Answers to reviews on "The impact of atmospheric CO_2 and N management on simulated yields and tissue C : N in the main wheat regions of Western Europe"

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Thanks for the comments and corrections. Comments are included in this document within "" followed by answers with updated texts and reference to new page and line numbers in the updated version.

1 Reviewer #1

"*While figure 2 does show the productivity results for different N treatments, the manuscript could be improved by more explicitly addressing whether the model is appropriately sensitive to N addition or whether it is too N limited or not N limited enough. What processes in the model control the sensitivity to N addition?*"

The sensitivity to N addition is a combination of several processes, most important are the C:N of the leaves and roots and their effect on the N-uptake, but also soil C–N dynamics plays an important role. In order to address the question, we added:
Modelled grain and above ground biomass C mass per kg N applied (19 and 46 $\mathrm{kg\,C\,kg\,N^{-1}}$) were in line with the observed response of 22 and 42 $\mathrm{kg\,C\,kg\,N^{-1}}$, which indicates appropriate sensitivity of yield and growth to nitrogen addition.
On line 5 page 22 in the updated manuscript.
We also added the following:
N demand from leaves and roots depend on their current C : N status, as the plant seeks to reach optimal C : N in leaves and roots. The mineral N accessible for the plant, depends on soil temperature and fine root biomass: see Smith et al. 2014 and Zaehle et al. 2010 for details.
On line 4–7 page 13 in the updated manuscript.

"*Other areas for improvement: The introduction leaves out any discussion about N20 emissions from croplands. N2O emissions are relevant to the goals of the manuscript because getting the N uptake correct is an important step to modeling the N that is available for N20 production.*"

The reviewer is of course correct, and while this aspect is not the focus of this current manuscript we revised the introduction as:

Still, only a few of today's DVMs account for crop processes and C–N coupling in crops (e.g. Arora, 2003; Drewniak et al., 2013), which is a prerequisite to accounting for fertiliser input, the associated effects it has on yields and the C cycle. These improvements will also facilitate global-scale modelling of N_2O emissions from agricultural soils, since accounting for N uptake through plants is important to constrain soil nitrogen available for N_2O production. While not the focus of this manuscript, the ultimate goal will be to assess how ecosystem fluxes affecting atmospheric composition and climate vary with changing environmental and socioeconomic conditions.
On line 19 page 5 in the updated manuscript.

"*More description about how the model handles the labile C pool would be helpful. Is there a max size of the labile C pool? What happens when the labile C pool become unrealistically large? Similarly, is there a labile N pool or is N allocation directly linked to N uptake from the soil?*"

We tested the ability of the model to simulate C allocation using data from Groot et al. (1991) (not shown). The ability to simulate the allocation to all organs improved significantly when adding the labile carbon pool as suggested by de Vries 1989. In order to clarify this a bit further, we have added the following statement:
Regarding carbon, the maximum C-mass in the labile C-pool is 40% of the stem C-pool (line 10 page 1058 of the old manuscript). We revised this as:
To represent this in the model, a labile C pool is filled with a fraction of the C allocated to the stem, set here to 0.4 for wheat (Penning de Vries 1989), and thus has a cap of the allocation to stem (g_{St}) times 0.4.
On line 5 page 11 in the updated manuscript.

On line 4-6 on page 1062 of the old manuscript, the transport of N to the labile N-pool is described. We added here:
In contrast to the labile C pool, there is no explicit cap on this pool, but the amount is constrained since leaves and roots act as labile N sources.
On line 17 page 14 in the updated manuscript.

"*Equation 11: Why is the nitrogen availability a function of projected leaf coverage by the plant?*"
Reflecting the historical development of many DVMs, in LPJ-GUESS, there is some difference in level of detail between above ground and below ground. The fine root fraction is assumed to be proportional to the leaf, analogue to how the relationships for activities and masses of C and N are treated. M_N,avail We have updated the text related to eq. 11:
where φ is the fraction of projected leaf coverage by the plant (proportional to the fine root area, similar to the functional balance concept Eq. 10), $M_{\mathrm{N,soil}}$ is the mineral N mass of the soil and θ is the mean water content of the soil profile.
On line 12 page 13 in the updated manuscript.

