A novel approach to assess efficiency of land use by livestock to produce human food

Herman Mollenhorst[1*], Cindy Klootwijk[1], Corina van Middelaar[1], Hannah van Zanten[1,2], Imke de Boer[1]

[1] Animal Production Systems Group, Wageningen University, the Netherlands
[2] Wageningen UR Livestock Research, Wageningen University and Research Centre, the Netherlands
[*] Corresponding author. E-mail: *erwin.mollenhorst@wur.nl*

ABSTRACT

The increasing demand for livestock products will intensify the claim on land. To use land efficiently, we need a method to determine the efficiency of land use to produce animal-source food. Life cycle assessment (LCA) has been used to assess the land use and shows that land required to produce, for example, 1 kg of protein is in the same range for eggs and milk. Methods used, however, do not take into account that laying hen diets contain more human-edible plant products than dairy cow diets. Furthermore, the suitability of land to grow human-edible plant products is not taken into account, as all land is counted equal. The aim of this study, therefore, was to develop a method to determine the efficiency of land use by livestock for human food production. We illustrated our novel approach for the case of egg and milk production systems in the Netherlands.

Keywords: animal production, land use efficiency, egg, milk, food

1. Introduction

For decades, the livestock sector has focussed on improving the feed efficiency at animal level, i.e., the ratio of kg product output over kg resource input. This focus increased global production of animal-source food, but also the demand for land by the livestock sector. The current livestock sector uses about 70% of all agricultural land in the world (Steinfeld et al., 2006). The demand for especially animal-source food will further increase, and, therefore, intensify the claim on agricultural land, implying that land use efficiency (LUE) will become increasingly important for livestock production.

Life cycle assessment (LCA) is most commonly used to assess LUE of animal-source food products along the entire chain. A generally accepted indicator is land occupation. Current LCA results show that land occupation is in the same range for eggs (35-48 m^2/kg protein) and milk (33-59 m^2/kg protein) (De Vries and De Boer, 2010). They, however, also concluded that interpretation of current LCA results is hindered, because they do not include the environmental consequences of competition for land between humans and animals. Compared to diets of ruminants, for example, diets of laying hens, generally, contain more products, such as cereal grains, that humans could consume directly. Direct consumption of these cereal grains by humans is more efficient from a land use perspective than consumption of milk or eggs produced by animals fed with these cereal grains, because energy is lost during conversion from plant to animal product (Goodland, 1997).

One way to gain insight into the efficiency of land use by livestock, while correcting for this competition between humans and livestock, is to compute human-edible energy or protein conversion ratios (Wilkinson, 2011; Dijkstra et al., 2013). This protein conversion ratio, for example, represents the amount of protein in animal feed that is potentially edible for humans over the amount of protein in the animal product that is edible for humans. Wilkinson (2011) computed human-edible protein conversion ratios above 1, except for milk and suckler-beef production. Ratios above 1 are not sustainable because animals produce less human-edible protein than they consume (De Boer, 2012).

Another limitation of the land occupation indicator is that it does not account for the suitability of occupied land to cultivate food crops. Conversion ratios, as presented by Wilkinson (2011), do not include the fact that, for example, grass fed to dairy cows can be produced on land suitable for the cultivation of food crops. Some LUE indicators were proposed that correct occupied land for its production capacity, like the net primary productivity of potential biomass (NPP_0) (Ridoutt et al., 2012) and the ecological footprint indicator (Ewing et al., 2010; Borucke et al., 2013) or the quality of the soil (Milà i Canals et al. 2007b). All these methods, however, do not sufficiently account for the suitability of used land to produce food crops.

To efficiently feed an increasing and wealthier population, we need a novel method that overcomes above mentioned limitations in LUE assessment methods. The aim of this study, therefore, was to develop a novel method to assess efficiency of land use by livestock to produce human food. We illustrated our novel approach for the case of Dutch egg and milk production systems .

2. Methods

2.1. Life cycle assessment

We first used a regular LCA approach to assess land occupation for the production of eggs and milk. In this study, we used an attributional LCA to quantify the current status of LUE to produce egg and milk.

