameters, mean annual temperature (r_s =0.49***; r_s =0.62***) and precipitation (r_s =0.52***; r_s =$0.31^{n.s.}$) and soil temperature (r_s =0.53***; r_s =0.61***) correlated with N_2O emissions. In Rheintal only soil temperature (r_s =0.27*) had a significant influence on annual N_2O emissions.

D3 Regional C and N budgets including N_2O emissions and nitrate leaching.

The table in the annex shows the net N budget including all soil types, climate stations and different land uses for each region in NitroAustria. This calculation contains all gaseous N losses, NO_3^- leaching and the N-pool in the mineral soil. Overall, N is stored in all six regions. The highest N storage is estimated for Grieskirchen with a rate of 11.7 kg N ha^{-1} a^{-1} while for Marchfeld a rate of 0.2 kg N ha^{-1} a^{-1} is calculated. N outputs are dominated by crop removal (more than 50%) and NO_3^- leaching, varying between 8.2 ± 3.4 kg N ha^{-1} a^{-1} in Rheintal and 43.0 ± 24.4 kg N ha^{-1} a^{-1} in Oststeirisches Hügelland. Amongst gaseous N fluxes, the highest losses are observed from N_2 emissions while N_2O emissions represent only approximately 1% of total N losses. With no regard on land use within the regions, lowest N_2O emissions are estimated for Marchfeld (1.0 ± 0.3 kg N ha^{-1} a^{-1}) whereas N_2O emissions in Ennstal or Rheintal are twice and three times, respectively, as high. NH_3 volatilization from soils varies between 0 kg ha^{-1} a^{-1} in Mühlviertel and 17.4 ± 2.2 kg ha^{-1} a^{-1} in Marchfeld. The largest components of N input are mineral fertilizer and manure, respectively. The highest biological N fixation rate was estimated for Mühlviertel with 8.8 ± 0.2 kg N ha^{-1} a^{-1} due to cultivation of legume grass.

The table in the annex shows the net carbon budget for each region in NitroAustria including the C-pool in the mineral soil. The largest amount of C output is total ecosystem respiration (TER) and exceeds almost 50% of total carbon losses. Heterotrophic soil respiration varies from 2.3 ± 0.3 Mg C ha^{-1} a^{-1} in Marchfeld to 5.6 ± 0.2 Mg C ha^{-1} a^{-1} in Ennstal. Compared to the N budget, crop removal is merely 20% of total C losses. Carbon input is dominated by photosynthesis. The highest rates are estimated in Oststeirisches Hügelland (19.2 ± 1.2 Mg C ha^{-1} a^{-1}) whereas lower rates occur in Mühlviertel (15.3 ± 1.2 Mg C ha^{-1} a^{-1}).

*D4 produced a draft for a scientific paper "*Exploring N_2O hot spots and hot moments with LandscapeDNDC*" Journal: Agriculture, Environment and Ecosystems; Date of Submission: March 30, 2018 (see annex).*

D5 Evaluation of GHG mitigation potential with improved agricultural management

For the two "hottest" soil types in the two land use categories we simulated N_2O fluxes with a reduced annual N application up to 20%. A reduction of N fertilizer by 15 % in Marchfeld (cropland) and 20 % in Rheintal (grassland) decreased the cumulative N_2O emissions up to 25% in Marchfeld and 42% in Rheintal. Yield performance of onion, winter cereals as well as summer barley was about 95% of regular N fertilization, whereas beet, corn and perennial grass were more sensitive to the mitigation of fertilizer and yields were reduced by approximately 10%.The GHG N_2O responded more sensitive to N mitigation as plant growth in both land use categories. This finding supports the intention of the Austrian government, as they in LE 14-20[8] stimulate by monetary compensation to the farmers to reduce N fertilization in practice. Results of other mitigation measures, as the effect of catch crops, can be found in WP4 (D3 and D4). With

[8] BMLFUW 2016: Agrarumweltprogramm ÖPUL 2015, Landwirtschaft Umwelt und Natur, Wien, ISBN 978-3-903129-15-3

the prospect of increasing temperatures, especially in the Alpine regions (IPCC, 2007), fertilization rates above plat uptake will be a challenge for climate friendly agriculture[9].

WP4 Providing data on agricultural management in Austria developed crop rotation scenarios from selected regions (Tables 3 – 5). WP leader AGES is conducting field trials for classification and authorisation of new cultivars of all arable crops in all relevant arable regions in Austria. Practical and concrete data on location, management (soil cultivation, sowing, fertilisation, harvesting), yields and N contents (from all cereals) are available. Based on this, the necessary site/regional/national arable management input data for the LandscapeDNCD model could be provided.

M1 Determination of the required management data for the model: The available management data (dates of tillage, drilling, N fertilization, harvest) from the AGES field trials for licensing procedure for new cultivars were summarized from 2005 to 2014 from Styria and Mühlviertel, the data from Marchfeld and Grieskirchen were completed with the actual dates of the last years (former data were available from FarmClim).

M2 Survey of the field trials results (yield and management data): The field trial results (yields and quality parameters) from the following crops were compiled and for modelling forwarded to WP 2: winter wheat, spring and winter barley, rye, triticale, rapeseed, maize, sugar beet, pea, potato and pumpkin. Due to different weather conditions the yields varied within a respectable range during this 10 year period: Mühlviertel: winter wheat 5.3 – 9.2 t/ha, triticale 6.5 – 8.7 t/ha, rape 3.6 – 5.1 t/ha; Styria: maize 10.8 – 12.7 t/ha; winter wheat 5.2 – 8.6 t/ha and winter barley 5.1 – 7.8 t/ha.

D1 Generating and forwarding of the scenarios for crop rotations in the different arable regions: From the INVEKOS data pool, the agricultural areas and crop percentages on arable were selected and compiled. On this database crop scenarios were proposed and arranged in cooperation with WP2.

Table 3: Agricultural areas in the regions (2013)

Region	Agricult. area (ha)	Grassland (ha)	Arable Land (ha)	Arable Land %
Mühlviertel	150 111	89 104	61 006	40.6
Rheintal	13 587	11 116	2 471	18.2
Grieskirchen	161 945	23 247	138 698	85.6
Südost Steiermark	136 187	31 285	104 902	77.0
Marchfeld	56 912	890	56 022	98.4
Ennstal und Seitentäler	33 303	32 339	964	2.9

Considering the relevant data crop rotations were generated, only conventional farming was included and high N demanding crops were selected. N-Fertilising

[9] van Groenigen, J.W., Velthof, G.L., Oenema, O., Van Groenigen, K.J., Van Kessel, C., 2010. Towards an agronomic assessment of N2O emissions: a case study for arable crops. European Journal of Soil Science 61, 903-913.

rates were in accordance with the Austrian recommendations[10]. For Styria, the proposed crop rotation comprises a share in corn (incl. for ensilage) of 75%, meanwhile restrictions entered into force as from 2017 the maximum share is fixed at 67% (Stmk. Maiswurzelbohrer-Verordnung 2015). Therefore the calculated results characterise a worst case scenario as much less N demanding crops such as soya and oil pumpkin corn will substitute corn.

