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Biogeosciences Discussions

Interactive comment on "Historical and simulated ecosystem carbon dynamics in Ghana: land use, management, and climate" *by* Z. Tan et al.

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We tried to address every comment and integrated them into the revised version. However, we would like to present our responses to Interactive Comments by focusing on the critical points as follows.

1. Why the same modeling approach applied in Senegal by Liu et al. (2204a) was used in this study.

The reason is simple and it is for consistency. Our long term plan is to apply the same modeling approach across sub-Saharan Africa. This study is part of the effort. Initially this project was intended to examine the historical soil organic carbon budgets and the sensitivity of SOC to changes in climate and major management practices in the more humid country of Ghana and to compare the responses along the gradient from forests to savanna. Because the model structure and performance of Liu's GEMS with results have been validated in Senegal, we believed that Liu's approach provides a solid basis for application in Ghana. This is similar to the applications of the CENTURY SOM model by numerous model users worldwide.

2. What kinds of management options (parameters) were used in modeling and why were they used?

The question raised for the first submission was due to that we did not address this point and did not present the management options in the context. As added to the revised MS, the information of management practices for this study was synthesized from sample site investigations across the study area and literature. The dataset of management practices for model simulations consisted of crop composition, crop rotation, fallow, and harvesting options (or residue management). These kinds of information and their parameters used in GEMS are listed in Table 1 and presented in the revised version. As well as crop residues retained in field (see Table 1-d), manure addition to cropped field has been thought a major nutrient source for crops and the amount of an average level of 2.0 Mg ha-1 was considered for modeling. Both hand- and animal-driven plowing methods were applied for tillage. The frequency of wood-fuel production from woodlands was assumed to be one time each year. In our study area, low nutrient (especially nitrogen) input has been thought the most critical limit to crop production, which is posing a threat to agricultural sustainability and food security due to a continuing depletion of soil organic matter and nutrients in Ghana. Therefore, the combinations of both nitrogen fertilization rates and climate change scenarios were designed to drive model simulations. As normally done for most experiments, to ascertain the role played by each factor, it is necessary that all the remaining factors be kept constant. In our study, in order to verify the effect of N fertilizers, we had to assume that the changing trends of all other management variables used for the 20th century will remain through the 21st century, even though many management practices may change over time. Because too many combinations of management options and

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both climate and fertilization rate scenarios, it is hard and not necessarily to include all possibilities in one study.

3. Why to set climate scenarios using the approach of Hulme et al. (2001).

There are about 35 climate change models that are involved in the Coupled Model Intercomparison Project (CMIP) (http://www-pcmdi.llnl.gov/projects/cmip/index.php) to estimate the global climate changes in the future for the IPCC 4th Assessment Report (http://www.ipcc.ch/ipccreports/ar4-syr.htm). Most of those models used in the CMIP were originally designed to focus on the climate change at regional or national scale. The results from the CMIP, however, were generated on the basis of the IPCC Special Report on Emissions Scenarios (SRES), part of the IPCC Third Assessment Report (http://www.ipcc.ch/ipccreports/tar/wg1/index.htm). Following the IPCC SRES, Hulme et al (2001) used several Global Climate Models (GCMs), coupled with the Model for the Assessment of Greenhouse Induced Climate Change (MAGICC) (Wigley et al., 2000), to evaluate the changes in both continental and regional seasonal-mean temperature and rainfall across the African continent. It is clear that the approach developed by Hulme et al. (2001) can be used to lead to the results that should be comparable to those derived from the approaches recommended in the IPCC Fourth Assessment Report (http://www.ipcc.ch/ipccreports/ar4-syr.htm) because of its Africa focus and compliance with the IPCC Special Report on Emissions Scenarios. Furthermore, this approach has been used by Liu et al. (2004a) to set climate change scenarios for Senegal.

4. How to set the application rates of nitrogen fertilizers for the 21st century.

The average N fertilizer application rate across the country from 1970 to 2000 was about 4 kg N ha-1yr-1 (http://earthtrends.wri.org/). According to the Crop Services Department of Ministry of Food and Agriculture of Ghana, the levels of fertilizers applied for maize production are recommended as: 120 kg ha-1 of compound fertilizer (consisting of nitrogen, phosphorus, and potassium) applied during planting, 120 kg ha-1 of ammonium sulfate ((NH4)2SO4) for top dressing, and another 120 kg ha-1 of ammonium sulfate applied during tussling stage (Communication with Tachie-Obeng, EPA of Ghana). The annual total fertilization rate recommended for maize production is about 60 kg N ha-1yr-1. Liu et al. (2004a) documented that the N fertilization rate of 30 kg N ha-1yr-1 is usually applied on intensive and extensive croplands in south-central Senegal. Therefore, we set 30 and 60 kg N ha-1yr-1 fertilization rate scenarios for all crops through the 21st century. Though higher N fertilization rate is better for sustaining crop yield and soil fertility, and even the rate 60 kg N ha-1yr-1 is not sufficient enough compared with that applied in developed nations and in Asia, the application of N fertilizers are commonly restricted due to financial difficulty and human capital (Kelly, 2006). Because of a high return of fertilization from the nutrient-depleted soils, moderate fertilization rates over large area should be good for safe of yield and soil under current economic capacity in Ghana.

5. Statistical tests for evaluating simulation results between scenarios, land use/land cover types, and crop species.

Table 3 and 4 were added to the context to show the significance test results of SOC and crop yields between climate change scenarios, crop species and N fertilization rates.

6. Implications of the results from this study.

Generally, the process-based model (e.g., GEMS, Century) are driven by variables that are characterized by "study area". In other words, simulation outputs are dependent on the parameterization of biophysical settings of the study area. Although the approach can be applied to handle similar issues in somewhere else, it is hard to guarantee a reasonable extrapolation of the simulation results from one area to others unless there are the same or similar biophysical conditions. Our study area is a representative of the forest-savanna transitional zone in Ghana and the results might be comparable to and useful for surrounding areas. The results and conclusions about the responses of crop

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yields to N fertilizers should be of referable and interesting to other regions because low soil N nutrient availability and low N fertilizer input are prevalent and well-known across Ghana. The results should be considered representative to other African regions with similar biophysical and climate conditions, and land management practices. However, any extrapolation based on model simulation results should be made with caution.

7. Interpretation of Figure 3

As addressed in "Study area", assuming all agricultural lands were derived from natural land covers such as semi-deciduous forest, forest reserve land, moderately dense savanna woodland, and herb/bush savanna. The starting point of SOC stock in Fig 3 for cropland is the simulated average SOC pools of those kinds of natural land cover types because cropland was directly converted from them. The SOC stock value for each LULC type was simulated only for what the land was (classified). In fact, the area of each LULC type used for C calculation at any time point is variable (depending on the land use at that time), which, however, is assumed to have little influence on the general dynamic trends because the value always represents the average from the same LULC type at a given time. That is why the unit of Mg C per hectare (rather than the total C) was used in Figure 3. The possible interpretation of the SOC decline curve over time for open forest has been addressed in the second paragraph under Section "3.2 Carbon dynamics in the 20th century". There were two major reasons for this. First, deforestation for cultivation started preferably from sites with high soil organic matter content, while the soils with higher baseline SOC stocks more easily lose SOC following cultivation (Tan et al., 2007). Second, the degradation of forest due to wildfires, charcoal production, and traditional slash (Allotey and Tachie-Obeng, 2006).

8. Technical comments

We tried to address and make corrections following every comment on our manuscript, which has been integrated into the revised version.

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