Land use assessment in an attributional LCA focusses on two main issues, i.e., the claim on land by production (e.g., the indicator land occupation) and the impact of used land on biodiversity and soil quality/life support function (Garrigues et al. 2012; Milà i Canals et al. 2007a). Indicators to quantify the impact on biodiversity and soil quality/life support function are still in development and it is not evident yet which indicators should be considered in LUE assessment of livestock systems (Helin et al. 2014; Koellner et al. 2013; Núñez et al. 2013), although some recommend to use soil organic matter (Milà i Canals et al. 2007b) as indicator for soil qualtiy (Food SCP RT 2013). Therefore, and because our focus was on the suitability of used land to produce food crops, we quantified only the claim on land by livestock production.

Land occupation in livestock production mainly results from cultivation of feed ingredients. Therefore, we took into account agricultural land use for feed production only.

2.2. Novel approach for land use efficiency assessment of livestock

Our approach for LUE assessment builds on current LCA calculations. A regular LCA sums occupied land for all feed ingredients per country of origin used for the production of, for example, a kg human-digestible (HD) egg or milk protein. Our approach sums the suitability of this occupied land per country of origin to directly produce HD protein from food crops. We chose HD protein production as parameter for LUE as livestock products contribute especially to the protein demand of humans (De Vries and De Boer 2010; FAO 2009). Protein digestibility was taken into account to correct for the quality difference of plant and animal protein. The concept behind our approach, therefore, is that to maximize LUE, HD protein production should be maximized per agricultural land unit. Our LUE ratio, therefore, was defined as:

$$\text{LUE ratio} = \frac{\text{HD prot livestock}}{\text{HD prot crop}} \qquad \text{Eq. 1}$$

where HD prot livestock is HD protein production from livestock (g HD protein/FU) and HD prot crop is HD protein production from most suitable food crop (g HD protein/FU).

For our case studies we chose kg HD egg or milk protein as FU. Current LCA studies, however, do not yet account for protein digestibility. Therefore, to compare our current land occupation results to values in literature, we expressed these results also in kg egg or milk protein. As the FU was expressed in kg HD livestock protein, the numerator of the LUE ratio was equal to 1000 g HD livestock protein.

The denominator of the LUE ratio was calculated according to Eq. 3.

$$HD\ prot\ crop = \sum_{i=1}^{n}\left(LO_{ij} \times \max_{k}\left(AY_{jk} \times Prot_k \times Dig_k\right)\right) \qquad \text{Eq. 2}$$

Where, LO_{ij} is current land occupation (m^2.yr/FU) for feed ingredient i and country j, AY_{jk} is average yield (g/m^2.yr) for country j and suitable food crop k, $Prot_k$ is protein content (%) for suitable food crop k, Dig_k is protein digestibility (%) for suitable food crop k and the max function is selecting food crop k with maximum HD protein yield for country j.

To calculate HD prot crop (Eq. 2), first, we identified the country of origin for all feed ingredients. Second, we assessed the suitability of these countries to grow food crops. Five major food crops were considered: wheat, rice (wetland and indica dryland), maize, potatoes (white and sweet) and soybeans. To identify country specific suitability for these food crops we used the GAEZ database on agro-ecological suitability and productivity (FAO and IIASA 2014). This database expresses country-specific suitability of land to grow food crops in a suitability index ranging from not suitable to very highly suitable. This suitability index is based on data of climate (e.g., wet day frequency, sunshine and temperature), crop requirements, prevailing soil conditions (e.g., pH, soil water holding capacity and total exchangeable nutrients), applied soil management, elevation and terrain slope, land cover and protected and administrative areas (FAO and IIASA 2014). If, according to the GAEZ legend, the suitability on country level was good, high or very high (i.e., suitability index >55), the land was considered suitable to produce the crop. Third, for every suitable food crop, the country-average yield in kg/ha was obtained from the FAOSTAT database (FAO 2014). Fourth, these yields were corrected for protein content and digestibility.

