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The key role played by livestock in the ecology of farming systems including the ability to deliver nutritious foods from non-human edible ingredients.

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Abstract. With the growing pressure on resources, it is critical that livestock production systems contribute positively to overall food supply. The globe has reached peak arable land availability so more will need to be made from this land as well as from non-arable land. The livestock industries, particularly those based on ruminants, offer exciting opportunities to converts human inedible fodder and forage grown on non-arable land into nutritious, safe and healthy food. Also, all livestock industries can utilise human inedible agricultural and food production co- and by-products and produce high quality human edible food. However, there is no doubt that the livestock industries will continue to face opposition from those who don't support an omnivore lifestyle. Therefore, those of us who are engaged in the animal industries, including the peak animal science organisations, need to develop strategies to counter these arguments.

Keywords: livestock, methane, farming systems, arable land, nutrition, efficiency

El papel clave que desempeña la ganadería en la ecología de los sistemas agrícolas, incluyendo la capacidad de producir alimentos nutritivos a partir de ingredientes no comestibles para el ser humano

Resumen. Con la creciente presión sobre los recursos, es fundamental que los sistemas de producción ganadera contribuyan positivamente al suministro general de alimentos. El planeta ha alcanzado el pico de disponibilidad de tierras cultivables, por lo que será necesario producir más de estas tierras, así como de las no cultivables. Las industrias ganaderas, en particular las basadas en rumiantes ofrecen oportunidades prometedoras para convertir el forraje y los forrajes no comestibles cultivados en tierras no cultivables en alimentos nutritivos, seguros y saludables. Asimismo, todas las industrias ganaderas pueden utilizar coproductos y subproductos agrícolas y de producción alimentaria no comestibles para el ser humano y producir alimentos de alta calidad comestibles para el ser humano. Sin embargo, es indudable que las industrias ganaderas seguirán enfrentándose a la oposición de quienes no apoyan un estilo de vida omnívoro. Por lo tanto, quienes trabajamos en las industrias ganaderas, incluidas las principales organizaciones zootécnicas, necesitamos desarrollar estrategias para refutar estos argumentos.

Palabras clave: ganado, metano, sistemas agrícolas, tierras cultivables, nutrición, eficiencia

O papel fundamental desempenhado pela pecuária na ecologia dos sistemas agrícolas, incluindo a capacidade de fornecer alimentos nutritivos a partir de ingredientes comestíveis não humanos

Resumo. Com a crescente pressão sobre os recursos, é fundamental que os sistemas de produção pecuária contribuam positivamente para o abastecimento alimentar geral. O mundo atingiu o pico de disponibilidade de terras aráveis, pelo que será necessário produzir mais produção a partir dessas terras, bem como de terras não aráveis. As indústrias pecuárias, particularmente as baseadas em ruminantes, oferecem oportunidades promissoras para converter forragem e forragem não comestíveis para humanos cultivadas em terras não aráveis em alimentos nutritivos, seguros e saudáveis.

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Além disso, todas as indústrias pecuárias podem utilizar coprodutos e subprodutos agrícolas e da produção de alimentos não comestíveis para humanos e produzir alimentos comestíveis de alta qualidade para humanos. No entanto, não há dúvida de que as indústrias pecuárias continuarão a enfrentar a oposição daqueles que não apoiam um estilo de vida omnívoro. Portanto, aqueles de nós que trabalham nas indústrias animais, incluindo as principais organizações de ciência animal, precisamos de desenvolver estratégias para combater estes argumentos.

Palavras-chave: pecuária, metano, sistemas agrícolas, terras aráveis, nutrição, eficiência

Introduction

With growing pressure on agricultural resources, it is crucial that all food production systems, especially livestock, contribute positively to the overall food supply. Livestock systems are of particular concern, as they may consume nutrients that might otherwise be used directly for human consumption. The latest update to the planetary boundaries framework reports that six of the nine boundaries (Biosphere integrity, Climate change, Land system change, Freshwater change, Biogeochemical flows, and Novel entities) have been severely perturbed by human activity and have now been transgressed, suggesting that the Earth is now well outside the safe operating space for humanity (Richardson et al., 2023). The other three boundaries (Ocean acidification, Atmospheric aerosol loading and Stratospheric ozone depletion), while still within safe operating space, have also been heavily impacted.

