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Interactive comment on "Soil Greenhouse Gas Emissions under Different Land-Use Types in Savanna Ecosystems of Kenya" *by* Sheila Wachiye et al.

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Authors Response:

The manuscript has been reviewed by 2 reviewers and an additional comment was made in the open discussion. Before, responding to each reviewer and comment individually, we would like to thank for the constructive comments and informative feedback. The document is structured as follows: each of the reviewer's comments (indicated by RC) is first repeated followed by our response (indicated as AC). Where relevant we either include a rephrased sentence already or explain how we intend to implement suggested changes.

Anonymous Referee #1

Overall comments: RC: The manuscript describes a study in four typical land-use types in Kenya, Africa. Soil fluxes of CO2, N2O, and CH4 were measured manually eight times over the course of a year. The main strength of the manuscript is that it produces flux estimates of these greenhouse gasses in under-represented ecosystems. Correlations with driving factors of moisture, soil C content, and vegetation activity (NDVI) were explored. The main weakness of the manuscript is the sampling campaign and methods are very limited and coarse, and thus interpretation of the driving factors of the fluxes are much more speculative than could be with greater initial and supporting data. My suggestion would be to reduce the length of the manuscript to focus just on the data collected and acknowledge the weaknesses in the data set. A shorter, more concise, manuscript would be much more effective to get the data out there. AC: Once again, we thank the reviewer for pointing out both, the strengths and the limitations in the originally submitted manuscript. Following the concern made on the length of the paper, we will reduce the revised manuscript, focus only on the important issues, and not compromise the quality of the manuscript.

Abstract RC: Ln 25 – the N2O flux was more than double the cropland than bushland, why do you say is was not different between the four sites? AC: We thank the reviewer for pointing this out. Actually the difference in annual mean N2O emissions were significantly higher in the cropland (2.7$\pm$0.6 μg m 2 h 1) than in the conservation land (1.6$\pm$0.4 μg m 2 h 1), grazing land (1.5$\pm$0.4 μg m 2 h 1), and bushland (1.2$\pm$0.4 μg m 2 h 1)(Kruskal-Willis rank test). In contrast, no difference was observed between the other three sites. RC: Ln 31 – Over the course of the measurement period or between sites, CO2 was correlated with soil moisture? AC: In all our study sites and across the seasons, soil CO2 emissions were positively correlated with soil moisture. RC: Ln 30-40 - The abstract does not have a clear message. Soil C is important, but soil moisture is driving fluxes, but NDVI is correlated. What is the take-home point? AC: We will rephrase the abstract as follows in order to provide a clearer message.

“Based on our results, soil C and soil moisture are key drivers of soil GHG emissions in all land-use types. In addition, vegetation cover explained the seasonal variation of soil CO_2 emissions as depicted by the strong positive correlation between NDVI and CO_2 emissions. We conclude that with more green (active) vegetation cover higher CO_2 emissions occur due to enhanced root respiration compared to drier periods in the year.

Introduction RC: The introductory paragraph never says what produces and consumes GHGs from the soil? AC: We will include the following information into the introduction of the revised manuscript. Each of the GHGs observed is either consumed or produced via biogeochemical processes. For instance, methane is produced by methanogenesis process under anaerobic conditions and consumed by methanotrophic microorganisms under aerobic conditions (Serrano-Silva et al., 2014). CO_2 is in our case (dark chambers) produced in the soil during decomposition of organic matter and root respiration which produces CO_2. Similarly, CO_2 is produced via plant respiration in the case plants were present in the chamber (Oertel et al. 2016). N_2O, on the other hand, is produced as an intermediate product of denitrification and nitrification processes amongst others (Butterbach-Bahl et al., 2013). RC: ASALs is an acronym that could be avoided by using drylands or arid ecosystems. Overall there are many acronyms used that could be avoided. AC: We thank the reviewer for this suggestion. Overall, we will have a look at the use of abbreviations. In the case of ASAL, we will use drylands in the revised manuscript. A similar point was made by reviewer 2.

