

Comments and suggestions for the Manuscript BG- 2015-478 (Global warming potential and greenhouse gas intensity in rice agriculture driven by high yields and nitrogen use efficiency: A 5-year field study).

Recommendation:

This manuscript reports results from a multi-year field experiment aimed at evaluating the effect of several 'integrated soil-crop system management (ISSM) scenarios (consisted of different rates of nitrogen fertilizer supplied by split application to synchronize in-season N supply with crop demand, with or without supplementary organic manure, Zn and Na₂SiO₃ fertilizer and different planting densities) on global warming potential (GWP) and greenhouse gas emissions intensity (GHGI) of grain (rice and wheat) production. For calculating GWP and GHGI, the analysis accounts for all GHG sources (i.e. CH₄ and N₂O and CO₂ emissions associated with agrochemical inputs and farm operations) and sinks (i.e., soil organic carbon sequestration).

Considering the global priority of developing cropping systems that are capable of increasing food production while minimizing the environmental impact, the manuscript is suitable for publication in the journal Biogeosciences. However, I find several issues (listed below), that must be addressed to improve the quality of the manuscript. Once these general comments and the specific comments on the manuscript text are satisfactorily addressed, the manuscript should be accepted for publication in this Journal.

General comments:

(1). It is stated that this study is a '5-year study'; however, the data presented in this paper covers only the last three years (2011 - 2014, Table 2 and 4) of the field experiment. Authors have simply reported the experiment was started in 2009 (Line 97) and the results for the first 2-yr were published in Ma et al. (2013) in lines 122-123; however, no attempt has been taken to analyze the overall 5-yr results. Therefore, the reference to '5-year study' is not supported by the results presented. I suggest, to call it as a '3-year study' or to include the first 2-year data in the overall analysis and then call it as a '5-year study' in the title and relevant locations elsewhere in the manuscript.

(2). I have several questions related to the emission factors used for the calculation of CO₂ emissions from agricultural inputs and farm management operations as explained below. These issues must be addressed and clarified in the manuscript text and/or in Table 4.

Line 165 - 167: Please explain how the emission factor for irrigation water (i.e. 5.16 kg C eq. cm⁻¹ ha⁻¹) was calculated, because Lal, 2004 provides several emission factors for irrigation water, depending on the amount of total irrigation water supplied and the type of irrigation system used. It is clear that this emission factor was based on the original value of 257.8 kg CE ha⁻¹ for a 50 cm of irrigation provided in Lal 2004. However, Authors need to explain briefly the applicability of this emission factor for the irrigation system used in this experiment. Please revise the text accordingly, to include this information.

Line 168: Please check the C emission factor used for herbicide. According to Lal (2004), it should be 6.3 kg CE per kg active ingredient, NOT 0.3 kg CE per kg active ingredient, used in Table 4. This should be corrected.

Line 169: The following several issues (listed a to f) related to the method of calculating CO₂ emissions associated with farm operations need to be clarified to improve the clarity of the methodology:

(a) Briefly explain the field operations such as tillage, planting, and harvest. The C emission factor for each of these operations will depend on the type of the machinery used. For example, it is necessary to mention how tillage was done. Was it done using one pass of rotary tiller and one pass of raking? There are two events of tillage: one for rice, one for wheat: two different systems. Explain briefly what was done to understand the applicability of the emission factor used.

(b) It is not clear what is presented as: 1 (one) kg/ha for all treatments in the column for crop planting in Table 4. Does it mean: 1 kg diesel fuel/ ha was used for crop planting? If that is the case, C emission factor for diesel fuel is 0.94 kg CE per kg diesel (Lal 2004). If it is '1' event, then 3.2 kg CE/ha (which authors have used) is correct; however, there are 2 events of planting per year (one event for rice, another event for wheat). It appears that only one event of crop planting is accounted in the Table 4. Please clarify.

(c) Was the emission factor for manure application used in Table 4, obtained from Lal 2004? (I am not sure Lal 2004 provided this emission factor).

(d) Similarly, there are two harvest events per year (one for rice, one for wheat). Was the 11 kg/ha diesel use reported in Table 4 for both harvest events? Please clarify.