While the global population is currently approximately 8.0 billion and is predicted to peak at around 10.4 billion people in 2080, the amount of arable land available to grow crops to feed this growing population appears to have peaked at about 10.5% of the Earth's land surface in the mid-1980s (Ritchie and Rodes-Guirao, 2024). Therefore, we will need to feed over 25% more people with probably less arable land than we have available now, as global warming is expected to decrease arable land in most parts of the world. Thus, the amount of arable land per person has halved over the past 60 years (Ritchie and Roser, 2010) and is predicted to decrease by a further 20% over the next 30 years (Windisch, 2021). Coupled with this, there has been a decline in crop productivity per hectare in many parts of the world. Meanwhile, as developing nations become more affluent, the growing world population is demanding more animal protein. Thus, meat demand is expected to follow a similar trajectory, with consumption projected to rise by 50% by 2050. The purpose of this mini-review is to highlight the importance of the livestock industries in providing nutritious foods, often through making use of feedstuffs that are either the by- or co-products of the production of human edible food or aren't suited for human consumption. While doing this we will touch on the differences between thermogenesic and biogenic methane and will finalise with a short note on what peak animal science organisations can do to reduce some of the nonsense and non-science directed at the livestock industries.

The unique ability of ruminants to utilise non-arable land

In the context of a decline in arable land per person, it is important to note that much of the remaining non-arable landmass comprises a diverse mixture of plant species that are inedible or indigestible to humans due to their high cellulose content. In contrast, ruminant species have evolved to digest plant cellulose through a complex microbial ecosystem in the rumen and other physiological adaptations. Thus, ruminants can convert these low-quality grasses and forage from this non-arable land into valuable and nutritious animal-sourced foods and fibre. The rumen fermentation of plant materials results in the production of short-chain fatty acids, which are used as energy sources for the animal. A consequence of rumen fermentation is the production of hydrogen ions that, if left to accumulate, would dramatically reduce the rumen pH and inhibit or kill the bacterial species responsible for digesting cellulose. To counter this, the rumen ecosystem has developed an efficient system of capturing hydrogen as methane. This methane is then removed from the system through eructation into the atmosphere.

It is well established that atmospheric methane is a potent greenhouse gas that contributes to global warming. Indeed, methane from anaerobic fermentation has approximately 27 times the CHG equivalency of carbon dioxide. Ruminants account for 80% of global livestock greenhouse gas (GHG) emissions, with methane accounting for approximately 50% of livestock emissions. Monogastric livestock produce significantly less methane than ruminants but contribute more to nitrous oxide. However, it is important to realise the differences between thermogenic and biogenic methane and carbon dioxide. Thermogenic methane and carbon dioxide are produced from the burning of ancient carbon in fossil fuels, which introduces new carbon into the atmosphere from deep reserves. In contrast, the biogenic methane and carbon dioxide produced by ruminants are recycled through sequestration into soil and ultimately into the plants that the ruminant animals consume.

Another point that is often overlooked is that vast numbers of wild ruminant species, such as bison, deer, elk, and others, inhabited the North American Great Plains before European settlement (Hristov 2012). Similarly, wild ruminants occupied vast expanses of other grassland and savannahs around the world. These wild ruminants also produce methane, and Hristov (2012) had calculated that wild ruminant's pre-colonisation produced approximately 86% of the current methane production of cattle in North America. Present-day methane emissions from wild ruminants represent a minor fraction of those from farmed ruminant livestock in the USA. Nevertheless, even though ruminant methane is biogenic, and ruminants have been producing close to contemporary amounts of methane for millennia, there is still an imperative to reduce livestock's contribution to methane and GHG emissions.