The LUE ratio corrects for both limitations in current LUE assessment methods. First, it corrects for differences in amount of HD plant products in livestock diets as these products, of course, are produced on land that has high alternative protein production from food crops, which makes the denominator larger. Second, we correct for suitability of used land to cultivate food crops. For example, when grass is grown on land that could have been used to grow food crops, the denominator becomes larger as well.

2.3. Case studies

We illustrated our approach for the cases of Dutch egg and milk production systems, because these systems yield similar LCA results for land occupation per kg of protein, whereas diets of dairy cows and laying hens differ in amount of HD plant products. As the diet of laying hens is relatively similar for different production systems, we took the most common egg production system in the Netherlands, i.e., a multi-tiered barn (Egg) (Dekker et al. 2011). Furthermore, we included two milk production systems in the Netherlands, i.e., milk production on peat soils (Milk Peat) and milk production on sandy soils (Milk Sand). We selected these milk production systems because of their differences in the suitability of land used for feed production to cultivate food crops.

Current land occupation for Egg was calculated based on data from Dekker *et al.* (2011), FeedPrint 2013.03 (Vellinga et al. 2013) and KWIN-V 2013-2014 (KWIN-V 2013). Data about the composition of the layer hen diet and the corresponding off-farm land use, feed intake and production values came from FeedPrint 2013.03. The egg price, slaughter price and round duration were obtained from KWIN-V 2013-2014.

When a hectare of land yields multiple products, land occupation needs to be allocated to these multiple products. Economic allocation was used to allocate land occupation between egg and meat production. Economic allocation means that occupied land is allocated proportionally to the economic value of the different products. Economic allocation was used for crops with an oil and a meal product also. Economic allocation values for these crops were based on FeedPrint 2013.03. According to FeedPrint 2013.03, residue co-products, like citrus- and beet pulp, maize glutenfeed and wheat middlings, had an economic allocation value of zero. The co-product straw was assumed to have an economic allocation value of zero.

Current land occupation for Milk Sand and Milk Peat was calculated based on data from the Dutch Farm Accountancy Data Network (FADN) database (FADN 2014) and FeedPrint 2013.03 (Vellinga et al. 2013). Data from the FADN database described average milk production, economic allocation percentages for milk as percentage of total revenues from milk and meat, on-farm land use with corresponding crop yields, total feed intake and the proportion of different feed ingredients in the milking cow diet over three years (2010-2012). To get a high contrast between production systems for dairy cows on peat and sandy soils, we selected FADN farms with >90% peat or sandy soils. Allocation rules were applied similarly to the laying hen case.

The HD protein production from food crops on land used for on-farm feed production was not solely based on the GAEZ and FAOSTAT databases. We assumed HD protein production from food crops on peat soils to be zero. Crop yields for wheat, i.e., 7,300 kg/ha.yr and white potatoes on sandy soils, i.e., 56,000 kg/ha.yr and wheat, i.e., 9,200 kg/ha.yr and white potatoes on clay soils, i.e., 50,000 kg/ha.yr were obtained from KWIN-AGV (KWIN-AGV 2012).

3. Results

Land occupation for egg production was about 26 m^2 per year per kg digestible protein (Table 1). On this land, which is spread all over the world, it is possible to produce about 2 kg of HD protein from food crops, resulting in a ratio of 0.5.

Table 1. Land occupation per kg human-digestible (HD) protein and LUE ratio for egg production (Egg) and milk production on sandy (Milk Sand) and peat soils (Milk Peat).

Product	**Land occupation (m^2.yr/kg HD protein)**	**LUE ratio**
Egg	25.8	0.5
Milk Sand	26.1	0.4
Milk Peat	31.6	1.7

Current land occupation was higher for Milk Peat than for Milk Sand, mainly due to higher grass and lower maize content in the diet on dairy farms on peat soils. On-farm maize yields were higher than on-farm grass yields, which led to lower land occupation for maize than for grass. The LUE ratio, however, strongly depended on the soil type. When a dairy farm was situated on peat soils, where hardly anything else than grass could be grown, the ratio was 1.7. This means that more HD protein from milk than from plants could be produced on the land where the feed ingredients are grown. When situated on sandy soils, however, the ratio was about 0.4, which means that production of milk on sandy soils is an inefficient way to produce HD protein.

