

We are thankful to the anonymous reviewer 2 for the constructive feedback and detailed solutions to improve the manuscript quality. We agree with most of their comments and altered the manuscript accordingly.

However, probably some ambiguities are related to some misunderstandings concerning the definition of measurement area, site, plots, replications and grassland management which were maybe partly not clearly written. In general the definition in manuscript version 3 was as follows: grassland parcel = adjacent management unit (approximately 8 ha); site/treatment = measurement area (12 x 12 m) containing three plots (which are the PVC-collars for the GHG measurements). Now we change the definition to avoid further confusions to: grassland parcel = adjacent management unit (approximately 8 ha), site = area within the grassland parcel (C_{org}-medium and C_{org}-high); plot = treatment (plot dimension 12 x 12 m) containing three PVC-collars as replications for GHG measurements.

Referee 2 report:

Referee 2: The manuscript with the new title “Short-term effects of biogas digestate and cattle slurry application on greenhouse gas emissions and N availability from high organic carbon grasslands” has improved. The new title is a little bit odd, in particular ‘high organic carbon grassland’. I suggest: “Short term effects of biogas digestate and cattle slurry application on greenhouse gas emission affected by N availability from peat grasslands”. Many passages are more concise and clear in the new version. However, there are still some points which should be addressed to make it acceptable for publication. In particular, the interpretation and extrapolation of the limited NH₃ loss data is still lacking.

Authors: Thank you for your suggestion for the new title. We change it to “*Short-term effects of biogas digestate and cattle slurry application on greenhouse gas emissions affected by N availability from grasslands on drained fen peatlands and associated organic soils.*” since the C_{org}-medium sites did not represent a typical peatland.

General points:

Referee 2: The ammonia part is still not convincing. The authors have still not included an explanation why there was such a strong difference between volatilization dynamics of both slurries. This is most striking and in harsh contrast to previous research. This is in particular with respect to the high DM content of the cattle slurry which suggests an extended volatilization process. But the contrary is the case.

Authors: We rewrote the section 4.5 to “*The NH₃ losses measured after splash plate application at the third application event followed the typical pattern of lost ammonia (Clemens et al., 2006), particularly at the digestate treatments. Significantly higher NH₃ losses from treatments fertilized with biogas digestate were observed compared to those fertilized with cattle slurry. This is in line with several other studies (Messner, 1988, Döhler and Haring, 1989 (cited in Döhler and Horlacher, 2010); Amon et al., 2006; Möller and Stinner, 2009; Pacholski et al., 2010; Ni et al., 2011), whereas Pain et al. (1990), Rubæk et al. (1996), Wulf et al. (2002b) and Clemens et al. (2006) found no differences between anaerobic digested slurries compared to other animal slurries. However, it has to be taken into account that the present results are based only on measurements from a single application event. The observed relative N losses of 36% of applied NH₄⁺-N at the biogas digestate treatments were in the range reported for liquid slurries and digestates applied via surface application, whereas the significantly lower relative N losses (15%) at the cattle slurry treatments stands in strong contrast to those reported in literature (e.g. Döhler and Haring, 1989 (cited in Döhler and Horlacher, 2010); Smith et al., 2000; Wulf et al., 2002b; Chantigny et al., 2004). However, compared to the EF of 60% used in the German national greenhouse gas inventory both estimated NH₃ loss rates were rather low (Haenel et al., 2014). It can be assumed that the higher concentration of NH₄⁺ (NH₄⁺/N_{tot} ratio 0.65 vs. 0.33) and the distinctly higher pH value (7.7 vs. 6.8) of the applied digestate compared to the cattle slurry caused the observed differences in the current study, since temperature and wind speed were equal. According to Sommer and Hutchings (2001) a change in the pH value from 7.7 to*