Utilisation of human edible and inedible food

A point of contention often raised against livestock production, specifically ruminant animals, is that some systems can be inefficient when it is considered how much feed is consumed to produce a kilogram of meat or livestock product. Indeed, it may take between 20 and 30 kg of plant dry matter to produce 1 kg of carcass in some extensive grazing beef or lamb production systems (Wilkinson and Lee 2018). However, it is essential to remember that these animals generally graze on non-arable land and consume plant material that cannot be consumed or digested by humans. When the efficiency is expressed in terms of human edible food, they are closer to 2 and in many cases lower than monogastric systems (Wilkinson and Lee 2018).

Notwithstanding this, livestock do consume a significant portion of human-edible food, with some estimates suggesting that this amounts to one-third of global grain production, with cereal grain use for livestock feed projected to grow by 1.4% annually. In northern Europe, nearly two-thirds of the protein in pig and poultry diets comes from feedstuffs that are also suitable for human consumption (Wilkinson and Lee 2018). However, this perspective often overlooks the fact that a substantial amount of grain from arable land fails to meet food-grade standards and must be diverted elsewhere (van Barneveld et al, 2023). It also neglects to consider the comparative nutritional value of grains versus animal products in human diets. Also, cereal grain production for human consumption produces substantial amounts of non-human edible byproducts. For example, the production of 1 kg of wheat flour results in 3 kg of straw and 2 kg of bran (Windisch, 2021). Additionally, many of the feedstuffs that are often considered specifically grown for livestock are indeed byproducts from the production of human edible food. For example, soybean and rapeseed are grown principally for their oil, and the soybean meal and rapeseed meal, which are important sources of protein in chicken and pig feeds, are byproducts of this oil production. Nevertheless, the sustainability and net food contribution of livestock systems remain key issues that must be critically addressed.

The growing challenges facing global food systems have increasingly shifted attention toward their sustainability, and popular discourse often promotes plant-based proteins as being more sustainable than livestock-based counterparts. These comparisons are typically grounded in environmental impact assessments or life-cycle analyses (LCAs), which evaluate factors such as water and energy use, greenhouse gas emissions, and land use or land-use change. While it is widely accepted that plant-based foods generally produce lower greenhouse gas emissions than animal-based products, these assessments often rely on single-score metrics that may oversimplify complex sustainability considerations.

Additionally, meals are consumed rather than individual foodstuffs, and the gap in GHG emissions between a meal containing some animal products such as pork and chicken and a vegetarian meal is not as significant as current commentary suggests. When assessed based on the nutrients consumed, digested and available for metabolism then animal products compare quite favourably. Most reported LCA studies comparing meat and plant protein foodstuffs do not account for the GHG emissions for the waste proportion of feedstuffs (production/manufacture, retail and household), with considerably higher waste attributed to plant foodstuffs.

Arable land use (ALU) and net protein contribution (NPC)

Agricultural land and human food security are coming under great pressure from climate change, rapidly increasing human population, urbanisation, demand for biofuels, and demand for animal protein. This situation led Lee et al., (2021) to re-assess the role of ruminant livestock in meeting our requirements for key nutrients in the broader context of global warming potential and land use, as this livestock sector has been particularly 'demonised' due to its higher kgCO_2e per unit of product. To date, while several studies have examined environmental consequences of different food consumption patterns at the diet level, few have addressed nutritional variations of a single commodity attributable to on-farm strategies, leaving limited insight into how agricultural production can be improved to better balance environment and human nutrition. Using seven livestock production systems encompassing cattle, sheep, pigs and poultry as examples, Lee et al., (2021) proposed a novel approach to incorporate nutritional value of meat products from two different sustainability driven metrics: i) Global warming potential (GWP) - mass of nutrient provision per kg CO_2eq; and ii) Arable land use (ALU) - mass of nutrient provision per m^2 of arable land. To assess overall value of the product associated with human nutrition a nutrient index scalar value to combine information on multiple nutrients, both beneficial and detrimental to human health was used as proposed by McAuliffe et al., (2018). (**Table 1)** The beneficial nutrients considered included protein content, essential fatty acids as well as key minerals and vitamins and the negative included saturated fatty acids and sodium. The nutrient index rankings (Figure 1) of the livestock products dramatically altered between chosen sustainability driven metrics, for GWP (1b) overall: poultry < pigs (pork) < cattle (beef) < sheep (lamb); whereas the inverse relationship was calculated for ALU (Figure 1a).

