The potential of carbon sequestration and N₂O emissions due to different sward ages after grassland re-sowing

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Abstract. In order to quantify carbon (C) sequestration and nitrous oxide (N₂O) emission rates from grassland of different sward ages (2, 5 and 18 years) after grassland re-establishment, a 2-year field experiment was conducted on a sandy loam in 2010/2011 (2011/2012). The trial was set up in a randomized plot experiment with three replicates including a control (no N-fertilizer) and a fertilized treatment (240 kg N/ha/year as cattle slurry). N₂O emissions were measured on a weekly basis using the closed chamber method. The soil carbon content was measured twice a year from soil cores. Results showed a lower soil carbon content (0 - 30 cm) in the 2-year-old sward (63.7 t C/ha) compared to the 5-year-old (72.8 t C/ha) and 18-year-old sward (77.1 t C/ha) (P ≤0.05). No significant relationship could be found between the cumulative N₂O emissions per year and sward age. On average, the 18-years-old fertilized grassland showed the highest N₂O emissions compared to all other treatments in both experimental years (2.56 kg N₂O-N/ha in 2010/11 and 1.17 kg N₂O-N/ha in 2011/12). Grassland renovation leads to a decay of soil C. In our experiment, this effect was compensated within five years of grassland re-establishment (P ≤0.05). On average, the N₂O emissions were low in younger swards compared to old grassland (n.s.).

Keywords: Nitrous oxide, soil carbon, ploughing, grassland renovation.

Introduction

In recent decades, dairy farming in Northern Europe has undergone continuous intensification. Various political decisions (such as programs to promote renewable energy sources) combined with the availability of marginal land have brought the issue of biomass production from grassland into focus. The renovation of grassland swards is a common procedure in intensively managed grassland systems to establish high yield and high quality grass varieties, when other management efforts have failed. In organic farming systems in particular, where the use of pesticides is restricted, ploughing for grassland renovation is necessary to provide good re-sowing conditions. In terms of greenhouse gas emissions (GHG) there are large concerns about increased carbon dioxide (CO₂) and N₂O emissions as consequence of enhanced soil mineralization after the ploughing of old grassland swards. Most of the studies showed highest CO₂-emissions 24 h after tillage, meanwhile N₂O emissions were observed for weeks (Yamulki et al. 2002; Reicosky et al. 2007; Velthof et al. 2010; Willems et al. 2011). How soil carbon stocks and N₂O emissions develop after grassland resowing in medium and long-term is not well known. The age of the grassland sward is closely related to the soil C and N stocks (Johnston et al. 2009; Muller-Stover et al. 2012). Further research is necessary to evaluate how short window of grassland resowing would affect the soil C and nitrogen (N) contents of permanent grasslands and finally how such development would contribute towards the national GHG inventories in northern Europe. The aim of our trial was to estimate changes in soil carbon and effects on nitrous oxide emissions from renewed grassland with different sward ages on field level. In addition, one of our main objectives was to determine if grassland renovation was suitable to increase forage yield and quality in the medium and long-term.

Materials and Methods

Experimental Site

The trial is located on the experimental farm “Lindhof” (54°27’N, 9°57’E) which belongs to the Christian-Albrechts-University in Kiel. The long-term mean annual temperature is 8.9°C and the long term mean annual of precipitation is 768 mm. The soil type is classified as sandy loam (pH 5.9) with 11% clay, 32% silt and 57% sand and 1.7% Corg in the topsoil (0 - 30 cm).