Table 4: Crops in % on arable land (2013)

Region	Winter - cereal s	Spring cereal s	Maiz e incl silag e	beet, potato, veget	oil plants (excl soya)	grain leg (incl soya)	forage crops & temp gl	fallow & nature conserv
Mühlviertel	30.8	12.2	16.2	1.0	0.9	1.8	33.8	3.2
Rheintal	5.1	0.6	48.2	3.0	0.0	0.0	40.0	3.0
Grieskirchen	40.7	2.8	29.7	5.3	5.9	7.7	4.0	3.9
Südöstl STMK	10.7	2.8	62.0	1.2	9.7	4.0	6.4	3.1
Marchfeld	39.7	8.1	8.8	26.2	5.4	3.8	2.1	5.8
Ennstal	1.8	0.5	42.5	1.2	0.0	0.0	44.5	9.5

D2: Generating and forwarding of the scenarios for grassland management from selected regions: For intensive grassland the number of mowing was at least four times, therefore the manure was applied in early spring and later immediately after mowing. Extensive grassland is used as pasture for the cattle, only one mowing date. N input from animal husbandry was calculated using regional INVEKOS data (number of animals) and N quantity acc. to the Offical Fertilizer Recommendations (Richtlinien für die sachgerechte Düngung, 6. Auflage, 2006)

Table 5: Manure and mineral fertilizer application in Autrian regions

		Manure	Mineral fertiliser
Region	Management	kg N/ha	kg N/ha
Ennstal	intensiv	154	23,6
	extensiv	34	0
Rheintal	intensiv	135	63
	extensiv	34	0
Mühlvietel	intensiv	134	44
	extensiv	39	0
STMK Südost	intensiv	196	0
	extensiv	39	0
Grieskirchen	intensiv	206	0
	extensiv	37	0

D3: Generating and forwarding of the scenarios in arable regions with and without agro environmental measures: For arable land, the most prominent agro environmental measures are focused on optimisation of adequate N fertilization in regions, where nitrate content in groundwater exceeds the limit, combined

[10] Fachbeirat für Bodenfruchtbarkeit und Bodenschutz: Richtlinien für die sachgerechte Düngung, 6. Auflage, Hrsg. BMLFUW, 2006.

with the obliged cultivation of cover crops at a minimum rate of 10% of arable area. The largest groundwater zone in Austria with still constant average nitrate contents above the limit is the Marchfeld region (80–90 % acceptance of these agro environmental measures). Therefore, we extended the scenarios for testing the combination of these two measures only in the Marchfeld: Three additional managements adjusted with the requirements of ÖPUL were tested on the two different sites (SALO: sandy loam and LOSI: loamy silt), altogether six additional scenarios were calculated in comparison to the base scenario.

Table 6: Crop rotation incl. cover crops and fertilizer N-Input in kg ha^{-1} (changes in relation to Base in %) at the four tested managements

	Base & cover crops	Minus-N & cover crops	Plus-N & cover crops	Base without Cover crops
S-BARLEY & Cover crop	55	45 (-18%)	75 (+36%)	55 (100%)
CORN	135	115 (-15%)	155 (+15%)	135 (100%)
W-WHEAT & Cover crop	130	115 (-12%)	160 (+23%)	130 (100%)
ONION	120	100 (-17%)	140 (+17%)	120 (100%)
W-WHEAT	130	115 (-12%)	160 (+23%)	130 (100%)
W-BARLEY & Cover crop	120	100 (-17%)	140 (+17%)	120 (100%)
W-WHEAT & Cover crop	130	115 (-12%)	160 (+23%)	130 (100%)
SUGAR-BEET	110	95 (-14%)	130 (+18%)	110 (100%)
Crop Rotation (Average)	**116.3**	**100 (-14%)**	**140 (+20%)**	**116.3 (100%)**

D4: Assessment of results and practical recommendations: The total amount of N_2O-N emissions and the EF was obviously influenced by all tested factors: At the porous sandy site SALO the N_2O-N EF (1.04%) is in good agreement with the IPCC 1% EF, at the loamy site LOSI the EF is 1.57 (Base management). At both sites the model results show that N_2O emissions tend to grow in response to additional N fertilization at a rate significant higher than linear: With a 20% higher N input the N_2O emissions increase exponentially up to 33.5 and 36.7%. Otherwise, with the 16% reduction of the N inputs a 25% and 26.4% decrease of N_2O-N emissions was calculated. The management without cultivation of cover crops, which causes a lot of harmful effects such as soil erosion, degradation of soil structure and nitrate leaching, showed significant lower N_2O emissions and an EF smaller than IPCC EF. The small reduction in N_2O emissions however cannot compensate for the immense environmental benefits of these measures.

Results from a growing number of field experiments with multiple N fertilizer rates indicate that emissions of N_2O respond in an exponentially increasing manner to increasing N inputs. Small fertilizer inputs will little affect N_2O emissions, but fertilization at levels greater than crop need will have a disproportionate and increasingly negative impact on N_2O emissions. Our results are in agreement with Hoben et al. (2011)[11] and Shcherbak et al. (2014)[12]. The

[11] Hoben JP, Gehl RJ, Milnar N, Grace PR & Robertson GP (2011): Nonlinear nitrous oxide (N_2O) response to nitrogen fertilizer in on-farm corn crops of the US Midwest. Global Change Biology 17 (2), 1140-1152.

results are of particular relevance esp. for an awareness campaign to the farmers, demonstrating the exponential increasing harmful effects to groundwater pollution and climate change, when the N fertilizer is given in excess to crop demand. The introduction of limited N inputs is an important first step in selected areas for groundwater protection. The effects of cover crops are still not accounted in fertilizer recommendations, improvements in the management of cover crops esp. in timing and manner of incorporation should be evaluated for increasing the N transformation from the cover crops residues to the following main crop. Efforts are necessary for improvement of N use efficiency (NUE), esp. by including the N inputs from crop residues and cover crops. Farmers also should become more aware of their fram specific NUE by using simple tools for calculation.

The scientific paper planned for D5 on "N_2O emissions in different regions of arable crop production in Austria" is combined with the scientific paper D4 of WP3.

WP5 Application of results and use for the GHG inventory

M1: Comparison of the different N_2O modelling approaches: The model LandscapeDNDC was discussed in the light of other process-oriented models (e.g. Daycent, Expert-N, CoupModel, EPIC, Sundial-Magec, CCB) and compared with the concept of the GHG inventory reporting laid down in the 2006 IPCC guidelines[13],[14]). The IPCC default value of 1.0 % (0.01 kg N_2O-N per kg N applied) for direct N_2O emissions from the soil is based on a regression relationship[15], which represents an empirical model to calculate fertilizer-induced emissions (FIE[16]). Process-oriented models of greater complexity have been developed over recent years. Key factors affecting N_2O emissions from fertilized agricultural soils are (i) environmental factors, (ii) management-related factors, (iii) measurement related factors. The process-oriented model LandscapeDNDC simulates relative growth rates of denitrifiers and concentration of DOC and N oxides in the soil for various land use types. The soil matrix is divided into aerobic and anaerobic zones[17]. Detailed model description and main evidences from comparisons of process-oriented models can be found in the annex. Future

[12] Shcherbak I, Milnar N &Robertson GP (2014): Global metaanalysis of the nonlinear response of soil nitrous oxide ((N_2O) emissions to fertilizer nitrogen. PNAS vol. 111, no. 25, 9199-9204

[13] IPCC – Intergovernmental Panel on Climate Change (2006): 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and anabe K. (eds). Published: IGES, Japan.

[14] Umweltbundesamt (2014): Anderl, M.; Freudenschuß, A.; Haider, S.; Jobstmann, H.; Kohlbach, M.; Köther, T.; Kriech, M.; Lampert, Ch.; Moosmann, L.; Pazdernik, K.; Pinterits, M.; Poupa, S.; Schmid, C.; Stranner, G.; Schwaiger, E.; Schwarzl, B.; Weiss, P.; Zechmeister, A.: Austria's National Inventory Report 2014 – Submission under the United Nations Framework Convention of Climate Change and the Kyoto Protocol. Report REP-475, Vienna

[15] Bouwman, A.F. (1996): Direct emissions of nitrous oxide from agricultural soils. Nutrient Cycling in Agroecosystems. Volume 46, Issue 1, pp 53-70.