Table 1. Arable land use per relative nutrient content (m^2/%RDI) computed separately for each desirable nutrient considered in the study of Lee et al. (2021) (McCauliffe et al. 2018).

Nutrient	Beef concentrate	Beef forage	Lamb lowland	Lamb upland	Chicken	Pork
Protein	0.015 (4)	0.010 (3)	0.006 (1)	0.008 (2)	0.016 (5)	0.019 (6)
MUFA	0.238 (5)	0.110 (3)	0.064 (1)	0.111 (4)	0.083 (2)	0.311 (6)
EPA+DHA	0.527 (6)	0.044 (3)	0.021 (1)	0.025 (2)	0.117 (4)	0.119 (5)
Ca	1.003 (6)	0.671 (5)	0.128 (1)	0.184 (2)	0.524 (4)	0.495 (3)
Fe	0.053 (4)	0.035 (3)	0.018 (1)	0.027 (2)	0.138 (5)	0.208 (6)
Riboflavin	0.033 (4)	0.022 (3)	0.013 (1)	0.019 (2)	0.066 (6)	0.047 (5)
Folate	0.090 (3)	0.060 (1)	0.073 (2)	0.105 (4)	0.183 (5)	1.414 (6)
Cobalamin	0.005 (4)	0.004 (2)	0.003 (1)	0.005 (3)	* (6)	0.011 (5)
Se	0.060 (5)	0.040 (2)	0.050 (4)	0.071 (6)	0.037 (1)	0.043 (3)
Zn	0.015 (4)	0.010 (2)	0.009 (1)	0.013 (3)	0.045 (6)	0.045 (5)

Numbers in brackets are relative rankings in descending order.
MUFA: monounsaturated fatty acids; EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid.
* Nutrient not detected.

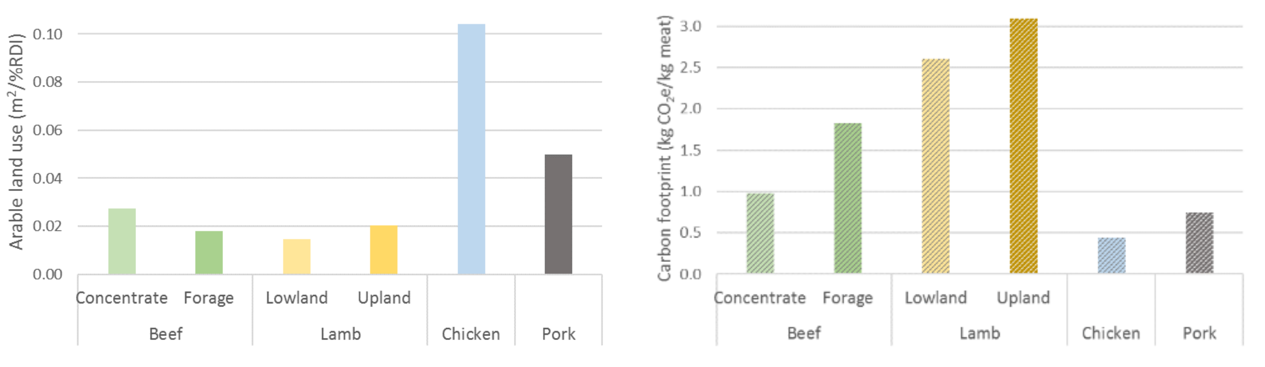

Figure 1. Arable land use per nutrient density score (*a*) and carbon footprint per mass of product (*b*) for six meat production systems commonly found in the UK. The striking contrast between the two figures demonstrates the extremely tenuous nature of the sustainability debate surrounding lives°tock farming. Panel (*b*) was produced from data originally reported in McAuliffe *et al.* (2018) under the Creative Commons licence CC BY 4.0 and reproduced by Lee et al. (2021).