8.0 will double the emission. However, the factors controlling the rise in pH are complex (Sommer and Husted, 1995b cited in Sommer and Hutchings, 2001) and the pH value was not determined after fertilization in the present study. Several authors propose that a lower dry matter content of slurries favors the infiltration into the soil with a subsequent faster decrease of NH_3 losses (Sommer et al. 1996; Ni et al. 2011). There over a limited range (slurry DM of 2–5%), NH_3 losses increase by approximately 6% for every 1% DM content (Smith et al., 2000). Although the observed dry matter content of the biogas digestates was very low and at the lower end of values reported in literature (e.g. Gutser et al., 2005; Möller et al., 2008; Quarkernack et al., 2011) no corresponding effect was found in the present study as was also reported by Möller and Stinner (2009). According to Döhler and Horlacher (2010) and Smith et al. (2000), water saturated grassland soils as well as very dry grassland soils high in organic matter lead to higher NH_3 -losses due to the reduced infiltration of slurries. Thus it could be assumed that the infiltration of the slurries was possibly hampered in the current study, removing the effect of the different DM contents, due to the strong rain event which took place before the fertilizer application. The cattle slurry in our experiment had very favorable characteristics for crust formation (high DM content, grass silage diet; Smith et al. 2007). Warm weather also supported crust formation after application of cattle slurry, which can effectively inhibit NH_3 exchange with the atmosphere and has been proposed as NH_3 mitigation measure for slurry storage (Smith et al. 2007). The emission pattern observed in our study on soil with limited infiltration capacity supports the effectiveness of crusts for low NH_3 losses. Additionally, at low dosage applications a large part of the organic fertilizer remained on the plant canopy and thus soil contact and infiltration was limited after spreading. We conclude that this was also the main reason why no significant differences in the pattern of NH_3 volatilization between the soil types were found in the present study. Nevertheless, the distinct lower relative N losses from cattle slurry compared to literature values could not be explained in this way, but NH_3 volatilization reported in literature showed a high variability in respect to climatic and soil conditions, slurry composition, and application technique. The observed relative N losses of 15–36% of applied NH_4^+ -N demonstrates that NH_3 volatilization is quantitatively the most important N-loss from slurry application, as was also proposed by Flessa and Beese (2000). Beside the negative effects of eutrophication and acidification of ecosystems (e.g. Fangmeier et al., 1994; Galloway, 1995; Smith et al., 1999; Galloway, 2001), distinct NH_3 volatilization decreases the N fertilizer use efficiency. One of the most effective measures to reduce NH_3 emissions from grassland is the incorporation of slurry (Rodhe et al., 2006). However, several studies reported a considerable increase of greenhouse gases (GHG), mainly N_2O , after injection of slurries and biogas digestates (Dosch and Gutser, 1996; Flessa and Beese, 2000; Wulf et al., 2002a). Up to date no study has examined the effect of the injection technique on organic soils.”

Referee 2: The results of one measurement cannot be extrapolated for two vegetation periods. The reply of the authors is correct, that the values of the single measurements were in the range of reported values but this range is rather large and ammonia emissions can strongly vary. This in particular applies to differences between relative ammonia losses between the two organic fertilizers, which are much larger as reported in several earlier studies. And this large difference may have a strong effect on NUE. So, I suggest to use absolute emission levels and relative differences from the literature which are based on a much larger data base as this single measurement for application dates without NH_3 loss measurements. Another option is to use the ALFAM (Sogaard et al. 2002) empirical model to estimate ammonia emissions for cattle slurry and to take the average increment of relative ammonia emissions from the literature. ALFAM available is under <http://www.alfam.dk>.

Authors: Thank you for the hint to the ALFAM model homepage. For comparison, we calculated the NH_3 volatilization from the third application event with the ALFAM model. The model predicted a cumulative relative N loss of 54% of total ammonia nitrogen (TAN) and an absolute loss of $10.84 \text{ kg N ha}^{-1} 20 \text{ h}^{-1}$ for the cattle slurry treatment. This was a three fold overestimation compared to the measured values in the present study, demonstrating the high variability in NH_3 losses and the resulting high uncertainty predicting ammonia volatilization. However, the ALFAM model did not provide values for anaerobic digested slurries, but Ni et al. (2011) tested a simple empirical regression model, based on the same approach as applied in the ALFAM model and found that NH_3 losses from biogas slurry were higher than from animal slurry under the same environmental conditions. Nevertheless, the few available field and laboratory experiments are contradictory regarding the effect of biogas digestate application on NH_3 volatilization in comparison to conventional animal slurry. Due to

this and the fact that NH_3 volatilization reported in literature showed a very high variability we decide to use the emission factors (EF) derived from the German national reporting for the calculation of gaseous and particulate emissions from German agriculture 1990 – 2012 (Haenel et al., 2014). Therein an EF of 0.6 kg kg^{-1} related to TAN were used for broadcast application of cattle slurry on grassland. However, no emission factors are available for the application of anaerobic digested slurries. For the calculation in the present study the same emission factor as for untreated slurry were used instead as was also done in the national inventory (see Haenel et al., 2014; page 91).

