Earth Syst. Dynam. Discuss.,
https://doi.org/10.5194/esd-2016-58-AC3, 2017

Earth System Dynamics
Discussions
Open Access

Interactive comment on "Future supply and demand of net primary production in the Sahel" *by* Florian Sallaba et al.

Florian Sallaba et al.

jonathan.seaquist@nateko.lu.se

Received and published: 29 June 2017

We thank RC3 for their insightful and constructive comments. What follows is a point-by-point treatment of these comments. Minor changes suggested by RC3 have already been implemented and indicated below.

RC3: 1. The introduction is very well-written and does an excellent job of framing the question and establishing the importance of the work.

Authors' Response: Thank-you very much. It is good to know that the effort we made crafting the introduction does not go unnoticed.

RC3: 2. Page 4, line 27: It is stated that the authors used 0.5 degree climate data from five GCMs, and [CO2] based on four RCPs (Representative Concentration Pathways).

Printer-friendly version

Discussion paper

The way it is phased it is unclear which RCPs were used to generate the climate projections for each GCM. The authors should have used climate data derived from runs across the 4 RCPs for each of the 5 models. Please clarify the text if this is the case. If not, please explain more fully why the climate data were not derived for all RCPs.

Authors' Response: We will clarify this in the updated manuscript and explicitly write the RCPs (2.6, 4.5, 6.0 and 8.5) and GCMs (HADLEY, GFDL, IPSL, MIROC and NorESM) that we used. We will also clarify that we ran the model for all RCPs with the selected GCMs.

RC: 3. Robustly representing future NPP trajectories is challenging due to the many potential counteracting feedbacks. The authors show a good fit with LPJ NPP simulations, but do not consider observational data or alternative runs of the LPJ model itself. I recommend further comparison against both census derived yield trends (Rey et al. 2013) and satellite-derived yield trends (Running et al. 2004). For instance, the authors could consider runs in which the CO2 fertilization effect is turned off. Currently all the NPP trends considered in the paper are increasing due to CO2 fertilization (page 9, line 24). This is an area of debate and may be counter to observational data (see Smith et al. 2016, Oberneier et al. 2016, and Ort & Long et al. 2014). Thus, I wonder if a scenario in which CO2 fertilization effects are isolated and removed would be a more realistic lower boundary on what to expect for the region? I would imagine very large increases in the NPP debt (without large irrigation efforts), much larger than what is currently considered in the paper.

Authors' Response: We thank this reviewer for underscoring these issues with the trends, and for suggesting some ways forward. In order to address these comments, we compare BME simulations with MOD-17 data for the period 2000-2006. Thereafter, we compare these results with country level census yield trends (1989-2008) for 4 major crops (rice, maize, wheat, and soybean) from appendix Data S1 of Ray et al. (2013), for some countries found in our study area. Finally, we compare BME trajectories of

NPP with and without CO2 fertilization for all scenarios for the period 2000-2100 in order to account for the fertilization effect. We also direct AR#3 to responses made to Thomas Pugh (R#1) that shed some additional light on these issues.

Our results show that between 2000 to 2006, MOD-17 derived NPP underestimate modelled NPP from BME by 42% (difference of 0.38 kg dry-weight m-2 yr-1), on average (Figure 1). Trends are similar, showing yearly increases of 0.55% (BME) and 0.51% (MOD-17) for the 6 year period of overlap. For the entire length of each series (1970-2006 for BME, and 2000-2010 for MOD-17), slopes indicate yearly increases of 0.40% and 0.62% respectively. Regarding magnitude differences, Ardö (2015) reports that that average annual MOD-17 NPP underestimated LPJ-GUESS carbon version) for Africa for 2000-2010 and attributes this to the fact that autotrophic respiration is considerably higher for MOD17 compared to LPJ-GUESS, due to large temperature sensitivity in the MOD-17 algorithm, differences in the biome-specific parameterizations in MOD17 as well as specification of plant functional types in LPJ-GUESS. Country-level yield trends for rice (Benin, Burkina Faso, Chad, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Nigeria, Senegal, Sierra Leone, Togo), maize (Benin, Burkina Faso, Cameroon, Chad, Ethiopia, Ghana, Guinea, Ivory Coast, Mali, Nigeria, Senegal, Togo), wheat (Cameroon, Chad, Eritrea, Ethiopia, Mali, Mauritania, Niger, Nigeria, Sudan) and soybean (Benin, Burkina Faso, and Nigeria) ranged from -5.98 to 2.80 (mean of -0.002), -0.94 to 4.08 (mean of 1.400), -2.58 to 3.1 (mean of 1.280) and 1.15 to 3.98 (mean of 2.280) respectively. Though the mean of BME and MOD-17 trends fall within most of these ranges for specific crops, it is impossible to generalize due to the number of uncertainties involved in this comparison (e.g. spatial/temporal sampling, and the fact that BME and MOD-17 represent natural vegetation and a mix of natural vegetation and crops, respectively).

