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Interactive comment on "The soil N cycle: new insights and key challenges" *by* J. W. van Groenigen et al.

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[We have uploaded the revised manuscript separately in our response to the editor]

We would like to thank the reviewer for the thoughtful and detailed comments on our manuscript, which certainly helped to improve the structure of our paper. Below, we respond to all points raised by the reviewer. In order to ensure a complete rebuttal, we have not deleted any text from the original review. Per issue raised, we have clearly indicated the comments of the reviewer as well as our response.

Reviewer #2: General comments. This review addresses 8 key scientific challenges in the soil N cycle in order to formulate a comprehensive research agenda of soil N role for food and energy security, biodiversity conservation as well as climate stability.

It's not said explicitly, but one gets the impression that the authors find that the importance of these processes, controlling factors and method for (the understanding of) the global soil N cycle has been underestimated. The first three key challenges concern assessment of the importance of the processes non- symbiotic N fixation, nitrifier denitrification and N2O consumption for the global soil N cycle. The 4th challenge focusses on peak rates and hot-spots of denitrification. The next three challenges focus on moderators of soil N processes; soil fauna, plant root and mycorrhiza. The last one focus on improving understanding of soil N cycling by modelling based on 15N/18O experiments. The language and figures are of good quality. This manuscript has in my opinion not yet reached its full potential. It contains eight mini reviews, some very good and some less good. What is the surplus value of addressing these key challenges in one paper? I suggest adding a discussion chapter in which the key challenges are weighted against each other by answering the questions; i) Are those key issues equally scientifically challenging? ii) Can solving one help unravelling another? More importantly, ii) Can you make a priority in the research agenda; which processes, moderators and modelling are most important for food and bioenergy security, which for biodiversity conservation and which for climate stability at the local, regional and global scales. How can new insights of these processes and moderators of the soil N cycle help to achieve multiple global challenges, food and bioenergy security, biodiversity conservation and climate stability? I anticipate that a good, general discussion chapter would greatly improve the conclusions, reach out and impact of this manuscript.

Response: We thank the reviewer for the kind words about our paper. We have certainly tried, greatly helped by the comments by this reviewer and the others, to improve the quality of the different sections, and we also edited and extended the introduction and discussion sections to further improve the internal coherence of the manuscript and our arguments. We are hesitant, however, to further discriminate or rank the key challenges that we mention, according to the suggestions by the reviewer. We strongly agree with Reviewer #3 when (s)he says that "...there is a qualified personal perspective to the topics and challenges, and this is admissible given this has been openly

declared. However, there needs to be some guarding against this becoming – or being intended or used – as a manifesto for any form of prioritisation – these are after all the opinions of the authors per se and have not been through a large scale ratification process".

Reviewer #2: In addition, more consistency in addressing the key challenges in soil C cycle is desirable. A simple thing like using the same units for the fluxes of N fixation and N2O consumption facilitates it for the reader to compare these fluxes.

Response: Throughout the manuscript, we have reformulated terms and restructured sections to achieve more consistency. We agree with the reviewer in principle that it would be desirable to have the same units for different processes. However, in the end this is a review paper citing primary papers, and we decided it was prudent to avoid extrapolation of data. Therefore, we decided to use the units as given in the original primary literature.

Reviewer #2: I found the division in soil N processes and moderators as presented in the abstract confusing as key challenge 2 is a combination of both and key challenge 4 neither of them. I suggest for each process including soil N processes moderated by soil fauna and/or mycorrhiza as well as rhizosphere processes, identify its moderators, hot-moments as well as hot-spots or hot-ecosystems (if there are any) and its challenges in progress of understanding, and as far as possible assess rates and uncertainties at the local, regional and global scales. That would be really helpful in establishing the research agenda of soil N role for food and energy security, biodiversity conservation as well as climate stability.

Response: We have reformulated and rearranged the subdivision of the key challenges throughout the manuscript. The three first challenges are all directly related to fundamental N cycling processes (nitrifier denitrification, N2O reduction resp denitrification) and deal with different aspects of them (quantifying them; their spatial variability; their basic nature). The final four challenges were aimed at indirect interactions on

these processes through ecological interactions (with fauna, plant roots and mycorrhizal fungi, as well N fixation, respectively). We hope that this is now clear. We do not favour a list for every process, stating the effect of fauna, mycorrhiza, hot moments, etc, as this would result in an exhaustive textbook type of paper, rather than a (relatively) short paper outlining research priorities.

Reviewer #2: Finally make sure that all statements are well founded and avoid restricting to self-citations, this way you can create a much more inviting, open-minded climate for discussing this very important issue, the research agenda of soil N role in food and energy security, biodiversity conservation as well as climate stability.

Response: We have added several references in response to comments by the three reviewers and Dr Pöschl, none of them self-citations. Inevitably with a paper where we outline a somewhat personal view on the soil N research agenda, we cited some of our own work, but with $\sim$35 self-citations out of a total of $\sim$230 we do not think this is excessive. We would be interested to hear where the reviewer thinks we overlooked important references in favour of our own work.

Reviewer #2: Specific comments. Abstract. Make sure the formulation of each key challenge corresponds to that in introduction and especially content of chapters 2 and 3.

Response: The abstract, introduction and conclusion sections have been extensively revised to ensure consistency within the manuscript with respect to the key challenges.

