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ESSAY

Soil carbon sequestration in grazing systems: managing expectations

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Abstract

Grazing systems emit greenhouse gases, which can, under specific agro-ecological conditions, be partly or entirely offset by soil carbon sequestration. However, any sequestration is time-limited, reversible, and at a global level outweighed by emissions from grazing systems. Thus, grazing systems are globally a net contributor to climate change and the time scale of key processes needs to be factored into any mitigation efforts. Failing to do so leads to unrealistic expectations of soil carbon management in grazing systems as a mitigation strategy. Protecting the large carbon stocks in grazing lands is also essential in order to avoid further climate change from additional CO_2 release. Despite the time-limited and reversible nature of soil carbon sequestration in grazing lands, sequestration should be promoted in cases where it delivers environmental and agronomic benefits as well as for its potential, particularly on degraded land, to increase the feasibility of limiting global warming to less than 2 or preferably 1.5 °C. Some peer-reviewed sequestration estimates are of a similar order of magnitude to other food systems mitigation options over a 10–20 years period, such as reducing food loss and waste by 15% or aligning diets with current health related dietary-recommendations. However, caution should be applied to such comparisons since mitigation estimates are associated with large uncertainties and will ultimately depend on the economic cost-benefit relation, feasibility of implementation and time frame considered.

Keywords Grasslands · Soil carbon · Climate change · Livestock · Cattle · Greenhouse gases

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1 Introduction

The Paris Climate Agreement marks the world's commitment to limit global warming to less than 2 °C above pre-industrial levels and to pursue efforts to limit the increase to 1.5 °C. While fossil fuel-generated carbon dioxide (CO_2) from the energy and industry sectors is the main climate change contributor, agriculture and livestock also contribute (Herrero et al. 2016). According to the latest estimates derived from a life cycle assessment approach, the global livestock-related value chain (i.e., from cradle to retail) currently emits about 15% of anthropogenic greenhouse gas (GHG) emissions. About 30% or 2.4 Gt CO_2-eq/yr (FAO 2018, see Appendix) of these livestock-related GHG emissions come from the planet's 3 billion hectares of grazing systems, defined as livestock production systems found in areas dominated by pastures and rangelands with short growing period (< 60 days) or very low human density (< 20 people per km^2), in which more than 10% of the dry matter fed to animals is farm-produced and in which annual average stocking rates are less than 10 livestock units per hectare of agricultural land (FAO 2017a; Robinson et al. 2011; Seré and Steinfeld 1996). These global estimates hide large variations in emissions and emission intensities across regions, systems, and commodities. Concurrently with a raising awareness about livestock-related GHG emissions, soil organic carbon sequestration has attracted significant policy attention as a possible climate change mitigation strategy (e.g., the 4 per 1000 initiative, www.4p1000.org). Grazing management has been suggested as one route to sequester soil carbon but its potential to offset the emissions the animals generate is contested. This essay highlights key factors to consider in the debate about soil carbon sequestration in grazing systems and questions overly optimistic expectations about the potential of grazing systems to contribute to climate change mitigation.

2 Limits of soil carbon sequestration—context-specific, time-limited, and reversible

Soil carbon sequestration rates strongly depend on agro-ecological conditions and past and present farming regimes. Meta-analyses find that "improved" grazing systems practices (e.g., adjusted grazing intensity, fire management, legume or grass sowing, pasture fertilization) tend to lead to soil carbon sequestration, by an average of 1.76 t CO_2/ha/yr (excluding other GHG emissions, Conant et al. (2017)). This mean gain, however, is derived from a limited number of observations and practices occurring in particular contexts or regions and cannot be extrapolated to the global grazed area since sequestration rates are highly context-dependant (see Appendix for examples of sequestration ranges). Evidence for sequestration benefits of holistic, adaptive, and other variants of rotational grazing is contradictory (Nordborg 2016), although recent studies suggest short-term promising results in some contexts (Stanley et al. 2018). One of the significant challenges to assess the sequestration potential of grazing practices lies in the complexity of the interactions between soils, vegetation, grazing animals, and human interventions which are difficult to capture in the farming management categories usually assessed in the scientific literature.