According to these changes, the N-use efficiencies and the N-balances were recalculated (see Table 6 and 7) and the corresponding manuscript parts were rewritten. However, recalculation did not change the overall results and statements.

Referee 2: The actual grassland management should be presented in more detail. I guess that the investigated applications were the fertilization for the 2nd and 3rd cuts in the respective years. How was fertilization done for the first cut and how could that have affected the results. Also the yield level of the first cuts would be helpful to have an idea of the productivity of the sites. So, a summary of the complete grassland management over both vegetation periods should be included and be considered for discussion of the results.

Authors: Perhaps, the text passage for the grass management was partly not clearly written. However, our study started in January 2010 and ended in January 2012. Between these period the farmers did their regular management without any adjustment because of our measurements. During this time period five mowing events and five fertilization events took place. Fertilizer application dates are presented in Table 2 and Table 5, additionally all mowing events including grass yields are listed in Table 5 as was also written in section 3.6. However, the management conducted did not follow the regular management practise in theory with fertilizer application in spring time, followed by the first cut some weeks later. In both years 2010 and 2011, firstly a mowing event took place and then fertilizers were applied.

For clarification, we include a new table (Table 1) which presents all management activities of both vegetation periods. Additionally in section 2.1 (Study site) we included the following sentence at line 156: “A summary of the complete grassland management over both vegetation periods can be found in Table 1.”

Additionally we changed the labelling of Table 6 to: “Grass yields, N uptake and N use efficiency for the years 2010 and 2011.”

Referee 2: Hypotheses : there exists an potential interrelationship between crop growth/NUE and N_2O emissions that should be stated here or in the introduction. Otherwise both research aims seem to be unconnected.

Authors: Thank you. The reviewer is correct that there is a relationship between grass growth and N_2O emissions. However, instead of plant growth we rather use the annual plant N-uptake (see Fig.) since this relationship seems to be more connected to N_2O production in the way that N-uptake could be considered as a proxy for N availability. Due to small sample size of cumulative annual mean N_2O emissions and grass yield, we used single collar specific values for regression analysis.

Nevertheless, the higher biomass production itself probably explained N_2O emissions due to the stimulating effect of plant roots on denitrification (Klemedtsson et al. 1987; Bakken, 1988), which can partly be ascribed to exudation of organic C (Hailer and Stolp, 1985) and partly to the O_2 demand by root respiration and an the increasing CO_2 partial pressure, promoting anaerobic microsites (Erich et al. 1984; Klemedtsson et al. 1987). Simultaneously the higher biomass production caused a depletion of mineral N in the soil and thus reduced N for nitrification and denitrification processes.

Therefore further investigations are necessary to prove whether increased biomass production favors N₂O emissions and which N pathways and processes are involved. We include the new figures and the following sentences in the manuscript:

New Fig. 5a and 5b. (Relationship between cumulative annual N₂O emissions and annual plant N uptake regarded for the treatments a) and for the investigated soil types b). Dots represent mean annual values of each PVC-collars. CS = Cattle slurry, BD = Biogas digestate, C = Control.)

Line 113 *"Furthermore it can be assumed that the plant N-uptake and the N₂O emissions are closely interconnected since N-uptake could be considered as a proxy for N availability, affecting N gaseous losses as well."*

Line 437 *"Observed collar specific cumulative annual N₂O fluxes were strongly related to collar specific annual plant N-uptake (Fig. 5a and 5b)"*

Line 467 *"This pattern was also found in the annual plant N-uptake which shows a clear partitioning between the treatments investigated (Fig. 5a)."*

Line 561 *"However, the much higher N-uptake at the digestate treatments (Fig. 5a) indicated that much more N must have been available at these treatments."*

Line 573 *"Probably the assumed higher SOM mineralization at the digestate treatments could partly be related to a priming effect since the higher biomass production probably caused a higher release of root exudates, containing easily available C and N which enhanced microbial activity (Mounier et al. 2004; Henry et al. 2008) promoting SOM mineralisation. However, further investigations are needed to prove this explanation."*

Line 602 *"Additionally the observed distinctly stronger increase of cumulative annual N₂O emissions with increasing N-uptake by plants (Fig. 5b) reveals that with increasing N availability a higher proportion is lost as N₂O at the C_{org}-high sites compared to the C_{org}-medium sites."*

