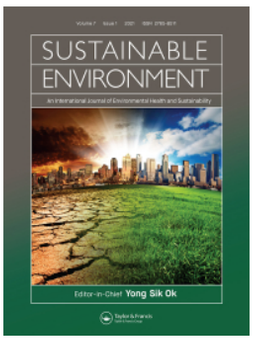

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Grazing intensity is key to global grassland carbon sequestration potential

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ABSTRACT

Grasslands are coming under ever-increasing pressure worldwide. Many grasslands are degraded due to overgrazing and inappropriate land management. This is impacting belowground biology and soil biological processes. One aspect that deserves far greater attention is the intensity of grazing and how this impacts grassland soil ecosystems. Grazing intensity impacts soil organisms including their diversity and activity, and the soil carbon cycle. However, environmental characteristics determine in part the effects of grazing intensity on soil processes. In addition, many questions remain to be answered in relation to the type of livestock and grazing regime. Only with a fuller understanding of the impacts of grazing on the soil ecosystem will it be possible to advise farmers and land managers on optimal grazing choices for a sustainable future.

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KEYWORDS
Environmental change; grazing intensity; livestock density; soil biology; Soil carbon

Food security and climate change mitigation are arguably the two most significant challenges facing humanity. Because agriculture accounts for an ever-increasing share of the world's net primary production, the management of agricultural land and soil has implications for the global carbon cycle and feedbacks to climate change. This is true for all agricultural systems be they arable, permanent crops or livestock focused. Land used for livestock grazing accounts for about 60% of total agricultural land (FAO 2020) and includes much of the grassland area worldwide, from arid rangelands, such as steppes and savannas, to wetter temperate grasslands. The demand for meat production from an increasingly affluent and growing human population (Ritchie, 2017) is adding pressure to many grasslands, many of which are now classified as degraded as a result of overuse and especially overgrazing. This degradation of grasslands will ultimately impact the sustainability of their use for meat production whilst also leading to positive feedback on climate change as carbon is both lost from grassland soils and less is being sequestered as a result of sparser vegetation. Despite much research being undertaken on the impacts of grazing on ecosystem function in grasslands, including on belowground processes, there is a dearth of information on how grazing intensity *per se* or livestock density impacts grasslands and their carbon balance. Indeed, much of the research to date compares grazed versus non-grazed grassland, although more recently there has been a belated focus on this issue of grazing intensity. In the last couple of years, a wealth of studies have highlighted how little we actually know about the effects grazing management choices are having on grassland ecosystem functioning.

As traditional livestock farming approaches disappear in favor of intensification, there is increasing evidence of the benefits of low-level livestock grazing in many systems. In Spain, for example, grazing abandonment in *Quercus* dehesa grassland has led to lower soil carbon content (Oggioni et al., 2020). However, in other systems such as alpine steppe in the Tibetan Plateau, it has been reported that the removal of grazing leads to increased soil carbon content (Liu et al., 2020). Zhan et al. (2020) highlight the lack of understanding of how grazing intensity impacts grassland ecosystem functioning, especially belowground. In a meta-analysis across grasslands in China, classified into low, medium and high grazing intensities, they found that soil microbial activity and soil organic carbon were the highest under low grazing intensity. Similarly, Jiang et al. (2020) found that low-intensity grazing increased soil carbon content in Chinese grasslands, whereas moderate to high grazing intensity decreased it. Going hand in hand with impacts on grassland soil carbon stocks, grazing intensity impacts the nitrogen cycle and availability of nutrients, including micronutrients, in the soil (Hou et al., 2020).

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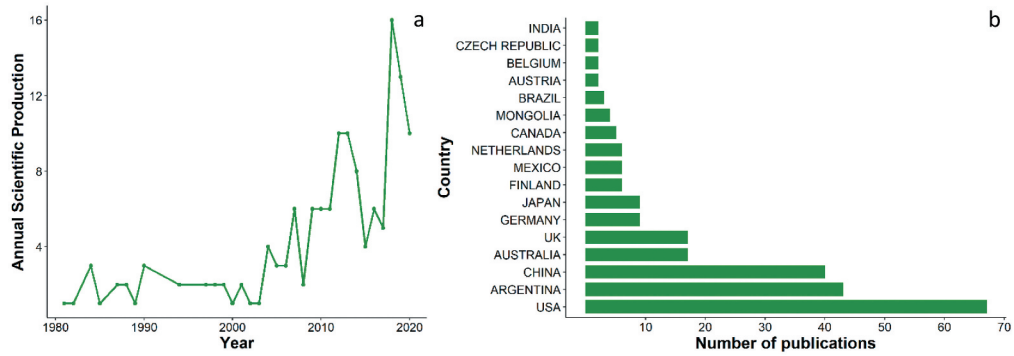