[16] Smith, K.A.; Bouwman, L. & Braatz, B. (2000): N2O: Direct Emissions from agricultural soils. Background Paper to the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000).

[17] Smith J.; Gottschalk, P.; Bellarby, J.; Richards, M.; Nayak, D.; Coleman, K.; Hillier, J.; Flynn, H.; Wattenbach, M.; Aitkenhead, M.; Yeluripurti, J.; Farmer, J. & Smith, P. (2010): Model to Estimate Carbon in Organic Soils – Sequestration and Emissions (ECOSSE). User-Manual.UK.

progress in modelling denitrification is strongly linked to the acquisition of new measurements data and to new experimental work to decrease uncertainty of model predictions. Calibration and validation is necessary, since the spatial and temporal variation of N_2O emissions is rather high.

M2 + D1: Evaluation of model results for GHG inventory use, Comparison and Discussion of the model outcome with NIR conception , D4 Scientific paper on Evaluation of regional N_2O emission factors based on model results for GHG inventory use: Direct N_2O emissions from the two following CRF source categories were investigated for 6 Austrian regions using the model LandscapeDNDC: (i) 3.D.a.1 Direct soil emissions - Inorganic N fertilizers and (ii) 3.D.a.2.a Direct soil emissions - Animal manure applied to soils. In addition to the application of fertilizers, the LandscapeDNDC model also considers N-inputs from crop residues, not as a separate source of N_2O-emissions, but model inherent. This is a main difference to the EF of the Austrian GHG inventory: In the UNFCCC reporting crop residues are treated as a separate source (CRF 3.D.a.4) This issue is been dealt by adjusting the resulting, modelled regional emission factors (EFs). Thus, adjusted, weighted, regional average LandscapeDNDC N_2O-N EFs have been derived and compared to the direct N_2O emissions from inorganic, mineral N fertilizer and manure N application on agricultural soils using the 2006 IPCC default emission factor (EF) of 0.01 kg N_2O-N/kg N applied.

Comparison of the input data showed further differences between LandscapeDNDC and national GHG inventory. For instance in the model LandscapeDNDC regional mineral fertilizer N was assumed as supplement to the estimated amount on available manure N per region in order to reach regional and crop specific requirements of N-input according to the fertilizing recommendations. Region-specific crop rotations reflect the most common region specific cultivars for the years 2005 to 2014. The national GHG inventory does not separate between cropland and grassland and does not use application rates per ha as activity data for emission calculation, but uses annual data of national mineral fertilizer input, crops and yields. Results of the LandscapeDNDC model in 6 different regions in Austria show high variations of fertilizer application amounts and calculated N_2O emissions per region. N_2O emissions from intensive grassland were higher than those emitted from cropland. Average weighted LandscapeDNDC N_2O-EF for all 6 modelled regions resulted in a lower mean value of 0.0062 kg N_2O-N/kg N applied compared to the 2006 IPCC default N_2O-EF of 0.01 kg N_2O-N/kg N applied. Furthermore, to allow conclusions to be drawn for the entire territory of Austria, detailed data on fertilizer amounts applied on grassland and cropland areas would be needed, which are not available yet. The modelled regional N_2O emission factors (EFs) in intensive, fertilized grassland areas (three and more cuts) turned out to be higher than the IPCC default value, the modelled regional N_2O EFs on fertilized cropland areas were lower.

M3 Trade-offs between GHG-emissions + D2 Discussion and trade-offs between GHG emissions: A literature review on the use of the term "trade offs" in relation to GHG emissions was conducted. Measures to reduce N_2O emissions from the model results (WP3), literature review and the previous ACRP-project "FarmClim" are discussed and their trade off effects on other GHG and N emissions and soil carbon stock change were shown.

Within this study we put emphasis on trade off effects of measures to reduce nitrous oxide emissions on other GHG and N emissions. At global scale nitrogen addition increased the global C sink, CH_4 emissions and also N_2O emissions and reduced CH_4 uptake (LIU & GREAVER 2009[18]). Potential trade-offs with conservation tillage occur between SOC sequestration and enhanced N_2O emissions (e.g. JOHNSON et al. 2007[19], FREIBAUER et al. 2004[20], DENDONCKER et al. 2004[21]). In the EU-project catch C the evaluation showed that N_2O emissions rose with most of the management practices that have been assumed to be "best management practices" so far (SPIEGEL et al. 2014[22]). If only the overall investigated Climate Change indicators SOC stock, CO_2-emissions, N_2O emissions and CH_4-emissions are considered, preferential management practices are: (i) Farm yard manure application, (ii) Crop rotation, (iii) Non-inversion tillage (iv) Compost application.

An overview on the N_2O reducing measures and their trade off effects on other GHG and N emissions as well as on carbon sequestration is given in the Annex to WP5, table 33. The effects on soil carbon levels and chemistry are considered, because of the important balance between fertilizer application and therefore increasing carbon sequestration through greater biomass production versus the undesirable alternative consequence of increased N_2O emission (THOMSON et al. 2012[23]). Improvement of nitrogen use efficiency (NUE) by use of urease inhibitors might prove to be an option to reduce both N_2O and NH_3 emissions (REIS et al. 2015[24]).

D3: Proposals for a policy framework towards climate friendly farming (24): Based on the regional mitigation measures worked out in WP3, a proposal towards climate friendly farming will be given. The focus of our proposals for a policy framework towards reduction of nitrous oxide losses lies on increased nitrogen use efficiency. It is therefore the goal, that as much as possible of the fertilized nitrogen is taken up by plant roots, is then optimally used for protein

[18] Liu, L. & T. L. Greaver (2009): A review of nitrogen enrichment effects on three biogenic GHGs: the CO_2 sink may be largely offset by stimulated N_2O and CH_4 emission. Ecology Letters 12, pp. 1103 – 1117.

[19] Johnson, J. M. F.; Franzluebbers A. J., Lachnicht-Weyers, S. & D. C. Reicosky (2007): Agricultural opportunities to mitigate greenhouse gas emissions. Environmental pollution 150, pp. 107 – 124

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[21] Dendoncker, N.; Van Wesemael, B.; Rounsevell, M. D. A.; Roeland, C. & C. Lettens (2004): Belgiums CO_2 mitigation potentrial under improved cropland management. Agriculture, Ecosystems & Environment 103, pp. 101 – 116.

[22] Spiegel H., Schlatter N., Haslmayr H.P., Lehtinen T., Baumgarten A., Grignani C., Bechini L., Krüger J., Zavattaro L. (2014): Compatibility of Agricultural Management Practices and Types of Farming in the EU to enhance Climate Change Mitigation and Soil Health. D3.334 „shortlist BMP Climate". www.catch-c.eu .

[23] Thomson, A.J.; Giannopoulos, G.; Pretty, J.; Baggs, E.M & Richardson, D.J. (2012): Biological sources and sinks of nitrous oxide and strategies to mitigate emissions. Philosophical Transactions of the Royal Society B 367, 1157-1168.

[24] Reis, S.; Howard, C. & Sutton, M.A. (2015) (eds): Costs of Ammonia Abatement and the Climate Co-Benefits. Springer.

formation in the plant and is then removed with the crop harvest. „Nitrogen Use Efficiency – NUE“ is also an Agro-Environmental Indicator (AEI) of the OECD, which is defined as the physical nitrogen input/output ratio. It has been used in the agro-policy context, e.g. during the revision of the UNECE Gothenburg Protocol to reduce acidification, eutrophication and ground-level ozone or in the EU climate and bio-energy policies. NUE can be calculated as the ratio between the amount of fertilizer N removed with the crop and the amount of fertilizer N applied and is expressed in percent (%).

