Experimental determination of emission factors and the greenhouse gas budget of grazing systems in Switzerland

Final Report Extended Summary

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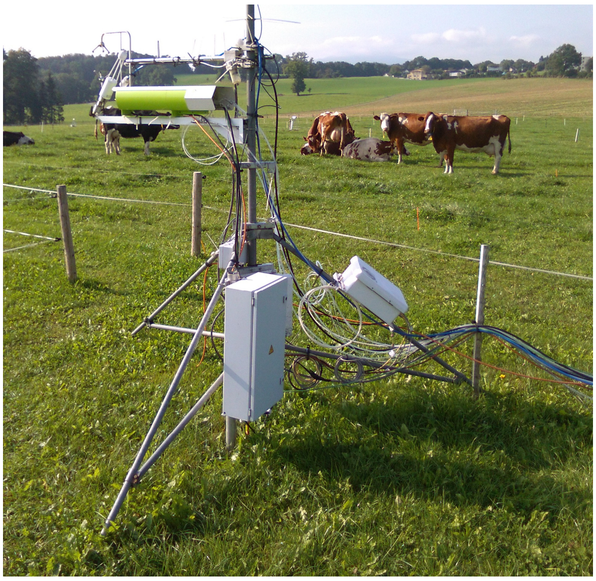

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Short Abstract

The present study analyzed the greenhouse gas flux measurements of a grazed pasture system for dairy cows in western Switzerland over five years. Based on the evaluation and the corresponding uncertainties the pasture has to be considered as near carbon-neutral and as a small source for CH_4. However, the pasture was found to be a considerable and significant source of N_2O attributable both to grazing excreta and to fertilizer spreading. The developed partitioning procedure allowed the determination of excreta-related and fertilizer-related emission factors. While the fertilizer-related emission factor was on average close to the corresponding IPCC default value, the excreta-related factor was significantly lower than the presently used default value of 2 %. It could also be shown that there is a clear difference in the individual emission factors for urine and dung patches on the pasture. For the development of country-specific emission factors for Switzerland, a combined use of process-based modelling and experimental results is recommended.

Kurzzusammenfassung

In der vorliegenden Studie wurden die fünfjährigen Messungen der Treibhausgasflüsse eines Weidesystems für Milchkühe in der Westschweiz analysiert. Basierend auf den Auswertungen und unter Berücksichtigung der Unsicherheiten kann die untersuchte Weidefläche als nahezu kohlenstoff-neutral und als geringe Quelle für CH_4 bezeichnet werden. Allerdings zeigen die Ergebnisse, dass die Weide eine deutliche Quelle für N_2O darstellt, die sowohl durch die Weideexkremente als auch durch die Düngergaben verursacht wurde. Durch Anwendung einer geeigneten Quellenzuteilungsmethode konnten die N_2O-Emissionsfaktoren für die Weide-exkremente und für die Düngergaben bestimmt werden. Während der beobachtete dünger-bezogene Emissionsfaktor im Mittel nahe am entsprechenden IPCC-Standardwert lag, war der Emissionsfaktor für die Weideexkremente deutlich tiefer als der derzeitig verwendete Standardwert von 2 %. Es konnte auch gezeigt werden, dass sich die separaten Emissions-faktoren für Harn- und Kotstellen auf der Weide stark unterscheiden. Für die Etablierung von landesspezifischen Emissionsfaktoren für die Schweiz wird ein kombinierter Ansatz aus prozessbasierter Modellierung und Verwendung experimenteller Daten vorgeschlagen.

Extended Summary

Background

Agricultural production is generally associated with cycling of nitrogen (N) and other nutrients in the soils of the used fields. As an intermediate or by-product of the microbial processing of N in the soil, gaseous nitrous oxide (N_2O) is emitted at varying rates to the atmosphere (Davidson et al., 2000). There N_2O acts as a long-living and potent greenhouse gas (GHG) and contributes to the depletion of the ozone-layer. The most important driver of N_2O emission is the N input into the agricultural ecosystem. This is largely dependent on the production type and management intensity. In Switzerland and other grassland-dominated regions of the world livestock production represents the dominant emission source for N_2O (Steinfeld et al., 2006). The N input to permanent agricultural grasslands on mineral soils happens mainly via fertilizer application or via direct deposition of excreta (dung and urine) by grazing animals. Beside this, also the N input via harvest residues and atmospheric deposition (wet and dry) need to be considered.

