We are very thankful to the anonymous reviewers for their detailed, constructive and positive feedback. We agree with most of their comments and will alter the manuscript accordingly.

Anonymous referee #1:

General comments:

1) Referee#1: A key issue, when relating the N_2O emissions to the applied amounts, is the spreading accuracy (rate and evenness). From the article, it is understood that there were some problems in the start with spreading and there for the spreading was performed with watering cans on small plots at first and forth spreading event. Splash plate spreading devices gives often very uneven spreading (variance of coefficient of more than 30%), and this must be discussed and there are a need of more technical description of the evenness of spreading and how the spreading was performed in order to secure an high evenness.

Authors: The technical problems at the first application event (only for cattle slurry) and at the forth application event (only for biogas digestate) refer to the fact that the landowners could not guarantee a simultaneous application due to their temporal availability. Because of this we decided to apply the slurry manually with watering cans.

We agree that the accuracy of the splash plate spreading technique is often not as high. However, the accuraccy can be increased by the choice of the used splash plate spreading device. For the biogas digestate a swivelling slurry spreader and for cattle slurry a gooseneck scatterer was used. Both systems are known for their comparatively high accuracy in their application evenness compared to conventional splash plates (Frick, 1999). The slurry application was accomplished by the landowners in close agreement with us. Via the known barrel content and the tractor speed the landowners were able to ensure the application of an equal volumetric slurry rate. At all sites, and all application events the tractor lane were 1 m in front of the collars which were placed in a row with a distance of 1.5 m to each other. Both systems had a spreading width of 12 m and no overlapping zones occurred. Nevertheless we can not give any conclusion about the actual achieved accuracy of the application evenness, but potentially occurred differences should be reflected through the three replications per site.

We include or alter following sentences: page 5771, line 6 “In 2010 and 2011, organic fertilizers were applied via splash plate (swivelling slurry spreader for biogas digestate; gooseneck scatterer for cattle slurry) on 14th June……”

Page 5771, line 13 “It is known that the splash plate application technique can result in very uneven spreading regarding the application rate and/or the evenness. Both chosen spreading devices are known for the higher accuracy in their application evenness compared to conventional splash plates (Frick, 1999). In the present study, the application of an equal volumetric slurry rate was controlled via the barrel content and the tractor speed. At all sites, the tractor lane was 1 m in front of the collars which were placed in a row with a distance of 1.5 m to each other. Both spreading systems had a spreading width of 12 m and no overlapping zones occurred. Nevertheless we can not give any estimation about the actually achieved accuracy of the application evenness.”

Detailed comments:

2) Referee#1: Line 66: Misspelling Rodhe, missing ; between the two references.

Authors: Changed; Thank you.

3) Referee#1: Line 120: Instead of “amounts”, do you mean “concentrations”? The amounts depend on application rate and concentrations.

Authors: We agree. We replaced “*amounts*” by “*concentrations*”.

4) Referee#1: Line 135: Take away the space in the word “annual”

Authors: Done.

5) Referee#1: *Line 153-155: Equipment (fabricate, sensor types) for measuring temperature, humidity and moisture?*

Authors: We include fabricate and sensor types as followed: “At each area a climate station was set up in March 2010 for the continous recording (every 0.5 hour; CR200X Datalogger, Campbell Scientific) of air temperature and humidity at 20 cm above soil surface (CS215-L, Campbell Scientific), soil temperatures at the depth of −2, −5 and –10 cm (109-L, Campbell Scientific) and soil moisture content at −5 cm depth (SM200, Delta-T Devices). 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)."

6) Referee#1: Line 178: No – before 2 in m2.
Authors: Changed; Thank you.

7) Referee#1: Line 202: Take away space in word "detector".
Authors: Done.

