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Livestock intensification and the influence of dietary change: A calorie-based assessment of competition for crop production

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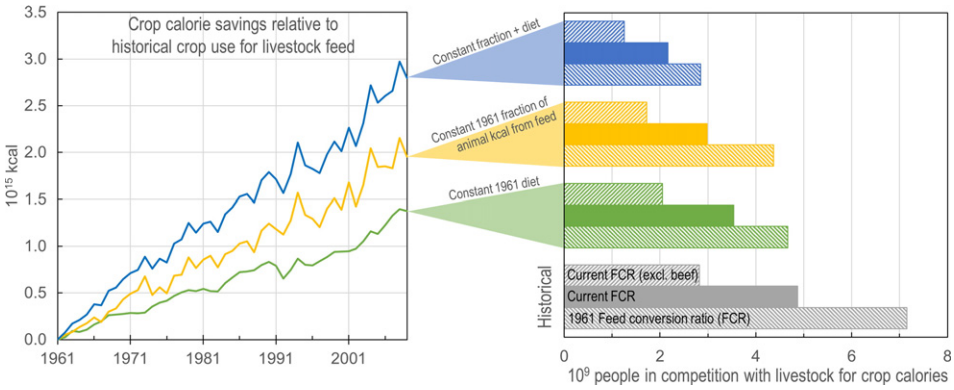
HIGHLIGHTS

- We examine the historical competition for crop use between food and feed.
- Currently, 56% of animal calories are 'free' to humans in terms of crop use.
- A constant per capita diet would mean 1.38×10^{15} fewer crop calories needed for feed.
- Crops lost via consumer waste of animal foods could feed 235 million people.

GRAPHICAL ABSTRACT



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ABSTRACT

Animal production exerts significant demands on land, water and food resources and is one of the most extensive means by which humans modify natural systems. Demand for animal source foods has more than tripled over the past 50 years due to population growth and dietary change. As a result, the livestock sector has transitioned towards intensive and concentrated production systems. Typically, studies have divided types of animal production into intensive, mixed and grazing production systems. However, because a large percentage of animal production originates from mixed systems, dividing by such production types can make it difficult to quantify competition for crop production between direct human consumption and use as feed. To this end we employ a calorie-based approach to determine which animal calories were 'free' – in that they did not compete with human consumption for crop use – and consider to what extent alternative scenarios could have reduced this competition between food and feed. We find that growth in non-feed animal systems has only been able to keep pace with population growth and that feed-fed production has necessarily met increases in human dietary demand for animal products. Through solutions such as moderating diets for animal calories, choosing less resource-demanding animal products and maintaining the relative contribution of non-feed systems, between 1.3 and 3.6 billion fewer people would be in competition with feed for crop use. We also estimate that the feed crop calories required to support consumer waste of animal calories could feed an additional 235 million people. With human demand for animal products expected to continue increasing in the coming decades, the findings here provide insights into

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potential solutions and what the magnitude of their effect may be and suggest that there exist real opportunities for humankind to substantially reduce competition for crop use.

1. Introduction

Global livestock production has rapidly increased over the past 50 years in order to meet the rising demands from population growth and dietary change (Delgado, 2005; Thornton, 2010). In this time both the global demand for animal products and the amount of crop production used for feed have approximately tripled (330% and 300% respectively) (Food and Agriculture Organization of the United Nations, 2014). While livestock production has been able to keep pace with human demand, its increase has had significant implications for food security and the environment (Tilman et al., 2002; Bouwman et al., 2013). Using roughly 30% of global ice-free land for grazing and the cultivation of feed (Steinfeld et al., 2006; Erb et al., 2007; Ramankutty et al., 2008), not only has livestock production played a major role in humankind's modification of Earth's surface but it is also one of several substantial and unprecedented demands being placed on crop production worldwide. This is particularly true given the recent growth in demand for animal feed as a result of livestock intensification and commodification (Steinfeld et al., 2006; Delgado et al., 1999). However, rangelands and other non-feed systems continue to play an integral role in global food supply (Godfray et al., 2010; Davis et al., 2014) while providing their own socio-economic and ecosystem services (Thornton, 2010; Herrero et al., 2009) as well as environmental impacts (Steinfeld et al., 2006).

