CORRESPONDENCE:

Uncertain effects of nutrient availability on global forest carbon balance

To the Editor — Fernández-Martínez *et al.*[1] show that nutrient availability is the chief determinant of net ecosystem production (NEP) and ecosystem carbon-use efficiency (CUEe, the ratio of NEP to gross primary production, GPP) in global forests. But their conclusions depend on an improper treatment of differences in the GPP range of nutrient-rich and nutrient-poor forests (uneven sampling effect) and outliers. A statistical re-analysis of their data sets while simultaneously excluding the uneven sampling effect and outliers indicates no significant control of nutrient availability on carbon balance.

First, NEP and CUEe both have a nonlinear relationship with GPP (Fig. 1a,b), and this indicates that an uneven sampling effect can result in misleading conclusions. Taking nutrient-poor forests as an example, CUEe within the GPP range of 1,000–2,000 gC m^{-2} yr^{-1} (16 ± 3%; mean ± s.e.m.) is significantly higher than that within the whole GPP range (6 ± 4%) (t-test, $P < 0.05$). A generalized linear model analysis indicates that such differences of GPP ranges significantly affect NEP ($P < 0.05$). Therefore, the statistical analysis of Fernández-Martínez *et al.*[1] should have been based on samples within a same GPP range to exclude the uneven sampling effect.

Second, three very young forests (<5 years) with extremely high GPP and NEP are likely to be outliers, because young forests commonly have low GPP and NEP[2,3]. When excluding these outliers, the slope of NEP against GPP within a common GPP range (1,000–2,200 g C m^{-2} yr^{-1}) showed no significant difference ($P = 0.49$) between nutrient-rich forests (slope = 0.44, $P < 0.05$) and nutrient-poor forests (slope = 0.63, $P < 0.001$) (Fig. 1c). The slope of ecosystems respiration (Re) against GPP for nutrient-rich forests (slope = 0.56, $P < 0.05$) also showed no significant difference ($P = 0.85$) from that for nutrient-poor forests (slope = 0.37, $P < 0.05$) (Fig. 1d). These results indicate that nutrient-rich and nutrient-poor forests do not show a significant difference in their allocation of GPP to NEP.

Statistical analyses by Fernández-Martínez *et al.*[1] have never simultaneously excluded both the uneven sampling effect and outliers. When doing so, a generalized linear model analysis indicates that nutrient availability ($P = 0.26$) and nutrient–GPP interaction ($P = 0.49$) both exert no significant control on NEP.

Moreover, we propose a nonlinear conceptual model of CUEe against GPP (Fig. 1b). Youngest forests commonly show very low GPP and negative CUEe because of higher Re than GPP (ref. 2), and CUEe then increases rapidly with growing GPP to a critical point which is carbon-neutral. CUEe continues to increase but starts to slow at a certain stage when one or more environmental factors become more limiting to GPP (for example, water deficit due to increasing water demand[4] or intensified nutrient limitation by biomass nutrient accumulation[5]); it then reaches a maximum after which CUEe declines slowly owing to increasing allocation of GPP to Re (ref. 6).