(e) It is not correct to apply the emission factor for spraying and thrashing (0.0725 kg CE/kg active ingredient) for calculating CO₂ emissions from 'farm machinery production' as presented in Table 4. Please correct.

(f) Was there any machinery used for fertilizer application? If machinery was used, split fertilizer application requires 3 or 4 passes for each crop, depending on how many split applications were done for rice and for wheat in each treatment. The C emission factors for fertilizer i.e. 1.3, 0.2, and 0.15 kg CE/kg of N, P₂O₅ and K₂O, respectively (taken from Table 5, Lal, 2004) do not include C emissions associated with fertilizer application (attributable to fuel use in machinery). Please clarify.

Authors should clarify the issues mentioned above by briefly explaining the facts in the relevant section under the Materials and Methods.

Specific comments on the manuscript text:

Line 37 – 39: Please re-phrase the sentence starting 'An increase in global food production....'

For example: 'An increase in global crop production of 100% would be necessary to sustain the projected demand for human food and livestock feed in 2050 (Tilman et al., 2011).

Line 40: Please add a reference to support the statement: 'Rice is the staple food for nearly 50% of the world's people, mainly in Asia.'

Line 42: Please add a reference to support the statement: 'With the region's population projected to increase by another billion by mid-century (reference?), ...'

Line 43: Please change: 'With a limited agricultural land area, the intensive.....'

Line 44: fertilizer... (not fertilizers)

Line 47: ...appropriate fertilizer compounds...

Line 48: ...advanced water management regimes,...

Line 49 – 50: Authors should indicate here exactly what they mean by: low carbon dioxide (CO₂) equivalent emissions per unit product or per unit land area?

Line 51: Please do not start a sentence with an abbreviation. Should be: Carbon dioxide, methane (CH₄) and...'

Line 52: delete the word: 'greatly'. Should be: ...the most important greenhouse gases (GHGs) that contribute to global warming...'

Line 52 – 55: Rephrase the sentence. For example: 'The concept of global warming potential (GWP) has been applied to agricultural lands by taking in to account of the radiative properties of all GHG emissions associated with agricultural production and soil organic carbon (SOC) sequestration, expressed as CO₂ eq. ha⁻¹ yr⁻¹ (Robertson and Grace, 2004; Mosier et al., 2006).'

Line 63 – 65: the following sentence seems to be out of place and break the 'line of reasoning' you are building as justification, consider deleting it:

'This indicates that agricultural ecosystems are not only a very important source of GHG emissions but also present substantial opportunities for mitigation.'

Line 65 – 69: Re-phrase this sentence. For example: Therefore, when determining the GWP of agroecosystems, there is a need to account for all sources of GHG emissions, including the emissions associated with agrochemical inputs (E_i) and farm operations (E_o) and sinks, e.g. soil organic carbon (SOC) sequestration (Sainju et al., 2014).

Line 70 – 71: ...and greenhouse gas intensity (GHGI) of agricultural systems is limited in China (...)

Line 72: Previous studies were mainly focused on the....

Line 72: A part of sentence is missing here. Should read as:.. influences of ISSM practices on CH₄ and N₂O emissions, but did not account for the...

Line 74 – 76: The sentence is not complete. Should read as:

'In this study, we evaluated GWP and GHGI of rice-wheat crop rotation managed under several scenarios of ISSM by taking CO₂ equivalent emissions from all sources and sinks into account for 5 years.'

Line 76: Please see my general comment on '5-year study'. Revise accordingly.

Line 84: Please see my general comment on '5-year study'. Revise accordingly.

Line 86: ...flooded rice...

Line 88 – 89: Here only three-years weather data are presented as per my general comment. If it is a 5-year study, authors should provide the readers about where other two years data can be found. (Ma et al 2013?).

Line 97: 'A completely randomized block design' or 'A completely randomized plot design' please explain.

