Meat Science 109 (2015) 2–12

Contents lists available at ScienceDirect

Meat Science

journal homepage: www.elsevier.com/locate/meatsci

Environmental impacts of beef production: Review of challenges and perspectives for durability

Pierre J. Gerber [a,c,*], Anne Mottet [a], Carolyn I. Opio [a], Alessandra Falcucci [a], Félix Teillard [a,b]

[a] Animal Production and Health Division, Food and Agriculture Organization of the United Nations, Italy
[b] INRA-AgroParisTech, UMR 1048 SAD APT, Paris, France
[c] Animal Production Systems group, Wageningen University, Wageningen, the Netherlands

ARTICLE INFO

Article history:
Received 11 March 2015
Received in revised form 15 May 2015
Accepted 16 May 2015
Available online 20 May 2015

Keywords:
Cattle
Production systems
Feedlots
Natural resource use
Sustainability
Mitigation

ABSTRACT

Beef makes a substantial contribution to food security, providing protein, energy and also essential micronutrients to human populations. Rumination allows cattle – and other ruminant species – to digest fibrous feeds that cannot be directly consumed by humans and thus to make a net positive contribution to food balances. This contribution is of particular importance in marginal areas, where agro-ecological conditions and weak infrastructures do not offer much alternative. It is also valuable where cattle convert crop residues and by-products into edible products and where they contribute to soil fertility through their impact on nutrients and organic matter cycles.

At the same time, environmental sustainability issues are acute. They chiefly relate to the low efficiency of beef cattle in converting natural resources into edible products. Water use, land use, biomass appropriation and greenhouse gas emissions are for example typically higher per unit of edible product in beef systems than in any other livestock systems, even when corrected for nutritional quality. This particularly causes environmental pressure when production systems are specialized towards the delivery of edible products, in large volumes.

The paper discusses environmental challenges at global level, recognizing the large diversity of systems. Beef production is faced with a range of additional sustainability challenges, such as changing consumer perceptions, resilience to climate change, animal health and inequities in access to land and water resources. Entry-points for environmental sustainability improvement are discussed within this broader development context.

1. Introduction

Within the livestock sector, beef emerges as the commodity receiving most attention for its environmental impacts. This is due to the evident aggregated contribution that beef production makes to global environmental issues such as climate change and land use. Globally, beef supply chains are estimated to emit about 2.9 gigatonnes of CO_2-eq, about 40% of all livestock emissions using a life-cycle approach (Gerber, Henderson, Opio, Mottet, & Steinfeld, 2013). The greenhouse gas emissions per unit of product (emission intensity) peak where beef is produced on newly deforested land (Cederberg, Persson, Neovius, Molander, & Clift, 2011). Cattle are also the dominant ruminant species making use of about one quarter of all emerged lands (Bouwman, Van der Hoek, Eickhout, & Soenario, 2005; Steinfeld et al., 2006). These issues are augmented by public health concerns related to high meat consumption levels and pollution from intensive production (Walker, 2005) as well as a growing attention to animal welfare (O'Donovan & McCarthy, 2002; Petherick, 2003).

The world has over 1.3 billion cattle — about one for every five people on the planet (FAOSTAT, 2015). While cattle are kept and raised for the wide range of products and functions they deliver, the vast majority is eventually culled and served as meat. Beef production thus takes multiple forms and involves a wide range of supply chains. The debate on beef production, and on livestock more generally, is however too often characterized by a lack of recognition of this tremendous diversity in production systems, in the goods and services they deliver as well as in the environmental interactions and options for improvement that exist (Smith, 2015). The general perception of beef production is biased towards specialized factory farming, while these represent a limited part of a sector that is still dominated by family farms operating on mixed-systems (Herrero et al., 2013).

This paper aims at providing a global overview of beef production systems, their diversity and their contributions to society. It also reviews how beef supply chains contribute to major global environmental issues and identifies specific entry points for intervention.

* Corresponding author.
E-mail address: p.gerber@worldbank.org (P.J. Gerber).

http://dx.doi.org/10.1016/j.meatsci.2015.05.013
0309-1740/© 2015 Published by Elsevier Ltd.

2. Cattle: their biology, diversity and related comparative advantages

The specificity of ruminant production (mostly cattle, buffalo, sheep and goat), its contribution to human societies and its interactions with their environment are deeply rooted in the biology of ruminants. Three features stand out: digestion, reproduction and diversity.

2.1. Digestion

The digestive track physiology determines the feed materials that animals can effectively utilize and also the efficiency with which nutrients in feed materials are used. Ruminants are well known for their ability to digest feed materials rich in cellulose and fiber (low in energy content and typically only 50–65% digestible), in contrast to monogastric species (e.g. pig and poultry) (Fig. 1). This is made possible by the microbial fermentation that occurs in the rumen. The products of this fermentation are absorbed by the animal in the following small intestines. This makes ruminants able to develop in conditions where monogastric species are excluded, and places them in a unique position to turn resources inedible by humans into high value food products but also into other outputs such as fiber, fertilizer and draft power.

