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Land use efficiency of beef systems in the Northeastern USA from a food supply perspective

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A R T I C L E I N F O

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A B S T R A C T

One widely recognized strategy to meet future food needs is reducing the amount of arable land used to produce livestock feed. Of all livestock products, beef is the largest land user per unit output. Whether beef production results in feed-food competition or a net positive contribution to the food supply, however, may depend largely on whether marginal land is used to grow forage. The land use ratio (LUR) was developed by van Zanten et al. (2016a) to identify livestock systems that produce more animal source food than would be produced by converting their associated feed land to food crop production – a perspective that is not addressed within life cycle assessment (LCA). van Zanten et al. (2016a) used country-specific and farm-level land suitability data, the latter of which is not available in many countries. To assess the LUR of beef systems in the USA, which may use large grassland areas of potentially varying quality across scales, an intermediate approach between farm and country-scale estimation is needed. In this paper, we enhanced the LUR by integrating geospatial data for crop suitability and yield estimation at multiple scales. By doing so, the LUR will also become more widely applicable for other studies. We applied our enhanced LUR for a grass-fed beef (GF) system and a dairy beef (DB) system in the Northeastern USA, including multiple scenarios limiting land conversion. All systems had LURs greater than one, indicating they produce less protein than conversion of their suitable feed land base to food cropping would. Because a large fraction of the forage land used in the GF system was suitable for crop production and moderately productive, its LUR was 3–6 times larger (less efficient land use from a food supply perspective) than the DB system. Future research should explore mechanisms to reduce the LUR and life cycle environmental burdens of both regional production systems.

1. Introduction

Over one-third of global land is used for agriculture, the majority of which (75%) is dedicated to livestock (Foley et al., 2011). Of all livestock products, beef is the largest land user per unit output (de Vries and de Boer, 2010). Land occupation varies tremendously between beef production systems, however, largely due to differences in calf origin, cattle diets, and management system (e.g., upland grazing) (de Vries et al., 2015). Producing beef from dairy cattle (calves and culls) requires less land than suckler beef production systems, primarily because land use is allocated between milk and beef (de Vries et al., 2015). However, dairy beef calves are often fattened on large quantities of cereals and/or oilseeds (Mogensen et al., 2015; Nguyen et al., 2010; Stackhouse-Lawson et al., 2012; Tichenor et al., 2017); feeding food crops to livestock instead of humans is an inefficient use of edible calories (West et al., 2014), with the magnitude of inefficiency dependent on the species.

On the other hand, beef systems that rely heavily on forages require a large land base (Mogensen et al., 2015; Tichenor et al., 2017) but convert substantial quantities of human inedible products (e.g., grasses) into edible nutrients. For example, upland suckler beef production in the UK, which included small amounts of concentrates (e.g., maize or soymeal) produced more human edible protein than it consumed (Wilkinson, 2011). In the Upper Midwest USA, grass-finished beef returned 69.1% of the human edible energy it consumed – over an order of magnitude more efficient than a feedlot-based system in the same region (Pelletier et al., 2010). By addressing feed efficiency from a human food supply perspective, these analyses are more nuanced assessments of the role of livestock in future food security compared to solely focusing on land use. However, they do not address the

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opportunity cost of using land to produce feed instead of human food. To meet future food needs in a sustainable way, it is necessary to critically examine the current allocation of land to livestock (Foley et al., 2011; Garnett, 2009).

Evaluations of land use by livestock systems must consider both quantity and quality (Ridoutt et al., 2014). van Zanten et al. (2016a) developed the concept of land use ratio (LUR) to identify livestock systems that produce more food directly than would be produced by converting their associated suitable feed land to food crop production. Systems that utilize byproducts and/or land unsuitable for producing food directly, thus, can be efficient in terms of protein production (van Zanten et al., 2016a). For example, beef production systems that rely on marginal land may result in a net positive contribution to the food supply (de Vries et al., 2015; Eisler et al., 2014; van Zanten et al., 2016a). However, roughly half of global pasture land is marginal, with the other half suitable for food crop production (van Zanten et al., 2016b). Whether the production of beef results in feed-food competition or a net positive contribution to the food supply may depend largely on whether marginal land is used to produce forages.

To estimate the land use ratio (LUR) for two types of dairy systems in the Netherlands, van Zanten et al. (2016a) combined data on land suitability and yields at the country level for purchased feeds and at the farm level for grassland. Country-level data may be appropriate for the Netherlands, which has a small and relatively homogenous agricultural land base, and for imported feeds when the region of origin is unknown. However, this approach is less informative for production systems in large countries with diverse land uses, geographies, and climates, such as the USA. Even if such a country is suitable for production of food crops, its regions may have quite different capabilities. Additionally, the forage land suitability data available at the farm level in the Netherlands is not available in many other countries. Because ruminant production systems may use large areas of grassland, having representative suitability data is critical to determine the LUR. In our case, to be able to assess the LUR of beef production systems in the USA, an intermediate approach between farm and country scale estimation is needed. By developing such an approach, the LUR will also become more widely applicable for other studies.

