Title
Satellite based estimates underestimate the effect of CO2 fertilization on net primary productivity

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CORRESPONDENCE:

Satellite based estimates underestimate the effect of CO_2 fertilization on net primary productivity

To the Editor — The recent study by Smith *et al.*[1] (hereafter S15) concludes that Earth system models (ESMs) overestimate the effect of CO_2 fertilization on net primary productivity (NPP). Whilst this finding is possible[2], here we highlight that the satellite derived NPP estimates used are likely to underestimate the CO_2 fertilization effect because they do not account for the primary effect of CO_2 on photosynthesis. Additionally the calculation of NPP sensitivity to atmospheric CO_2 is misleading, invalidating the comparison with free air CO_2 enrichment (FACE) data.

Satellite derived NPP estimates have often been treated as observations[3], however they are not[4]. S15 uses three independent satellite based proxies for NPP: a light use efficiency (LUE) model, a model tree ensemble[5] (MTE) constrained by ecosystem carbon flux measurements, and remotely sensed vegetation optical depth[6] (VOD). The LUE and MTE models assume that CO_2 affects NPP solely through changes in the observed fraction of absorbed photosynthetically active radiation (fAPAR), which is closely related to leaf area. However, the primary biochemical effect of rising CO_2, which both these models ignore, is an increase in photosynthesis due to increased LUE[7].

At the two longest-running forest FACE sites, we calculated the change in LUE due to CO_2 using NPP, growing season photosynthetically active radiation, and the Beer–Lambert law, relating annual maximum leaf area index to fAPAR. We found a large increase in LUE due to CO_2 across all years: mean = 17.4% (range = 8.9–32.6%) and 24.3% (8.0–35.9%), at Oak Ridge (1998–2008) and Duke (1996–2007), respectively. By contrast, the indirect change due to CO_2 (that is, via changes in fAPAR), which is accounted for in the satellite models, is small across all years: 0.3% (1.3–2.0%) and 2.9% (−0.3–6.0%), at Oak Ridge and Duke, respectively. Other, more open, canopies may experience larger changes in fAPAR due to CO_2 fertilization, but will still experience the large direct effect of CO_2 on LUE that is incorrectly ignored by the LUE and the MTE models used by S15.

The third proxy for global NPP used by S15 is based on VOD, which is closely related to above-ground biomass (AGB). However, AGB (a state) is not the same thing as NPP (a flux). Standing biomass, particularly in long-lived forest stands, will not fully reflect increases in NPP until many years after the rise in CO_2. In addition, AGB excludes below-ground allocation[8], which contributes to total NPP. As a result, VOD will systematically underestimate the effect of CO_2 on whole-ecosystem NPP.

The conclusions of S15 are bolstered by comparing model results with data from FACE experiments. S15 defines β as the percentage enhancement of NPP per 100 ppm CO_2 increase, and their values of β appear to be consistent with those estimated from FACE experiments. However, this definition of β ignores the saturating response to CO_2 (ref. 9), which means that values of β estimated from a low CO_2 concentration range (such as the range for the satellite record, which is ~350–400 ppm) should be higher than values estimated over a higher CO_2 concentration range (such as the range for