Line 669-693 *"Nevertheless, as mentioned before, the much higher N-uptake at the biogas treatments (Fig. 5a) indicates that the application of this fertilizer resulted in a distinctively higher N availability, promoting N₂O production. It could be assumed that the high pH and the lower C/N ratio of the biogas digestate, obviously slightly enhanced SOM mineralization probably due to increased microbial activity compared to cattle slurry fertilizer, leading to extra N for nitrification and denitrification. Moreover, as proposed before it is also conceivable that the higher biomass production at these treatments itself is related to the increased N₂O emissions, due to the stimulating effect of plant roots on denitrification activity (Klemetsson et al. 1987; Bakken, 1988). Considering that increasing biomass production means increasing root growth and activity it could be assumed that exudation of easily available organic C and N (Hailer and Stolp, 1985), as well as the O₂ demand due to root respiration is higher at the digestate treatments, promoting more anaerobic microsites and thus denitrification compared to cattle slurry (Erich et al. 1984; Klemetsson et al. 1987). Furthermore several authors have suggested that root exudates may increase bacterial metabolism (Klemetsson, 1987; Mounier et al. 2004; Henry et al. 2008), further lowering the oxygen concentration and thus increasing denitrification (Klemetsson et al., 1987). However, the enhanced biomass production simultaneously should have depleted mineral N in the soil and thus reduced available N for nitrification and denitrification processes. Obviously, despite the negative apparent N balance of the biogas digestate treatment, there was no real nitrogen competition between plants and microbes. However, further investigations are required to prove whether digestates enhanced SOM mineralization or to what extent increased biomass production favors N₂O emissions and which N pathways and processes are involved."*

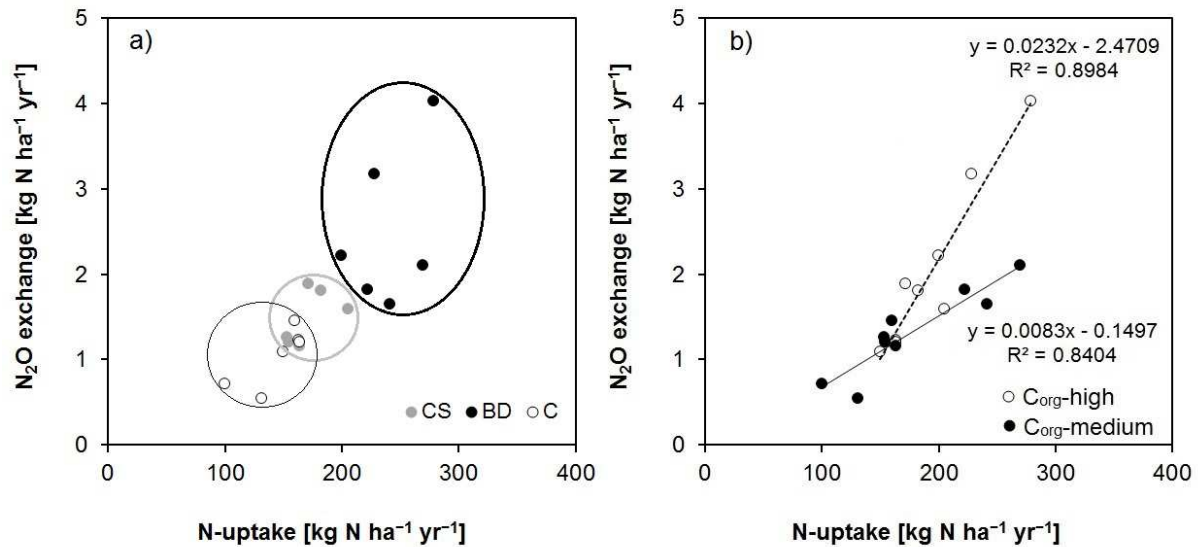


Fig. 1 Relationship between cumulative annual N₂O emissions and annual plant N uptake regarded for the treatments a) and for the investigated soil types b). Dots represent mean annual values of each PVC-collars. CS = Cattle slurry, BD = Biogas digestate, C = Control.

