Reply to 'Uncertain effects of nutrient availability on global forest carbon balance' and 'Data quality and the role of nutrients in forest carbon-use efficiency'

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Re-analysis of global forest database confirms the key role of nutrient availability on forest carbon balance

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Met opmaak: Frans (België)

Du suggested in his comment that our analysis was flawed for several reasons and offered a novel hypothesis. Our analyses and conclusions were not based on the simple regression presented in Fig. 1. The figure was merely meant for visualization purposes, showing the data and the differences between fertile and infertile sites. We relied instead on generalized linear models (GLMs; see Supplementary Information (SI) in Fernández-Martínez et al., 2014 (hereafter FM14)). Our study showed that NEP was affected not only by fertility and GPP, but also by stand age, mean annual temperature, water deficit, and management (Table 1). Conclusions can therefore not be based on linear regressions restricted to a partial set of predictor variables. Stand age in our models in fact interacted with GPP and therefore presented a non-linear relationship with NEP, precisely as Du suggests in his conceptual model. The comment further claims that three young forests with the highest Carbon Use Efficiency (CUEe) confounded our analysis. This claim is incorrect. Our analyses were supported by leverage tests (Fox, 1991), which showed that these sites did not affect our results. Nonetheless, as shown in the SI of FM14, we repeated all analyses using only data from the eddy covariance towers (excluding these three sites with the highest CUEe), and yet the patterns remained unchanged. Similarly, the comment suggested the use of different GPP ranges, but all analyses in the original paper also excluded all high-GPP forests and thus used similar GPP ranges for fertile and infertile sites (see SI), and the models again revealed a strong nutrient effect on CUEe. Even when excluding the "*uneven sampling effect*" (only considering forests with GPPs ranging from ~1000 to 2200 gC m^{-2} y^{-1}) and the conjectured "*outliers*" (the three very young forests), nutrient availability remains significant for NEP and CUEe (P = 0.0064 and P = 0.0008, respectively) in a GLM model also including MAT and GPP (only for NEP) as significant factors.

Werner L. Kutsch and Pasi Kolari (hereafter WKPK) also suggested that our analysis was flawed for various reasons. After removing 47 forests from our study (~35% of the dataset) for questionable reasons, they suggested that nutrient availability had no significant effect on forest carbon balance and that the results in FM14 were driven by a few outliers. Their statement, however, is incorrect. When we analyse the much restricted data set of WKPK using the same GLM as in FM14, in contrast to their simple linear model, the effect of nutrient availability on forest NEP remains unequivocal. The GLM model reveals a statistically significant interaction between GPP and nutrient availability on NEP and on Re (P = 0.026) and a marginally significant effect of nutrient availability on CUEe (P = 0.073).

WKPK's reasons for deleting forests from the analysis were: i) data quality, ii) history of the young forests, and iii) complex terrain affecting C flux measurements. Regarding these points:

i) Important in the discussion about unavoidable uncertainties in the GPP, Re, and NEP estimates is that inaccuracies (e.g. typesetting, errors on site-level calculations) were not responsible for our results (i.e. there was no bias towards any category of nutrient availability, ANOVA, $P = 0.32$). Moreover, the equation of the carbon balance is not GPP – Re – NEP = 0, as WKPK assumed, but the sum of the variables with their associated errors: $GPP \pm E_{GPP} - Re \pm E_{Re} - NEP \pm E_{nep} = 0 \pm E$. Including these uncertainty terms in the equation is relevant because several sites also provided chamber-based estimates. In this sense, only one of the 129 sites used in our study presented a carbon imbalance larger than the uncertainty. The one site (La Mandria), with many zero values, was included in our visual presentation (Fig. 1) but not in the statistical analyses upon which we based our conclusions (because stand age was unknown). Therefore this site did not affect our conclusion.

ii) We see no reason to remove forests under 15 years old, as WKPK suggested, because we included stand age as a covariate in our models interacting with GPP. Furthermore, the effect of nutrient availability on CUE was not driven by young forests (Fig. S4 in FM14).

iii) The criterion that WKPK suggested of removing sites in complex terrains is questionable, subjective, and not generally accepted, in contrast to ustar filtering applied to all sites, which is the most accepted method to address the advection problem. Also, in WKPK's comment, differences in CUEe for forests with contrasting TDA cannot be statistically assessed, because they did not present the significance of the test nor the description of the error bars in their Figure 1.

We agree with WKPK on the general statement of the importance of high standards of data quality in multi-site statistical analyses. WKPK, however, failed to demonstrate in their specific comments why data quality, site history, or complex terrain should cause a bias in favour of our main hypothesis. We continue to insist on our strong factual base that these 36 forests should not be removed from the original data set. In fact, all the additional analyses performed with subsets of the original data set for points i), ii), and iii) and with WKPK's data set strengthen our finding that nutrient availability plays a key role in forest carbon balance.

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