A simple emission factor (EF) concept is usually used for quantifying and reporting agricultural N_2O emissions based on the guidelines of the IPCC (IPCC, 2006). In this concept the annual N_2O emission is estimated as a fraction (=EF) of the sum of the N inputs I_N by fertilization and other sources. Thus, the total N_2O emission flux of a grassland field is described as:

$$F_{\mathrm{N_2O-N}} = EF_1 \cdot \left(I_{\mathrm{N-fertil}} + I_{\mathrm{N-dep}} + I_{\mathrm{N-resid}}\right) + EF_3 \cdot I_{\mathrm{N-excreta}}$$

According to the default IPCC methodology a common emission factor EF_1 is used for the fertilization and other N inputs that are uniform over the entire field (note: the special case of additional N input from significant net mineralization loss of soil organic matter, as expected for managed organic soils and for land use changes, is not considered here). However, for the N input by animal excreta, which is intrinsically heterogeneous in the small scale with locally high rates due to the scattered individual urine and dung patches, a different emission factor EF_3 is used. The latter is also denoted as EF_{PRP} for 'pasture, range and paddock'. While for fertilizer-induced N_2O emissions, a default EF_1 value of 1 % is proposed by IPCC (2006), the default EF_3 related to excreta of grazing cattle (denoted as $EF_{3PRP,CPP}$) is 2 %. One explanation for this difference is the higher local N input densities by excreta patches (400 to >1000 kgN ha^{-1} within the small patch area) compared to the moderate N input densities of broad-spread fertilizer applications (typically 30-50 kg N ha^{-1} per event and 100-250 kg N ha^{-1} per year).

Most countries including Switzerland presently use the global default values of the IPCC to calculate emissions in the national GHG inventory. However, the default EF_3 value often overestimates observed pasture emissions (Bell et al., 2015; Chadwick et al., 2018) and does not take into account country-specific conditions concerning climate, soil, and management.

Therefore, some countries have developed a country-specific EF_3 (e.g., New Zealand, Saggar et al., 2015) as recommended by the IPCC guidelines. Additionally, it has been shown that separate EF values for urine and dung might be beneficial in describing the emissions and understanding the contributions of the different emission sources on a pasture (Bell et al., 2015).

Beside N_2O, also the greenhouse gases methane (CH_4) and CO_2 are exchanged by pasture fields (Soussana et al., 2010). The grasslands can either act as a sink or source for CO_2 depending on the long-term carbon (C) storage change in the soil. The soil also has the ability to either release or uptake atmospheric CH_4 which often depends on environmental conditions (Schaufler et al., 2010). These fluxes are typically small, but taking into account the strong global warming potential of CH_4 (IPCC, 2014) the effect is not negligible. CH_4 emissions of pasture soils may also result from the decomposition of dung patches from the animals, but studies looking into that effect are very rare.

Objectives and field experiment

Based on the background described above, the main objective of the present study was to determine the N_2O emission and corresponding EF for grazing excreta for an intensive pasture system under typical weather and management conditions in Switzerland. The second objective was to compare the N_2O emissions to the other relevant greenhouse gases in a full annual GHG budget. For this purposes, the exchange fluxes of CO_2, CH_4, and N_2O were continuously measured during a five-year field experiment by the eddy covariance technique on an intensively grazed pasture in Posieux (western Switzerland). These measurements were complemented by small-scale chamber flux measurements in 2016. The experimental work was carried out in collaboration with the projects 'NICEGRAS' and 'GEOGS' funded by the Swiss National Science Foundation (SNF). The details of the experimental setup are described in Voglmeier et al. (2018; 2019), Felber et al. (2016), and Ammann et al. (2019).

Carbon budget results

From the CO_2 exchange fluxes and other detailed carbon fluxes in the agricultural system, the net ecosystem carbon budget (annual carbon storage change) was determined for the two years 2013 (Felber et al., 2016) and 2016 (Voglmeier et al., 2020). The average carbon budget over both years of 60 ± 77 g C m^{-2} yr^{-1} may be compared to the modeled carbon stock change for corresponding soil and management conditions (model stratum: intensively managed grassland in lowland zone with 20% clay content) of the Swiss soil carbon stock inventory (Wüst et al., in preparation). Averaged over the two study years the modeled carbon stock change was -9 ± 50 gC m^{-2} yr^{-1}, very similar to the decadal mean carbon stock change (2007-2016). Thus, no significant difference between the measurement and model results was found, that both indicate a near carbon-neutral behavior. The relatively large uncertainties of both approaches, and the large spatial averaging of the model stratum, do not allow a better precision of the carbon budget evaluation. The uncertainties for experimentally determined pasture carbon budgets are difficult to reduce with the applied flux method. For this purpose, long-term (decadal) repeated soil carbon stock measurements would be necessary as e.g. presented by Leifeld et al. (2009) and Oberholzer et al. (2014) for cropland sites. But it needs to be considered, that pastures may have a higher variability in their soil carbon distribution than arable field due to the often non-flat terrain, the inhomogeneous input of excreta and the lack of soil turnover by ploughing.

