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Reconsidering the land resource for food production: quantifying feed-food competition in dairy systems

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Abstract

Purpose Land used in agricultural production provides different services and causes various impacts. The potential of the land resource to produce biomass can e.g. be reflected by exergy-based methods using net primary productivity indicators. However, the potential to produce food, feed, fuel and fibres is currently not considered by common resource indicators. In this study, indicators for quantifying the feed-food competition in animal production in terms of energy and protein supply for human consumption were used.
Methods The *food-competition indicator* reflects the direct competition and quantifies human edible protein and energy contained in the feedstuffs used in relation to the milk and meat produced. The *land-competition indicator* refers to the indirect competition for land use, and quantifies the potential of the land used to produce protein and energy for human nutrition by food crops relative to human edible proteins and energy from milk and meat. Protein quality (using the DIAAS method) was systematically taken into account for both indicators. They were applied to 25 Swiss dairy farms.
Results The food-competition indicator (0.01-0.54 for protein, and 0.03-0.68 for energy) showed a low direct competition. There was a strong correlation with the use of concentrates per unit of milk. The use of by-products from food and feed production led to lower food competition. The land-competition indicator showed a strong competition in most cases (0.69-2.64 for protein, and 1.52-5.93 for energy). Only two farms had an indicator value of <1 for protein. Determining factors were the arable land area, its yield potential, and milk-production efficiency parameters (feed utilisation, restocking rate). Both indicators showed lower competition with regard to protein than with regard to energy, as the protein quality in animal products is rated higher than that of the protein in food crops.
Conclusions The food-competition and land-competition indicators describe different aspects of competition and do not correlate. The combination of indicators helps to assess feed-food competition in a comprehensive way. Furthermore, the land-competition indicator can be used in agricultural LCA studies to describe the food production potential of the land occupied.

Keywords: *Land resource indicators, feed-food competition, land-competition indicator, dairy production*

Introduction

Land used in agricultural production provides different services and has various impacts. The aspects of biodiversity and soil quality are typically included as impact categories in LCA. The potential of the land resource to produce biomass can e.g. be reflected by exergy-based methods using net primary productivity indicators (Alvarenga *et al*., 2013). However, the potential to produce food, feed, fuel and fibres is currently not considered in common LCIA resource indicators. Particularly in animal

production systems, conflicts between food and feed production can occur, which should be quantified. Cows and other grazers are able to convert biomass not usable by humans, such as herbage, into human-edible food. If, however, animal feed is used which could also be consumed directly as food by humans, or which is produced on land which could otherwise be used to grow arable crops, we are then faced with competition between the growing of feed for milk production on the one hand and food for human nutrition on the other. The ability to measure and strategically reduce feed-food competition between animals and humans is crucial for this efficient use. In this study (Zumwald *et al*., 2019), two indicators for determining feed-food competition in terms of energy and protein supply for human consumption were applied to Swiss dairy farms.

Material and methods

The *food-competition* indicator reflects the direct competition between animal feed and human food (Ertl *et al*., 2016). It originates from nutritional sciences and answers the question "What is the contribution of milk production, in the form of milk and meat, to human protein and energy supply, compared to the feedstuffs used?" This indicator refers to the utilised feedstuffs, and describes their proportion of potentially human-digestible energy (Eq. 1) or protein (Eq. 2) in relation to their use for the production of milk and meat:

$$FC_{hde} = \frac{HDE_{feed}}{HDE_{milk} + HDE_{meat}} \quad (1)$$

$$FC_{hdp} = \frac{HDP_{feed} * PQ_{feed}}{HDP_{milk} * PQ_{milk} + HDP_{meat} * PQ_{meat}} \quad (2)$$

where

FC_{hde} = food competition related to human digestible energy [-]
$HDE_{feed/milk/meat}$ = human digestible energy of feedstuffs/milk/meat [MJ]
FC_{hdp} = food competition related to human digestible protein [-]
$HDP_{feed/milk/meat}$ = human digestible protein of feedstuffs/milk/meat [kg]
$PQ_{feed/milk/meat}$ = protein quality (DIAAS) of feedstuffs/milk/meat [-]