8) Referee#1: Line 253: Add analyzing methodology (standards).
Authors: We include the analyzing methodology as followed: "To determine the total carbon (C_{tot}) and total nitrogen (N_{tot}) concentrations of plant biomass, dried grass samples were milled (0.5 mm) and mixed sub samples were analysed according to DIN ISO 10694 and DIN ISO 13878 by the AGROLAB Labor GmbH (Bruckberg, Germany)."

9) Referee#1: Line 357: Take away . after Table.
Authors: Done. Thank you.

10) Referee#1: Line 859: Missing an inter-space between 384, and 2010.
Authors: Done. Thank you.

11) Referee#1: Line 955: Misspelling Germany
Authors: Done. Thank you.

Figures:

12) Referee#1: Figure 1: Shortage of Application "APL" perhaps better "APPL"?
Authors: We agree and changed Figure 1 and Figure 2 accordingly.

13) Referee#1: Figure 2 caption: Misspelling of "mark"
Authors: Done. Thank you.

14) Referee#1: Figure 6: The model function for cattle slurry is missing "x" in the formula. Should it be -0.0114x?
Authors: Yes. Thank you.

Anonymous referee #2:

General comments:

1) Referee#2: There is no field replication of slurry treated plots at each site which is to some degree reflected in the statistical analysis. However, missing field replication of slurry application is a very strong shortcoming of this contribution, due to very uneven distribution of slurry by the chosen machinery. In addition, the way slurry was applied was very imprecise and the authors should give an estimate of the accuracy of the amount of slurry applied. All these aspects should be discussed in some detail in the discussion.
Authors: We partly agree. We don't have any field replications. However there are several studies in literature which used a comparable experimental design which does not correspond to an randomised field experiment (e.g. Flessa et al., 1998; Chadwick et al., 2000; Regina et al., 2004; Clemens et al., 2006; Dietrich et al., 2012) Nevertheless it has to be kept in mind that it is not always possible to apply a randomised block experiment due to changing soil conditions (especially in the transition zone from peatlands to mineral soils). In the present study the spreading width was 12 m, resulting in correspondingly large management strips. (To guarantee a high spreading accuracy the start distance in order to achieve the necessary tractor speed is also in minimum 20 m).
In addition, the used collar size partly compensates the spatial variability (see also *17) Referee#2*). According to Freibauer (2008) and Heinemeyer et al. (1995) a minimum surface area of 1 m² covered by chambers is recommended for N_2O measurements at ecosystem level.
For spreading accuracy see General comments: *1) Referee#1.*

References:

(Freibauer, A.: Designing an observation strategy for N_2O, in: The Continental-Scale Greenhouse Gas Balance of Europe, edt. By Dolmen, A.J., Freibauer, A. and Valentini, R., Ecological Studies, 203, 2008)
Heinemeyer, O., Munch, J.C., and Kaiser, E.A.: Variabilität von N2O-Emissionen – Bedeutung der Gasauffangsysteme, Mitt Dtsch Bodenkundl Ges, 76, 543-546.

2) Referee#2: This in particular also applies to the ammonia loss measurements which were only done at one application date. The obtained results cannot be transferred to other application dates as done in this study due to strong effects of temperature and precipitation on emissions. So the obtained cannot be used in the N balance and the authors should find other solutions. The very strong difference between anaerobic digestates and cattle slurry is also startling, also the completely different dynamics of emissions. According to the presented precipitation data there was considerable rainfall at the day of application or the day thereafter. An explanation could lie in the fact that both slurries were not applied at the same time and that the cattle slurry derived emissions were affected stronger by precipitation than those from AD. The authors should discuss this point in detail and probably the comparison between the NH_3 emissions from both fertilizers is not possible. In addition one measurement is not sufficient to validate a hypothesis on differences between fertilizer types. So, the conclusions should be drawn more carefully and hypotheses c) should be omitted as the experimental design and testing was by far not sufficient for its testing.

Authors: We partly agree. Cattle slurries were applied ½ hour after the digestate. During the application of both fertilizers only a very weak drizzle occurred (precipitation amounted to 3 mm in the time span between 16:00 to 23:59). Therefore differences in the effect on NH_3 volatilization due to different rainfall events and/or application time can be ruled out.