4. Discussion

According to De Vries and De Boer (2010) the range in land occupation of egg production systems was 35-48 m^2.yr/kg protein. Our current land occupation value, recalculated to kg protein was below this range (25 m^2.yr/kg protein). This can be explained by the relative low feed conversion ratio (FCR) from FeedPrint. Besides, the range of De Vries and De Boer (2010) was based on two studies from 2006. Additional possible explanations, therefore, can be decreasing FCR and increasing crop yields over years. Furthermore, in the current study, only land occupation by feed production, i.e. agricultural land, was considered.

Current land occupation was 25 m^2.yr/kg protein for Milk Sand and 30 m^2.yr/kg protein for Milk Peat. According to De Vries and De Boer (2010) the range in land occupation of milk production systems was 33-59 m^2/kg protein. This range was based on studies from 2000-2009. Our relatively low current land occupation values, just as for the laying hen case, can possibly be explained by decreasing FCR and increasing crop yields over years. Two Dutch studies were used in the review of De Vries and De Boer (2010). These Dutch studies found a land occupation value for Dutch milk production of about 39 m^2/kg protein), which is on the lower side of the range as well (Thomassen et al. 2009; Thomassen et al. 2008).

Current land occupation was highest for Milk Peat, followed by Milk Sand and Egg, but still close to each other (25-30 m^2.yr/kg protein). This land occupation, however, was relatively similar for these livestock systems. This is in accordance with the findings of De Vries and De Boer (2010) that the amount of land required to produce 1 kg of protein is in the same range for eggs and milk. Opposite to our findings, Williams *et al.* (2006) found lower current land occupation values for milk production systems (33-35 m^2/kg protein) than for egg production systems (41-48 m^2/kg protein). This difference can possibly be explained by our relatively low FCR for egg production. Besides, compared to the ranges of De Vries and De Boer (2010) for land occupation of egg and milk production, Williams *et al.* (2006) found relatively high land occupation for egg production and relatively low land occupation for milk production.

The novel approach to assess LUE of livestock systems led to a change in conclusions of livestock systems on their LUE. Wilkinson (2011) found the same conclusions at animal level about the loss or gain of HD protein during the production of eggs and milk on peat soils. Our results for milk production on sandy soils, however, were different, because Wilkinson (2011) didn't include the fact that, for example, grass fed to dairy cows can be produced on land suitable to grow food crops.

The land use inefficiency of dairy farms on sandy soils compared to dairy farms on peat soils could be explained mainly by the difference in suitability of both soils to grow food crops. Production capacity of land is not fully used for the case of milk production on sandy soils, as grass is grown on land that has high suitability to grow food crops. This shows that animals that convert non-HD protein, originating from land with low capacity to grow food crops, into HD protein efficiently, could contribute to increase global HD protein production. This finding is in agreement with the conclusion of Dijkstra *et al.* (2013) that we should fully utilize the ability of ruminants to convert non-HD products into HD products.

5. Conclusion

Our novel approach to assess efficiency of land use by livestock to produce human food led to a change in conclusions on the LUE of livestock systems. We found highest LUE for livestock production on land that has low suitability for HD protein production from food crops. These results show that animals that convert non-HD protein, originating from land with low capacity to grow food crops, into HD protein efficiently, could contribute to increase global HD protein production. This means that not only the actual type of land use (meadow, arable land, etc.) has to be taken into account in the assessment of efficiency of land use, but also its natural status (e.g. soil type), determining its suitability to produce food crops.