Referee 2: Hypotheses a) is not tested in this study as the same amounts of NH₄⁺ were applied or were aimed for during application. So this study cannot be used to test hypothesis a) which explicitly states that NH₄⁺ concentrations (amounts) are the cause for higher emissions. Only higher concentrations are an implausible explanation. The same applies to hypothesis c) if the same amount of slurry NH₄⁺ is applied there exists no reason for higher ammonium availability, so this study design cannot be used to test hypothesis c) and it is also in contrast to the assumption that there are higher ammonia emissions: same amount of ammonium and higher losses - lower yields (if there are no other factors)

Authors: The reviewer is partly right. This point needs further clarification. In the year 2010, the same amounts of NH₄⁺ were accidentally applied, but in the year 2011, biogas digestate treatments received 15% more NH₄⁺-N compared to the cattle slurry treatments. This seems not much but it has to be taken into consideration that the study based on the application of equal volumetric rates of slurry and not on adapted NH₄⁺-N or N_{tot} application rates since we assumed from literature that the digestate contains significantly higher concentrations of NH₄⁺-N than cattle slurry. This assumption was confirmed, but only for the year 2011 differences were observed. We agree with the referee that only higher concentrations are an implausible explanation, but when applying the same equal volumetric rates, higher concentrations result in higher amounts of NH₄⁺-N.

Therefore hypothesis a) and c) were proven in this study.

The hypothesis of higher ammonia losses were omitted in the actual manuscript as written in the respond to referees (Author comment 2) Referee#2). In the actual version EF for NH₃ were assumed to be equal (see above) therefore more N should be available at the digestate treatments. Additionally, the third application event revealed that beside significantly higher NH₃ volatilization, significantly more N was available for plant growth at the digestate treatments (approximately 68% more)!

The effect of higher N₂O emissions due to a higher amount of NH₄⁺-N was also indicated by the observed linear relationship in figure 6 (old Fig. 5).

Nevertheless, as written in section 4.3, the significantly higher N₂O emissions from the digestate treatments can not solely be explained by the higher content of available N in the biogas digestate, since differences were only small.

We specify hypothesis a) to *“More N₂O is emitted after biogas digestate than after slurry application because of higher NH₄⁺-N concentrations in the substrate and thus, higher NH₄⁺-N amounts when using equal volumetric application rates.”*

Referee 2: Fig 5: Mean values of N₂O emissions should be used in this analysis rather than single measurements in this regression as groundwater level and application rate characterize plot properties while N₂O emissions show microsite variation within a plot.

Authors: Fig 5 (now Fig 6) based on plot-wise mean 16 days cumulative N₂O emissions after fertilizer application for the four application events and not on single collar specific N₂O emissions!

Referee 2: Please rethink frequent use of “enhanced” and “affect”

Authors: Partly done

Points in detail:

Referee 2: L 18 “has resulted”

Authors: Done (now line 19)

Referee 2: L 19-20 “..huge amounts of nutrient rich residues, the by-products of the fermentative process, are used as organic fertilizers.”

Authors: Done (now line 20-22)

Referee 2: L21 “..are increasingly cropped..”

Authors: “Used” is more appropriate in this context since it is more generally and considered different landuse types as potentially biomass sources. (now line 22)

Abstract: NUE and N₂O emissions are interconnected and should therefore be investigated at the same time.

Authors: NUE and N₂O are not interconnected but N₂O exchange and plant N-uptake. See above.

Referee 2: L 27: ammonia emissions are not studied extensively enough to support this statement. I suggest adding: in addition NH₃ emissions were determined in one trial to obtain first clues with respect to the effects of soil and fertilizer types....or the like

Authors: Thank you, we included following sentence at line 30: *“In addition NH₃ volatilization was determined at one application event to obtain first clues with respect to the effects of soil and fertilizer types.”*

Referee 2: L 29: “The study was conducted at two areas within a grassland site, which differed in their SOC contents. At each area...three plots were established...”

Authors: We change this to: *“The study was conducted at two sites within a grassland parcel, which differed in their soil organic carbon (SOC) contents. At each site (named Corg-medium and Corg-high) three plots were established, one was fertilized five times with biogas digestate, one with cattle slurry and the third served as control plot.”* (now line 32)

Referee 2: L 32: “On each plot...”

Authors: Changed to: *“On each plot, fluxes of N₂O and CH₄ were measured on three replicates over two years using the closed chamber method.”* (now line 36)

Referee 2: L 34: “For NH₃ measurements we used...at one application.”

Authors: not necessary as clarified in line 30.