You are right that the transferability of NH_3 volatilization rates is questionable. However, daily mean temperatures at the third and fourth application event were comparable (11.4 vs. 11.2 °C), but soil moisture conditions were distinctly different at the application events in 2011. According to Döhler and Horlacher (2010) both, water saturated as well as dry soils lead to a reduction of slurry infiltration and thus to higher NH_3-losses. Nevertheless, the observed relative N losses of 15-36% of applied NH_4^+-N at the third application event were in the range reported in literature (Sommer et al., 1996; Clemens et al., 2006; Quakernack et al., 2011).

Due to the fact that the N-balance is only a simplified estimation (which not include important N paths like N_2 fluxes, nitrogen leaching or the real N turnover), the resulting error for the estimated NH_3 volatilization at the last two application events may be neglected especially as an estimation based on literature would not lead to a reduction in the uncertainty.

In our opinion it is not as surprising that distinct differences in the NH_3 volatilization occurred between the anaerobic digestate and the cattle slurry. As written, at the third application event distinctly more NH_4^+ (51 vs. 23 kg NH_4^+-N ha^{-1}) was applied at the digestate treatments. Additionally the pH value of the digestate was distinctly higher (7.7 vs. 6.8) compared to the cattle slurry. Both properties are the main drivers for the rate of NH_3 volatilization when temperature and wind speed is equal.

We agree that measurements from a single application event are not as meaningful as a result based on several application events. However, several studies in literature based on a single application event (e.g. Amon et al., 2006; Clemens et al., 2006; Rodhe et al., 2006).

Nevertheless, we omitted hypothesis c and include following sentences: Page 5788, line 9 "However, it has to be taken into account that the present results are based only on measurements from a single application event, on which the largest differences in the fertilizer compositions occurred (see Table 2)."

3) Referee#2: *The data presented on N uptake and N balance is rather extensive as compared to the topic of the paper and the presented hypotheses. That makes the paper somewhat unbalanced and not strait to the point. This section should be shortened to a great extent in all relevant sections of the manuscript. The presentation should focus on those aspects which have a high relevance for the interpretation of N_2O and NH_3 emissions. On the other hand, if the authors to retain these contents, the title should be changed, hypotheses derived and the discussion restructured.*

Authors: Thank you for this important note. We changed the title to "Short-term effects of biogas digestate and cattle slurry application on greenhouse gas emissions and N availability from high organic carbon grasslands".

Following hypothesis were included at page 5769, line 20 "c) Biogas digestate leads to a significantly higher grass yield and N-use efficiency compared to cattle slurry due to the higher N availability of the digestate.

We include following sentences:

Page 5766, line 11 "…..as well as the mineral nitrogen use efficiency (NUEmin) and grass yield, and b) how different….."

Page 5766, line 25 "Significantly higher NH_3 losses, NUE_{min} and grass yields from treatments fertilized

with biogas digestate compared to those fertilized with cattle slurry were observed.
Page 5769, line 12 “The anaerobic fermentation leads to distinct differences in the composition of the remaining residues compared to untreated slurries, as mentioned before. The different properties of these fertilizers (e.g. higher NH4+ concentrations, narrower C/N ratio, higher pH values) directly effect N transformation processes, plant N availability and thus crop yield. Currently, the effect of anaerobic digestates on crop growth after surface application under field conditions is contradictory, since some authors reported higher crop yields compared to undigested slurries (e.g. Odlare, 2005 cited in Möller an Müller, 2012) whereas others found no effects (e.g. Möller et al., 2008). However, only a few studies exist for grassland but it seems that fertilization with biogas digestates positively affects grass yields, but only in single years (Elsässer et al., 1995; Rubæk et al., 1996; Möller et al., 2008; Möller and Müller, 2012). In general the application technique seems to have the greatest influence as this directly affects ammonia losses and thus immediately available N for plant growth (Möller and Müller, 2012).”
Page 5769, line 15 “Additionally it should be tested to what extent biogas digestate and cattle slurry application affect N availability and grass yield.”
Page 5782, line 10 “We hypothesized that the application of biogas digestate leads to a significantly higher grass yield and N-use efficiency compared to the application of cattle slurry due to the higher N availability of the digestate. This could partly be confirmed, but the much higher grass yields…..”
Additional the discussion was restructured as followed: Chapter 4.1 at page 5780, line 20 was divided into two chapters 4.1 “Drainage and fertilizer effects on N-availability and N-transformation” and chapter 4.2 “Fertilizer effect on N-use efficiency and grass yield”.
Furthermore relevant sections were rearranged according to the new headings.