To test the upward scalability of findings associated with ALU, Lee et al., (2021), performed a second analysis using regional-scale information from France. Data were collected from 571 agricultural subregions (PRA, *petites régions agricoles*) that collectively constitute the country's landmass. Each PRA was characterised based on its relative dependency on ruminant to monogastric farming, using the proportion (0–1) of the former's contribution to the total count of European livestock units and the relative stocking density (LU/ha). ALU for each PRA across all enterprise groups was quantified by means of national-scale modelling, also accounting for land displacement that occurs outside its geographical boundary. Each PRA's capability to supply essential nutrients through livestock products was quantified using McAuliffe et al., (2018) as with the initial product level assessment but using French data for nutritional compositions. This value, expressed as %RDI/g product, was multiplied by the PRA's total output (in grams) of that particular commodity and aggregated across all commodities. The nutrient provision capability thus derived was subsequently divided by ALU, yielding the final metric in the unit of %RDI/ha. A clear and positive association was observed between the share of ruminants in a PRA and its capability to provide essential nutrients from a given area of arable land (Figure 2). This tendency was universally shared across all subregions regardless of their stocking densities but was especially strong for those with higher production intensity, as evident by an interaction between the ruminant share and the stocking density ($p < 0.001$). This finding suggests that the most land-efficient method to produce nutritionally valuable foods from livestock is likely achieved through management of non-arable lands and the use of non-human edible by-products via ruminants.