Any soil carbon sequestration that may arise under specific conditions is time-limited and reversible. Several decades after introducing an improved practice, sequestration rates diminish to zero as soils approach new carbon equilibria (Smith 2014). Sequestered carbon can also rapidly be lost through management change, seasonal or climatic fluctuations (Knapp et al. 2002) or fires (Pellegrini et al. 2018). Grazing land degradation (e.g., wind and water erosion of soils, vegetation biomass reductions), while associated with uncertainties in terms of extent and implications for the climate, needs to be halted, since soil carbon can be lost much faster than it can be sequestered (FAO and ITPS (2015), Orr et al. (2017)). Alternative uses of the land, such as forestry, conservation agriculture, or rewilding, can also deliver carbon sequestration and a different mix of non-climate change-related costs and benefits.

3 Net balance of all GHG emissions and removals to be considered

The overall contribution of grazing systems to climate change depends on the net balance of all GHG emissions and removals. Methane (CH_4) emissions from ruminants should not be ignored, nor should potential nitrogen losses from grazing systems, which may be higher under improved pasture (Appendix). Efforts to sequester carbon and reduce CH_4, CO_2, and nitrous oxide (N_2O) emissions may not always align (van Groenigen et al. 2017).

At the global scale, grazing systems are currently net emitters of GHGs and climate-neutral grazing systems are the exception rather than the norm. Though some non-peer-reviewed studies claim that as much as 12,600–30,240 Mt CO_2/yr (Itzkan 2014) or 45,290 Mt CO_2/yr (Savory Institute 2013) could be sequestered in grazing systems, estimates in the peer-reviewed literature are more modest. According to the latter, global grasslands could potentially, and under still optimistic assumptions, sequester between 37 and 2090 Mt CO_2/yr depending on the approaches considered (Batjes (2019), Henderson et al. (2015), Smith et al. (2008), see Appendix). Even these estimates are optimistic as sequestration is time-limited and reversible. They also do not capture the many socio-economic barriers to the large-scale adoption of grazing best practices, which differ largely among regions, villages, and households (Godde et al. 2018). At the higher end, Batjes (2019)'s biophysical sequestration potential of 2090 Mt CO_2/yr assumes annual carbon increases of 3 to 5‰ with respect to estimates of present soil organic carbon mass (assumption similar to the 4 per 1000 initiative) on all degraded grasslands. This upper estimate is thus based on a proportional annual increase in soil organic carbon to align with the 4per1000 aspirational mitigation target rather than on best estimates for soil carbon gains which, as acknowledged in Batjes (2019), provides a picture that is too optimistic in a context of climate change mitigation. Further, an implicit assumption of the approach is that possible carbon gains will be greatest where soil organic carbon stocks are the largest which may not always be the case since depleted soils have the greatest potential to gain carbon (FAO 2017b). In the same study, sequestration potentials considered as "achievable" are lower and range from 37 to 330 Mt CO_2/yr depending on the methods and assumptions on total land area subjected to improved management practices.

4 Changing contribution of grazing systems to the net climate balance

Changes in the structure and trajectories of animal production systems mean that the contribution of grazing systems to the net climate balance is changing. The expansion of grazing systems has historically driven deforestation and associated CO_2 release, but the current global trend towards grazing systems intensification will influence the balance in complex ways (Godde et al. 2018). For example, productivity gains may reduce land pressures and emissions per kilogram of milk and meat produced from grass-fed animals but can be associated with emissions trade-offs such as increases in nitrogen leaching. Higher absolute GHG emissions can also occur where increases in animal numbers outweigh mitigation benefits from efficiency improvements. Other production-side mitigation strategies such as the adoption of new technologies that reduce GHG emissions may also influence the net GHGs balance. In addition, changes in environmental factors not directly related to grazing management, such as temperature, precipitation, atmospheric CO_2 concentrations, and atmospheric nitrogen deposition, may also affect soil carbon sequestration dynamics (Boone et al. 2018; Fornara and Tilman 2012).