6. References

Borucke M et al. (2013) Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework Ecological Indicators 24:518-533

De Vries M, De Boer IJM (2010) Comparing environmental impacts for livestock products: A review of life cycle assessments Livestock Science 128:1-11

Dekker SEM, De Boer IJM, Vermeij I, Aarnink AJA, Groot Koerkamp PWG (2011) Ecological and economic evaluation of Dutch egg production systems Livestock Science 139:109-121

Dijkstra J, France J, Ellis JL, Strathe AB, Kebreab E, Bannink A (2013) Productions efficiency of ruminants: feed, nitrogen and methane. In: Kebreab E (ed) Sustainable animal agriculture. CAB International, Wallingford, pp 10-25.

Ewing B, Goldfinger S, Wackernagel M, Stechbart M, Rizk SM, Reed A Kitzes J (2010) Ecological footprint atlas 2010. Global Footprint Network, Oakland

FADN (2014) Farm Accountancy Data Network Wageningen UR LEI

FAO (2009) The state of food and agriculture. Livestock in balance. FAO, Rome, Italy

FAO (2014) FAOSTAT

FAO, IIASA (2014) GAEZ Global Agro-Ecological Zones. Accessed 22-12-2013

Food SCP RT (2013) ENVIFOOD Protocol, Environmental Assessment of Food and Drink Protocol, European Food Sustainable Consumption and Production Round Table (SCP RT), Working Group 1, Brussels, Belgium

Garrigues E, Corson MS, Angers DA, Van der Werf HMG, Walter C (2012) Soil quality in Life Cycle Assessment: Towards development of an indicator Ecol Indic 18:434-442

Helin T, Holma A, Soimakallio S (2014) Is land use impact assessment in LCA applicable for forest biomass value chains? Findings from comparison of use of Scandinavian wood, agro-biomass and peat for energy Int J Life Cycle Assess 19:770-785

Koellner T et al. (2013) UNEP-SETAC guideline on global land use impact assessment on biodiversity and ecosystem services in LCA Int J Life Cycle Assess 18:1188-1202

KWIN-AGV (2012) Quantitative Information Arable farming and Open-air horticulture 2012 (Kwantitatieve Informatie Akkerbouw en Vollegrondsgroenteteelt 2012). Wageningen UR Praktijkonderzoek Plant en Omgeving, Lelystad

KWIN-V (2013) Quantitative Information Livestock 2013-2014 (Kwantitatieve Informatie Veehouderij 2013-2014). Wageningen UR Livestock Research, Lelystad

Milà i Canals L et al. (2007a) Key elements in a framework for land use impact assessment within LCA Int J Life Cycle Assess 12:5-15

Milà i Canals L, Romanyà J, Cowell SJ (2007b) Method for assessing impacts on life support functions (LSF) related to the use of 'fertile land' in Life Cycle Assessment (LCA) 15:1426-1440

Núñez M, Antón A, Muñoz P, Rieradevall J (2013) Inclusion of soil erosion impacts in life cycle assessment on a global scale: application to energy crops in Spain 18:755-767

Thomassen MA, Dolman MA, van Calker KJ, de Boer IJM (2009) Relating life cycle assessment indicators to gross value added for Dutch dairy farms Ecological Economics 68:2278-2284

Thomassen MA, van Calker KJ, Smits MCJ, Iepema GL, de Boer IJM (2008) Life cycle assessment of conventional and organic milk production in the Netherlands Agricultural Systems 96:95-107

Vellinga TV, Blonk H, Marinussen M, Zeist WJv, Boer IJMd, Starmans D (2013) Methodology used in FeedPrint: a tool quantifying greenhouse gas emissions of feed production and utilization. Wageningen UR Livestock Research, Lelystad

Wilkinson JM (2011) Re-defining efficiency of feed use by livestock Animal 5:1014-1022

Williams AG, Audsley E, Sandars DL (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Bedford: Cranfield University and Defra

This paper is from:

Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector

LCA Food 2014

8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

The full proceedings document can be found here:
http://lcacenter.org/lcafood2014/proceedings/LCA_Food_2014_Proceedings.pdf

It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

Questions and comments can be addressed to: staff@lcacenter.org

ISBN: 978-0-9882145-7-6