Optimising land use and consumption of livestock products in the human diet with an increasing human population in the Netherlands

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ABSTRACT

Land use related to food production is generally quantified using product-based life cycle assessments. We, however, quantified land use of diet scenarios with a land use optimization model. Energy and protein requirement of human populations, varying from 15 to 30 million people, were met with the consumption of arable crops, meat and milk. Diet scenarios explored contained 0% up to 80% of animal protein. First findings show that a limited contribution of animal protein in the diet resulted in lowest land use per capita, because of utilization by livestock of products inedible for humans. Moreover, utilization of land unsuitable for crop production provides the opportunity to sustain a larger population compared to a situation in which these soils were not used to produce food.

Keywords: human diet, land use, land optimization modelling, crop production, animal production

1. Introduction

Currently, about 40% of all terrestrial land area in the world is used for agriculture (FAOSTAT 2013). Non-agricultural land area consists of (tropical) forest, desert, mountains and tundra, but also of cities, industrial areas and roads. Pressure on land will increase, because of increasing land degradation (Stringer 2008) and increasing demands for food, biofuel, biomaterials, housing and infrastructure for an increasing population of 9.6 billion in 2050 (United Nations 2013). Simultaneously, there is need for preservation of nature (Smith et al. 2010, The Royal Society of London 2009, TheWorldBank 2007).

One way to feed an increasing world population with a limited land area is to increase productivity per hectare, commonly referred to as sustainable intensification (Tilman et al. 2011). Other ways to feed an increasing world population with a limited amount of land area include reducing the amount of food waste along the chain (Gustavsson et al. 2011, Kummu et al. 2012) or a change in human diets towards food products requiring less land area (Meier & Christen 2013).

Various scientific studies have assessed the impact of a change in human diet on land use (Collins & Fairchild 2007, Gerbens-Leenes & Nonhebel 2002, Peters et al. 2007, Rabbinge & Van Latesteijn 1992, Risku-Norja et al. 2008, Stehfest et al. 2009, Thibert & Badami 2011, Wirsenius et al. 2010). These studies support the general conclusion that plant-based diets require less land than animal-based diets (Meier & Christen 2013, Stehfest et al. 2009, Van Kernebeek et al. 2014, Wirsenius et al. 2010). Some studies even propagate to substitute ruminant meat by monogastric meat to lower land area requirements for food production (Collins & Fairchild 2007, Stehfest et al. 2009, Wirsenius et al. 2010). However, compared with diets of ruminants, diets of pigs and poultry are relatively rich in products such as cereals, that humans could consume directly (De Vries & De Boer 2010). Moreover, in a situation where arable land is limiting, ruminant production on land being unsuitable for crop production may contribute to global food security (Peters et al. 2007).

To avoid competition between humans and animals for land and products, such as cereals, we could stimulate to feed by-products from crop cultivation or the food industry to animals, and to feed grass from land less suitable for cultivation to ruminants. Peat soils in the Netherlands, for example, are not suitable for production of arable crops, such as grain or potatoes, but are valuable for grass-based livestock production. The objective of this paper is to examine the relative contribution of livestock production in a human diet, with an increasing human population, given a limited land area in a region. We used the Dutch agricultural system with different population scenarios as an illustration, assuming no import and export of food and feed.

2. Methods

To fulfil our research objective, we assessed agricultural land area required to feed a growing population in the Netherlands with various dietary choices, using linear programming. We varied population sizes from 15 million people, which is the approximate current Dutch population size, up to the maximum number of people that could potentially be fed, with steps of 5 million people. Diet scenarios ranged between 0% animal protein in the diet up to 80% animal protein, with steps of 5%.

The system studied was directed at production of food (i.e. energy and protein) for a given human population in the Netherlands, assuming no import and export of food and feed. We distinguished cultivation of food crops (grains, root- and tuber crops, oil crops and legumes), feed crops (maize silage) and grass. Crops could be cultivated on clay and sandy soils. Peat soils could be used for cultivation of grass. Our system also included dairy and pig production. Land area for animal production consisted of feed production. In the modelling study, we assumed typical, current agricultural yields for both crop and animal production (PPO 2009, 2012, Vermeij 2012). We excluded products from fisheries and aquaculture as these are not land-based systems. We also excluded products from greenhouses as these do not require agricultural land. For the same reason, we did not account for land required for infrastructure and production sites for, e.g., artificial fertilizer and machinery.

