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Interactive comment on "Processes regulating progressive nitrogen limitation under elevated carbon dioxide: a meta-analysis" *by* J. Liang et al.

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The hypothesis of progressive nitrogen (N) limitation (PNL) presented by Luo et al. in 2004 stimulated important research on how terrestrial ecosystems response to elevated CO2 (eCO2) and if these responses are limited by N availability. One decade of research has not fully clarified if a PNL will develop, as results are inconsistent across different ecosystems. As Liang et al. state, a "comprehensive assessment of the processes that regulate PNL is still lacking" (p. 16954, l. 5). Despite their claim that "all major processes and pools in terrestrial N cycle" were synthesized (p. 16954, l. 6), several important N cycle process, which have the potential to regulate PNL, are not included in the meta-analysis. Therefore, the paper by Liang et al. does not provide the needed comprehensive assessment. Liang et al. ask two specific questions

(p. 16955, l. 29ff): "(i) How do the major processes in terrestrial N cycle respond to CO2 enrichment? (ii) Does the CO2 fertilization effect on plant growth diminish over time?" While the first question (i) cannot be answered satisfactorily, as major N cycle processes are not considered (which will be discussed below), the second question (ii) has been answered already. In the meta-analysis by Feng et al. (2015) the ecosystem-scale responses of plant productivity and N acquisition to eCO2 in FACE experiments were explored. One of the main findings is that "Effects of eCO2 on productivity and N acquisition did not diminish over time" (see Figs. 7 & 8 in Feng et al., 2015), answering the question (ii) by Liang et al. Moreover, Feng et al. (2015) showed that only in one long-term FACE study plant growth enhancement decreased over time. Therefore, PNL seems to be rather the exception than the rule, at least over the decadal scale of current FACE experiments.

Which processes control N availability in terrestrial ecosystems? Liang et al. conclude that enhanced biological N2 fixation and decreased N leaching alleviate PNL. However, this concept neglect that the majority of N is made available by mineralization of N during the (microbial) decomposition of soil organic matter (SOM). In that context, gross rates of mineralization are of importance and not the net rates, but Liang et al. only looked at net rates. As pointed out by Davidson et al. (1992) "net rates reveal only a small fraction of the true rate of mineralization", the "true rate" being gross mineralization. To illustrate why gross mineralization is far more important for N availability than N2 fixation in most non-managed ecosystems (with the exception of those harbouring plant species with symbiotic N2 fixation), data compiled for the Höglwald spruce forest can be used (Butterbach-Bahl and Gundersen, 2011). In this ecosystem N2 fixation contributes 2 kg N ha-1 yr-1, while gross mineralization provides 550 kg N ha-1 yr-1. The N leaching was estimated to be 20 kg N ha-1 yr-1. As the plant N uptake is 100 kg N ha-1 yr-1, N2 fixation is by far not able to meet that demand, but plant N uptake relies on N mineralization. The N uptake by plants likely increases under eCO2 and Feng et al. (2015) found an average increase by 8 %. For the Höglwald that means an additional N demand of 8 kg N ha-1 yr-1. Even with a reduction of N leaching by 25 %

(as found by Liang et al.), an additional N input of 3 kg N ha-1 yr-1 is required. That mean that N2 fixation would need to increase by 150 %. In contrast, gross mineralization would only need to increase by 0.5 % to meet the demand. If N leaching would be unchanged, a five-fold increase in N2 fixation is required, while gross mineralization still need to be enhanced by only 1.5 %. We recently found that, across all available data, eCO2 increased gross mineralization in N limited ecosystems (i.e. those prone top PNL) by 13 % (Rütting and Andresen, 2015). This is far more than is required to fulfil the enhanced plant N demand under eCO2 in the above exercise. Ignoring this stimulation in gross N mineralization under eCO2, Liang et al. overestimate the importance of N2 fixation for alleviating PNL. An alternative scenario emerges (See Figure; adapted from Luo et al., 2004).

Enhanced carbon inputs to soil (van Groenigen et al., 2014) accelerate in a priming-like mechanism the gross N mineralization rate (Dijkstra et al., 2013), leading to an sustained availability of labile (inorganic) N, maintaining the N demand by plants. As N is generally faster cycled between SOM and inorganic N, the availability of N can be maintained by remineralization, even if (microbial) N immobilization is stimulated as well.

Overall, availability of N for plant uptake in terrestrial ecosystems depends on the N supply from (gross) N mineralization, while inputs from N2 fixation are of minor importance in most ecosystems (Butterbach-Bahl and Gundersen, 2011). Therefore, it is rather the response of gross N mineralization than of N2 fixation which is regulating if a PNL is developing under eCO2. By ignoring this process, no comprehensive assessment of PNL is possible.

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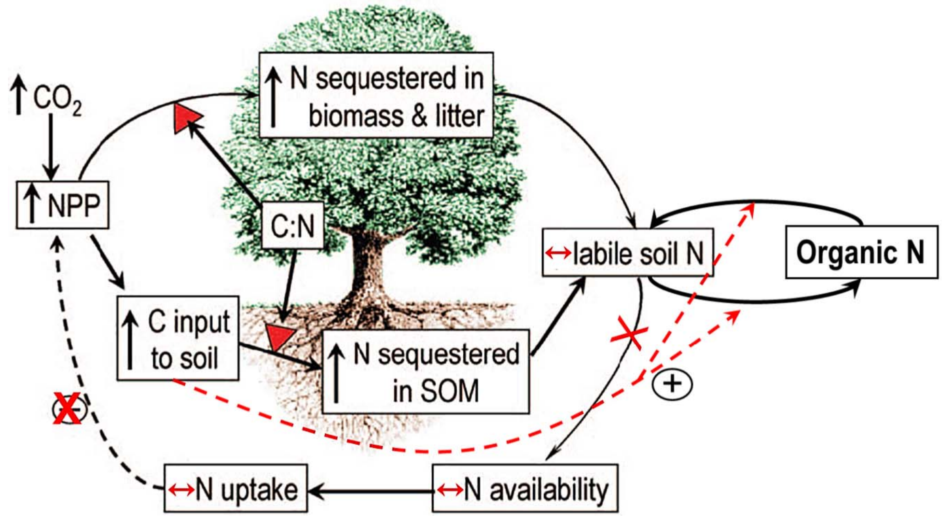
↑CO2
↑NPP
↑N sequestered in biomass & litter
C:N
↑C input to soil
↑N sequestered in SOM
↔labile soil N
Organic N
↔N uptake
↔N availability

Fig. 1.