Reviewer #2: The title creates high expectations. What are the new insights and the take-home message or conclusions?

Response: We have extensively changed the paper and think that the conclusions are now much more clearly formulated in the extended conclusions section, as well as in the abstract. We hope that the new insights are reflected in the (revised) description of the key challenges in their respective sections.

Reviewer #2: P624 L6-7 suggestion to replace 'further understanding, measurement and mitigation of the soil N cycle' with 'further understanding and improved quantification of the soil N cycle allowing to enhance positive and mitigate possible negative effects'.

Response: In line with comments by another Reviewer, we changed this statement into " ...further understanding, measuring and altering the soil N cycling", which we think is in the same spirit as the suggestion by this reviewer".

Reviewer #2: P624 L24-25 Suggestion: Integrating improved understanding of soil N processes by advanced modelling based on tracing experiments

Response: We prefer to keep the original formulation as it states more precise what the exact challenge is, in our view: not generally better understanding soil N processes, but disentangling gross processes, using labelling of both 15N and 18O.

Reviewer #2: Introduction P625 L10 replace 'after World War II' with 'since 1950's'

Response: Changed.

Reviewer #2: P625 L8-L19 Much better than in abstract and figure 1 is really helpful, thanks! Still, double check that each description corresponds to the content of its key challenge and that each key challenge is placed in right chapter. If key challenge 4 is focusing on difficulties in measuring than it might suit better in Chapter 4 on methodology N2O consumption instead of reduction.

Response: We assume the reviewer means P627 instead of P625. Thank you! We have reformulated the description of the key challenges in the abstract to make them correspond more to the description in this section. However, notice that an abstract should be written concisely, so descriptions are necessarily shorter. Above, we already responded to the nature of key challenge 4 (now 3) and reformulated its description to makes it place with the first 3 challenges more clear.

Reviewer #2: N2 fixation 1. How large is the contribution of non-symbiotic N fixation

in natural systems? This section clarifies that non-symbiotic N fixation is important in tropical forests in different succession phases, it also quantifies it, but non-symbiotic N fixation in other natural systems receive little attention. Much more attention is given to symbiotic N fixation in tropical forests. A more thorough discussion of and estimates of peatland's, cryptogamic non-symbiotic N fixation globally would be helpful.

Response: We extended the N2 fixation section by including: N2 fixation in cryptogamic covers, N2 fixation via methanotrophic bacteria in sphagnum mosses and the potential role for associative N2 fixation via endophytes or diazotrophs in roots or stems for sustainable bio-energy production (e.g. Miscanthus) with minimal fertilizer input.

Reviewer #2: Nitrifier denitrification 2. How important is nitrifier denitrification and what are its main controlling factors? This section highlights nitrifier denitrification but it does not discuss controlling factors thoroughly or its global importance

Response: As previously stated in response to comments by Reviewer #1, we very much agree that these are very important questions, and therefore it is in fact one of the key challenges we formulate in our manuscript. It is a question to be answered in the future rather than now from the published literature, as only recently methodology was developed to measure the process reliably. We have added more information on the nature of nitrifier denitrification and included some speculation on its controlling factors, but this is necessarily short and not conclusive.

Reviewer #2: N2O Consumption 3. What is the greenhouse gas mitigation potential and microbiological basis for N2O consumption? This section discusses thoroughly biological N2O consumption but does not answer up to part 1 in key challenge formulation 'the greenhouse gas mitigation potential'.

Response: The likely role of N2O consumption is not a greenhouse gas mitigation potential, but to alleviate net N2O release from soils. The recent discovery of atypical N2O reductase needs more research on how widespread this gene is in various soil and ecosystem types. If the latter is indeed the case we argue for the introduction of

an in situ N2O consumption component in biogeochemical models that aim to simulate topsoil N2O fluxes.

Reviewer #2: Denitrification 4 How can we characterize hot-spots and hot-moments of denitrification? This section answers well to the formulated key challenges and could serve as a model for the other sections. Please improve bases or moderate the statements in introduction.

Response: The section has been revised to clarify just how characterization of hot-spots and hot-moments of denitrification can be done in a variety of systems.

Reviewer #2: P634 L20 'most poorly understood' and P637 L13 'new ideas' and 'powerful new tools for extrapolation and validation' which tools?

Response: Both of these lines have been revised as described above in response to comments from Reviewer #1.

Reviewer #2: Soil fauna, plant roots and mycorrhiza I fully agree that these are important moderators but prefer processes and moderators be integrated in sections as suggested in general comments.

Response: See our response to this point raised in the reviewers' general comments

Reviewer #2: P637 L17 'influence of fauna other than humans' what about animal husbandry?

Response: We have rephrased this statement. It now reads "... influence of soil fauna...."

Reviewer #2: P641 L4-5 please clarify 'directs' and 'indirect' effects of what on what?

Response: This line has been revised in response to comments from reviewer #1.

Reviewer #2: 15N tracing modelling P648 L22-24 skip L22-23 and reformulate to 'This section focus on how process-oriented modelling based on 15N enriched techniques

(references) can progress our understanding of soil N cycling dynamics.

Response: Changed according to the suggestion, thank you.

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Interactive comment on SOIL Discuss., 1, 623, 2014.