Figure 1. Annual scientific production in terms of paper counts (panel a) and the world's most productive countries (panel b) on the interaction between arbuscular mycorrhiza and livestock. The selection of peer-reviewed publications were retrieved from ISI Web of Science (WoS) on the 10 December 2020. The search strings used are as follows: "arbuscul*" OR "mycorrhiz*"AND "*graz*" OR "defoli*" OR "brows*" OR "clip*" OR "live-stock" OR "livestock" OR "herbivor*" OR "cow" OR "cattle" OR "sheep" OR "goat" OR "ewe" NOT "insect*" NOT "ectomycorrhiz*". This search resulted in a list of 169 documents and then the titles were screened to remove unrelated studies which resulted in a final list of 102 documents.

A key component of soil biota in grasslands is the arbuscular mycorrhizal fungi, which form symbiotic associations with plant roots (Staddon et al., 2002). Mycorrhizal fungi assist the plant with nutrient acquisition and, also act as a direct pathway for movement of carbon from the plant to the soil. As such, they are a central component of the soil carbon cycle and play a significant role in determining soil carbon sequestration (Staddon, 2003). Only relatively recently has much effort been spent investigating the impact of livestock on mycorrhizal fungi (Figure 1), leading to a focus on the impact of grazing intensity on mycorrhizas. Faghihinia et al. (2020b) demonstrated that increasing grazing intensity led to decreasing mycorrhizal hyphal density in the soil, which would have implications for both the nutrient uptake capacity of mycorrhizas and carbon translocation into the bulk soil. Focusing on soil microbial biomass more generally, Toledo et al. (2020) showed that high grazing intensity decreased microbial biomass carbon in three ecological areas in Patagonia. They however noted that the effect of grazing intensity on soil microbial communities is moderated by environmental characteristics of the ecological areas, including seasonality (Toledo et al., 2020). This seasonality effect on the impact of grazing intensity was also reported for mycorrhizal fungi in North China steppe (Faghihinia et al., 2020a).

It is also worth highlighting that with regard to grazing impacts on grasslands, it is not only intensity that has often been overlooked but also the make-up of the grazing livestock involved, namely single or multiple species. Indeed, it has recently been shown that grazing by a mix of cattle and sheep can stimulate net carbon sequestration in grassland when compared to either of the species alone (Chang et al., 2020). Due to the dual challenges of securing food security (especially protein) and mitigating climate change, much more effort is required to better understand the impacts of grazing intensity and types on grassland ecosystem functioning. Only then will it be possible to advise farmers, landowners and governments on optimal grazing choices to secure the best long-term sustainable outcomes for ecosystem services under a range of conditions, including those resulting from climate change.

Public Interest Statement

Climate change and sustainability are now important considerations for governments and the public worldwide. The understanding that land needs to be managed more sustainably to secure food and water for future generations, as well as mitigate climate change, is now accepted by the public. In many cases, however, there is a lack of evidence as to what are the most appropriate solutions for maximizing target ecosystem services. How grasslands are managed is a case in point. This short communication offers a perspective on the knowledge gaps with regard to livestock management on grasslands. The optimal grazing density or grazing approach for the sustainable use of different grasslands is unknown. Yet without a sound scientific evidence base, it is not possible to advise land managers on which grazing management choice is the most appropriate for the sustainable provision of ecosystem services.

Author description

Dr Staddon is a principal lecturer in environment and sustainability at the Countryside and Community

Research Institute, University of Gloucestershire. He also teaches environmental science at the Royal Agricultural University and Shandong Agricultural University. He has published widely on the impacts of environmental changes, especially climate change, on terrestrial ecosystems. He has also published on the impacts of climate change on human health. Dr Staddon has held visiting positions at the University of Exeter, Xi'an Jiaotong-Liverpool University, University of Liverpool, and Open University.

Dr Faghihinia completed her PhD in *Environmental Sciences* at the University of Liverpool, on the "*Effects of long-term grazing intensity on arbuscular mycorrhizal fungi and soil carbon fluxes in a steppe ecosystem*". Her work has significant implications for grassland ecosystem management and carbon cycling. She is about to start a postdoctoral fellow position investigating "*the role of bacteria in organic nutrient exploration by arbuscular mycorrhizal fungi*", in the Laboratory of Fungal Biology at the Czech Academy of Sciences Institute of Microbiology.

Disclosure statement

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