Agricultural Systems xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Agricultural Systems

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

Feed conversions, ration compositions, and land use efficiencies of major livestock products in U.S. agricultural systems

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ARTICLE INFO

Article history:
Received 4 December 2013
Received in revised form 2 June 2014
Accepted 5 June 2014
Available online xxxx

Keywords:
Animal agriculture
Dairy
Eggs
Meat
Systems model

ABSTRACT

A sustainability transition will require a clear understanding of the environmental impacts of human food needs. To this end, accurate data on the feed requirements of livestock production are essential. Unfortunately, approaches used to estimate overall feed conversion ratios per unit output of livestock product vary and the reported values used in environmental analyses may be inconsistent. This paper presents a spreadsheet model for determining the aggregate, herd (flock) level feed needs of six major livestock commodities (beef, chicken, dairy, eggs, pork, and turkey) based on contemporary U.S. production practices. In this model, each system is represented as a set of stocks and flows, each of which is estimated based on performance metrics, such as reproduction and mortality rates. Parameter estimates were made primarily from U.S. government surveys or comparable peer-reviewed literature. Nutritional needs of livestock were based primarily from National Research Council reports. The model estimates the feed intake and ration composition for each life stage of each livestock system. Results were summarized as feed conversion ratios per unit output, herd (flock) average ration composition, and land use requirements for all feed ingredients. The findings confirm conventional wisdom that the total feed use efficiency of livestock products varies widely across livestock systems. However, the differences appear more subtle when the requirements for individual feed ingredients are considered. Similarly, the land requirements of livestock production also vary widely, but the differences are more nuanced when viewed in light of the land quality required to supply each feed ingredient. While the findings are consistent with some other past efforts to determine feed and land use efficiency of livestock production, greater transparency and consistency is needed in this area of research.

1. Introduction

Few subjects in agriculture spark debate as rancorous as the role of livestock in feeding the world. For at least forty years, since the publication of Lappé's (1971) *Diet for a Small Planet*, this topic has proven contentious. Until recently, the prevailing view in the scholarly literature appeared to be that global food production could keep pace with population growth and projected changes in consumption patterns through the first quarter of this century (see for example Rosegrant and Ringler, 1997; Alexandratos, 1999; Johnson, 1999). However, consensus opinion seems to be shifting. The Royal Society of London (2009) claimed that global food supplies must increase over current levels by 50–100% by 2050, and several articles in major scientific journals have concluded that changing diets must be part of a strategy for sustainably meeting global food needs (Foley et al., 2011; Godfray et al. 2010; Pelletier and Tyedmers, 2010). Each article identifies consumption of livestock products as the key issue to be addressed. This raises a significant question; what specific changes in consumption of livestock products would reduce the negative environmental impact of agriculture?

1.1. Estimating the impact of livestock

A variety of approaches are being used to estimate the environmental impact of livestock. They fall into at least four categories. First, comparisons of the net edible energy return from livestock systems have been made by animal scientists, who describe typical systems in given environments (Bradford, 1999; Oltjen and Beckett, 1996; Wilkinson, 2011). Second, economic models such as time series projection models or market equilibrium models are often used to estimate future food supplies (van Tongeren et al., 2001). For example, the feed and land use implications of

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http://dx.doi.org/10.1016/j.agsy.2014.06.005
0308-521X/

growing global demand for livestock products have been explored using the IMPACT model (e.g. Rosegrant et al., 1999). Third, life cycle assessment (LCA) has been adapted to investigate the environmental impact of food production in terms of its land use, water use, energy use, and greenhouse gas emissions. Some of this work is specific to livestock products (e.g. de Vries and de Boer, 2010; Nijdam et al., 2012), while other studies examine impacts across the food system (e.g. Weber and Matthews, 2008; Canning et al., 2010). Fourth, an assortment of empirical (e.g. Burke et al., 2008; Kissinger and Rees, 2010) and integrated modeling approaches (e.g. Bouwman et al., 2005; Le Cotty and Dorin, 2012; Lesschen et al., 2011; Mekonnen and Hoekstra, 2012; Wirsenius et al., 2010) have been used to estimate the impact of livestock production on feed needs, land use, water use, and greenhouse gas emissions. These models are not readily characterized as belonging to a common framework, but rather range widely in format and scale.