Line 99: Provide within parenthesis the N rate for local FP rate: Should read as: ...local FP rate (300 kg N ha⁻¹)

Line 100 - 105: Re-phrase the sentence. For example:

'The designed ISSM scenarios (only for rice but not for wheat) included a redesigned split N fertilizer application, a balanced fertilizer application that included sodium silicate, zinc sulphate, rapeseed cake (C/N=8) providing an additional 112.5 kg N ha⁻¹, and additional phosphorus and potassium, and different transplanting densities, used as the main techniques for improving rice yields...'

Line 107: delete: 'detailed'. Should reads as: Further information was...

Line 114 – 115: ... rapeseed cake manure were applied as basal fertilizers for both crops. Does this mean that rapeseed cake was applied to both crops? If so, it is missing in Table 1.

Line 119 – 120: Re-write to be consistent (example): 'Harvests included crop grains and rice and wheat straws which were removed out of the fields of all the treatments in this study.'

Line 122: Please re-phrase (example): We measured the CH₄ and N₂O emissions from each plot...

Line 125 – 130: Somewhere under this section, please explain briefly the following: gas sampling frequency, length of chamber deployment, gas sample drawing time interval (e.g. 0, 10, 20, 30 minutes) and sample volume, gas sample storage length until analysis). Alternatively, you may provide a previous paper related to this study, that explains these details.

Line 137: somewhere here, explain briefly gas flux calculation method used (Alternatively, you may provide a previous paper related to this study, that explains these details).

Line 144: Provide units for SOC_t and SOC₀.

Line 149: Re-phrase (for example): 'To better understand the overall GHG impact of the rice-wheat crop rotation managed under different ISSM scenarios, the GWP and GHGI were calculated...'

Line 154: Provide units for each: E_i, E_o and SOCSR.

Line 156: ...The global warming potential of 1 kg CH₄ and 1 kg of N₂O are 25 and 298 kg CO₂ equivalents respectively, based on 100-yr time scale (...)

Line 157: It is not correct to write as: The 12 and 44... You could write as (for example): 'In the equation 2, 12 and 44 refers to molecular weights of C and CO₂, respectively.'

Line 160:...SOC change per unit land area.

Line 160 - 164: It is not correct to say 'hidden CO₂ equivalent emissions'. It is well known that agricultural inputs and farm operations produce greenhouse gas emissions. Please re-phrase part of the sentence (for example you may revise this as):

In addition to CH₄ and N₂O emissions, we considered CO₂ equivalent emissions associated with the use of agrochemical inputs (E_i), such as...

Line 165 - 167: Please explain how the emission factor for irrigation water (i.e. $5.16 \text{ kg C eq. cm}^{-1} \text{ ha}^{-1}$) was calculated, because Lal, 2004 provides several values for irrigation water, depending on the amount of total irrigation water supplied and the type of irrigation system used. It clear to me that this emission factor was calculated from the original value of $257.8 \text{ kg CE ha}^{-1}$ for a 50 cm of irrigation provided in Lal 2004. However, you need to explain briefly the applicability of this emission factor for the irrigation system used in this experiment. Revise the sentence accordingly to include this information.

Line 168: Please check the C emission factor used for herbicide. It should be $6.3 \text{ kg CE per kg active ingredient}$ (Lal 2004), NOT $0.3 \text{ kg CE per kg active ingredient}$, you have used in Table 4.

Line 169: I have number of questions related to how the CO₂ emissions were calculated for farm operations. The questions (a to f) are listed below. Please revise the text to explain briefly the main type of farm operations listed in Table 4 in order to clarify the emission factors used and how CO₂ emissions were calculated.

(a) What type of machinery was used for field operations such as tillage, planting, and harvest? The C emission factor for each of these operations will depend on the type of the machinery used. This information is important. For example, it is necessary to mention how tillage was done. One passes of rotary tiller and one passes of raking? There will be two events of tillage: one for rice, one for wheat.

(b) It is not clear what it means: 1 (one) kg/ha given for all treatments in the column for crop planting in Table 4. Does it mean: 1 kg diesel fuel/ ha was used for crop planting? If that is the case C emission factor for diesel fuel is $0.94 \text{ kg CE per kg diesel}$ according to Lal 2004. If it is 1 event, then 3.2 kg CE/ha (which you have used) is correct; however, there are 2 events of planting per year (one event for rice, another event for wheat). It appears that only one event of crop planting is accounted in the Table 4.