If the effect of CO2 fertilization is negated, per capita demand has an equal chance of exceeding per capita supply in 2036 for the SSP2-6.0 scenario (Figure 2a), as opposed to 2043 if CO2 fertilization in included (Figure 3a in the manuscript), with a very high

Printer-friendly version

Discussion paper

likelihood of continuous supply shortfall beginning in 2056 as indicated by the black dots (as opposed to 2073 with CO2 fertilization). The effect on all other scenarios is an earlier shift to the onset of supply shortfalls, by about 10 years (Figure 3b). Supply shortfalls with high likelihood of occurrence (black dots showing non-overlapping 95% confidence intervals) are similarly shifted, and occur with greater consistency and frequency.

Therefore the results in our manuscript provide an upper bound for NPP supply, and the analysis of the balance of supply and demand contained there may provide an optimistic account of the timing and duration of shortfalls across all scenarios.

We can provide an abbreviated account of this in a revised version of the manuscript.

RC3: 4. Page 5, line 4: When the fractional agricultural landcover estimates from Hurtt et al (2011) were applied, was it assumed that natural and agricultural NPP were similar? If so, this assumption should be revisited after considering differences between agricultural vs. natural NPP for the region. For instance, the authors could compare census based estimates of crop productivity with their estimates as a reality check. Smith et al. 2014 (see reference below), found that agricultural productivity for the region is significantly lower than natural productivity. If this potential reality is not considered, then the scenarios in this manuscript may be overly optimistic.

Authors' Response: Yes, it is true that we considered the NPP to be equal for all land covers. However, by using a relatively low (0.235) harvest index, we have implicitly accounted for at least some of that lower productivity. We will add to the discussion that our estimates of cropland NPP are in the upper range. Thank you for the reference.

RC3: 5. I would recommend revisiting all crop allocation parameters based on those reported by Monfreda et al. (2008). Given the high variability in crop specific harvest fractions, it seems it may be necessary to parameterize the model for each individual crop grown in the region.

Authors' Response: It is true that the representation of crop allometry in the current setup is simplistic and cannot likely capture all the variability present in agricultural landscapes in the region. But the approach taken here, by having one root-to-shoot ratio and harvest index for all crops in the region is consistent with the underlying theme of the study, e.g. have a simplistic modelling framework to be able to explore supply-demand outcomes with a minimum of input data. Furthermore, as we do not know how these cropping systems would develop in the future across the scenarios, we think a simple approach is the safest bet.

RC3: 6. Page 12 line 24-26: This statement is not representative of the literature (see below references). I would suggest more nuanced discussion of the potential limitations of the supply approach used in this analysis. For instances, how much did CO2 fertilization drive increases? How uncertain are the precipitation estimates? Were nutrient constraints considered and if so what are the management implications? If not, how might nutrient constraints limit NPP? How will increases in atmospheric water demand (Vapor pressure deficit) affect yields and productivity? Could increased drought and desertification also represent a potential scenario had the CO2 sensitivity been adjusted? The way that this section is currently written is a gross over extension of the simplified NPP modeling that the paper is based on.