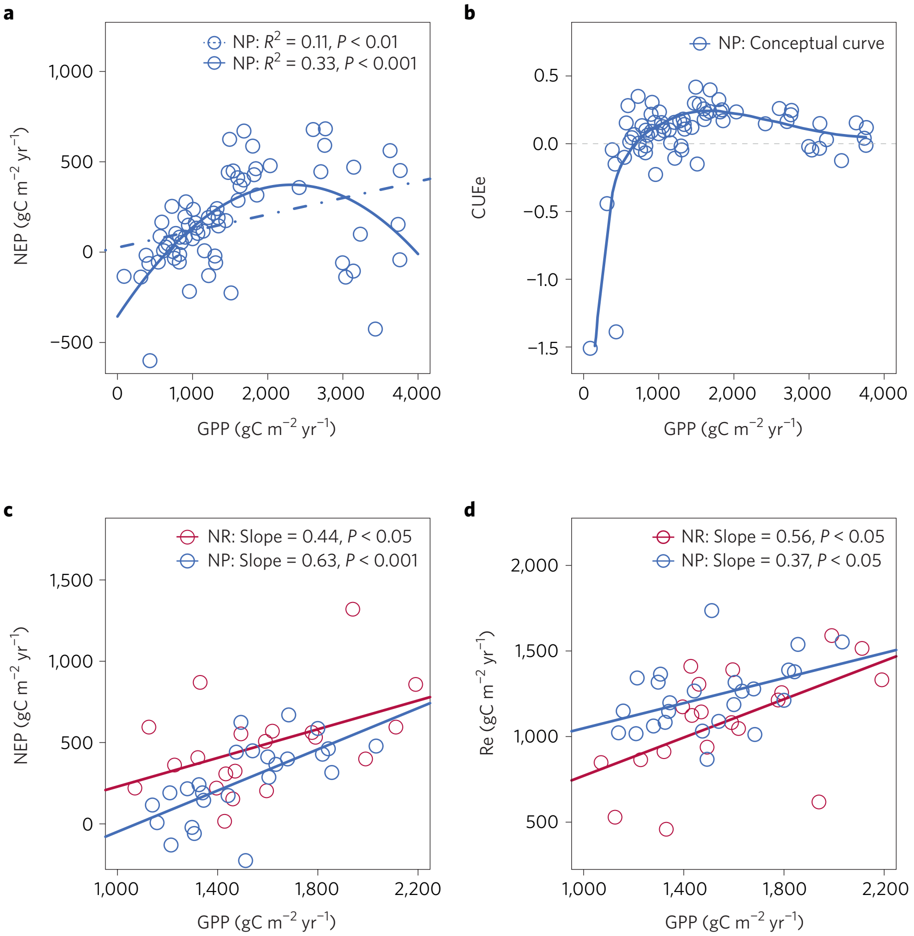

Figure 1 | NEP (gC m^{-2} yr^{-1}), CUEe and Re (gC m^{-2} yr^{-1}) against GPP (gC m^{-2} yr^{-1}) in nutrient-rich (NR) and nutrient-poor (NP) forests. **a**, Change in NEP against GPP within whole GPP range in nutrient-poor forests; **b**, nonlinear conceptual model of CUEe against GPP based on data set in nutrient-poor forests; **c**, comparison of the slopes of NEP against GPP; and **d**, comparison of the slopes of Re against GPP in nutrient-rich and nutrient-poor forests.

This conceptual model implies that GPP and stand age may intrinsically determine carbon allocation of GPP to NEP in global forests. ❐

References

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CORRESPONDENCE:

Data quality and the role of nutrients in forest carbon-use efficiency

To the Editor — Predictions of future forest carbon storage are uncertain because of restricted knowledge about drivers of forest carbon cycling. Fernández-Martínez *et al.*[1] state that nutrient availability is the key regulator of global forest carbon balance. This conclusion was drawn from carbon balances of 92 forests mainly derived from eddy covariance data. The key variable was ecosystem carbon-use efficiency (CUEe), defined as ratio of net ecosystem carbon uptake (NEP) to gross primary production (GPP). In their study, comparing ecosystems with high, medium and low nutrient availability resulted in a fivefold higher average CUEe for nutrient-rich forests. Our re-analysis shows, however, that the underlying data set contained flawed data, and the study ignored factors such as site history and topographical site characteristics that influence the quality of eddy covariance data. Including these factors as a quality control results in a data set that does not show any significant influence of nutrient availability on CUEe.

Our re-analysis focused on three aspects of the data (for details see Supplementary Information).

Is the quality of the data of the same high standard for all sites? For this purpose, it is important to understand the provenance of the data used in the study. The final data set (FMD, one average per site) is an extract from a global forest database[2] (SLD, several annual values per site) built on literature data and extracts from databases of international networks (EFDC, half-hourly values). All steps in this data chain were partly re-checked. Unreliable data were found in all three data sets, and 11 sites had to be removed.

In a second step, data from very young forests were re-analysed because the authors considered age but not previous history.

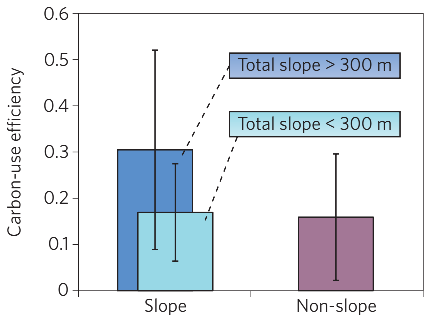

Figure 1 | Average CUEe for sites in complex terrain compared with sites in flat terrain. Sites in complex terrain were split into sites with differences in altitude >300 m and <300 m.

However, history strongly influences ecosystem carbon balances, mainly via soil carbon stocks, whereas nutrient availability plays only a minor role[3]. All sites aged younger than 15 years old were binned into 'afforestation', 'disturbance' or 'unknown'. Each group showed high correlation between CUEe and age, but the group 'afforestation' showed an initially high CUEe that decreased thereafter, whereas the forests with 'disturbance' had a highly negative CUEe at the beginning that increased thereafter. Around an age of 15 years the difference between the two groups vanished. This is in accordance with recent observations on land-use changes[4]. Twenty-three sites younger than 15 years were excluded from the re-analysis because the authors did not consider the site history of young forests in their statistics.

Terrain features were analysed for the remaining 95 sites. Complex terrain has been a focus of research for some time, but even substantial efforts to understand its influence on flux measurements[5] did not lead to a clear description of the phenomenon[6]. Therefore, the basic hypothesis of most of the FLUXNET community became that complex terrain probably causes a random but not a systematic error. Across a large number of sites, this would balance out and could therefore be ignored. This hypothesis was tested in this study: if terrain causes random error, CUEe should not correlate with any parameter describing the terrain around flux towers, and average CUEe from towers in complex terrain should not differ from that from towers in flat terrain. Forty-four sites were identified as being located in complex terrain. For these sites, CUEe was correlated to the total difference in altitude of the terrain (TDA). A positive correlation between TDA and CUEe was found, and average CUEe was significantly higher for sites with more than 300 m TDA (Fig. 1). Therefore, this difference in altitude was taken as threshold for a severe influence of advection, and 13 sites were excluded. Supplementary Table S4 details the sites removed during the different data quality checks and correction steps.

The remaining sites (n = 82) were re-analysed. Plotting Re against GPP gave a surprisingly high correlation throughout all sites ($r^2 = 0.899$, Fig. 2a). Only a small but not significant influence of nutrient availability on CUEe was detected (Fig. 2b).

The study by Fernández-Martínez *et al.*[1] shows clearly the necessity of improvements in integration studies related to eddy-covariance-derived data.

Data curation has to be improved. Some data were too low-quality for the purpose of this study. This shows the importance of high standards of data quality and is a big challenge for further integration (for example within FLUXNET). Infrastructures such as ICOS, Asiaflux, Ameriflux, Chinaflux, Ozflux or NEON need to ensure the highest standards of data quality and provide