(c) Was the emission factor for manure application used in Table 4 taken from Lal 2004? (I am not sure Lal 2004 provided this emission factor).

(d) Similarly, there are two harvest events per year (one for rice, one for wheat). Was the 11 kg/ha diesel use reported in Table 4 for both harvest events?

(e) It is not correct to apply the emission factor for spraying and thrashing ($0.0725 \text{ kg CE/kg active ingredient}$) for calculating CO₂ emissions from 'farm machinery production' as presented in Table 4.

(f) Was there machinery used for fertilizer spreading? Split fertilizer application requires 3 or 4 passes for each crop depending on how many split applications were used for rice and for wheat in each treatment.

Line 170 – 173: Rephrase the sentence. (for example): 'We collected the data specific to China's fertilizer manufacture and consumption, and calculated the C emission coefficients to be 0.07 and $0.1 \text{ kg C eq. kg}^{-1}$ of active ingredient for Si and Zn fertilizer, respectively. These coefficients were used to estimate the CO₂ equivalent emissions associated with applied Si and Zn fertilizer.'

That is a good approach. Please explain why this approach was not possible to be done for other fertilizer types used in this experiment, given the fact that coefficients published in Lal (2004) were largely based on European and North American studies.

Line 176: Please check: SAS Institute, USA, 2007 (missing in the reference list).

Line 177: should read as: ...to determine whether there were significant differences among treatments, years, and their interactions at $p < 0.05$.

Line 180 - 181: should read as: ...determine whether significant differences occurred between the treatments at a level of $p < 0.05$.

Line 186: Revise the line to include reference to the Table 2. (for example): ...varied significantly among the treatments (Table 2).

Line 187: delete the reference to Table 2 here, once you do the above revision in line 186.

Line 197- 198: Revise the sentence. For example, it should read as: 'The higher NUE in the wheat season was mainly due to the relatively lower N fertilizer (40%) rates used for wheat compared with that for rice.'

Line 201: delete the word: 'merely'. The difference between FP vs. N1 and N2 is statistically significant, as indicated by different letters (b vs. a and a) in Fig 1.

Line 201: should read as ...NUE increased by 12 and 14% in the N1 and N2 scenarios, respectively, and slightly decreased in the N3 and N4 scenarios...

Line 206: Include the reference to Fig 2 here at the end of line: ...wheat season (Fig 2).

Line 207: delete the reference to Fig 2 here, once you do the revision above in line 206.

Line 216 – 217: should read as: 'The annual N_2O fluxes varied from -33.1 to $647.5 \mu g N_2O-N m^{-2} h^{-1}$, with most N_2O emissions occurring during the wheat-growing season after fertilization events, and several smaller emission peaks during the rice-growing season (Fig. 3).'

Line 220: ...higher than that in NN...

Line 222: should read as: 'The N4 scenario significantly increased the cumulative N_2O emissions by 46% ($P < 0.05$), because this system received additional...

Line 222 – 224: Was additional N received from rape seed cake the main reason for highest cumulative N_2O emissions in the N4 scenario relative to FP? N3 scenario also received additional N as rape seed cake, but there was no significant difference in cumulative N_2O emissions in N3 vs. FP. It seems the main reason for highest cumulative N_2O emissions in N4 is highest inorganic N fertilizer (25% higher than that in FP) rate it received. Please explain all the possibilities.

Line 228: Should be ...'The CO_2 equivalent emissions associated with E_i and E_o ...'

Line 228: replace the word 'classified' with 'presented'.

Line 228-229: Results in Table 5 indicates that irrigation contributed 19 – 31% of the total CO_2 equivalent emissions from agricultural management ($E_i + E_o$). Yes, it is lower than the CO_2 equivalent contribution from N fertilizer (which were 46 – 51% $E_i + E_o$), but you cannot say that it is much less important. I would say it is the second largest source of CO_2 equivalents associated with agricultural management after N fertilizer.