4) Referee#2: *The discussion of comparatively low N_2O emissions should be organized more clearly. For example it is argued in line 568 that quick uptake of fertilizer N shall account for such low emissions. However, in cattle slurry there was fertilization in excess of plant demand: why was no effect found in this treatment but on the contrary in the digestate treatment? In addition it is stated in the introduction that grassland is characterized by comparatively higher N_2O emissions but this in contrast to generally high N uptake efficiency of grassland (l 84 ff.).*
Authors: Here it is important to distinguish between the generally low observed N_2O emissions and the observed differences of the two fertilizers on N_2O emissions. Observed N_2O emissions are in general low, independent if fertilized with cattle slurry or biogas digestate. This was attributed inter alia to the quick plant N uptake and NH_3 losses which reduced the proportion of immediately available N for nitrification and denitrification, particularly at low dosage application rates as in the present study. Distinctly higher N_2O emissions in literature are mostly related to distinctly higher N fertilization rates (e.g. Velthof et al., 1996, 484 kg N ha^{-1} yr^{-1}; Augustin et al., 1998, 480 kg N ha^{-1} yr^{-1}; van Beek et al. 2011, 557 kg N ha^{-1} yr^{-1}). Furthermore, in the introduction it is stated that grassland soils in Europe and Germany produce more N_2O per unit of fertilizer-N than croplands (according to Freibauer and Kaltschmitt, 2003; Dechow and Freibauer, 2011) and not generally higher N_2O emissions. Why this is so can not be answered, but provides an exciting topic for further investigations with regards to the generally high N uptake efficiency of grassland as mentioned by the 2# referee.
We partly agree that the N fertilization at the cattle slurry treatments apparently exceeds the N demand by plants in respect to the calculated N-use efficiency (at least at the third application event; the N-use efficiency calculated for the second application event has a high uncertainty due to the fact that the application was assigned to the third cut, which took place more than a half year later). The calculated N-use efficiency based on the assumption, that a fertilized site received an equal amount of N from SOM mineralization, as a non-fertilized control site. However, it is unclear from which source (SOM mineralization, N deposition, fertilizer NH_4^+-N, mineralization of actual fertilizer N_{org}, mineralization of older fertilizer N_{org}) the plants actually obtain their nitrogen, without the use of the ^{15}N tracer technique. The N balance additionally provides N surpluses for the treatments fertilized with cattle slurry compared to biogas digestate. However, it has to take in mind that the utilization of organically bounded N is relatively small in the year of application, due to its slow release. Upon consideration of the total applied NH_4^+ and the total N uptake by plants no NH_4^+ surpluses occurred and differences between cattle slurry and biogas digestate were only small. As written, the significantly higher N_2O emissions from the digestate treatments can not solely be explained by the higher content of available N in the biogas digestate, since the amount of applied NH_4^+-N in the substrate was not distinctively different in particular when accounting for NH_3 losses. We further conclude that the high pH and the lower C/N ratio of the biogas digestate, obviously slightly enhanced SOM mineralization compared to cattle slurry fertilizer, leading to extra N for nitrification and denitrification. Thus the significantly higher N_2O emissions from the digestate treatments compared to the cattle slurry treatments could probably be attributed to a priming effect caused by increased SOM mineralization. However, further investigations are required to prove whether digestates enhanced SOM

mineralization or if the additional released Nmin is derived from the organically bounded N in the fertilizer.

