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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Reply to 'Emissions from cattle farming in Brazil'

de Oliveira Silva *et al.* reply — Goulart *et al.* make some interesting observations about the context of our study, its modelling assumptions and data. We clarify these issues but refute that our study is unrealistic or misleading. Indeed, we have been conservative with some assumptions and it would be possible and plausible to accentuate the counterintuitive result we present.

In our reference to sustainable agricultural intensification (SAI) we note the contested nature of the concept and do not imply a comprehensive characterization of the term. This includes the equity and governance trade-offs undoubtedly encountered in more granular research on mitigation. Our contribution provides one mathematical example of a plausible SAI scenario developed at a meaningful scale. We hope it partly fills a conspicuous gap in the literature, largely populated by normative conceptual papers rather than 'empirically based mechanisms' that might form policy evidence.

We suggest that the scenarios are based on sound empirical evidence, referenced in our supplementary information. This includes the recently observed decoupled livestock deforestation (DLD) scenario that resulted from more rigorous deforestation control and a changing market environment[1,2]. The DLD contrasts with the coupled livestock deforestation scenarios, which encompass worst case assumptions about how deforestation responds to demand. We suggest these are likely to accommodate potential Jevons paradox effects.

The profit maximization assumption is contestable, but we note that alternative assumptions are no less subjective. Furthermore, deviations from profit maximization will not significantly affect the results or main conclusions. This is because the level of intensification is not based on profit maximization, as land availability and demand are exogenous to our model. In unreported analysis other objective functions were tested (for example, minimization of land use change) with similar results.

While important, the heterogeneity of local ecosystem dynamics and gamma diversity are largely beyond the resolution of the model we employed. Nevertheless, we can draw some conclusions in relation to the impacts of intensification on biodiversity. We contest the characterization of large intensive farms versus smallholdings suggested by Goulart and co-authors: recent monitoring suggests the opposite[3–5]. Due to legal enforcement, large ranchers are reducing deforestation to avoid prosecution, while significant deforestation is attributable to smallholders[1].

There is considerable experimental and practical evidence showing that pasture recovery can be accomplished with fertilization in much of the Cerrado[6]. Moreover our scenarios account for all related greenhouse gases using a life cycle approach. Since little nitrogen is applied in the Cerrado[7], the issue of water pollution is negligible. Water consumption for intensification measures is also small, demand being mostly for livestock. On deforestation emissions, we suggest that it is impossible to know in advance where deforestation is going to happen in the biome for the period of study. We are confident that alternative assumptions on which physiognomies would be converted to grasslands would be at least as open to being contested.

The study proposes recovery of degraded areas already planted with exotic grasses. We stated that recovery strategies are based on existing *Brachiaria* spp. pastures as the preferred species for pasture recovery, productivity and costs (see supplementary information). We also note evidence that degraded pastures have worse effects on ecosystem function than productive pastures[8]. The use of native Cerrado species for cattle production is of minor importance[9].

Finally, there is no reason to believe that land would be abandoned or taken out of production within the demand range we studied. Note that the scenarios were based on projections to 2030. Even in the demand scenario of 30% below baseline ($D_{BAU-30\%}$) productivity would remain approximately at the current level. ❐

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