By contrast, the *land-competition* indicator refers to the indirect competition for land use (van Zanten *et al*., 2016), and answers the question "To what extent could the direct production of foodstuffs on the land used for dairy production contribute to human protein and energy supply compared to dairy production?" Based on LCA theory, this indicator refers to land use, and describes the food production potential in terms of the digestible energy (Eq. 3) or protein (Eq. 4), which would be made available to humans. This potential is also compared to the effective food from dairy production on the land area used:

$$LC_{hde} = \frac{HDE_{land}}{HDE_{milk} + HDE_{meat}} \quad (3)$$

$$LC_{hdp} = \frac{HDP_{land} * PQ_{land}}{HDP_{milk} * PQ_{milk} + HDP_{meat} * PQ_{meat}} \quad (4)$$

where

LC_{hde} = land competition related to human digestible energy [-]
HDE_{land} = human digestible energy production potential on the land used [MJ]
$HDE_{milk/meat}$ = human digestible energy of milk/meat [MJ]
LC_{hdp} = land competition related to human digestible protein [-]
HDP_{land} = human digestible protein production potential on the land used [kg]
$HDP_{milk/meat}$ = human digestible protein of milk/meat [kg]

PQ_{land} = protein quality (DIAAS) of the potential production on the land used [-]
$PQ_{milk/meat}$ = protein quality (DIAAS) of milk/meat [-]

For the food and land competition indicators, values of >1 mean that the feed or the arable land provides more human edible protein or energy than contained in the milk and meat produced. Similarly, values of <1 mean a net contribution of milk and meat production to the food supply. Protein quality (using the DIAAS method) was systematically taken into account for both indicators, in order to reflect the suitability of protein for human nutrition.
Both indicators were implemented in the context of Swiss dairy farming, and the methodology was refined and adapted. The list of the feedstuffs considered was substantially expanded, so that a wide range of feedstuffs can be taken into account. The yield potential of crops was based not only on the best crop, but on an optimised crop rotation. The arable potential of the land was estimated in detail for Switzerland on the basis of available spatial information and farm data.
Both indicators were applied to 25 selected commercial dairy farms (Table 1). They differ according to region, production zone, milk yield, type of farm (organic, integrated) and the proportion of forage production on arable land. The farms are located on the Swiss Central Plateau and in the hill and mountain regions. The farms studied do not constitute a representative sample of Swiss dairy farms.

Table 1: Characteristics of the investigated farms.

Characteristics of the farms	Number of farms or value
Integrated/organic	21/4
Lowlands/hills/mountains	14/7/4
With/without arable crops	14/11
Milk yields below/above 8'000 kg ECM/cow/year	14/11
Average milk yield kg ECM/cow/year	7'545 (±1'598)
Average concentrate feed (kg DM/kg ECM)	0.108 (±0.073)

Results

For the food-competition indicator, the farms had values between 0.01 and 0.54 for protein, and 0.03 and 0.68 for energy (Figure 1). This indicates that there is low direct competition with respect to the utilised feed, or that the milk-production system produces more protein or energy that can be utilised for human nutrition than was contained in the forage. The food-competition indicator values correlate strongly with the use of concentrates per unit of milk produced. For farms using only small amounts of concentrates or none at all, values stand at around zero. Farms which have low indicator values despite using a significant proportion of concentrates in their total ration are increasingly using by-products from food and feed production as feed, such as rapeseed cake, feed potatoes or brewer's spent grain.
For the land-competition indicator, results range between 0.69 and 2.64 for protein, and 1.52 and 5.93 for energy. Only two farms have an indicator value of <1 (for protein). In most cases, growing arable food crops would contribute more to human nutrition than milk production on the land area used. The decisive factor for the indicator values of a farm is the arable area. This applies in particular to the farm's own land, since in the majority of cases it accounts for most of the differences. The two farms with the lowest indicator values are in the mountain zone; 100% of their acreage was judged as unsuitable for arable farming. Furthermore, the milk-production efficiency parameters (feed utilisation, restocking rate) play an important role. In addition to the land requirement per unit of milk produced, the suitability of the land for arable crops is of major importance.