The annex works in detail on possible measures to increase NUE. Here, we summarise the main points: (i) N-fertilization at the right time, (ii) N-fertilization at the right level, (iii) N-fertilization with right fertilizer type, (iv) N-fertilization at right soil conditions.

Many of these measures are already implemented in the Austrian agricultural practice and supported in the Austrian agri-environmental–climate measure (AECM) as part of the Rural Development Programme (RDP). More improvements and combinations of different measures towards higher nitrogen use efficiency could introduce a more intensive N_2O emission reduction. Chemical soil analyses to determine nitrogen pools and availability in the soil, like implemented in the ÖPUL-Maßnahme „Vorbeugender Grundwasserschutz“, should be prescribed also in other measures as an effective tool to adapt N-fertilization rate. Accompanied by retrospective nitrogen use efficiency (NUE) calculations and splitting of fertilizer amounts this would lead to further improvements in the nitrogen fertilizer management. Easy available knowledge on the variety of crops and their different nitrogen needs could assist these efforts towards better nitrogen use efficiency.

Furthermore new developments of sensor technology decision systems and satellite images taking into account weather conditions and forecasts to regulate nitrogen fertilizer amount at field (parcel) level should be evaluated for their possible use and expansion, as well as the increased use of enhanced nitrogen use efficiency products.

Finally agricultural policy should support the worth of individual experiences of the farmers grounded on their historical decisions by providing easy available and to fill out recording tools at field level, that serve many purposes (“one tool – fits all”) to lower administrative burden for the farmers. Best tools are those that support the farmers by calculating figures that express, what has been before more intuitive good practice knowledge.

D4: Scientific Paper on Evaluation of Austrian regional N_2O emission factors based on process-oriented model results for GHG inventory use and proposal for a policy framework towards N_2O emission reduction (24): see Annex

WP6: Climate change scenarios and statistical analysis of modelling results: We run simulations and determined N losses under climate change scenarios from 2031-2040. We determined factors influencing N losses (gaseous

N_2O) and identified regions where N losses will increase under CC Scenarios (temperature increase and precipitation change). Site, management and setup files from the selected regions in Austria provided by WP2 were used for simulation runs. Climate files with climate change scenarios were compiled to run the simulations under climate change scenarios.

M1: Assembly of climate input data for LandscapeDNDC modelling: All available meteorological data (10 years) for the baseline scenario were extracted from the ZAMG database and gap-filled with nearby stations; We compiled a database with daily values of air temperature (mean, min, max), precipitation, air humidity, wind speed, global radiation in daily resolution. The climate data were processed and brought into the input format that is needed for LandscapeDNDC.

D1: Database of climate scenarios for model regions: Climate change scenarios provided by Strauss et al. (2012)[25] were extracted from the webpage and assembled for the climate input files for the different scenarios. The first scenario is where the mean temperature for the period 2008–2040 is at its maximum (Sc. 10x), the second where it is at average (Sc. 20x) and the third at minimum (Sc. 30x). Furthermore, precipitation scenarios (-20% (Sc. y09), +20% (Sc. y05), no change (Sc. y01)) were used.

M2: Run simulation with LandscapeDNDC: The input parameters for LDNDC were kept constant as for the baseline scenarios (2005-2014), only climate input data was changed accordingly. The chosen climate scenarios showed the following temperature and precipitation changes (**Figure 3**). Highest increase in mean annual air temperature over a 10 year period is predicted for the MF region (1.5-1.8°C) followed by RT (1.1-1.6°C). In GK and ET the lowest increase was shown (0.1-0.7°C). Prior to the selection of climate clusters we ensured that the average precipitation in the baseline do not differ significantly from the unchanged precipitation scenarios (101). However, it turned out to be that at some sites the baseline data almost reached (GK, ET Irdning) or already reached (MV, RT Bregenz) the + 20% precipitation increase scenarios (105), which unfortunately makes a statement on effects of a 20% precipitation increase on N_2O fluxes on these sites impossible.

[25] Strauss, F. (2012): Modeling climate change and impacts on crop production in Austria. Dissertation, Universität für Bodenkultur, Institut für Nachhaltige Wirtschaftsentwicklung.

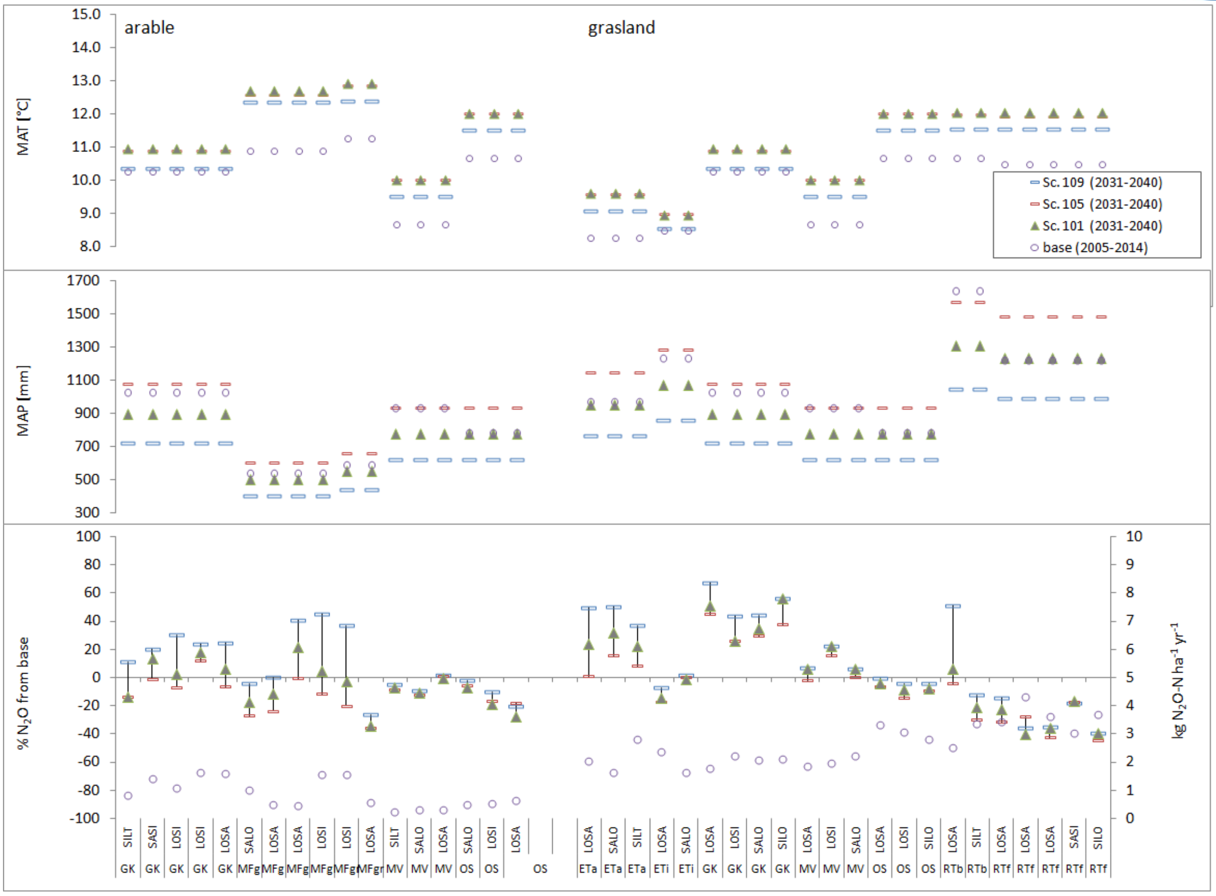


Figure 3: Mean annual air temperature (MAT), mean annual precipitation (MAP), mean N_2O flux (kg N ha-1 yr-1) and % change of N_2O simulated for Sc. 101, 105, 109 from baseline runs (2005-2014) and scenarios 101-109 (2031-2040) at arable and grassland sites seperated by region. GK= Grieskirchen, MF=Marchfeld (climate station: g=Gänserndorf, gr=Grossenzersdorf), MV=Muehlviertel, OS=Oststeiermark, ET=Ennstal (climate station: a=Aigen, i=Irdning), RT=Rheintal).