The site was used as arable land in a 5-years crop rotation until 1993. In 1994, a grass-clover ley was undersown in a cereal crop and kept as grassland. From 1994 – 2006, grassland was used for two silage cuts and two periods of grazing with suckler cows per year. In 2005, a randomized field experiment with three replicates was conducted on that site. Since the experiment started, the grassland was used for four silage cuts per year. Plots were harvested with a forage harvester (Haldrup, Logstor, Denmark) at a stubble height of 5 cm. Manuring was carried out for each grass growth period [80, 60, 60, 40 kg N/ha] with cattle slurry in the N-fertilized treatment. A non-N-fertilized-treatment served as control. In addition, all plots received 24 kg Mg/ha, 100 kg K₂O/ha and 68 kg S/ha and
Soil sampling and analysis

Soil samples were taken to a soil depth from 0 to 30 cm in spring and autumn 2010 and 2011. Each soil sample was bulked from three replications per plot. The soil organic carbon (C\textsubscript{org}) content was measured according to the international standard ISO 10694 with a C/N-Analyser “Vario Max CN” (Elementar, Hanau, Germany).

To estimate the total amount of soil carbon, the soil density (g/cm\textsuperscript{3}) of undisturbed soil cores (100cm\textsuperscript{3}) at a depth of 10 to 15 cm were taken from all plots with two replications in spring 2010 and 2011. Dry matter weight of soil cores were determined by oven drying at 105°C until constant weight.

\textit{N\textsubscript{2}O emission measurements}

Nitrous oxide emissions were measured irregularly but with intervals never exceeding one week for a period of two years (April 2010 – April 2012) using the closed chamber method (Hutchinson \textit{et al.} 1981). At the beginning of each experimental year, one PVC-ring with a diameter of 60 cm and a height of 15 cm was installed 5 cm into the soil of each plot. For \textit{N\textsubscript{2}O} emission measurements, soil rings were closed with a gas tight chamber for 40 minutes. Gas samples were taken in 20 minutes intervals (0, 20 and 40 minutes) and stored in 12ml pre-evacuated septum capped vials (Labco, High Wycombe, UK) (Glatzel \textit{et al.} 2008). Gas samples were analyzed for \textit{N\textsubscript{2}O} concentrations by ECD gas chromatography (model 7890a, Agilent technology Inc., Santa Clara, CA, USA).

\textit{Herbage yield and forage quality}

Aboveground biomass samples were taken with a hand-clipper on one square meter at five cm stubble height every week during the growing season. Biomass samples were subdivided into grass, legumes and other species. All samples were weighed and then dried in an oven at 60°C to determine the total dry matter yield of each subsample. All dried subsamples were milled to pass a 1mm sieve (Cyclotech mill, Tecator, FOSS Gmbh, Rellingen, Germany). Forage quality parameters were estimated using near infrared reflectance spectroscopy (NIRS). All samples were scanned twice with a NIR-System 5000 monochromator (Perstrop Analytical Inc., Silver Spring MD, USA) over a wavelength range of 1100-2500 nm in 2nm intervals.

\textit{Data processing and statistical analysis}

Nitrous oxide fluxes were calculated for each treatment and replicate by linear regression between measured \textit{N\textsubscript{2}O}-concentrations and a defined period of time. \textit{N\textsubscript{2}O} flux was accepted when R\textsuperscript{2}>0.6. In case of R\textsuperscript{2}<0.6, flux was assumed to be 0. The cumulative \textit{N\textsubscript{2}O} emissions were calculated by linear interpolation between measured daily fluxes. For statistical evaluation the software R (2012) was used. The data evaluation of \textit{N\textsubscript{2}O} and soil carbon started with the definition of an appropriate statistical mixed model. The data were assumed to be normally distributed and have to be heteroscedastic. These assumptions are based on a residual analysis. The statistical model included sward age, fertilizer treatment and year as well as all their interaction terms (two-fold and three-fold) as fixed factors. In terms of cumulative nitrous oxide emission, the amount of soil carbon was modeled as covariate. The plot was regarded as random factor. Based on this model, an analysis of variances (ANOVA) was used to answer the questions of the trial. After this, multiple contrast tests were conducted to compare the several levels of the influence factors, respectively. If a factor of interest had no significant interactions with the remaining factors, then the levels of these remaining factors were pooled.