Methods RC: Ln 187 – ssp AC: Corrected to spp RC: Ln 240 – This is a large assumption. Does the sampling really represent the average flux of the day for your ecosystem? At least one of those references is for a temperate forest where they did measure the 24-hour cycle, which likely has a very different cycle than these ecosystems due to differences and vegetation type and environmental variables. AC: We agree that this is partially an assumption, and yet one has to compromise, as a more frequent sampling was impossible. Overall, the theory of sampling in the respective morning hours is

sound (Parkin and Venterea, 2010), as temperatures increase during the day and thus microbial processes similarly are enhanced. Of course, the fact that moisture and other factors are essential drivers following our results may be misleading and yet again the drivers suggested are for the whole dataset, i.e. across seasons and not necessarily aiming at explaining diurnal variations. We have done diurnal GHG measurements in other regions in Kenya with a portable laser absorption spectrometer where we found clear temperature dependencies during the course of the day (data not shown here, as this is part of another study, Butterbach-Bahl in prep.). RC: Ln 252 – The pooling method reduces the sample # to 3 for each LUT time period instead of 9? AC: This is correct, the three gas flux estimates that we have at the end of the day for each LUC type is thanks to the pooling method derived from 9 distinct locations (chambers). With this approach, one can still account for spatial heterogeneity while reducing the overall number of GHG samples to be analyzed in the laboratory (Arias-Navarro et al., 2013). RC: Ln 290 – was temperature measured in the chamber? AC: We recorded the air temperature in the headspace of each chamber at the same interval as gas pooling (recorded at T1, T2, T3, and T4). This temperature is then used to correct the gas flux during flux calculation.

Results RC: Ln 385 – What are the errors on the fluxes? They are so small for soil CO_2 fluxes. Report error and sample size. AC: The sample size per season is seven daily average values derived from three flux values per day from each land use type. The error bar presented here is the standard error of the three flux values per day. RC: Figures 4 and 5 are good. Keeping the color scheme, the same would be helpful. AC: The two figures provide different information and having them in the same color scheme might be misleading. Figure 4 shows the difference in emissions between the land uses types while figure 5 gives the differences in emission between the wet and dry season. RC: Figure 6 – put in same color scheme. AC: This is a relevant point and we tried to have them in the same color scheme of figure 4. However, this then made it very difficult to differentiate between the LUC types. RC: Figure 7 – this is at such a large scale, I don’t find it very informative. Fig 6 shows the data used. AC: We agree and we will move Figure 7 into the appendix and keep Figure 6 in the revised manuscript.

Discussion RC: Different terms are being used, soil respiration; soil CO_2 emissions, ecosystem soil respiration (?) Make this consistent. AC: We thank the reviewer for pointing this out. In the revised manuscript, we will only use the term "soil CO_2 emission". RC: There is quite a bit of speculation in the discussion. It would be better shortened and more focused on the data collected, not the data lacking that could explain the patterns. This is true for CO_2 and N_2O sections. AC: Following this suggestion and a similar point being raised by Reviewer 2, we will make the discussion shorter and more concise – some examples are: Example 1 Original - CO_2 emissions from the soil differed significantly between the land-use types. Higher CO_2 emissions were particularly observed in the conservation land followed by grazing land and bushland, while lowest levels were recorded from the cropland. We observed the same trend with SOC, and thus we attributed the difference in CO_2 emissions between the land uses to SOC as observed (see Table 1). This is in line with a similar study by La Scala et al. (2000), which recognized SOC as a key driver of CO_2 emissions from the soil, as it is the primary source of energy for soil microorganisms (Lal, 2009). Revised - Highest mean CO_2 fluxes were observed from the conservation land followed by grazing land and bushland, and the lowest from cropland. Soil C content also showed the same trend (conservation land > grazing land > bushland > cropland), which is the primary source of energy for soil microorganisms (Lal 2009) and thus affecting CO_2 emissions. Therefore, we attributed this variance to the difference in land use and management activities playing a major role in modifying both biotic and abiotic factors (Pinto et al., 2002). Example 2 Original - Soil CO_2 emissions and mean soil C content were lowest in cropland. Root respiration in cropland depends on periods of live roots in annual crop fields and on the biomass of roots during the initial growing season (Raich et al., 2000). Therefore, the continued removal of crop residues during harvesting and frequent tillage affected both root respiration and SOC. As much as crop residues contribute to carbon stocks through their mineralization (Nandwa, 2001),