Referee 2: L 44: "...following the splash plate..."
Authors: Done (now line 48)

Referee 2: L48: replace 'due to' by "with mean groundwater level and ammonium application rate..."
Authors: Done (now line 51)

Referee 2: L 55: "have been operated"
Authors: Done (now line 58)

Referee 2: L56: sentence structure not clear, biogas production not necessarily reduces GHG emissions. "Heat and energy from biogas substitute fossil fuels and biogas production can reduce GHG emissions."
Authors: Done (now line 59)

Referee 2: L 62: delete ',thus', "...representing the second..."
Authors: Done (now line 65)

Referee 2: L 63: delete "are left over" – "generated/produced as by-products"
Authors: Changed to: "*During the fermentative process high amounts of nutrient rich residues are produced as a by-product*" (now line 67)

Referee 2: L 68-69: delete "additionally" – "both further favoring N₂O..."
Authors: Done (now line 73)

Referee 2: L 71: delete great interest ---"are of major concern.."
Authors: Done (now line 74)

Referee 2: L 74: old figure and not appropriate reference, give actual figure and direct source (e.g. German GHG inventory)
Authors: Done. Changed to „*In Germany, about 78% of N₂O emissions originate from the agricultural sector (UBA, 2014).*” (now line 77).

Referee 2: L 106: give references for grassland sites
Authors: We include following references:" (e.g. Wulf et al., 2002a, Clemens et al., 2006). (now line 110)

Referee 2: L 111: give appropriate reference for acidifying and eutrophying effect.
Authors: We include following references:" (e.g. Fangmeier et al., 1994; Galloway, 1995; Smith et al., 1999; Galloway, 2001). The same references were also included at line 787. (now line 127)

Referee 2: L 116: Quakernack et al did not investigate emissions after splash plate application
Authors: The referee is correct; Wulf et al., 2002b was meant. (now line 133)

Referee 2: L 132 NH₃ should be excluded here as it was investigated by far less intensively. Give a short sentence, that NH₃ was additionally investigated at one particular treatment.
Authors: Done, we include following sentence at line 139: "Furthermore NH₃ volatilization was determined at one application event to obtain first clues with respect to the effects of soil and fertilizer types."

Referee 2: L 144 "Study site"
Authors: Done (now line 151)

Referee 2: L 163 "at each grassland site three adjacent plots"

Authors: We change following sentences: Line 166 *“In October 2009, we selected two sites within the grassland parcel...”*

Line 171-191 *“At each site of the grassland parcel, three adjacent plots (plot dimension 12 x 12 m) were selected. At one plot biogas digestate and at another plot cattle slurry was applied, whereas the third plot served as control (without fertilization). Centrally at each plot, three PVC-collars for GHG measurements (inside dimension 75 x 75 cm) were permanently inserted 10 cm into the soil with a distance of 1.5 m to each other. To prevent oscillations of the peat through movements during the measurements, boardwalks were installed. At each site a climate station was set up in March 2010 for the continuous recording (every 0.5 hour; CR200X Datalogger, Campbell Scientific) of air temperature and humidity at 20 cm above soil surface (CS215-L, Campbell Scientific) and soil temperatures at the depth of -2, -5 and -10 cm (109-L, Campbell Scientific). For NH₃ measurements, sensors for wind speed and wind direction (Kleinwindsensor, Thies Clima) in 2 m height were additionally integrated from May to July 2011, with a logging frequency of 5 seconds (GP1, Delta-T Devices). For measuring the ground water table, plastic perforated tubes (JK-casings DN 50, 60 mm diameter, 1 m length) were inserted close to each collar to obtain individual groundwater tables for all repetitions during each gas flux measurement. In April 2010, we equipped one tube per plot with a water level logger (Type MiniDiver, Schlumberger water services), which logged the water tables every 15 minutes. Additionally to the recorded data, plot-specific soil temperatures in three soil depths (-2, -5 and -10 cm) were determined with penetration thermometers at the beginning and end of each gas flux measurement.”*

Line 207 *“At all plots, the tractor lane was 1 m...”*

Line 217 *“...by watering cans on the collars and on a 120 m² adjacent area.”*

Line 263 *“.....were inserted into the upper soil (3 cm) at each plot, from...”*

Line 324 *“.....at two soil depths (0–10, 10–20 cm) at each plot during every gas flux measurement.”*

Line 339 *“.....were randomly taken at four depths (0–5, 5–10, 10–15, 15–20 cm) for each plot.”*

Line 354 *“...(individual collar)...”*

Referee 2: L 195 what does higher accuracy imply? give figure/estimate

Authors: We include following sentence in line 202 *“Both chosen spreading devices are known for the higher accuracy in their application evenness compared to conventional splash plates (approximately 15% and 18-27% application accuracy for swivelling slurry spreader and gooseneck scatterer and up to 47% for conventional splash plate; Frick, 1999).”*

Not only evenness at the plot level but also amount of slurry applied at each measurement collar is of importance for the measurements!

Authors: This is right. With plot the PVC-collar was meant!