We, therefore, enhance the land use ratio (LUR) concept developed by van Zanten et al. (2016a) by incorporating geospatial analyses of land suitability and yield potential of food crop production on different land cover types at multiple scales (e.g., field-scale, regional). We illustrate this approach with two case studies in the Northeast USA: a management-intensive grazing (MiG) grass-fed beef system, and a confinement dairy beef system. Beef is the primary product for both systems. We also expand the system boundary for dairy beef to include milk production to estimate results for the whole dairy and beef system.

2. Methods

2.1. Existing and enhanced land use ratio

The land use ratio (LUR) measures the land-use efficiency of livestock systems from a food supply perspective (van Zanten et al., 2016a). The LUR is estimated using Eq. (1):

$$\text{LUR} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}(\text{LO}_{ij} \times \text{HDP}_{j})}{\text{HDP}_{a}} \quad (1)$$

where LO_{ij} is the whole herd land requirement for the production of feed ingredient i (i = 1, …, n) in country j (j = 1, …, m), resulting in the production of 1 kg of animal source food (ASF), and HDP_j is the maximum amount of human-digestible protein that could be produced per year from conversion of suitable land to human food crop production in country j (van Zanten et al., 2016a). The ASF derived from a system could be meat, milk, eggs, or a combination, depending on the boundary of analysis. This sum is divided by the HDP_a, the amount of human-digestible protein from 1 kg of ASF produced by the system. While the focus of the LUR is on protein, results are also calculated on an energy basis (i.e., human digestible energy – HDE) for an additional perspective. We enhanced the LUR by including multiple sub-country scales of production (i.e., field and region scale) and assessing yield potential for food crop production on different land cover types at those scales using publicly-available geospatial data in the USA. Our enhanced LUR is estimated using Eq. (2):

$$\text{LUR} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{p}(\text{LO}_{ijk} \times \text{HDP}_{jk})}{\text{HDP}_{a}} \quad (2)$$

where all variables an indices are as in Eq. (1), except k (k = 1, …, p), which indicates the livestock feed land requirement at the sub-country scale for country j. As in van Zanten et al. (2016a), the enhanced LUR is computed in four major steps. First, the land area occupied (LO_{ijk}) to cultivate the amount of each feed ingredient (i = 1, …, n) in the different areas of origin (j = 1, …, m; k = 1, …, p) that are needed to produce 1 kg ASF is quantified. Second, the suitability of feed land area occupied to directly grow food crops is assessed using a suitability index (country-scale) or spatial data. Third, for each area of land suitable for food crop cultivation (LO_{ijk}), the maximum HDP_{jk} from food crops is determined by combining information about crop yield per hectare for each suitable crop with its protein content and human digestibility (highest HDP per hectare from one crop). At the country-scale, reported food crop yields are used, whereas food crop yields are simulated at sub-country scales using crop productivity indices. The amount of HDP that can be produced on all land required for feed production is then summed and used as the numerator. Fourth, the amount of HDP in 1 kg ASF is quantified, which is the denominator of the calculation. The LUR can be calculated for representative livestock systems at varying scales, from highly localized to country average. The locations of the land required (indices j and k, above) are not necessarily co-located with the livestock system being analyzed. The detailed steps are described sequentially in the following sections.

2.1.1. Quantifying land requirements of feed production

We used data from a recent life cycle assessment of Northeast grass-fed beef (GF) and dairy beef (DB) as the basis of the production systems (Tichenor et al., 2017). The foundation for these system models is a livestock model that calculates direct and indirect herd-level feed needs, land requirements, and food output (Tichenor et al., 2017). Regionally representative herd sizes and parameters were developed using a multi-stage approach that combined published regional data, expert opinion, and producer interviews (Tichenor et al., 2017). We defined the Northeast region in accordance with the U.S. Department of Agriculture's National Institute of Food and Agriculture.[2]

The GF system is based on a 30 cow herd, which produces approximately 24 market-weight steers and heifers per breeding cycle (Table 1). Producers practice management-intensive grazing (MiG), moving cattle between paddocks 0.4–6 times per day. During the grazing season, herd feed requirements are met with grass-legume pasture, milk from the dams, and a mineral mixture. During the winter, cattle are fed grass hay or grass-legume bale silage and a mineral mixture.

The DB system is a combination of two production systems: dairy production and finishing of dairy beef calves (Tables 2 and 3). The dairy system is a 328 cow herd, plus associated breeding bulls and replacement stock, which produces milk, culled cows and bulls, and surplus calves to be raised for either veal or dairy beef (Table 2). Cattle are fed a mixture of harvested forages (hay and silage), grains, oilseeds, and associated coproducts, and a mineral mixture year round. Newborn

[2] The Northeast includes the following states: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia (USDA-NIFA, 2012).