most maize residues were used as livestock feed and sometimes as fuel, while bean residues were removed completely during the harvest and burned. Revised - With the lowest CO_2 emissions being reported from the cropland, we attribute this observation to the continued tillage and removal of crop and crop residues during land preparation, weeding and harvesting, affecting both root respiration and soil C content (Raich et al., 2000; Nandwa, 2001). In East Africa and in smallholder farming systems, most of the crop residues are used as livestock feed and fuel. Example 3 Original - Manure inputs provide easily degradable substrates of C and N leading to enhanced soil CO_2 emissions (Janssens et al., 2001; Davidson and Janssens, 2006). However, manure input in cropland was very low (approximately 20 kg in a 1.5 ha farm per month) and thus no measurable effects in CO_2 emissions were detected. This was opposite to our hypothesis. Another reason could be that soil fertility was too low to have a detectable influence on CO_2 emissions (Pelster et al., 2017). Our results are in the same magnitude with those of Rosenstock et al. (2016); Farai Mapanda et al. (2011), and Pelster et al. (2017), who also did not detect any change in CO_2 emissions after manure application and attributed this to the low input of manure to the maize and sorghum plots. Revised - Manure inputs in cropland were very low (about 20 kg per month on a 1.5 ha farm) and thus no measurable difference in CO_2 emissions was detected. Several other studies observed the same scenario from low manure input in maize and sorghum plots (Rosenstock et al., 2016; Farai Mapanda et al., 2011, and Pelster et al. 2017). Example4 Original - Soil N_2O emissions can vary highly over time, as regulated by factors such as soil moisture, temperature, aeration, ammonium and nitrate concentrations, pH, and mineralizable carbon (Butterbach-Bahl et al., 2013). However, we did not document any significant difference in N_2O emissions between the four land uses. At all the sites, N_2O emissions were very low, and this we attributed to the observed low soil N content (see Table 1). According to Pinto et al. (2002) and Grover et al. (2012), savanna ecosystems have a very tight N cycling, which transcends to low N availability. Thus, available N is taken up by vegetation, leaving very little for denitrification (Castaldi et al., 2006; Mapanda et al., 2011). Our results are consistent with low

N_2O emissions 610 observed in a Brazilian savanna (cerrado) by Wilcke et al. (2005), who also reported low N levels in their study area. Very low N_2O emissions due to poor nutrient availability have also been observed in other savanna landscapes (Scholes et al., 1997; Castaldi et al., 2016). Soil N_2O in cropland match those of Rosenstock et al. (2016), who also attributed the low soil N_2O emissions to poor nutrient availability in the soil Revised - Our results showed low N_2O emissions from all the LUTs, which we attributed to the low soil N content observed (see Table 1). Savanna ecosystems are characterized by very tight N cycling, which transcends to low N availability (Pinto et al., 2002 and Grover et al.,2012) and most of this N is taken up by vegetation, leaving very little for denitrification (Castaldi et al., 2006; Mapanda et al., 2011). The flux results observed from the conservation land, grazing land and bushland are consistent with those observed in a Brazilian savanna by Wilcke et al. (2005). Many other studies from similar ecosystem reported comparable N_2O flux magnitudes (Scholes et al., 1997; Castaldi et al., 2016; Mapanda et al., 2010). The higher N_2O emissions observed in June and July from our cropland site after the maize and bean harvests are likely occurring due to the absence of plants. RC: Interesting CH_4 just gets one sentence because it is small::: but this is important too! AC: For the completeness of the paper, methane emissions have to be mentioned. Even though Reviewer 2 suggested to remove everything related to CH_4, we decided to keep this information in the manuscript for 2 reasons: (1) completeness in terms of greenhouse gases, and (2) even if the contribution of CH_4 is low, this is an important results and similar measurements may not have to be repeated. âĂČ

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