"*Please provide a more thorough description of LAIn on page 1059 line 15. How does it differ from LAI?*"
We have added a description on where LAI_N stems from and also its purpose, as it is a bit disconnected to Eq. 13 where it is used:

From theory on optimal N distribution in a crop canopy, Yin et al. 2000 derived a relationship between the LAI that can be supported given the amont of N that is currently in the leaves ($\mathrm{LAI_N}$) and $\mathrm{k_N}$:

$$LAI_N = \frac{1}{\mathrm{k_N}} \ln(1 + \mathrm{k_N} \frac{M_{\mathrm{N,L}}}{\mathrm{N_b}}) \tag{8}$$

where $M_{N,L}$ is the leaf N mass and $\mathrm{N_b}$ (Eq. 9) is the minimum N requirements for the leaf to function.

$$\mathrm{N_b} = \frac{1}{\mathrm{C\!:\!N_{L,max}SLA}} \tag{9}$$

where $\mathrm{C{:}N_{L,max}}$ reflects the minimum N required for photosynthesis and SLA is the specific leaf area ($\mathrm{m^2\ kgC^{-1}}$). $\mathrm{LAI_N}$ is then compared to LAI to determine the N status of the canopy, see Sect. 2.1.3.
On line 4–14 page 12 in the updated manuscript.

"It seems that the authors did not have data at the FACE site on the total magnitude of N addition, timing of individual N additions, and magnitude of individual N additions. To overcome this lack of data, they simulated an ensemble of magnitudes and timings and used the combination that produced yields that best fit the observations. One limitation to this approach is that it assumes that the rest of the model structure and parameters are correct. To address this assumption, it would be helpful to show the sensitivity to N addition from the ensemble of magnitudes and timing. Is the range large, therefore fitting the model to the yield data is critical, or is the range small, therefore choosing the magnitude and timing of N addition is not absolutely critical? The authors could also be clearer about whether the total magnitude of N addition over the growing season is known but just the timing and magnitude of individual additions are unknown"

Regarding the FACE simulations, the description in the original manuscript was a bit vague, we have modified to read as follows:
Due to the lack of information on the timing and amount of the individual fertiliser applications, these parameters were set using the results from the regional comparison (Sec. 3.3), total amount of N added in the experiments are listed in Table 3.
On line 5 page 19 in the updated manuscript.

The reviewer also raises an important issue about the sensitivity to timing and application rates of N fertilisers. Although fertiliser application rate is the most important thing to consider, timing has also a pronounced effect. This can be seen when comparing the different experiments in terms of the mean yield (averaged over all grid cells and permutations within one simulation setup) and the range of grid cell means across all permutations within one experiment setup. We have added the following to the revised version of the manuscript (page 25, line 1–12):
The grid cell average yield over the region and all permutations in the $F_{opt(T,A)}$ simulations was 5.2 ton. $\mathrm{ha^{-1}\ y^{-1}}$, ranging from 2.4 to 10.3 ton. $\mathrm{ha^{-1}\ y^{-1}}$ between the different application rates and timing. For $F_{opt(T,a)}$ the same measures were 5.5 ton. $\mathrm{ha^{-1}\ y^{-1}}$ (3.1–8.7 ton. $\mathrm{ha^{-1}\ y^{-1}}$) and for $F_{opt(t,A)}$, 5.2 ton.

ha^{-1} y^{-1} (3.2–8.6 ton. ha^{-1} y^{-1}). The average yields for all simulations were of the same order of magnitude. For $F_{opt(t,A)}$ and $F_{opt(T,a)}$ the ranges in yield were also of similar size whereas the range for the $F_{opt(T,A)}$ was larger although smaller than the sum of the ranges of $F_{opt(t,A)}$ and $F_{opt(T,a)}$. Most importantly, both the optimisations with either fixed timing or application rate, resulted in a better agreement with the reported yields compared to a mean uniform N management over the region (Ft,a, Table 5), but optimising the application rates gave a considerably better fit than optimising the timing. While timing had a large effect, these results imply that highest priority is to obtain data on application rates.

We also revised the conclusion as to:
These findings support the aim of this study, to find a level of complexity in the implementation of the N management that can be applied on larger regions. Such implementations are crucial e.g. for studying the effects of climate and global environmental changes on simulated yield at regional to global spatial scale. Regional differences in timing as well as total application rates are required to fully capture cropland dynamics in simulations of global C and N cycles. However, since this level of detail is rarely available in future projections of fertiliser use, our results demonstrate that as long as estimates of total N applications are available for a given region, adopting a mean fertiliser timing that is based on the development stage is sufficient for representing the mean and variance of regional yields.
On line 22 page 32 in the updated manuscript.