\textbf{Results}

\textit{Soil Carbon}

A comparison of the different sward ages after grassland renovation showed a significant lower soil carbon content in the 2 year old sward (63.7 t C/ha) compared to the 5-year old sward (72.8 t C/ha) (P<0.05, Fig. 1). No significant difference was detected between the 5- and 18- year (77.1 t C/ha) old grassland. The factor fertilizer treatment showed a significant effect on the soil carbon content. The fertilized plots contained on average 6.9 t C/ha higher soil carbon content.

\textit{Nitrous oxide emissions}

We found no significant difference between sward age and...
cumulative N₂O emission for the experimental years 2010 and 2011. On average of two years the unfertilized 2 year old sward showed the lowest N₂O emissions (0.42 kg N₂O-N/ha/year). The N-emissions on the fertilized 18-year old plots accounted for 1.87 kg N₂O-N/ha/year, with N-loses exceeding more than 60 % per year from November to March. Based on the average grassland ages, the application of organic N-fertilizer resulted in additional emissions of 0.67 kg N₂O-N/ha/year.

Herbage yield, quality and sward composition
We observed no significant differences for herbage yield or quality regarding sward age. Manuring resulted, on average, in higher DM (1.8 t/ha) and GJ NEL (11.7 GJ/ha) yield. Highest herbage yield was reached in the fertilized 18-year old sward (11.6 t DM/ha). In the N-treated plots the proportion of white clover yield declined from 31 to 13 % (annual average of clover yield to total yield). With regard to sward composition, we found a decreasing amount of *Lolium perenne* with increasing sward age. In contrast, other grass species like *Poa trivialis*, *Dactylis glomerata* and *Festuca rubra* increased. The total number of species was 7 in the 2- and 5- year old swards and 8 in the 18-year old sward. In particular we find a higher amount of *Taraxacum Sect. Ruderalia* in older grassland.

Discussion
Grassland renovation with associated ploughing leads to a reduced gross primary production by plants coupled by enhanced soil respiration and a decline of soil carbon in short term (Willems et al. 2011). In our experiment, the soil carbon stock in the upper soil layer was still reduced compared to the control after two years. Five years after grassland renovation, this difference was not significant (P≤0.05). Similar results were reported by Linsler et al. (2013) who carried out measurements on the same soil site. They showed lower soil carbon content and a decreased amount of water-stable aggregates in the upper soil layer (0 – 10 cm) two years after grassland renovation (Linsler et al. 2013). Velthof et al. (2010) found increased N₂O emissions in different grassland renovation treatments in short-term. In the presented study, the N₂O emissions were not increased in the medium or long term. In contrast, our results showed on average the lowest cumulative N₂O emissions in the 2 year old swards compared to the 5 year old swards and the control treatment. The same results were found by Muller-Stover et al. (2009). They compared younger grass-clover swards with a 16 year old control in an incubation experiment and concluded that higher amounts of organic N and higher microbial activity could be responsible for increased N₂O fluxes in older swards. However, in our field experiment the differences were not significant. The statistical analysis showed a significant two-fold interaction between N-fertilizer and soil C stocks regarding N₂O emissions. That fact indicates an increased risk for N₂O emissions after N-fertilization on grassland with comparable high soil C contents. This effect was quite small, but could become more significant with increasing levels of N-fertilization and/or other fertilizer types (Jäger et al. 2011).

In our experiment grassland renovation did not fulfill the aim of improved herbage and quality yields in medium or long term (18 year old sward showed in average higher yield compared to the younger swards). This result is corresponding to other studies (Hopkins et al. 1990; Velthof et al. 2010). Nitrogen fertilization only led to a slight increase in herbage yield through reduced amount of white clover and reduced symbiotic N₂-fixation rates, respectively in the N-treatment.

Conclusion
In the light of our results even old grassland swards have high yield and energy potentials compared to younger swards. If this is the case, grassland renovation should be the last management option in order to avoid soil N and C losses in short term. If grassland renovation becomes necessary we don’t expect long term effects regarding to N₂O emissions and changes in soil C stocks respectively.

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References