In Figure 3 the mean annual N_2O fluxes at baseline conditions (N_2O-base) and the % change of the Scenarios 101, 105 and 109 separated by region are shown. The N_2O loss is significantly lower from arable land compared to grassland sites (see also WP3). Independent of soil type the regions MV and OS showed the lowest N_2O losses followed by the loamy sand at MF Gänserndorf. Highest N_2O losses were simulated for the grasslands in RT (see WP3). Under the chosen climate change scenarios, an increase in N_2O fluxes was simulated for the – 20% precipitation scenarios (Sc. 109) at all arable soils and at almost all grassland soils (exception is RT Feldkirch). At GK, ET Aigen, MF and RT Bregenz N_2O fluxes will significantly increase. Increases of up to 70% were predicted at the LOSA in GK. When precipitation increases peak emissions are not as high as in the precipitation decrease scenarios (Sc. 109). Soil water content, one of the main drivers of N_2O fluxes, is higher throughout the year in Sc. 105 and peak emissions after rewetting events are not as pronounced. Almost no effect of temperature and precipitation changes on N_2O emissions could be predicted for grassland and arable soils in MV and OS and ETi. Lower soil N_2O losses (up to -

40%) are predicted for the soil type LOSA at MFgr, MV, OS and RTf.

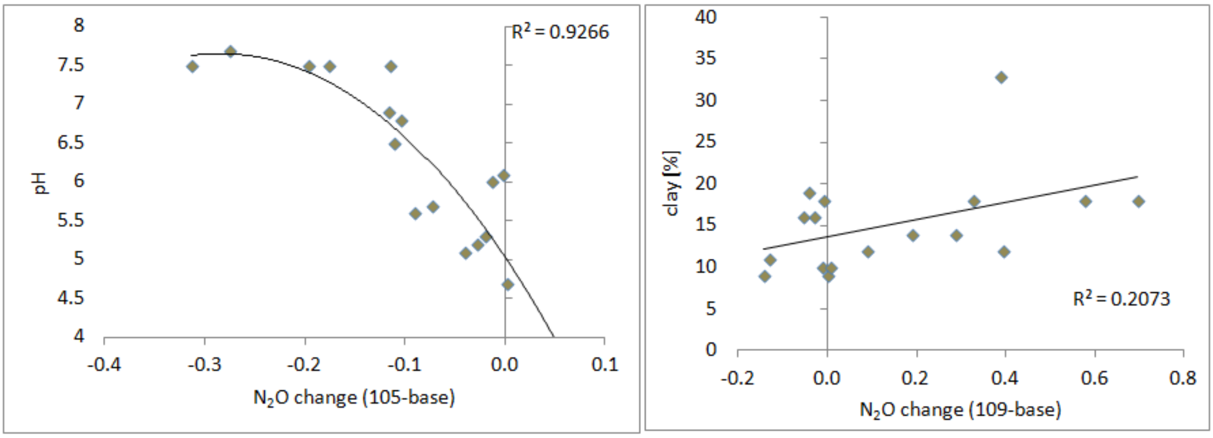


Figure 4 Dependency of N_2O changes (left: 105-baseline and right: 109-baseline) at arable soils in dependency of pH and clay content.

At arable soils, mean annual N_2O emissions from all scenarios and from baseline runs correlate positively with clay content and field capacity (up to $r=0.6$, $p<0.01$). At arable soils, N_2O flux changes are predicted depending on soil pH value (Figure 4), at grassland soils a similar dependency is visible (data not shown). Furthermore, LDNDC predicts lower annual N_2O losses at higher annual precipitation (Sc. 105) at sites with higher soil pH. At these sites and under these conditions denitrification and the production of N_2 instead of N_2O is the main pathway for gaseous N-losses. Independent of soil pH, lower soil N pools, higher NO_3 leaching and higher N_2 losses were predicted at the +20% scenarios (see also N-Budgets for the 9 different scenarios). Our data show that under reduced future precipitation (Sc. 109) N_2O production is especially favoured at arable sites with higher clay content (Figure 4). Soils with higher clay contents are suitable habitats for microorganisms = peak emissions get higher after drier periods at these sites. During drier periods, N leaching is reduced and N cannot be accessed that easy by plants or microorganisms. After rainfall, favourable conditions for microorganism establish and enough nitrogen is available for N_2O production.

D2: Maps of N_2O emissions from modelled regions under climate change scenarios: Maps of actual and future N_2O fluxes of the scenarios 101, 105 and 109 were created for all regions, in Figure 5 Grieskirchen is shown as an example. All other maps from the other regions and all other scenarios are shown in the Appendix.

D3: Generating N-budgets for the selected regions under climate change scenarios: Nitrogen budgets were estimated by calculating export and input of all relevant fluxes for each region with the LandscapeDNDC model. Tables in the annex show the net nitrogen budget from the scenarios 101, 105 and 109 including all soil types, climate stations and different land uses, crop rotation and years for each region. Positive values indicate fluxes from the ecosystem to the atmosphere while fluxes from the atmosphere to the ecosystem are negative. All values are weighted means (method see WP3) (according to area of soil type) from 2031 to 2040. This calculation contains all gaseous N losses, NO_3^- leaching and the N-pool in the mineral soil. In five of six regions the soil is a net sink of N in all three scenarios (101 – 109). At average the soil N increases with 3 to 16 kg N ha^{-1} a^{-1} in Muehlviertel, Rheintal, Oststeirisches Hügelland, Grieskirchen and Ennstal. Only in Marchfeld a depletion of soil N in the scenarios 101 and 105 with minus 5 and 2 kg N ha^{-1} a^{-1} is calculated in scenario 109 the N budget in Marchfeld is in balance.