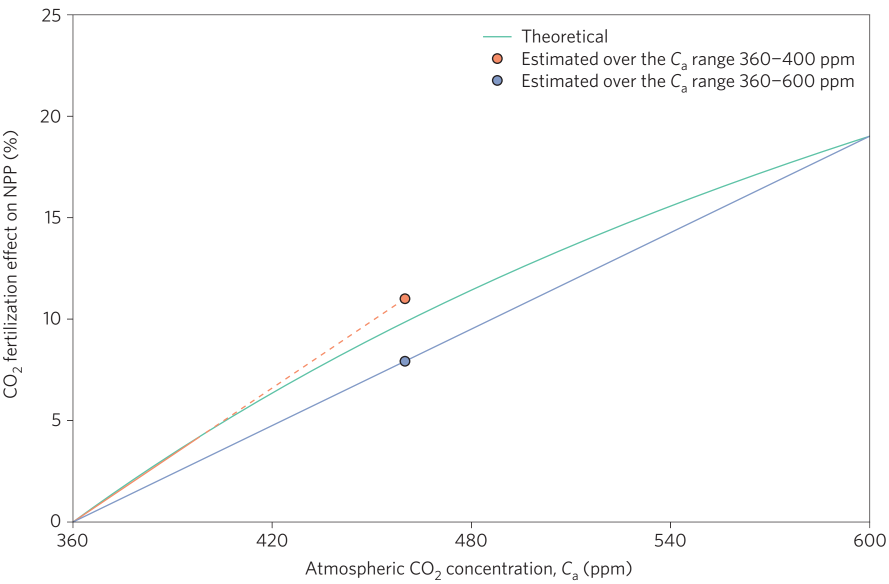

Figure 1 | Illustration of the effect of different measurements of atmospheric CO_2 concentration (C_a) ranges on estimation of β, defined as the relative change in net primary productivity (NPP) for a 100-ppm change in C_a. We assume there is a universal, saturating response of NPP to C_a (green line; here illustrated as the response of RuBP-regeneration-limited photosynthesis to C_a, taken from ref. 12). The red point extrapolates the straight line joining 360 and 400 ppm to 460 ppm (360 + 100), thus indicating the value of β that would be estimated from measurements over the C_a range 360–400 ppm (corresponding to satellite measurements). Similarly, the blue point interpolates the straight line joining 360ppm and 600 ppm to 460 ppm, thus indicating the value of β that would be estimated from measurements over the C_a range 360–600 ppm (corresponding to FACE experiments).

the FACE experiments, which typically increase CO_2 from ~370 ppm to ~550 ppm) (Fig. 1). Furthermore, S15's synthesis of FACE data is incomplete as it omits several years of published data[10,11], and incorrectly estimates an overall effect size by taking the median across experiments, species and years, rather than calculating a more appropriate response ratio[12].

S15 concludes that CESM1-BGC, the ESM most consistent with the satellite NPP estimates, is an improvement over other ESMs, likely due to its inclusion of explicit carbon–nitrogen interactions. We agree that the inclusion of such interactions in ESMs is a desirable objective, and that neglect of these in 'carbon only' ESMs risks overestimating long-term CO_2 effects on NPP[2]. However, it is premature to reach this conclusion given the inability of CESM1-BGC to capture the magnitude of recent CO_2 uptake[13] or even (uniquely among models tested) the 'sign' of the relationship between tropical land temperatures and CO_2 uptake[14]. In addition, the land surface model (CLM4) in CESM1-BGC underestimates the measured NPP response to elevated CO_2 from the two longest-running FACE experiments — predicting a smaller response than ten other ecosystem models that included nutrient limitations on NPP[15].

In summary the comparison of satellite and FACE estimates of CO_2 fertilization is invalid, and the discussion of nitrogen limitations is based on a single model that poorly represents the response of NPP to CO_2. ❒

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CORRESPONDENCE:

Emissions from cattle farming in Brazil

To the Editor — de Oliveira Silva and colleagues[1] have proposed that, if decoupled from deforestation, increasing beef consumption may reduce greenhouse gas emissions, while at the same time suggesting that reducing consumption may not significantly alter greenhouse gas emissions. However, the analysis contains unrealistic assumptions and disregards a series of other analyses corroborated by historical data, affecting the robustness of the conclusions. Sustainable intensification is presented as a feasible socioecological solution, despite the fact that this concept is still a matter of controversy. At the most general level, it lacks any solid empirically based mechanism. More specifically, it fails to address equity and local governance aspects that ought to be inherent in its definition[2].

Furthermore, the authors assume a scenario in which deforestation can be decoupled from changes in pasture area, something that has not happened in the historical record of the Brazilian Cerrado. This assumption is based on the idea that increases in yield efficiency will result in spare land returning to its natural state[3]. Historically, however, agricultural productivity increases have usually been accompanied by farmland expansion[4,5], to meet growing demand: this is often referred to as the Jevons paradox by agricultural economists[6]. The authors may have reasons to doubt the substantial empirical evidence supporting this issue, but they should acknowledge their rejection of it in their underlying assumptions.

Similarly, their assumptions of profit maximization and construction of a production-optimization model are problematic and arbitrary, considering the voluminous existing literature showing the importance of deviations from the maximization motive[7] and the need to explicitly grapple with the assumptions made in any optimization analysis.

The analysis does not take into consideration the local dynamics of small farming and indigenous resource management. Livestock production by traditional peoples and small farmers is generally regarded as less harmful to biodiversity and more sustainable than intensive livestock on exotic grass monocultures, although the outcomes are very context specific[8]. The assumption that the Cerrado may behave as a single large profit-maximizing farm does not reflect the socioeconomic diversity of extant landholders or the remarkable gamma diversity of its various ecosystems.

Another questionable assumption is the idea that pasture recovery can be accomplished with fertilization in most of the Cerrado, which is implausible even before accounting for its negative effects on soil, water, and greenhouse gas emissions. The model also assumes a fixed value for emissions as a result of deforestation in the Cerrado, neglecting the ecological heterogeneity of the biome. The authors propose recovery of degraded areas using exotic grass, even though such exotic species have potentially profound effects on the functioning and biodiversity of the Cerrado[9]. Furthermore, the model ignores the regrowth of woody vegetation when pasture is taken out of production. Thus, it effectively assumes that secondary succession back to forest, which results in carbon sequestration in biomass and carbon soil, can never occur[10]. These assumptions limit the practical utility of this modelling exercise. ❒

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