Referee 2: L 204: please add NH₄⁺/N_{tot} ratio in Tab.2, Tab 2 does not contain characteristics but mainly application rates.

Authors: We include NH₄⁺-N/N_{tot} ratios in Table 2. However, all relevant characteristics which are available for the present study are shown or can be derived from Table 2!

Referee 2: L 278: this procedure for harvesting is rather imprecise, why no hand harvest or combine harvests in the plot - effect of trace gas measurement on grass growth!

Authors: Harvesting was conducted by hand with a scissor at the same time when the farmer started the harvesting as written in section 2.5. It can be assumed that if the trace gas measurement affects the grass growth, it would equally affect all treatment variants. The same method to determine the annual crop/grass yield were also applied in earlier studies by Elsgaard et al., 2012, Beetz et al., 2013 and Leiber-Sauheitl, 2014. Additionally Matsunaka et al., 2006 calculated the grass yield from lysimeter which were also used for greenhouse gas measurements. Furthermore several German institutes, which were involved in the joint research project “Organic soils; Acquisition and development of methods, activity data and emission factors for the German climate reporting under LULUCF/AFOLU” funded by the Thünen Institute, define this procedure as the appropriate method to obtain the annual crop/grass yield for calculating carbon and GHG budgets. However, due to the high heterogeneity in soil properties of adjacent areas, only sampling inside the collars allowed to relate grass yield and N uptake with N₂O emissions. We include following sentence at line 289 *“There was no visible disturbance from trace gas measurements in the collars. The grassland parcel showed a strong spatial heterogeneity in grass yield so that only sampling inside the collars allowed to relate grass yield and N uptake with N₂O emissions.”*

Referee 2: L 293: this correction for NH₃ losses is not viable and should be changed as proposed above!

Authors: Changed. See upper part.

Referee 2: L 356: where are presented the soil moisture values which have been monitored?

Authors: Since the soil moisture did not have any explanatory power in the current study, we did not show them. Furthermore the recording accuracy is partly questionable since TDR sensors not always work in an appropriate way on organic soils. However, to avoid open questions and for simplification we removed the sentence at line 179.

Referee 2: L 450: this test is not viable as yields should be obtained on a whole plot level. Cuts from the collars should be pooled to mean yields per plot. Such small harvesting areas within measurement rings are not representative for undisturbed growth conditions and plot based yields.

Authors: The presented grass yields are mean values per plot, calculated from the three replicated PVC-collars per treatment! Therefore the used statistical analysis (ANOVA) is the standard proceeding to test for significant differences by comparing more than two means in case that the test requirements were fulfilled! For representatives see upper part!

Referee 2: L 454: N balance should be revised as consideration of NH₃-emissions is not appropriate.

Authors: Done

Referee 2: L 477: the properties referred to are not reported on Tab 2!!

Authors: All listed properties at line 477 to 482 (now line 495-500) are also represented in Table 2 or can be derived (NH₄⁺-N/N_{tot} ratio) from this! However for simplification NH₄⁺-N/N_{tot} ratio were included in table 2.

Referee 2: L 482: see comment on hypotheses a) and c)

Authors: Not distinctly, but in 2011 biogas treatments received 15% more NH₄⁺ compared to the cattle slurry treatments.

We change the sentence in line 500 to: *“However, the amounts of NH_4^+ were not distinctly different between the applied organic fertilizers but, in 2011 biogas treatments received 15% more NH_4^+ compared to cattle slurry treatments.”*

Referee 2: L 514 ff. do not understand this argument: 1. Mineralization usually is influenced by fertilizer amount and application rate, 2. Mineralization appears always as negative in an N-balance (as lost from the system by N-uptake)

Authors: To 1) The referee is correct, this was also stated in line 517 ff. However, it is just an assumption, that the fertilized plots received at least the same amount of N from peat mineralization as the control plots. Perhaps higher amounts of additional N can be expected through the stimulation of the fertilizer.

To 2) It is right that N from the peat mineralization is lost as was also written in line 533. However, it is important that farmers include the additional N from peat mineralization in their N-balance otherwise enormous N surpluses are the result. This is the reason why peat mineralization was handled as positive values in the current study.

Referee 2: L 532 not in this study (see above)!

Authors: NH_4^+ -N/ N_{tot} ratios are wider and C/N ratios are narrower in the digestate compared to cattle slurry (see Table 2). (now line 552)

Referee 2: L 536: but why? What can be the processes: could it also be that NH_4^+ is adsorbed in DM of cattle slurry not in contact with the soil or immobilized during decomposition of the much higher amounts of slurry dry matter?