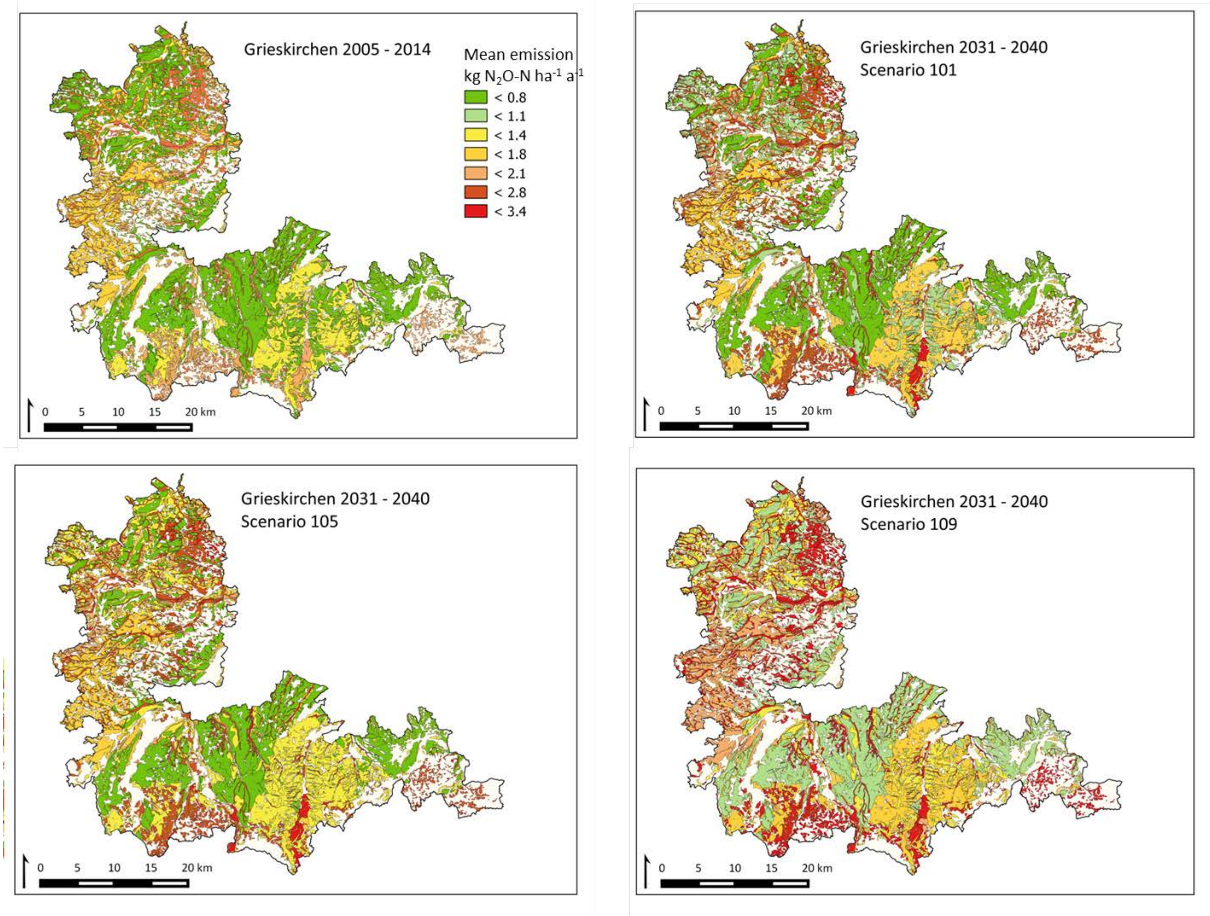


Figure 5 Map of mean annual baseline N_2O emissions (years: 2005-2014) and mean annual emissions (years: 2013-2014) of Sc. 101, 105 and 109 of the region Grieskirchen

General findings – N budgets: In all future climate scenarios more N is stored in soils at Muehlviertel, Grieskirchen, Ennstal, Oststeirisches Huegelland and in Rheintal. In these regions the average accumulation of soil N ranges from 3 to 22 kg N $ha^{-1}a^{-1}$. Overall, the highest soil N storage is calculated for Sc. 209 with temperature increase and 20% less precipitation. In Marchfeld there is a depletion of soil N in most scenarios ranging from 2 to 7 kg N $ha^{-1}a^{-1}$. In scenario 109 the net N budget for Marchfeld is in balance and in Sc. 209 a gain of 5 kg N $ha^{-1}a^{-1}$ is estimated. Since the management options were kept constant for all scenarios the difference in input is only minor and due to small differences in deposited N from the atmosphere. The calculated net balance is therefore mainly driven by climate related changes in N output especially the quantity of crop removal, NO_3 leaching and gaseous losses (i.e. N_2 emissions). Findings in detail can be found in the Appendix.

D4: Scientific paper on comparing current and future N losses of arable soils in selected regions in Austria: Title: N_2O losses from Austrian grassland soils under climate change. A modelling approach. Journal: Nutrient cycling in agroecosystems; Date of submission: 01.05.2018

2.2.5 Description of difficulties, if any, encountered in the achievement of project targets

All project targets, milestones and deliverables have been reached. No difficulties are to be reported here. The planned peer reviewed publications are on track and will be published in 2018.

2.2.6 Description of project "highlights"

WP1: The most prominent of NitroAustria specificities of is the immense commitment of the project team. A total of ten project meetings proofs the highly intensive collaboration and partners. Major outcomes have successfully been shared with the agricultural and scientific community.

WP2 and WP3: Within the NitroAustria project, the LandscapeDNDC model was further developed and adapted, especially for grassland management. We gathered a large dataset of site specific parameters and regional N_2O fluxes. Overall, our results showed that there are significant differences between arable and intensive grassland manged soils. On intensively managed grassland sites N_2O emissions were in tendency higher compared to arable sites whereas in extensively managed grassland they were rather low.

The analysis of hot moments of N_2O emissions showed that in intensively managed grassland continuous fluxes all year round are predominating. However, N_2O peaks can represent up to 53% of mean annual emissions and occur mainly after fertilization and in the vegetation period between April and October. N_2O emissions from arable soils are more event-related (e.g. harvest, fertilization, crops, etc.) compared to grassland. Especially crops with high demand for fertilizer leaving most of the soil uncovered as temperatures in late May and beginning of June rises are exposed for extreme N_2O emissions peaks, representing up to 80% of yearly emissions. According to the soil types (hot spots), we found significant differences in N_2O emissions within the regions but no general trend for hot spots across all modelled regions in Austria. In summary, high nutrient availability together with favorable air temperature and soil water content seem to trigger N_2O emission.

In each region various factors (e.g. soil temperature, precipitation or soil parameters) are limiting N_2O fluxes. Furthermore, N_2O emissions varied between years, crop rotations and climate. Reduced N fertilisation rates can significantly decrease N_2O emissions in cropland as well as in grassland. It can be stated that the LandscapeDNDC model is a suitable tool to reflect the complexity of biochemical processes combined with the heterogeneity of local and regional agro-ecosystems in Austria.

WP4: Due to the different site and climate conditions in Austria, highly diverse land use systems are existent: cereals, sugar beet and vegetables in the Marchfeld, maize in Styria, crop rotations dominated by maize and cereals in the Alpenvorland and forage crops and grassland in Alpine regions. The importance of regional specific EF for national greenhouse gas inventory and practical recommendations is evident. LandscapeDNDC calculated a distinct exponential increase of N_2O-N emissions accompanied with increasing N input at the two sites in MF compared to the linear IPCC-EF. This finding is in accordance with the results of a Global metaanalysis of the nonlinear response of soil nitrous oxide (N_2O) emissions to fertilizer nitrogen. The great importance of an efficient nitrogen use management is evident and should be calculated for each year by the farmer and on this basis N use efficiency should be improved by adequate management of the following crop.

WP5 evaluated regional denitrification model results for their potential use in the Austrian Greenhouse gas inventory. The modelled regional N_2O emission factors (EFs) in intensive, fertilized grassland areas (three and more cuts) turned out to be higher than the IPCC default value, the modelled regional N_2O EFs on fertilized cropland areas appeared to be lower (see table). Thus, the IPCC default value for direct N_2O emissions from the soil turned out to be valuable for Austrian conditions. LandscapeDNDC model helps to extend the limited information covered by the current default approach based on the IPCC methodology. It shows bandwidth of possible N_2O-emissions in different Austrian regions for intensive grassland and arable land areas. Hot moments in cropland can lead to 60-80 % of the annual N_2O-emissions during one to two weeks. In intensive grassland soils positive correlation with fertilizer amounts was asserted and hot moments could be observed one to two weeks after fertilization (in June) in combination with high average and soil temperature, resulting in up to 60 % of the yearly total N_2O emissions within this period. The focus of our proposals for a policy framework towards reduction of nitrous oxide losses lies on increased nitrogen use efficiency. Nitrogen Use Efficiency – NUE is also an Agro-Environmental Indicator (AEI) of the OECD, which is defined as the physical nitrogen input/output ratio. In future national fertilizer recommendations a proposal for a kind of feedback tool at field level by calculating nitrogen balances should be implemented. Calculation of N use efficiency per field could give an even deeper insight, whether the recommended fertilizer level has been adequate or not. This and other measures towards reduction of nitrous oxide emissions were compiled by the interdisciplinary project team.