Direct comparison of the results obtained by different approaches is generally impossible because of differences in assumptions and system boundaries. Nonetheless, some common themes emerge from the literature. First, ruminant livestock generally use more land than monogastric species, because of differences in feed conversion efficiency (de Vries and de Boer, 2010; Nijdam et al., 2012, Wirsenius et al., 2010). Second, meat from ruminants generally is associated with greater greenhouse gas emissions per unit product than meat from monogastric species because of the methane released from ruminant digestion (de Vries and de Boer, 2010; Lesschen et al., 2011; Nijdam et al., 2012). Third, much of the plant material ruminants consume comes from perennial forage crops and grazing land and their return of edible product per unit of humanly-edible feed may actually be higher than non-ruminants (Le Cotty and Dorin, 2012; Oltjen and Beckett, 1996; Wilkinson, 2011). No consensus exists on how to balance the potential food security benefits of ruminant livestock with their greater total land requirements and carbon footprint. Nonetheless, one aspect of the literature is indisputable: feed needs and ration composition are critical determinants of the environmental impact caused by livestock.

1.2. Challenge of estimating feed needs

Feed requirements of livestock can be broken into two basic elements; feed intake and ration composition. Animal scientists have studied feed intake for decades, and the peer-reviewed literature is summarized periodically by the National Research Council (e.g. National Research Council, 1994, 1996, 1998, 2001) for major classes of livestock. Computer-based tools are available to balance rations and calculate feed needs for beef (NRC, 1996), dairy (NRC, 2001; Tylutki et al., 2008), and swine (NRC, 1998) operations. However, aggregate feed intake across an entire production system is not calculated frequently in the literature. The rations supplied to livestock change with shifts in input prices, and while many tools are available to balance rations, data on the typical balance of feed ingredients across a production system is not available. Likewise, neither variable is well-defined in published statistics. National databases, like USDA QuickStats (USDA-NASS, 2012), and international databases, such as FAOSTAT (FAO, 2012), contain records of historical agricultural production. They include estimates of the area planted, area harvested, total production, and yield for scores of crops. In addition, they track livestock inventories, livestock slaughter, and production of livestock products. However, agricultural databases do not report estimates of the feed intake or conversion efficiency of livestock. As a result, analysts must estimate feed needs as part of their studies.

Three general approaches to estimating feed needs are found in the literature, each with its own disadvantages. First, primary data collection is often used in LCA and in some farming system models. Such studies provide excellent data on the hot spots within a livestock system that cause the greatest environmental impact, but the data from individual operations are not necessarily representative of livestock production in a region (Dalgaard et al., 2006; Crosson et al., 2011). Second, data from published statistics are used in input–output based LCA, economic models, and empirical approaches to estimate feed needs based on trends in total feed use and livestock inventories. While excellent for tracking changes over time, these data do not necessarily capture the non-linear relationships between feeding practices and the availability of forages (Keyzer et al., 2005) or the availability of byproducts, such as oilseed meals (Elferink et al., 2008). Third, integrated modeling approaches sometimes rely on feed intake equations developed from reviews of animal science literature (e.g. Wirsenius, 2003a). The scientific foundation of such approaches may be strong, but it is challenging to present the methods clearly and in sufficient detail to enable replication of the approach.

1.3. Purpose of this paper

In hopes of improving the transparency of livestock feed estimates and the representativeness of the data used in the model, we present a systems approach for estimating livestock feed requirements. This approach begins by diagramming each system as a cycle of stocks and flows then defining each system quantitatively. We rely primarily on estimates from peer-reviewed literature, government reports, and national statistics to characterize these systems and determine the nutritional needs at each life phase. These nutritional needs are converted into livestock requirements from major feed and forage sources. In addition, land use efficiencies of each system are compared. A goal of this paper is to present a consistent approach for estimating livestock feed requirements for the major livestock classes that can readily be applied to other locations or production situations. Our analysis attempts to represent common, contemporary production practices in the U.S. for six livestock classes: beef, chicken, dairy, eggs, swine, and turkey. To our knowledge, such an analysis of feed requirements and land use efficiencies has not been conducted for the U.S.

2. Methods

2.1. Overview of approach

Feed conversion ratios, aggregate ration composition, and land requirements for each livestock class were calculated using a five-step approach. First, each class of livestock was characterized diagrammatically as a system of stocks and flows to identify the major life phases and the relationships between them. Second, values for each stock and flow were calculated based on performance metrics (e.g. rates of reproduction, mortality, and culling of livestock) gathered from the literature to represent conditions on common, contemporary production systems in the United States. Third, feed intake and ration composition were estimated for individual life phases of each livestock class using data on nutritional needs collected from National Research Council (NRC) publications and the peer-reviewed literature. Fourth, the data were summarized by tabulating total intake of all component feeds across life stages within each livestock class and normalizing per unit of output to generate feed conversion ratios and aggregate ration composition. Finally, the feed needs were converted to the area of land required per unit output. Each step is described in greater detail below, with references made to the Supplementary material for specific numbers or individual assumptions.

Please cite this article in press as: Peters, C.J., et al. Feed conversions, ration compositions, and land use efficiencies of major livestock products in U.S. agricultural systems. Agr. Syst. (2014), http://dx.doi.org/10.1016/j.agsy.2014.06.005