Reviewer (R#1) comments and author responses to ms bg-2020-230

Reviewer comments are given in italic and with author responses in normal style

Sub-soil irrigation does not lower greenhouse gas emission from drained peat meadows

by Stefan Weideveld et al.

General comments:

The authors investigate the GHG reduction potential of drained peatlands by using sub-soil irrigation. The topic of the paper is of relevance to Biogeosciences and will be of interest to an audience interested in mitigating greenhouse gas emissions from agriculturally used peatland. It is a novel approach, which needs further research. For the evaluation of the effect of sub soil irrigation on GHG emissions, a paired design of a control site and a sub-soil-irrigated site is used. Four different sites were investigated.CO2, CH4 and N2O fluxes were measured with chambers over a two 2 years period. Carbon and greenhouse gas budgets are determined and compared for the paired sites.

> **Response(1):** We thank the reviewer for the positive comments and constructive inputs. This will help us improve the manuscript.

I do not understand the experimental setup: The basic hypotheses of the manuscript that main GHG emissions comes from soil layers deeper than 70 cm is not well explained.

> **Response(2):** In the Netherlands, the aim of the government is to reduce CO_2 emission from peat meadow areas by 1 Mt by 2030, from which halve is expected to be achieved with the SSI technique (PBL, 2018). To come to this reduction, an area of 50.000 ha with SSI drainage pipes are planned and a CO_2 reduction of 50% is expected from this area. This technique has, however, never been validated by measured CO_2 emission data. Expectations are based on pilots with only soil subsidence measurements. In these pilots a relation between lowest GWT and soil subsidence is found, therefore the elevation of summer GWT is expected to contribute most to the reduction of CO_2 emission. So, our hypothesis is based on the state of the SSI technique according to policy in practice.

Moreover, no information about soil properties and soil moisture of this relevant depth are given in the manuscript. As these soil data are missing, it is not clear, which amount of soil organic carbon is exposed to oxygen due to the alterated ground-water level. Often the bulk density is low in deeper peat layers.

> **Response(3):** We agree that the current table providing soil data is inadequate. In the revised version we will replace the averaged soil properties with data of a higher resolution per soil layer. More details will be provided on the mineral cover layer, the schalter layer, the degraded peat layer and the less degraded peat layer.

It would be interesting to calculate the additional % of aerated carbon due to the alteration of the groundwater level and to compare it to GHG emissions.

> **Response(4):** It would have been interesting to measure the change in soil moisture though out the and time with fluctuating water tables, in combination with soil oxygen. To see what the true effects are on the aeration of the soil as a result of the SSI. However, we did not measure it during this field experiment.

Moreover, the authors should estimate if the small differences in groundwater level (<20 cm) can lead to a theoretical GHG reduction, which can be measured with this method (and associated uncertainties) and experimental set up.

Response(5): GWL are in summer even elevated for up to 60 cm difference. This is again not our own expectation, but the expectations are based on previous pilot studies which are now commonly accepted in policy.

Unfortunately, soil moisture was only measured to soil depth of20cm. (At site A, C, D, soil moisture and temperature is measured only in the mineral soil cover). Moreover, these data are not presented in the paper, although the importance of soil moisture is discussed in the discussion section.

Response(6): Soil moisture data will be included in the table to expand the soil properties. This will be data from a sampling done during the Peak of the drought period indicating the effect of SSI throughout soil profile.

The main conclusion that SSI does not lower GHG emissions cannot be drawn from the presented data as most of time the difference in ground water level between the treatments was relatively small. However, when the differences in ground water level were > 20 cm a reduction of GHG emissions was observed. In my view, the conclusion from this paper would be that a substantial increase in groundwater level is needed to allow large enough effects in the emissions to be measured.

Response(7): The current design of SSI, at a depth of -70 cm and spaced 6 or 5 meters apart, was not capable of raising the water table to a level to have a sufficient effect on the GHG emission. Even with a flexible ditch water level, inflow of water as not able to raise the water table to higher level. The conclusion was intended to state that the current way that the SSI was implemented does not allow for large enough effects on the groundwater table to have a measurable effect on the emission. Optimization of the SSI technique was not part of the main conclusion, but indeed a substantial higher water table is needed.

For two sites, the comparability of control and SSI treatments is not given. This may influence the mineralization processes and thus the results. In particular, Site A: SSI has considerably higher organic matter content (39 vs 27%) as the control, and C/N ratios (29 vs 20) indicate different organic matter quality. Moreover, Site D: Control site has nearly the double amount of organic matter than SSI (38 vs 61%). This aspect is not discussed in the manuscript and might bias the results.

Response(8): The differences in organic matter content are largely due to the thickness of the mineral top layer. However, the soil organic carbon stock is of a similar size for both sites. To avoid confusion, the indication of soil organic matter will be changed into g/l soil. And it will be indicated for the different soil types to give a better sign of the comparability between the treatment and control and the different sites.

In particular, the methods used to measure the carbon and greenhouse gas fluxes and management are not described in sufficient detail.

Response(9): The method is expanded upon, and described in further detail.