WP6 determined factors influencing N emissions with the aim to identify regions where N losses will increase under CC Scenarios. The highlight of this WP is the finding that N_2O losses are predicted to increase under drier conditions. Soil rewetting after dry periods can be responsible for hot moments of N_2O production which contribute with a high percentage to the annual N_2O losses. Peaks in N_2O emissions are predicted to be higher under lower annual precipitation. The simulation results show that soil types has not such a big influence in the magnitude of N_2O production compared to the agricultural region. Grassland soils emit significantly more N_2O compared to arable sites. The regions Grieskirchen, lower altitudes in the Ennstal (climate station: Aigen) and Marchfeld in the very eastern part of Austria will undergo highest changes in N_2O losses already in the near future (up to 70%). No changes in N_2O losses were calculated for the regions Mühlviertel, Oststeirisches Hügelland and higher altitudes in the Ennstal (climate station: Irdning).

2.2.7 Description and motivation of deviations from the original project application

WP4 (D3): The submitted proposal provided two scenarios in three different arable regions (with and without agro environmental measures). As the results showed in two arable regions distinct lower nitrous oxide EF compared to IPPC-EF, we decided to evaluate the agro-environmental measures in the particular arable region with EF close to IPPC-EF and where major environmental problems are existing: The largest groundwater zone in Austria with average nitrate contents still constant above the limit of 50 mg L^{-1} is the Marchfeld, there the acceptance of agro-environmental measures (limited N fertilizer rate and cultivation of cover crops) shows the highest acceptance, covering 80-90% of the relevant area. Three additional managements adjusted with the requirements of ÖPUL were tested on the two different sites (SALO: sandy loam and LOSI: loamy silt), altogether six additional scenarios were calculated in comparison to the base scenario.

5 Schlussfolgerungen und Empfehlungen

– *Which findings have been derived from the project by the project team?*

WP1:

Collaboration of a broad field of expertise proofed to be the key to the success of NitroAustria. Expertise from crop production (science as well as close communication with practicioners), modelling, inventory preparation, climate scenarios, etc. were the basis of the outcome of NitroAustria. They frequent and intensive project meetings were indispensable as discussion sparkled there and the close collaboration between work packages was enabled. Communication of NitroAustria results was strongly promoted by the wide range of national and international contacts of the project team.

WP2 and WP3:

Our results showed that N_2O emissions differ significantly between the regions and land use types. N_2O emissions from intensively managed grassland soils are higher compared to arable soils. Highest mean annual N_2O emissions in grassland occurred in Rheintal and Oststeirisches Hügelland mainly due to higher MAT and MAP. On arable sites, N_2O emissions in GK and MF were approximately 50% higher compared to MV or OH.

We found that several different parameters are influencing N_2O fluxes. W e can highlight that mean annual temperature, soil water content and content of soil texture together with N fertilization turned out to be the most important drivers for N_2O emissions. A small reduction of N fertilization rate decreased N_2O emissions significantly.

In summary it can be stated that the LandscapeDNDC model is a suitable tool to reflect the complexity of biochemical processes combined with the heterogeneity of local and regional agro-ecosystems in Austria. LandscapeDNDC facilitates hot spot and hot moment identification in order to design suitable mitigation measures for different agroecosystems.

WP4:

Adequate N fertilizing rates according to crop demand is the crucial factor. The LandscapeDNDC results show the exponential increase of environmental hazards, when N fertilizer rates exceed crop demands. At a loamy sand as well as at a silty loam site in Marchfeld the model results show that N_2O emissions tend to grow in response to additional N fertilization at a rate significantly higher than pictured by a linear model such as IPCC. A 20% higher N input causes an increase of the N_2O emissions up to 33.5 and 36.7% and nitrate leaching up to 36 and 39% (+7 and + 10 kg NO_3-N per ha). On the other hand, a 16% reduction of the N input led to a decrease of the N_2O-N emissions of 25% and 26.4% and nitrate leaching of 17 and 18% (-3 and – 5 kg NO_3-N per ha).

Extra amounts of N fertilizer sometimes might assure the required quality goals, esp. in quality wheat production in years with higher yields. But for the most other crops over-fertilization reduces crop quality (potato, sugar beet, oil seed rape, vegetables). Also in years with high yields, mainly based on sufficient rainfall and favourable temperature, the soil releases more nitrogen due to optimal mineralization conditions, therefore the optimal amount of N fertilizer does not increase proportionally with the yield potential. These weather conditions were determined as the prerequisite for increasing N_2O emissions by the used model. Applying high N fertilizer amounts to ensure N sufficiency is unnecessary also from an economic point of view in exceptional high yielding years, and will induce an exponential increase of N_2O emissions and NO_3 leaching.

WP5:

Summing up the main points that can be derived from the regional model results for GHG inventory use are: (i) The IPCC default value for direct N_2O emissions turned out to be valuable for Austrian conditions; (ii) the LandscapeDNDC model helps to extend the limited information covered by the current default approach based on the IPCC methodology. It shows bandwidth of possible N_2O-emissions in different Austrian regions for intensive grassland and arable land areas. (iii) The model results show differences between N_2O emissions from arable land and intensive grassland areas, with higher emissions occurring in intensive, fertilized grassland areas (three and more cuts), which turned out to be higher than the IPCC default value, whereas the modelled regional N_2O EFs on fertilized cropland areas appeared to be lower; (iv) Hot moments in cropland can lead to 60-80 % of the annual N_2O-emissions during one to two weeks. N_2O emissions correlate with N-input, N_{total}-content in the soil and soil water content and are highest in loamy silty soils. (v) In intensive grassland soils maximum emissions occurred in regions with higher mean annual temperature. Positive correlation with manure (liquid and solid manure) amounts was asserted and hot moments could be observed one to two weeks after fertilisation. (in June) in combination with high average and soil temperature, resulting in up to 60 % of the yearly total N_2O emissions within this period. (vi) The model approach with LandscapeDNDC pictures regional specific management practices and is a suitable tool to derive regional differentiated measures to avoid conditions which increase N_2O emissions.

Compared to the model LandscapeDNDC the national GHG inventory does not separate between cropland and grassland and does not use application rates per ha as activity data for emission calculation. The IPCC N_2O-N emission factors are based on total national N-inputs. Anyhow, for reason of comparison, we related the total direct N_2O emissions reported under the source categories mineral fertilizer application, animal manure application and crop residues in Austria's national GHG inventory to Austria`s cropland and intensive grassland area. This calculation resulted in an average value of 1.44 kg N_2O-N/ha agricultural land (cropland and intensive grassland) and year. Although the mentioned restrictions for comparison, the values for nitrogen input, emission factors and nitrous oxide emissions give the indication that the regional modelled values and the GHG inventory figures seem to be in reasonable dimensions and are well matched.