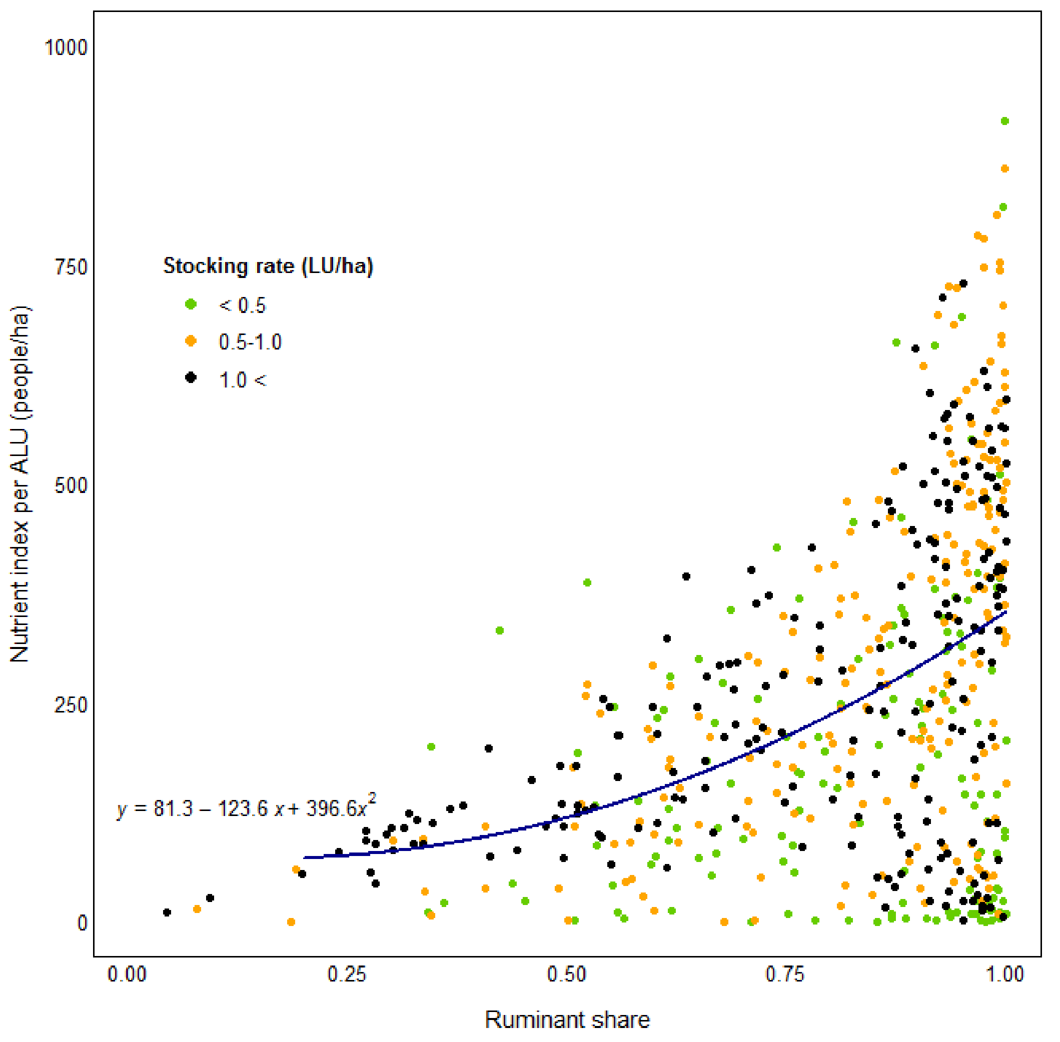

Figure 2. Regional-level relationship between ruminants' share in livestock population and arable land use per nutrient density score in France (Lee et al., 2021).

The study of Lee et al (2021) found that the ALU tended to increase with increasing share of ruminants in the system, although there was a heterogeneity in the response at high ruminant share (Figure 2). Therefore, some high ruminant systems performed very efficiently whereas others did not. In this context, it should be noted that many monogastric producers are making great efforts to reduce the amount of human edible food they use and make greater use of by-products from the food and agricultural industries. For example, van Barneveld et al (2023) set out to capture the net protein contribution (NPC) of a major pork production supply chain in Australia. NPC refers to the ratio of human edible protein produced and consumed and if the value is above 1.0 then the system is making a net contribution and has net benefits. Their estimate was based on actual, published or estimate values for (a) human edible protein fractions of feed, (b) proportion of human edible protein available within raw materials, (c) aminos acid scoring patterns for humans, (d) digestible indispensable amino acids scores, (e) carcass yield and composition and, (f) actual feed formations and usage from the supply chain. The calculated NPC was 3.26 which means that this supply chain produced over 3x more human edible protein than it consumed. While this is higher than some other estimates it is largely because of the extensive use of food and agricultural byproducts and protein sources that realistically never be used for human consumption because they fail to meet market specifications.

The role of peak animal science organisations in disseminating these messages

Animal scientists are constantly facing criticism for supporting the livestock industries and the purported damage that these industries cause to the environment. However, as outlined briefly here and in more depth at recent international livestock events such as the Dublin Declaration and The Denver Call for Action (www.dublin-declaration.org) it is vital that those that of us who are engaged in the livestock industries become active in debates and discussions relating to the societal role of livestock. Too often, we consider ourselves too busy or reluctant to engage in these discussions, but we should be aware that those who oppose livestock production are very vocal and have substantial resources to mount and broadcast their arguments. They are also savvy in the use of social media and other forms of modern communication. Therefore, it is imperative that committed individuals and peak animal science societies become better prepared with counter arguments using traditional and modern communication platforms. Linking in with local and national human nutrition societies may also offer avenues to promote healthy food production systems.

Conclusions

With the growing pressure on resources, it is critical that livestock production systems contribute positively to overall food supply. The globe has reached peak arable land availability so more will need to be made from this land as well as from non-arable land. The livestock industries, particularly this based on ruminants, offer exciting opportunities to converts human inedible fodder and forage grown on non-arable land into nutritious, safe and healthy food. Also, all livestock industries can utilise human inedible agricultural and food production co- and by-products and produce high quality human edible food. However, there is no doubt that the livestock industries will continue to face opposition from those who don't support an omnivore lifestyle. Therefore, those of us who are engaged in the animal industries, including the peak animal science organisations, need to develop strategies to counter these arguments.

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