Authors' Response: Thank-you very much for directing us to the salient literature. In response to this, we suggest this following alteration to the section 'Additional Perspectives' and present it here:

"Our finding that supply increases for all SSP-RCP scenarios, partly due to increasing rainfall and CO2 fertilization. However, recent observational evidence suggests that the effect of CO2 fertilization on plant growth may be constrained by counteracting feedbacks associated with increasing atmospheric moisture demand and nutrient availability (e.g. Smith et al., 2016; Wieder et al. 2015). For example, NPP is reduced under warmer and dryer conditions due to moisture stress, particularly in temperate and arid ecosystems. Future trends NPP trends in the Sahel could therefore be strongly determined by changes in the frequencies of wet years versus dry years, with the dry years counteracting the CO2 fertilization effect. Furthermore, nutrient supply rates may not be able to keep up with extra demand associated with CO2 fertilization, and leading to a depletion of soil nutrients, as current evidence suggests. This could also curtail the CO2 fertilization effect, particularly in the more southerly parts of our study area, where nutrients tend to become a limiting factor.

All of this suggests that that the current trend of Sahel greening identified from satellite sensor-based mapping studies (e.g. Eklundh and Olsson, 2003; Hickler et al., 2005; Seaquist et al., 2009) may may not continue into the future, even if with increasing rainfall.

Livestock mobilization is one way local populations generally employ to manage risk (e.g. Herrmann et al. (2014). This strategy may help regulate supply shortfalls locally, and over the short term. Even if the Sahel were to continue to green (increase in NPP supply) this would not necessarily imply an increase in the amount of usable NPP or an enhancement in health and well-being. Recent studies in the Sahel show that much of the recent greening, at least in some regions, is due to undesirable shifts in species composition (e.g. Herrmann et al. (2014)), reductions in biodiversity and an increases in woody biomass (e.g. Brandt et al. (2015))."

RC3: Minor Comments: 1. Page 3, Line 17: "Three different aggregation levels are considered, including Sahel, the country, and the local". Please define what is meant by local level. Pixel level? What resolution? 2. Page 12 line 12: missing end of parentheses.

Authors' Response: with the term local level, we mean the level of the cell, with a resolution of 0.5 x 0.5 degrees. This allows the inspection of supply and demand variations at a sub-national level, across cells. We have already clarified this in our manuscript and have fixed the typo.

CAPTION FOR FIGURE 2

Printer-friendly version

Discussion paper

The per capita NPP supply, demand and balance for the entire Sahel region over the time period without CO2 fertilization. 2a) shows NPP supply (red) and demand (blue). The solid curves illustrate the mean of the SSP2-RCP6.0 combination. The dashed blue curves show supply uncertainty (95% confidence interval around the mean) based on the five GCMs NPP results. The dashed red curves show demand uncertainty (95% confidence interval around the mean) based on the uncertainty related to the interpretation and quantification of SSP2. 2b) shows the different magnitudes of the NPP balance and the varying onsets of shortage across all SSP-RCP combinations. Black dots illustrate years with a shortage outside of the 95% confidence intervals. The combinations are grouped according to the socio-economic scenarios (y-axis). The RCPs are ordered from low to high radiative forcing in each SSP group. The temporal trajectory is shown along the x-axis and the colouring indicates the sign of the annual NPP balance. Blues show a surplus of the NPP supply while yellow to red represent small to very large NPP shortages (i.e. the gap between supply and demand). SSP-RCP combinations in bold indicate the most likely SSP-RCP pairs based on Tables 3 and 4 of Engström et al. (2016b).

References in our responses

Brandt, M., Mbow, C., Diouf, A. A., Verger, A., Samimi, C., and Fensholt, R.: Ground- and satellite-based evidence of the biophysical mechanisms behind the greening Sahel, Global Change Biology, 21, 1610-1620, 2015.

Eklundh, L. and Olsson, L.: Vegetation index trends for the African Sahel 1982–1999, Geophysical Research Letters, 30, 8, 1430, 2003.

Herrmann, S. M., Sall, I., and Sy, O.: People and pixels in the Sahel: a study linking coarse-resolution remote sensing observations to land users' perceptions of their changing environment in Senegal, Ecology and Society, 19, 2014.

Hickler, T., Eklundh, L., Seaquist, J. W., Smith, B., Ardo, J., Olsson, L., Sykes, M. T., and Sjostrom, M.: Precipitation controls Sahel greening trend, Geophysical Research

Letters, 32, L21415, 2005.