The annual N2O budget was calculated based on only few measurement campaigns. In my opinion, it is not possible to calculate annual N2O budgets from 6-9 daily values, which were measured within 6 month in 2017. This is most evident at Site B Control: Linear interpolation of the high N2O emission in March probably overestimate the N2O emissions for the whole winter time. Moreover the material and methods section is misleadingly stating that N2O was measured for each measuring camping, but at Site B 38 campaigns were made, whereas I counted only 17 data points in Figure C1.Researchers reading the manuscript without looking at the supplementary data could extract the N2O data for annual budgets. Due to the low temporal resolution of the N2O data, it is not possible to distinguish between background N2O emissions and fertilizer-induced N2O emissions.

Response(10): In 2017 we experienced infrastructural constraints to measure N_2O fluxes more frequently. The extended winter gap is a consequence of mal-functioning of the Picarro 2508 under field conditions with low temperature. We agree that 7 flux days and 90 measurements are too few for year budget estimation. The methods and results will be adjusted so that it becomes clear that the year budget of 2017 is a rough estimation based on average fluxes from 7 flux days. We will discuss the importance of generally higher winter emissions that were not measured for year budget estimates, which made our estimation a conservative underestimation. However, we believe that the measured data is still valuable for evaluating the N_2O emissions under influence of SSI. The results show no structural higher or lower N_2O emissions between the control and SSI sites. The measured data fits our expectations and references of these types of systems. Therefore, we would like to keep the annual budget estimation for the general discussion of the total GWP. But clarification will be added to methodology and discussion the stress the low temporal resolution of our measurements, and daily measured data will be presented. The moments between frost and thaw was measured for Farm B and C in the beginning March 2018. However due to technical difficulties with low temperatures and the gas measure equipment these moments were still sparse.

As no daily data are presented for the CH4 budget, the data coverage and thus quality of annual budget cannot be evaluated.

Response(11): Daily data will be added to the manuscript to improve the data evaluation.

The description of management is very short and important information about cutting days, fertilization events, and amount of applied fertilizer are missing, which makes it difficult to understand N2O and NEE data.

Response(12): Cutting days and fertilization events will be added to Figure 7, Appendix B1, C1. Furthermore, fertilizer information will be included in the methods.

E.g. Why are the cutting days not visible in the GPP data? In other studies, the decrease in GPP after management events can be nicely seen (Poyda et al. 2016 or Beetz et al 2013,). In comparison to their data, the GPP stayed rather constant and relatively high (-10 g CO2 m-2 d-1) throughout the year. Accordingly, it is difficult to evaluate the quality of GPP modeling.

Response (13): We will re-calculate the GPP of 2017 campaign-wise with inclusion of the cutting events where the GPP will be reduced. This will result in a different GPP value and different figures 7 and appendix. Seeing the effect of the higher biomass on the dark respiration of the plants, we agree that the effect of the biomass is important for the total value of the GPP and Reco. In order to see the effect of cutting a correction for both interpolations will be applied. The harvest dates will be included in the figures to visualize these moments. And to give a better estimate for the total emission.

The uncertainty assessment is nicely done for the gap filling method of NEE, but the uncertainty estimates are not integrated in the results and transferred to GPP and Reco. For NEE, Reco, and GPP an uncertainty is indicated, but it is not stated what it is(error of SD or 95% confidence interval...). The uncertainty range is given for NEE as3-16 t CO2 ha-1 yr-1, (L 370), but NEE uncertainty from NEE gap filling is given as 14-25 t CO2 ha-1 yr-1). For N2O and CH4 the uncertainty assessment is missing. Other sources of uncertainty (systematic errors of the use of chamber methods or random errors) are not discussed. Please provide a more thorough uncertainty estimation of all component of the net ecosystem carbon balance and included this values in Table2 and

Response(14): Uncertainty will be discussed and quantified in more detail. Specifically, ranges of R_{eco} and GPP will be presented by propagating model parameter variations to the gap-filled annual fluxes. Uncertainty from gap-filling method selection that was already discussed will be used as range of annual NEE, since we consider this as the major source of the uncertainty.

3.Specific comments:

Experimental set up and management Table 1: please provide more information about soil properties of the mineral soil cover, and underlying peat layers (carbon content, bulk density, C/N and carbon stock) in a higher resolution for the entire aerated soil depth. Please state how many soil samples were taken per depth and where. Please also add the information of the depth location of the schalter.

Response(15): A table with higher resolution will be added to provide more information on the soil characteristics. The methodology will be updated.

Figure 2: please provide information about the location of the chambers of the control site relative to the main ditch.

Response(16): The distance to the main ditch is added. The distance variated between 25 and 40 meters. The location was chosen to exclude a direct effect of the ditch on the water table in the control sites.

Please provide data of cuttings days, fertilization events and measurement campaigns for CO2, N2O and CH4 as the growth of the grass and thus GPP strongly depend on time of measurement (days after cutting). Information can be added in Figure 7, Appendix B1, C1.

Response(17): We agree and in the revised version we will include the cutting days and fertilization events into the figures.