"*How does this study show the crop model is applicable under climate change? The response to climate is not described or evaluated.*"

The reviewer is correct in that we have not here included experiments addressing climate change impacts. The main reason was to keep focus of the manuscript on model description and evaluation (and hence focus on near-historical and present-day data and simulations), see answer to previous question.

"*Table 1 – the three columns under N app need more explanation. Are there three different treatments applied to three different plots or three different times within the year?*"

The caption of the table was revised as:
Site and treatment specific data after Groot et al. 1991. For all trials (I–VI), three experiments with different applications of N fertiliser were performed (1,2 and 3). Their timing is expressed here by the development stage (DS).
On page 44 in the updated manuscript.

"*Table A.3. The column NUTS2 needs to be defined so that a reader just looking at the table can understand.*"

NUTS2 is now spelled out in the revised table caption:
Nitrogen fertiliser applications and timing for each NUTS2 (Nomenclature of Territorial Units for Statistics in the EU; statistical administrative areas) re-

gion used in the regional simulations resulting from optimising modelled yields against observations ($F_{opt(T,A)}$), see Sect. 3.3, together with the statistics (the 2 last columns). Number of years with reported yields for each region (n. y), fraction of the wheat area covered by winter variety (Ar.), fraction with spring variety: 1 – Ar., reported yields and AgGrid N input data for each region.
On page 51 in the updated manuscript.

2 Reviewer #2

Specific questions and remarks. 1) "*Abstract suggests to me more of an evaluation paper. Title suggests an impacts study. I think the problem is with the abstract not saying much about the impact as advertised by the title.*"
That is correct, the title now reads:
"Modelling the response of yields and tissue C:N to changes in atmospheric CO2 and N management in the main wheat regions of Western Europe"

2) "*p. 4 line 26: pls correct "the reasons ... is"*", corrected to "the reason ... is".

3) "*p. 9 first paragraph on Development Stage: my perception of the difference between DS and HU is subtle (possibly even non-existent) because HUs can have thresholds for DS transitions, as they do in AgroIBIS and CLMcrop as far as I know. So pls clarify or correct.*"
The reviewer is correct that this is not a general case, and it is now phrased more specific regarding the difference between the two implementations in LPJ-GUESS:
Compared to the HU implementation currently in the model, the use of DS facilitates a more detailed division of the growing period into the different crop phenological stages (Wang et al. 1998). Periods when the plant is more susceptible to heat and nitrogen stress can thus be represented in a more precise manner.
On line 13 page 8 in the updated manuscript.

4) "*p. 10 line 19: you say "e.g." which means "for example" and I wonder whether this applies also to heat and cold stress or whether you really mean "i.e." which would limit the list to water and nitrogen. Pls clarify or correct.*"
The sentence was a bit vague and is now updated as follows:
When a plant experiences water or nutrient deficit during the vegetative phase, it starts to invest a relatively larger fraction of the assimilates into roots to overcome the stress (Keulen 1989).
On line 11 page 9 in the updated manuscript.

5) "*p. 10 line 23: I suggest replacing the vague statement "can be treated as conserved" with "is treated as constant" unless I have misunderstood, in which case pls reword as you see best fit. Similarly with "can be established." Do you mean "is established" or even "is calculated" in this model?*"
We replaced conserved to constant, but we believe that it should still be "can be established", as this reflects an opportunity to derive such a relationship.

6) “*p. 11 line 13: add "fig 1b" after "above" if it seems appropriate to you. My impression is that you need to change "fig 1b" to "fig 1a" in line 14. And change "were" to "was" in line 13.*”
The reviewer is correct that the reference should be to Fig. 1a and not b, the *above* does not refer to the figure, but the text above. Were is also changed to was.

8) “*Carbohydrate retranslocation: maybe should compare to the Drewniak et al. approach in the CLM, mentioned in one of her recent papers.*”
Thanks for this suggestion, which would indeed be interesting to include. However, after reading Drewniak et al 2013, Bilionis et al. 2014, Levis et al. 2012 and 2014 we could not find a detailed description of how the carbohydrate retranslocation is done in CLM. Perhaps the paper the reviewer mentions is as yet unpublished or we have overlooked the appropriate reference?