Each system of animal production (e.g. feed-fed, rangelands, grass feeding, mixed crop-livestock) offers unique benefits and shortcomings. Feed-fed animal production typically produces animals more efficiently (Pimentel and Pimentel, 2008) and separates livestock production from a number of local resource constraints (Steinfeld and Gerber, 2010). Because the recent intensification of animal production is mostly attributable to non-ruminant species (e.g. poultry, pigs) (Food and Agriculture Organization of the United Nations, 2014), this means that more animals can be raised in a smaller area (Cassidy et al., 2013). On the other hand, this form of animal production can mean greater competition for land use between food and feed production (Naylor et al., 2005), a separation of consumption from its environmental impacts (e.g. virtual nitrogen trade (Galloway et al., 2007)), a higher concentration of waste per area (Tilman et al., 2002) and issues of animal welfare and disease (Thornton, 2010). Conversely, animal production from other types of systems (hereafter referred to as 'non-feed' systems) offers a distinct advantage in that it does not reduce humankind's crop resource base and instead often makes use of crop residues as well as biomass on "marginal lands" where crop cultivation would not be possible (Tilman et al., 2002; Pimentel and Pimentel, 2008; Herrero et al., 2013). However, systems that rely more heavily on non-feed sources also typically require larger areas to produce the same amount of animal calories, as forage does not have the same nutritional value as animal feed (Krausmann et al., 2008). In addition, a more direct reliance on land also means that animal production from many non-feed systems is tied to local climate and affected by its uncertainty. Moreover the use of and conversion to grassland and rangeland can carry its own set of environmental consequences (e.g. desertification, deforestation, greater total GHG emissions) (Steinfeld et al., 2006; Asner et al., 2004; McMichael et al., 2007).

Indeed there exists a rich literature exploring the various production systems of the livestock sector and their role in global food security (Thornton, 2010; Steinfeld et al., 2006; Delgado et al., 1999; Herrero et al., 2013; Kastner et al., 2012). While livestock have historically ensured food security in numerous ways (e.g. human consumption, transport, manure for fertilizer) (Galloway et al., 2007), their direct use as food has recently grown in importance while their indirect roles have become secondary. The emerging human demand for animal products, how it may be expected to grow in the future and how supply will need to increase have all been thoroughly studied (Tilman et al., 2002; Wint and Robinson, 2007; Robinson and Pozzi, 2011; Pradhan et al., 2013). In addition, recent detailed studies and life-cycle assessments have quantified the distribution of major types of animal production as well as their environmental impacts (Steinfeld et al., 2006; Steinfeld and Gerber, 2010; Food and Agriculture Organization of the United Nations, 2013a,b). However, the reliance of the livestock sector on crop production – and how this has changed through time – has not been quantified to date. This is largely due to the difficulty in distinguishing between livestock production derived from feed and non-feed sources particularly given that a large portion of animal production is the result of mixed feed/grass feeding (Food and Agriculture Organization of the United Nations, 2013a,b; Sere and Steinfeld, 1996).

A calorie-based approach offers an alternative perspective in that it gives a clearer picture of which animal calories are 'free' to the agricultural system in terms of crop use. Specifically here we employ an approach in which animal calorie production is converted to equivalent animal biomass demand and compared to the calories present in feed crops. In this way, we can determine what portion of animal biomass demand was met by feed – as well as in competition with direct human consumption of crop production – and in turn quantify the fraction of animal calories that originated from non-feed biomass. While we expect that non-feed biomass has contributed substantially to historical animal production, we posit that scenarios in which animal production either relied more heavily on non-feed biomass or in which growth in human demand was reduced could have further reduced competition for crop use between food and feed. By examining past changes along with alternative scenarios, it is possible to gain a better understanding of the interplay between feed-fed and non-feed animal supply, the capacity of each to react to demand over the past half-century and the potential crop calorie savings that could have been realized under situations of less intensive production and moderated dietary demand. This study therefore provides a simple and effective approach for evaluating potential pathways with which to minimize human impacts from the livestock sector.

2. Methods

We defined animal production as calories from bovine meat, pig meat, poultry meat, eggs and milk. Collectively these animal food groups comprised 76% of global human demand for animal calories (including for seafood) (Food and Agriculture Organization of the United Nations, 2014). We included 40 feed products – each contributing at least 100,000 tonnes to global feed use in the year 2009 – in our study (Table S1); these products made up ~93% of global feed production in any given year (Food and Agriculture Organization of the United Nations, 2014). Data for animal production, caloric content and crops/products used for feed for 1961 through 2009 came from FAOSTAT. Oilcake production for feed was transformed to its equivalent primary crop based on cake-to-crop conversion factors (Table S2), calculated as the tonnes of total oil cake production in equivalent primary crop units divided by the tonnes of total oil cake production (Food and Agriculture Organization of the United Nations, 2014). Data on animal and feed crop production were converted from tonnes to calories using the FAO Food Balance Sheets (Food and Agriculture Organization of the United Nations, 2014). Calories from each animal product were then converted to equivalent plant calories (i.e., total animal demand for plant calories) using sub-regional product-specific plant-to-animal feed