For inventory use a consistent set of activity data and emission factors for both, regional and national level, is needed. Following IPCC the sector estimates calculated at different regions, and then aggregated in the final inventory should be self-consistent, e.g. N-inputs from crop residues should be calculated consistently for the entire country, not using different approaches for different regions. There should be no emissions or removals omitted or double counted in the aggregated inventory and the different parts of the inventory should use assumptions and data consistently as far as practical and appropriate.

The use of modelled activity data and EFs for the six model regions and official statistic data and IPCC default EFs for the rest of Austria's cropland areas would result in an inconsistent treatment of Austria's N flow and inconsistent calculations of Austria's total N_2O emissions from agricultural soils. A mix of Tier 1 (for almost all regions) and Tier 3 (for LandscapeDNDC model regions) is not in line with the methodological choice provided in the 2006 IPCC guidelines Chapter 4 and has been therefore not carried out.

Furthermore, for inventory use in Austria's greenhouse gas inventory an independent evaluation with a completely independent set of data based on measurements from a monitoring network or from research sites that were not used to calibrate the model parameters has to be made to provide a rigorous assessment of model components and results.

The focus of our proposals for a policy framework towards reduction of nitrous oxide losses lies on increased nitrogen use efficiency. This seems to be one of the most promising win-win measures taking into account trade-off effects on other N and GHG emissions. In the Austrian fertilizer recommendations, a feed-back tool could be proposed, that would include calculations of N use efficiency per field as a yearly field record. This would be a valuable tool especially in field vegetable production (e.g. oil pumpkin), where a rather high nitrogen amount is left on the field via crop residues.

WP6:

Our simulation results show that climate change may lead to increases in N_2O losses under drier conditions. Soil rewetting after dry periods can be responsible for hot moments of N_2O production which contribute with a high percentage to the annual N_2O losses. Peaks in N_2O emissions are predicted to be higher under lower annual precipitation.

Different soil types have not such a big influence in the magnitude of N_2O production compared to the location of the agricultural region. Grassland soils emit significantly more N_2O compared to arable sites. The regions Grieskirchen, lower altitudes in the Ennstal and Marchfeld in the very eastern part of Austria will undergo highest changes in N_2O losses already in the near future (up to 70%). Hardly any changes in N_2O losses were calculated for the regions Mühlviertel, Oststeirisches Hügelland and higher altitudes in the Ennstal.

Under all future climate scenarios, more N is stored in soils at Muehlviertel, Grieskirchen, Ennstal, Oststeirisches Huegelland and in Rheintal. Overall, the highest soil N storage is calculated for the Sc. 209 with an average temperature increase and 20% less precipitation. Only at Marchfeld there is a depletion of soil N in most of the scenarios. The calculated changes in net N balance is mainly driven by climate related changes in N output (crop removal, NO_3 leaching and gaseous losses (i.e. N_2 emissions)).

– *Which further steps will be taken by the project team on the basis of the results obtained?*

The LandscapeDNDC model requires further development in order to be able to model important management options and their influence on N_2O emissions. Factors such as e.g. depth of crop residue incorporation or C/N ration of crop residues, intercropping, above and below ground biomass, N fixation potential, depth of root penetration. BOKU and KIT are currently looking for the possibility to apply for research funding to work on these issues.

With regard to the implementation of LandscapeDNDC model results into the national GHG inventory, it is essential to follow the regulations of the 2006 IPCC guidelines. Following the 2006 IPCC guidelines, it is good practice to have independent measurements to confirm that the model is capable of estimating emissions and removals in the source categories of interest. An independent evaluation should be based on measurements from a monitoring network or from research sites that were not used to calibrate the model parameters. Uncertainties should be quantified to provide a rigorous measure of the confidence attributed to a model estimate.

Adequate basis for the calculations of N use efficiency should be provided, e.g. by a monitoring of the nitrogen contents of different crops and crop residues (maize, rape etc.) and by evaluating the effects of timing and manner of incorporation of crop residues and cover crops, which seem to have contradictory effects on nitrous oxide emissions. To conclude for the Austrian situation their nitrogen and also carbon input and the effects of timing and manner of incorporation should be evaluated in detail and taken into account in the fertilizing regime.

The results are of particular relevance especially for an awareness campaign to the farmers, demonstrating the exponential increase of harmful effects to groundwater pollution and climate change, if the N fertilizer is given in excess to crop demand. Especially Partner AGES is very active in giving presentations for farmers.

As laid out in the results section, draft versions of three peer reviewed publications exist and will be completed in short time.

- *Which other target groups can draw relevant and interesting conclusions from the project results and who can continue working on that basis*?

A large range of national and international institutions has been integrated and informed on NitroAustria activities since the project's inception. NitroAustria results will be fed into national Austrian working groups on the ÖPUL evaluation and on good practice guidance of crop fertilisation. Further dissemination activities will be secured by participation in the international meetings of the EPNB, EPMAN, TFRN, TFEIP, FAO and IPCC.

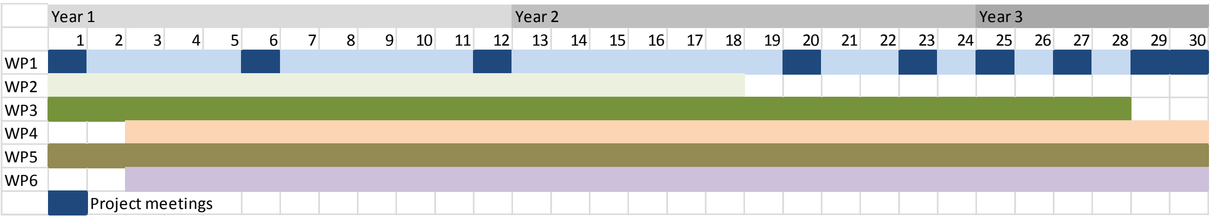
C) Projektdetails

6 Methodik

Angaben zur Methodik sind im Abschnitt „Ergebnisse“ enthalten.

7 Arbeits- und Zeitplan

Figure: Final Work flow of NitroAustria



Nitro Austria was divided into six work packages. WP1 was responsible for the coordination and management of the project and for the dissemination of project results. WP2 “Data acquisition and harmonization” collected data and provided them to WP3 “Estimating N_2O emissions from arable soils” and WP6 “Climate change scenarios and statistical analysis of modelling results” where the data were used to model N_2O emissions and nitrate leaching from arable soils. WP3 performed process based modelling at site, regional and national scale. It delivered C and N budgets, region specific emission factors and potential mitigation options with improved agricultural management for current and future climatic conditions. Management according to good practice was displayed in the model. WP4 “Providing data on agricultural management in Austria” obtained at site scale arable management data from experimental data from AGES field trials or observations. WP4 provided crop rotation scenarios from arable regions and of agro-environmental measures. In WP5 ”Application of results and use for the GHG inventory”, the regional model results were compared with the National Greenhouse Gas Inventory approach based on the emission factors (EF) for nitrous oxide emissions. Trade-offs between the effects of agricultural measures on different GHG emissions, other N losses and soil organic carbon content in the soil were discussed. Furthermore measures for a policy framework towards climate friendly farming were derived. WP6 performed site/regional/national LandscapeDNDC simulations considering scenarios of climate change, assessed factors that influence N_2O emissions in various Austrian regions and suggested site/region specific mitigation measures.

8 Publikationen und Disseminierungsaktivitäten

Amon, B., Kasper, M., Foldal, C., Schwarzl, B., Sedy, K., Zethner, G. Anderl, M., Baumgarten, A., Dersch, G., Kitzler, B., Zechmeister-Boltenstern, S. (2016): Nitrogen losses from Austrian agricultural soils – modelling to explore trade off-effects (NITROAUSTRIA). In: 19th Nitrogen Workshop Skara, Sweden 27-29 June 2016.

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