The energy-efficiency of microbial fermentation is however limited by the emission of enteric methane (CH_4). It is estimated that about 8–12% of the energy in a feed is lost through methane and cannot be utilized by animal (Huysveld et al., 2015). This is an issue for the producer, and also for the environment given methane's global warming potential. In a similar way, ruminants are not particularly efficient in using high quality dietary proteins: a high share is broken down in the rumen and partially used for microbial growth, resulting in ammonia exhalation and losses of N in feces (Opio, Gerber, & MacLeod, 2013).

2.2. Reproduction

Reproduction performance (driven by fertility, prolificacy and mortality among offspring) is a key driver of population dynamics and thus of productivity, essential to the replacement of milked cows and to the production of young animals for fattening. However, a cow is likely to produce at best a single calf per year, and commonly produces a viable calf every 1.5 to 2 years (Ball & Peters, 2004). This is much lower than for other ruminant and non-ruminant species that are generally more fertile and prolific (Table 1). In addition, cows typically become fertile at later age than females of other species. This results in a greater share of the animal herd that is dedicated to reproduction (the "reproduction overhead"), compared to other species, and therefore an increased part of the metabolizable energy that is dedicated to maintenance at herd level. It is thus estimated that between 50 and 80% of total metabolized energy is used for maintenance (Opio et al., 2013). Further effects of late age at first calving, and relatively limited fertility and prolificacy are the slow nominal growth of herds, particularly problematic after crisis that may have caused drastic falls in animal numbers, and the reduced pace at which new genes can be introduced into the herd. (Ball & Peters, 2004).

Table 1
Main reproduction features among dominant livestock species.
Source: Gordon (2004).

	Gestation (days)	Offspring/female/year (mortality not included)
Sheep	147	1-3
Beef	270	1
Dairy	270	1
Pig	114	7–14
Poultry	22–22	100–300

2.3. Diversity and hardiness

Cattle and buffalo breeds represent 25% of the world's 10,512 recorded mammalian livestock breeds, a similar share than sheep, followed by horses, goats and pigs, all around 12 to 14%. For comparison, only 3,505 avian breeds are reported, of which chicken represent 60% (FAO, 2007). Thousands of years of migrations and trade spread domesticated animals from their original habitats, exposing them to new agro-ecological conditions. South Asian Zebu cattle were for example introduced in Latin America during the early twentieth century, and now support most of the production in this major producing and exporting region (FAOSTAT, 2015). Natural selection and human-controlled breeding gave rise to the great genetic diversity observed today (FAO, 2007).

In all regions of the world, reported mammalian breeds outnumber avian breeds (FAO, 2007). This large diversity reflects a tight adaptation of mammals, and cattle in particular, to their environment and to the needs of the human populations looking after them. Resistance to diseases (e.g. to trypanosomiasis), tolerance to particularly harsh climatic conditions, and poor feed quality are among the traits that have placed cattle, together with small ruminants, in a position to sustain livelihoods and human settlements where crop agriculture and other mammalian and avian species could not.

In more favorable agro-ecological conditions, selection among and within breeds as well as the use of crossbreeding to exploit heterosis have allowed to reach high levels of productivity and quality, expressed in daily weight gains, conformation and fat to muscle ratio (Cundiff,

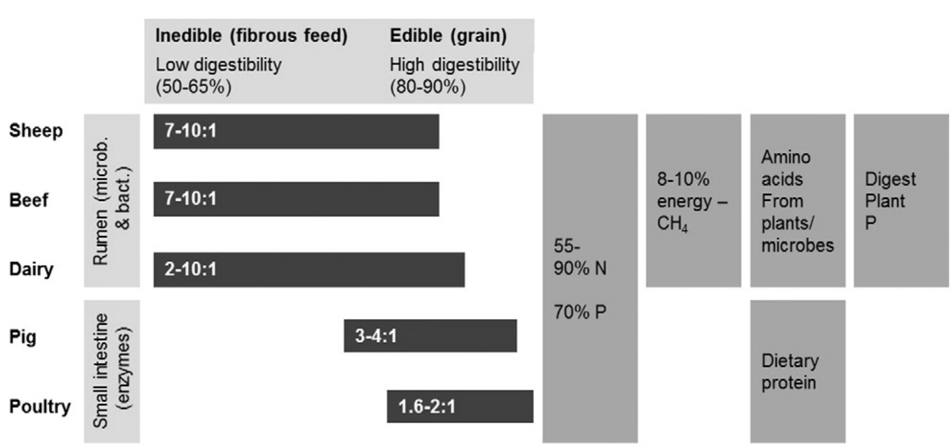

Fig. 1. Main features of digestive systems among dominant livestock species.
After Smil (2002).