Authors: (now line 556) As written higher amounts of NH_4^+ -N were available in the digestate (at least at the third application event 3). Additionally, microbial immobilization could also be an explanation as stated in line 555. However, the much higher N-uptake at the digestate treatments (Fig. 5a) clearly reveals that much more N must be available at these treatments. Additionally the consistently higher NUE_{min} of > 100% at the digestate treatments indicates that some organic N derived from the fertilizer or from the SOM pool has been mineralized. Therefore it can be assumed that the digestate enhanced SOM mineralization more than cattle slurry, or that N mineralized from SOM or fertilizer had a larger share in the uptake by the plants due to lower competition of microbial immobilization as was reported by Gutser et al. (2010). Probably the assumed higher SOM mineralization at the digestate treatments could partly be related to a priming effect since the higher biomass production maybe caused a higher release of root exudates, containing easily available C and N which enhanced microbial activity (Mounier et al. 2004; Henry et al. 2008) promoting SOM mineralisation. However, further investigations are needed to prove this theory mentioned above.

Referee 2: L 547: this argument is not clear: if digestates stimulate microbial soil carbon break down why should it not be immobilized in this process. However, results may look different after correction of the N-balance.

Authors: It is just an assumption for explanation, but the relationship of cumulative N_2O emissions and N-uptake indicated that much more N must have been available at the digestate treatments. Since the available N in the digestate could not solely explain the observed differences, enhanced SOM mineralisation or N mineralized from fertilizer can be assumed. Correction of N-balance and N-use efficiency did not change the overall results. For further explanation see new Manuscript, line 561 ff.

Referee 2: L 639: It cannot be explained by concentrations as ammonium application rates were almost the same.

Authors: As written not solely. But to some extent as was also shown in Figure 6 (Relationship of cumulative 16 days N₂O emissions to mean groundwater level and amount of applied NH₄⁺-N.). Further explanations are given in the new manuscript at line 669 ff.

Referee 2: L 642 ff: but this nitrogen is also taken up by the crop, as shown in the strong differences in the N balances. Is it probably not an increased microbial activity as such which may explain the differences? And it may probably also explain higher N₂O emissions from grassland sites which in general have a very high NUE.

Authors: We agree with the reviewer that the mineralized nitrogen is taken up by the plants but in the course of SOM breakdown and N transformation gaseous N losses are expected. Perhaps it is right that the digestate increased the microbial activity and thus enhanced N₂O losses. It can be assumed that an increased SOM mineralization is closely related to increasing microbial activity.

We include the reviewer's suggestion as followed; line 669-693 *"Nevertheless, as mentioned before, the much higher N-uptake at the biogas treatments (Fig. 5a) indicates that the application of this fertilizer resulted in a distinctively higher N availability, promoting N₂O production. It could be assumed that the high pH and the lower C/N ratio of the biogas digestate, obviously slightly enhanced SOM mineralization probably due to increased microbial activity compared to cattle slurry fertilizer, leading to extra N for nitrification and denitrification. Moreover, as proposed before it is also conceivable that the higher biomass production at these treatments itself is related to the increased N₂O emissions, due to the stimulating effect of plant roots on denitrification activity (Klemedtsson et al. 1987; Bakken, 1988). Considering that increasing biomass production means increasing root growth and activity it could be assumed that exudation of easily available organic C and N (Hailer and Stolp, 1985), as well as the O₂ demand due to root respiration is higher at the digestate treatments, promoting more anaerobic microsites and thus denitrification compared to cattle slurry (Erich et al. 1984; Klemedtsson et al. 1987). Furthermore several authors have suggested that root exudates may increase bacterial metabolism (Klemedtsson, 1987; Mounier et al. 2004; Henry et al. 2008), further lowering the oxygen concentration and thus increasing denitrification (Klemedtsson et al., 1987). However, the enhanced biomass production simultaneously should have depleted mineral N in the soil and thus reduced available N for nitrification and denitrification processes. Obviously, despite the negative apparent N balance of the biogas digestate treatment, there was no real nitrogen competition between plants and microbes. However, further investigations are required to prove whether digestates enhanced SOM mineralization or to what extent increased biomass production favors N₂O emissions and which N pathways and processes are involved."*

Referee 2: L 685 ff: the strong differences in NH₃ loss dynamics between the two slurry types call for explanation which is still missing.

Authors: Done, see upper part.