Obermeier, W.A., Lehnert, L.W., Kammann, C.I., Müller, C., Grünhage, L., Luterbacher, J., Erbs, M., Moser, G., Seibert, R., Yuan, N. & Bendix, J. (2016). Reduced CO2 fertilization effect in temperate C3 grasslands under more extreme weather conditions. Nat. Clim. Chang., 7, 137–142.

Ray, D.K., Mueller, N.D., West, P.C. & Foley, J.A. (2013). Yield Trends Are Insufficient to Double Global Crop Production by 2050. PLoS One, 8, e66428.

Seaquist, J. W., Hickler, T., Eklundh, L., Ardo, J., and Heumann, B. W.: Disentangling the effects of climate and people on Sahel vegetation dynamics, Biogeosciences, 6, 469-477, 2009.

Smith, W.K., Reed, S.C., Cleveland, C.C., Ballantyne, A.P., Anderegg, W.R.L., Wieder, W.R., Liu, Y.Y. & Running, S.W. (2016). Large divergence of satellite and Earth system model estimates of global terrestrial CO2 fertilization. Nat. Clim. Chang., 6, 306–310

Wieder, W.R., Cleveland, C.C., Smith, W.K. & Todd-Brown, K. (2015). Future productivity and carbon storage limited by terrestrial nutrient availability. Nat. Geosci., 1–5.

Please also note the supplement to this comment:
https://www.earth-syst-dynam-discuss.net/esd-2016-58/esd-2016-58-AC3-supplement.pdf

---

Interactive comment on Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2016-58, 2016.

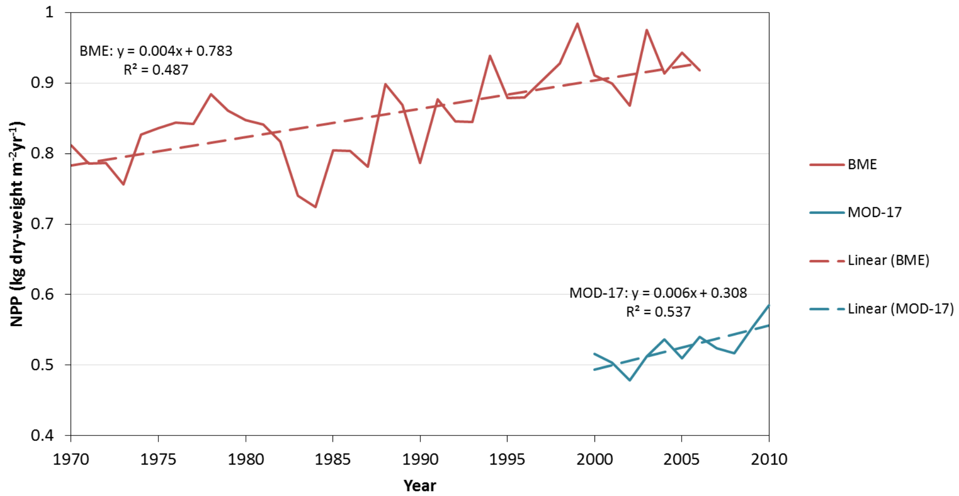

Fig. 1. Total mean annual NPP over the greater Sahel region estimated by BME (red) and MODIS (blue) with trends for the two estimates (dashed lines).

Printer-friendly version

Discussion paper

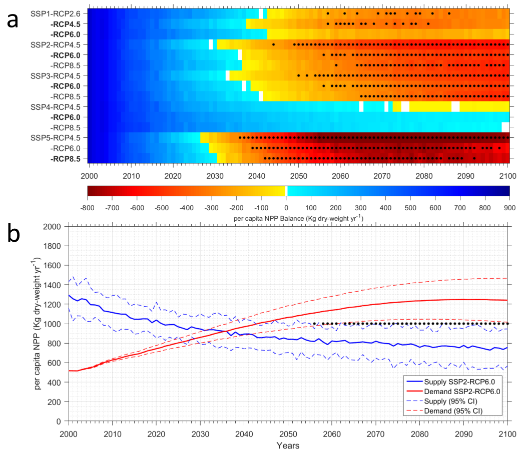

Fig. 2. Please see end of main body of text, just before references, for caption (too long to place here)