Please add information about amount and determination of N und C input through slurry application. Please add information about the determination of the yield (dry mass of the grass).

Response(18): This information will be added in the methods and results. From every manure application manure samples were taken. Bulk-density was determined, Total nitrogen (TN) and total carbon (TC) was determined in dry slurry material (3 mg) using an elemental CNS analyzer (NA 1500, Carlo Erba; Thermo Fisher Scientific, Franklin, USA)

According to Table 1 Site A und B were grazed. How was carbon import through cattle manure determined? How was the carbon export through grazing determined? Was the yield only determined within the chambers or for the entire grassland? How was the grass height determined?

Response(19): The management of the whole field was grazing, however our field site was fenced off to prevent the mentioned problems. The yield was determined inside the chamber frames, to close the carbon budget. Grass height was estimated using a straight scale with a plastic disk with a diameter of 30cm to determine the top of the grass.

Gas fluxes Chambers: Was the location of the frames fixed over the two years? Did the vegetation change within the chambers during the experiment?

Response(20): The frames where fixed trough out the two measurement years. The vegetation though out the years remained dominated by *Lolium perenne.* However in spring there were always other species coming up in the frame. However after the first harvest these species disappeared.

Please add the transparency of the chambers? Was a correction term introduced due to a reduced transparency?

Response(21): We corrected the PAR values outside the chamber since the acrylic glass of the transparent chambers reflected or absorbed at least 8% of the incoming radiation

Please add information about the used sign convention, positive fluxes= loss of carbon? Please add information about the used equation for the calculation of GHG balances and assumptions (harvest is assumed to be released as CO2?, loss of dissolved organic carbon?

Response(22): The methodology is expanded upon. The atmospheric sign convention was used. All C fluxes into the ecosystem where defined as negative (uptake from the atmosphere into the ecosystem), and all C fluxes from the ecosystem to the atmosphere are defined as positive. This also holds for non-atmospheric inputs like manure (negative) and outputs like harvests (Positive). Both harvest and manure input are expected to be released as CO_2 again. This will be described better in the methods. Dissolved organic carbon was not sampled during the experiment.

L242ff: what is the accuracy of precipitation data derived from satellite images?

Response(23): The accuracy is four square kilometer. Giving a precipitation value every 3 hours.

L243: June 2017 seemed to have received more than the average precipitation June is included in the drought period?

Response(24): The average precipitation in June was higher than average, however this is due two days with heavy rain at the end of the month, ending the drought. We will include the dates of the determined drought periods.

Figure 4: As there were 3 groundwater measurements per site, it is not clear which groundwater table is presented, average of all 3?, what is the SD of the three wells? How is the variability of groundwater level of the control site? Please explain DRN

Response(25): The presented data is data from the logger in the field site, the other groundwater measurements are manual dip wells, recorded each measurement campaign. The data shown in figure 4 is a good depiction of the situation in the control site. Only close to the ditch (Less than 10 meters) there is a higher groundwater table in the summer and lower in the winter.

L276: I do not understand the sentence "There is variation.." please clarify.

Response(26): There is difference (variation) between the SSI and control site on the different days in regards to temperature and grass height.

L327-330: What is meant by uncertainty of 3-16 t CO_2 ha^{-1} yr^{-1}. What is represented by 1.6 t CO_2 ha^{-1} yr^{-1} I for NEE in 2017?L326-332: What is the difference between annual NEE of 47 t CO_2 eq. ha^{-1} yr^{-1}(L327) and emissions of 62 t CO_2 eq. ha^{-1} yr^{-1} (L313)

Response(27) This part will be rewritten to help clarify what parts are the uncertainty of the interpolation of NEE and what parts are the SD of the NEE. What parts are the NEE budget (GPP – R_{eco}) and what part are the total carbon budget.

L 334-338: Please provide daily CH_4 data.

Response(28): Daily data will be added to the manuscript

Table 2 and Table 3: Please add uncertainty estimates for all components of GHG balance.

Response(29): Modeling and gap-filling uncertainties will be added to R_{eco}, GPP and NEE.

L. 380: Reco was lower when the differences of groundwater level was >20 cm

Response(30): Correct, this will be adjusted in the manuscript.

L. 420: N_2O emissions are not only driven by fertilization events, but also by soil moisture, which should be differ by the treatment. Thus, the comparison can be biased by missing peak events.

Re~~p~~sponse(31): See response(10) Soil moisture is an important driver for the N_2O fluxes from these drained peatland systems. We assume that with the method used we missed peaks induced by fertilization and rewetting. However a comparison between the treatments effects on the basis of the different measurement campaigns can still provide insight into the effect of SSI on N_2O emissions.

L428: please use the same sign convention for all cited references.

Response(32): The references will be updated and check more thoroughly.

Technical comments: L310: Please state was the 4 t are, SD?,...,

Response(33): this will be clarified in the manuscript. In this case it is the SD

Please indicate A und B in Figure 6

Response(33): A and B will be included in figure 6

Figure 7: please use colors, which can be clearly distinguished

Response(34): Figure 7 will be improved to increase the understandability of the figure.