9) “*p. 15 line 5: change "Sect. 2.1" to "Sect. 2.1.1"*”, that is corrected.

10) “*p. 18 line 10: correct "these fraction"*”, corrected to "these fractions"

11) “*p. 18 line 17: maybe I missed it; did you define pF earlier?*”
No, pF was not defined previous to that. We have now revised that sentence to read:
where Ψ_i is the actual pressure head (m) and θ_i is the actual volumetric water content ($\mathrm{m^3\,m^{-3}}$).
On line 4 page 17 in the updated manuscript.

12) “*p. 19 line 20: you say "were changed" and do you mean permanently or temporarily for this particular case?*”
The sentence is updated to the following:
Based on an initial calibration of the model using leaf phenology data from Trial I, the parameters a and b in the allocation function f_2 (Eq. 4) were changed from 0.88 and 0.09 to 0.8 and 0.2 respectively, for this application.
On line 8 page 18 in the updated manuscript.

13) “*p. 19 line 24: change "data ... was" to "data ... were" and explain your choices of 100 vs later 200 kgN/ha/y and "applied on day 150 from the time of sowing."*”
We have updated and split the sentence to make it more clear:
To initialise (spin up) N and C pools in the model, climate data for the year 1979 were repeated for 500 years. In Groot et al. 1991, there is no information on management practices in previous years, so we decided to implement a moderate level of 100 $\mathrm{kg\,N\,ha^{-1}\,y^{-1}}$ as a single application, 150 days after sowing for the spinup. The year before the trials started (1982 for Trials I, III and V and 1983 for Trials II, IV and VI) 200 $\mathrm{kg\,N\,ha^{-1}\,y^{-1}}$ was applied, following Table 1 Groot et al. 1991.
On line 10–17 page 18 in the updated manuscript.

14) “*p. 20 line 14: do you mean spring or winter cereals? Or both?*”
Updated for clarity as follows:

Also LPJ-GUESS does not model wheat and barley explicitly, but temperate cereals (Bondeau et al. 2007,Lindeskog et al. 2013) represented by wheat (spring and winter) in the model, therefore growth of cereals was simulated for all years. On line 25 page 18 in the updated manuscript.

15) "*p. 26 lines 1 and 7: so is the modeled in fact more accurate than the observed?*"
If the reviewer are referring to the modelled N application rates as compared to the input data used in this study, we would not say that they are more correct. But the modelled data reflects some of variation in the spatial patterns of N fertiliser applications that is not available in the input data.

16) "*p. 26 line 3: change "despite of" to "despite the" and in line 17 clarify "relative to C-only" or do I misunderstand?*"
The reviewer is correct, that was a bit unclear and is now corrected as follows: As expected, optimised N management ($F_{opt(T,A)}$ and $F_{t,A}$) improved the fit of the model results to spatial variation in the data, but all the C–N enabled simulations except for $\max(F_{T,A})$ increased the agreement between the modelled and observed variance (Table 5), when compared to F_{C}.
On line 11 page 24 in the updated manuscript.

7) "*eq. 6 is reminiscent of the CLM-CN allocation equations. If there's any connection, then pls add corresponding reference(s).*"
They stem from the same source, Penning de Vries 1998, see below.

17) "*CLMcrop now includes a representation of variable C:N. I think Oleson et al. (2013) mentions this and probably Drewniak et al. in a recent paper.*" As far as I can interpret the implementation in Drewniak et al. (2013), the C:N of the various organs are dependent on the crops stage. N retranslocation is therefore the result of the crop entering a new stage, and thus not on its current status being dependent on auxiliary factors.
We have added the following to the discussion:
CLM (Drewniak et al. 2013), e.g. includes N limitation for crops, and this model also simulates the retranslocation of N during the grainfilling period based on prescribed C : N of the plant organs pre- and post anthesis. The C allocation scheme implemented in CLM has the same origin (Penning de Vries 1989) as the one implemented here for LPJ-GUESS. On line 11 page 31 in the updated manuscript.

18) "*Table 4: C:N here is whole plant? grain? leaf?*"
Grains, updated accordingly.

19) "Figures 2d and 3: are there better ways of presenting this information?"
We believe that this shows the temporal development of both C:N and the leaf phenology.

20) "*Figure 7: by "red dots" do you mean "red triangles"*""
Triangles, updated in the text.

21) "*Check the year in the Rosenzweig reference. I thought it was 2014...*"

True, and we have updated it.