CH_4 emission results

The observed methane emissions of the pasture soil represent the smallest contribution to the full GHG budget of the pasture field. If only the emissions by excreta patches are taken into account, an MCF emission factor of 0.5% ± 0.2% is obtained. This value is smaller but of similar magnitude like the 1 % IPCC default MCF value presently used in the Swiss national inventory. The difference may be due to the limited period (July-October 2016) of dedicated chamber measurements on excreta patches under predominantly dry conditions. The average surface CH_4 emission rates over the two entire years 2013 (Felber et al., 2016) and 2016 (Voglmeier et al., 2020) measured by eddy covariance were much higher and obviously dominated by 'background' fluxes not directly influenced by the grazing excreta. This type of CH_4 emissions from mineral soils is presently not considered in the Swiss GHG inventory, and it is not clear to date, how frequent conditions for such CH_4 emissions occur in Swiss grasslands. For clarification, more dedicated measurements would be necessary and a thorough analysis of existing datasets.

N_2O emission results

The most specific results, which have potential to support improvements in the national GHG inventory, were found for N_2O. It needs to be considered, that the method (combination of eddy covariance and chamber measurements) used in the present study to investigate N_2O emissions on real practice grazing systems is exceptional, as the existing parameterization of excreta related emissions have been mostly based on experiments with controlled artificial excreta applications on small plots without real grazing. Since the eddy covariance measurements integrated the emissions over a large number of dung and urine patches on various parts of the pasture field and provided a continuous monitoring over the entire grazing season of several years, it yielded average results with relatively low statistical and methodological uncertainty. The investigated pasture, like most intensively grazed pastures in Switzerland, received additional fertilizer applications (beside the direct animal excreta input) either in the form of synthetic fertilizer (ammonium nitrate or urea) or cattle slurry. Therefore a partitioning procedure was developed to attribute the measured total field emissions to fertilizer input, excreta input, or background (related to plant residue and atmospheric inputs). The observed average fertilizer-related EF_1 (1.1 ± 0.5 %) was close the IPCC default value of

1 % despite the limited number of available fertilizer events (16) and the considerable variability between them. The disaggregated EFs for synthetic and other (organic) fertilizers suggested in the new refined IPCC guidelines (IPCC, 2019), are in good agreement with the correspondingly separated emission factors found in this study. Yet, these experimental results are based on only few application events, and the influence of different application times (mainly cold season for slurry and warm season for synthetic fertilizers) could not be disentangled with the available data. For that purpose, an experiment with simultaneous application of both fertilizer types would be necessary.

It has been shown in this study, that the contribution of excreta-related emissions to the field-scale emissions are substantial and that the corresponding average EF_3 value (1.16 ± 0.49 %) is considerably lower than the default EF_3 used in the Swiss greenhouse gas inventory (2 %) but higher than the proposed new default value (IPCC, 2019). This indicates the need for a revision of the used EF_3 value and is in accordance with other countries, which already apply a country-specific EF_3 with a lower value (e.g. between 0.04 % and 1 % for Canada, UK, New Zealand) while there are very few higher values used (Netherlands: EF_3 = 3.3%).

The results of the parallel experiment with an optional N-reduced diet in 2016 (Voglmeier et al., 2018; Voglmeier et al., 2019; Ammann et al., 2019) demonstrated that the optimization of N in the feed of dairy cows has a considerable potential to reduce the N in the animal excreta which mainly affects urine N content (see also Bretscher et al., 2018). A lower excreted urine N amount can reduce not only the direct N_2O emission on grazed pastures but also the corresponding NH_3 emissions (Voglmeier et al., 2018) and thus the indirect N_2O emissions. It is therefore important that the actual N content of the main feed (grass, grass silage, and hay) is known, so that it can be considered in the feeding strategy by the farmer and adequately represented in the emission inventory calculations. The large difference of the EFs for urine and dung observed in this study and in the literature supports the suggestion of Krol et al. (2016) to disaggregate the EF by excreta type in emission inventories. The implementation of excreta-specific EFs could allow for a more precise calculation of the grazing-related N_2O emissions when implementing more balanced feeding regimes.

Towards country-specific N_2O emission factors for grazing excreta

An establishment of country-specific N_2O emission factors for grazing related urine and dung deposition on pastures in Switzerland requires the development and demonstration of the corresponding scientific basis. Since for Switzerland (and even for the neighboring countries) only a very limited number of measurements about grazing related emissions are available, a purely data driven assessment of country-wide emissions, as e.g. proposed by Dechow and Freibauer (2011) for EF_1 across Germany, is not possible. However, the development of a country-specific emission factor seems feasible with the support of a process-based model to quantify how emissions vary as a function of pasture management as well as soil and climatic conditions in different regions of Switzerland. An important issue in this respect is to understand the differences in the processes relevant for N_2O formation (and consumption) that lead to different emission factors for spatially uniform fertilizer inputs and heterogeneously distributed excreta inputs. These questions will be investigated in the coming years within the recently approved SNF project REFGRASS (Towards representative N_2O emission factors for grazed grasslands in Switzerland).

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