Detailed comments:

5) Referee#2: 18: strong development of biogas plants; rephrase
Authors: We changed the sentences at page 5766, line 1 to "The change in the German energy policy resulted in a strong increase in the number of biogas plants in Germany.", and at page 5767, line 11 to "The strong increase in the number of biogas plants caused a land-use change towards agro-biomass production and additionally raised the land-use intensity to satisfy the huge demand for fermentative substrates (Don et al., 2011)."

6) Referee#2: L 20 ff unclear (substrate = energy crops) give reference.
Authors: Fermentative substrate covers the entire product spectrum which can be used for the production of biogas (e.g. energy crops, grass, slurry, sewage sludge, intercrops, etc.). A reference is not included in the Abstract as it is unusual for this chapter.
We alter the sentence at page 5766, line 4 to "Drained peatlands are increasingly used to satisfy the huge demand for fermentative substrates (e.g. energy-crops, grass silage) and the digestate is returned to the peatlands."

7) Referee#2: L 29 within a grassland parcel, rephrase
Authors: Thank you, but we found no synonymous word for parcel which described it better. (Maybe the English copy editing can give some suggestion?).

8) Referee#2: L 53 give actual figures
Authors: We updated the sentence at page 5767, line 8 to "At the end of 2012, more than 7,500 agricultural biogas plants operated in Germany (Fachverband Biogas, 2014)."

9) Referee#2: L 62 rephrase
Authors: We change the sentence at page 5767, line 17 to "During the fermentative process high amounts of nutrient rich residues are left over."

10) Referee#2: L 65 not that general, rephrase
Authors: We change the sentence at page 5767, line 19 to "Several studies reported a significant increase in nitrous oxide (N_2O) emissions due to the application of nitrogen fertilizers (e.g. Bouwman, 1996; Chadwick et al., 2000; Rodhe et al., 2006; Ruser, 2010)."

11) Referee#2: L 84 peasant structure (rephrase)
Authors: Page 5768, line 11; we changed "peasant structure" to "smallholder structure".
Additionally we change the sentence at page 5771, line 9 to "smallholder structure of the region."

12) Referee#2: L 88 imprecise
Authors: We alter the sentence at page 5768, line 14 to "Moreover agricultural soils in the southern part of Germany emit, about three times more of the applied N as N_2O than soils in the rest of Germany, which is attributed to the more frequent frost-thaw cycles and enhanced precipitation rates (Jungkunst et al. 2006, Dechow and Freibauer 2011)"

13) Referee#2: L 102 contradictory as compared to what
Authors: The results from literature are contradictory if biogas digestate reduce or enhance N_2O emissions compared to other conventional fertilizers as slurries or mineral fertilizers.

14) Referee#2: L 116 give reference
Authors: We include following references in the sentence at page 5769, line 11. "High NH_3 emissions particularly occur after splash plate application on grassland (Rubæk et al., 1996; Quakernack et al., 2011), which is still common practice in the smallholder farms of South Germany."

15) Referee#2: L 120 higher amounts – imprecise
Authors: We change the sentence at page 5769, line 15 as followed: "More N_2O is emitted after biogas digestate than after slurry application because of higher NH_4^+-N concentrations in the substrate."

16) Referee#2: L 141 what is a grassland parcel?
Authors: It means a contiguous area which is uniformly managed. No synonymous word found.