5 Soil carbon sequestration in the broader context of mitigation efforts

Soil carbon sequestration potential in grazing systems needs to be placed within the broader context of mitigation efforts (Poore and Nemecek 2018; Rogelj et al. 2018; Springmann et al. 2018; Willett et al. 2019; Wollenberg et al. 2016). Wollenberg et al. (2016) identified a preliminary global target for reducing non-CO_2 emissions from agriculture of ~1000 Mt CO_2-eq/yr by 2030 to limit warming in 2100 to 2 °C above pre-industrial levels. Yet, they found that plausible strategies relying on existing practices with non-CO_2 emission mitigation co-benefits deliver only 21–40% of the mitigation target. This large gap indicates the need for more transformative technical and policy options.

Soil carbon sequestration in grazing systems is one strategy, with a global mitigation potential of 37–800 Mt CO_2/yr according to studies building on empirical data (economic potentials of 144 and 800 Mt CO_2/yr in 2030 at US$20 and US$100 per t CO_2-eq). However, as highlighted above, contrary to non-CO_2 mitigation options (Smith et al. 2014), it is time-limited and reversible. Other key options, as identified by Wollenberg et al. (2016), include reducing deforestation due to agriculture, which would mitigate 1710–4310 Mt CO_2-eq/yr in 2030 at US$20 per t CO_2-eq according to Carter et al. (2015) and Havlík et al. (2014). Improvements in crop and rice management as well as restoration of degraded croplands (including organic soils) would mitigate 1240 and 2900 Mt CO_2-eq/yr in 2030 at US$20 and US$100 per t CO_2-eq (Smith et al. 2008). Reducing food loss and waste by 15% would reduce emissions by 790–2000 Mt CO_2-eq/yr in 2030 (Stehfest et al. 2013). Dietary shifts to meet the World Health Organization recommendations (Stehfest et al. 2013) or in response to increases in carbon prices (Havlík et al. 2014) would mitigate 310–1370 Mt CO_2-eq/yr in 2030. Targets focused on the livestock supply chain indicate potential reductions of 1770 Mt CO_2-eq/yr (Gerber et al. 2013, excluding changes in carbon stocks not involving land-use change).

These mitigation estimates are however strongly influenced by the studies' choice of interventions and methods. They are associated with large uncertainties and will ultimately depend on the economic cost-benefit relation and feasibility of implementing the different strategies.

6 Conclusion

In conclusion, grazing systems at an aggregate global level currently emit more GHGs than they sequester. While grazing-induced sequestration should not be ignored as a mitigation strategy and should be promoted where possible by tailored farming strategies in tandem with institutional support (IPCC 2014), its global mitigation potential is lower than often implied. To meet the goals of the Paris Climate Agreement, other mitigation strategies should, therefore, be implemented.

7 Future research needs

Since sustainability encompasses concerns wider than climate change, defining the role of grass-based livestock production within the planet's natural resource capacity and in the context of other environmental, ethical, and societal goals will require a food systems approach that seeks to understand relationships among different and sometimes competing objectives and to harmonize where possible. For example, comparisons between the climatic performance of grazing systems and other production systems were not examined in this essay but merit research. The criticism of sometimes overly optimistic claims on grazing systems' mitigation potential does not challenge the potential sustainability benefits of grazing systems along a number of other indicators, which have not been addressed in this study. A particular focus will need to be placed on ensuring that grazing systems are managed to perform well across several sustainability themes (e.g., food security, livelihoods, animal welfare, disease outbreaks prevention, biodiversity conservation, ecosystems protection). However, further research is needed to understand the integrated impact of grazing systems on these other areas.

Authors' contributions T.G. and C.M.G. conceived and led the project, reviewed the literature, analyzed the data, wrote the paper. I.J.M.B., E.Z.E., M.H., C.E.M., A.M., E.R., C.S., P.S., and H.H.E.Z. conceived the project, reviewed the literature, analyzed the data, and edited the paper.

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