Both indicators showed lower competition with regard to protein than with regard to energy, as the protein quality in animal products is rated higher than that of the protein in food crops.

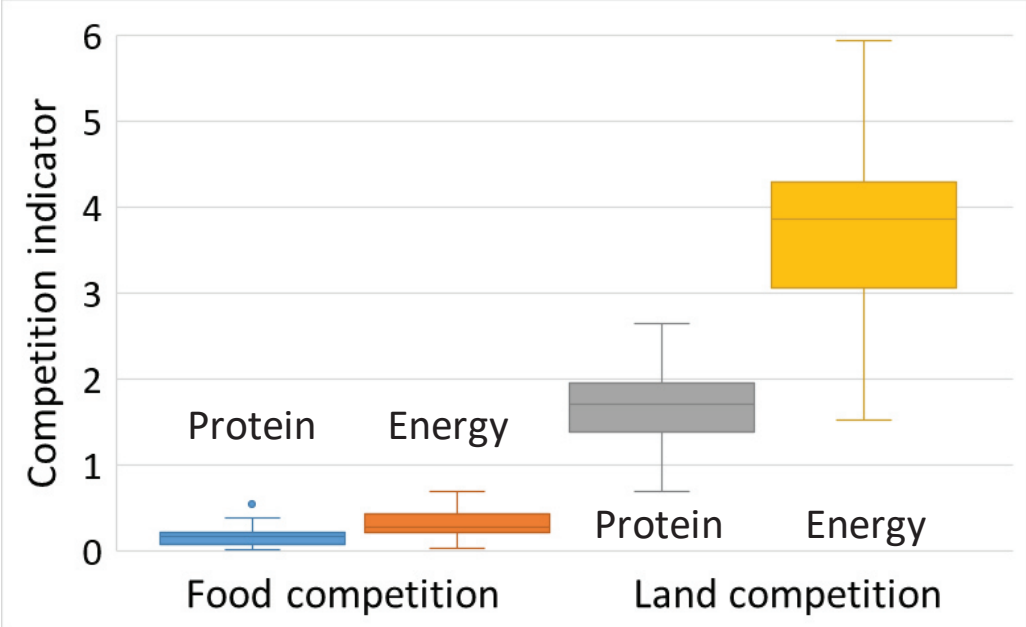

Figure 1: Food and land competition for protein and energy for 25 Swiss dairy farms.

Discussion

The results of the studied farms cannot be extrapolated to Swiss milk production as a whole, since the sample investigated was too small and not representative. Nevertheless, the results indicate that land competition between milk production and arable use for direct human consumption is stronger than food competition between animal feed and human food.

Both indicators show lower competition with regard to protein than to energy. This is because in relation to human requirements, dairy products contribute more to protein consumption than to energy consumption, and because high losses occur when ruminants convert feed energy into animal products. In addition, the quality of the protein in the animal products is rated higher than that of the protein in the feed. The food-competition and land-competition indicators describe the same issue with a different focus, which is why they do not correlate with one another on the farms studied. Nevertheless, the combination of indicators helps to assess feed-food competition more thoroughly from two different perspectives, so that it is measurable as a whole. A farm which uses only small amounts of concentrates, but which uses arable land for forage production, has low food competition; by contrast, its land competition is high. Conversely, a farm that produces its forage on non-arable land, but which uses high amounts of concentrates, has low values for land competition, but higher ones for food competition.

Conclusions

The indicators from the two approaches enable the objective representation of land and food competition in dairy production, and thus help to improve food security. They can also be applied to other types of land-based animal production like meat or eggs. The land-competition indicator can be used in agricultural LCA studies to describe the food production potential of the land occupied. If the land occupation (m^2*a) of a production system is related to the production potential for human edible protein and energy, it can be directly used as a resource indicator in LCA, which allows to cover this important aspect.

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