Line 234-235: Please check the **negative** or **positive** symbol for the values of CO_2 equivalent emissions due to SOC sequestration presented in Table 5. A negative value indicates soil is a sink for C sequestration and a positive value indicates a soil as a source for CO_2 emissions from SOC loss.

Line 235: ...in these cropping systems.

Line 237: ...(contributed 5 – 10% decrease of the GWP except in the NN plot).

Line 238: Of the CO₂ equivalents from agricultural management practices, emissions associated with E_i (2449-4256 CO₂ eq. ha⁻¹ yr⁻¹) were higher than those associated with E_o (...)

Line 245: The GHGs (kg CO₂ eq. Mg⁻¹ grain)...

Line 245-246: Significant differences in the GHGs of grain was found...

Line 248: reduced GHG emissions (relative to FP) were only observed in N1 and N2. Please revise the sentence to correctly reflect the results.

Line 258: Should be: 'Compared with the FP, rice yields increased significantly by all four ISSM...

Line 264-265: What is the meaning of reasonable N split? I would say 'N split application to match the crop demand'. Please revise or clarify. For example:

'Second, split application of N fertilizer to match crop demand in the N1, N2, N3 and N4 scenarios would significantly increase agronomic NUE and rice yield which had been reported previously by Liu et al. (2009).

Line 267: This finding is consistent with the results...

Line 270: What are the 'modified farmer's practice' in that study?

Line 274: ...produced higher yields (...)

Line 275 – 277: Was applying rape seed cake manure with FP rate or with 25% higher N was the only reason for higher rice grain yields in N3 and N4? P, and K were higher, in combination with Si and Zn fertilizer as well as a different planting density (in N3).

Should read as: As expected, when the total N rate was at the FP rate and/or increased by 25%, in combination with other ISSM strategies (e.g. rapeseed cake manure, additional P and K, applying Si and Zn fertilizer), the rice grain yield in N3 and N4 systems increased substantially by 28 and 41%, respectively.'

Line 279-280: This may have resulted from the organic fertilizer applied in combination with adequate nutrients contributing to alleviate potential yield limiting factors of rice.

Line 282 – 285: It is not clear exactly what you are explaining in this sentence. Especially, I could not understand the phrase: '**In spite of the high proportion...**' Do you mean to say the following?:

'In addition to **high rates** of N and improper timing of N application, rapid N losses (via ammonia volatilization, denitrification, surface runoff, and leaching) are important factors that cause low agronomic NUE of irrigated rice in China (Peng et al., 2006).'

Please revise the lines 282-285.

Line 287 - 289: You did not measure N leaching and volatilization losses. You cannot be certain about this and therefore, the use of the word: 'primarily' is not correct. Please revise. May be you can say:

'The higher rice agronomic NUE in our study over the experimental period was **likely** due to the decreased N losses and improved N uptake realized through the better synchrony of N supply and crop N demand, due to the split application of N fertilizer in the rice cropping season.'

Line 303: delete the word 'emissions'. ...scenarios emitted 87 and 118% more CH₄, respectively (...)

Line 313 – 314: ...the higher biomass may have facilitated more CH₄ emissions (...)

Line 314-317: This is a repetition of the same, you have already discussed in previous several sentences. Avoid repetition.

Line 319: ...strongly influenced the soil N₂O...

Line 323: ...conditions may have enhanced...

Line 324 – 325: What is the likely reason for increased N₂O emissions due to alternative drainage and flooding? Coupled nitrification and denitrification?

Line 326: Please check: Wang et al., 2013. In the reference list it is listed as 2012.

Line 327: ...N₂O emissions...cultivation practices and years (Table 3).

Line 328: Replace the word 'greatly' with the word 'significantly'.

Line 335: ...which also probably contributed increased CH₄ emissions (Banger et al. 2013).

Line 342: ...as well as additional CO₂ emissions due to the use of machinery/equipment for irrigation...

Line 339 – 344: If possible, please provide an approximate quantity of additional CO₂ emitted due to ISSM strategies in the present study relative to studies cited here.