17) Referee#2: L 146-148 no true replications
Authors: We agree that this is not a randomised block experiment. Nevertheless, each site contains three replications which covered a total measurement area of 1.69 m². Several other studies in literature use a similar design for the comparison of different landuse or management types; e.g. Flessa et al. (1998) four replication within one site with a total measurement area of 0.28 m², Regina et al. (2004) three replications within one site with a total measurement area of 1,08 m², Clemens et al. (2006) four replications within one site with a total measurement area of 1.0 m², Beetz et al.(2013) same design like in the present study; Leiber-Sauheitl et al. (2014) same design like in the present study. Furthermore, the temporal pseudoreplication is considered in the statistical analysis. See also *1) Referee#2.*

18) Referee#2: L 325 ff. report rainfall at onset of application
Authors: We include the following sentences at page 5777, line 7: "With the exception of the third application event, no rainfall occurred during the application of the organic fertilizers. However, precipitation during and after the third application event was only weak and amounted to 3 mm in the time span between 16:00 and 00:00 hours."

19) Referee#2: L 447 'content' – 'amount' or 'concentration' according to what is intended
Authors: You are right the sentence is imprecise. Thanks. We change the sentence at page 5781, line12 as followed "However, the amounts of NH_4^+ were not distinct different between the applied organic fertilizers (with one exception)."

20) Referee#2: L 484 –the digestates have a very low viscosity/dry matter concentration affecting the infiltration behaviour. This is quite different to the usual characteristics of co-fermented slurries. This should be addressed and probably affects the extrapolation of the results to other digestates.
Authors: You are right the dry matter content of the digestate is very low and at the lower end of values reported in literature (e.g. Möller et al., 2008, Gutser et al., 2010; Quarkernack et al., 2011; Möller and Müller, 2012). Nevertheless, digestates generally have lower dry matter contents compared to undigested slurries due to the depletion in easily degradable C compounds as written at page 5768, line 21.
In the present study the infiltration behaviour of both fertilizers seems to have no particular impact on the NH_3 volatilization due to different reasons. Firstly, at low dosage applications a large part of the organic fertilizer remains on the plant canopy and thus soil contact and infiltration was limited after spreading. Secondly, it could be assumed that the infiltration of the slurries was possibly hampered due to the strong rain event which took place before the fertilizer application (for this see Döhler and Horlacher, 2010).
We include following sentences at page 5788, line 12 "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). However, 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. According to Döhler and Horlacher (2010), water saturated and dry soils 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 due to the strong rain event which took place before the fertilizer application. Additionally, at low dosage applications a large part ……"

21) Referee#2: L 509 do not agree: why lower yields of the cattle slurry treatments under such high mineralization rates. It should be discussed in more detail why yield and N-uptake differences occurred.
Authors: We agree that the observed different yields are to some extent surprisingly. In general, the N mineralization is only a rough assumption since we did not measured real (gross) N mineralization rates. Furthermore as mentioned before ((*4) Referee#2*) it is difficult to give any conclusion from which source (SOM mineralization, N deposition, fertilizer NH_4^+-N, mineralization of actual fertilizer N_{org}, mineralization of older fertilizer N_{org}) the plants obtain their nitrogen, without the use of the ^{15}N tracer technique. As written due to the wider NH_4^+/N_{tot} ratio and the narrower C/N ratio of the digestate more N was immediately available for plant growth. Nevertheless, the much higher grass yields from biogas digestate treatments cannot solely be explained by differences in applied NH_4^+, since differences were only small, in particular when accounting for NH_3 losses. Many studies have shown that the utilization of N derived from organic fertilizer is relatively small in the year of application, due to the slow release of organically bound N (Jensen et al., 2000; Sørensen and Amato, 2002; Gutser et al., 2005). However, 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 (Gunnarsson et al., 2010). Since the digestate is considered as more recalcitrant (Clemens and Huschka, 2001; Oenema et al., 2005; Möller and Stinner, 2009), it can be assumed that the digestate enhanced SOM mineralization more than cattle slurry, or that N mineralized from SOM had a larger share in the uptake by the plants due to lower competition of microbial immobilization.
We include following sentence at page 5782, line 21 “However, in the present study the observed yield differences between the treatments fertilized with biogas digestate and cattle slurry cannot fully be explained on the basis of available N in the applied fertilizers and further investigations are necessary.”