The objective function of our optimization model was to minimize the use of land for the defined crops and grassland on clay, sand and peat soils, whilst meeting human nutritional requirements. Current existing agricultural land area in the Netherlands was set as physical boundary.

Daily per capita human requirements were defined as 2000 kcal, 57 grams of protein and a maximum of 90 grams of total sugars (EFSA 2009, 2012).

2.1. Production of crops and crop products

Crop production and yields were based on typical current agricultural practices in the Netherlands. We distinguished between crop production on clay, sand and peat soil. We used multiple-year average yields for each soil type. Apart from differences in yields across soil types, no further geographical differences in yields and inputs were assumed, as the Netherlands is a small country with a relatively homogeneous climate. We accounted for 2-7 percent land area requirement for the production of seeds and tubers.

We distinguished four groups of food crops: grains, root- and tuber crops, oil crops and legumes. From each group, we included the crop with the largest land area in the Netherlands as a model crop, except for the group of root- and tuber crops, where we included two model crops. We included wheat as model crop for grains, potatoes and sugar beet for root- and tuber crops, rapeseed for oil crops and brown beans (Phaseolus vulgaris) for legumes. In addition, we included maize silage and grass as forage for dairy cattle.

Crops are grown in crop rotations. We used rotation schemes as provided by Van Ittersum et al.,(1995). Grass and silage maize were considered as mono crop rotations, whereas the other crops were considered in four to six year rotations.

Agricultural area in the Netherlands totals 1,842 x 10^3 hectares in 2012 (CBS 2013). Based on the land use map by Lesschen et al. (2012), we attributed the total agricultural area to three soil types:

779 10^3 hectares of clayey soils, 839 10^3 hectares of sandy soils, and 224 10^3 hectares of peat. Due to the vulnerability of peat to soil subsistence and oxidation after tillage, we assumed that these soils can only be used for grass production to feed cows.

We included various post-harvest processes to convert harvested products into human edible products and feed ingredients. Processes included were: dry milling of wheat, wet milling of potato, peeling of potato, sugar processing and crushing of oil seeds. The nutritional value of the output products were taken from (PDV 2011) for feed and (RIVM 2013) for food products.

2.2. Animal production

We modelled the pig and dairy production system using the concept of an animal production unit (PU), based on typical current management (Vermeij 2012). A PU consisted of one animal unit per year for an average Dutch farm, including associated breeding animals and offspring. Per PU, we defined output in terms of meat and milk. We computed associated nutritional requirements in terms of energy, protein and fiber. Moreover, other feeding constraints, e.g. daily intake capacity, were defined. The optimization model, finally, composed the feed ration.

For the pig production system, a PU comprised a fattening pig unit, including the associated rearing gilts and breeding sows. Per PU per year, 3.26 fattening pigs were slaughtered, producing 170 kg pork per year.

For the dairy production system, a PU comprised one milking cow, including associated young stock. A Dutch dairy cow PU produced on average 8120 kg milk (8586 kg FPCM; Fat and Protein Corrected Milk) and 141 kg meat per year (LEI 2013, PDV 2012) available for human consumption.
We assume no impact of ration composition on production parameters such as protein content in milk, dressing percentage and carcass quality.

2.3. Losses and waste

Losses and waste of arable and animal products were modelled on weight basis using Gustavsson et al. (2011) and Biewenga et al. (2009). These include losses in the feed chain during conservation and feeding, losses during transport and distribution, and waste by the consumer.

3. Results

The first findings of our analysis show the agricultural land area for diets varying in percentage of animal protein for various population sizes (Figure 1).

Diets containing no animal protein had slightly higher land use compared to diets that contained a modest amount (5-30%) of animal protein. This is due to the utilization by animals of products that cannot be consumed by humans, such as wheat straw and sugar beet molasses. At higher levels of animal protein, additional feed crops are produced, which results in increasing land use. Besides, with increasing percentage of animal protein, peat soils are taken into use for the production of grass for dairy cows.

The figure also shows that, at higher population numbers, a vegan diet cannot provide sufficient food to sustain the population. Crop production on clay and sandy soils does not produce sufficient protein for this large population size. Due to the utilization of peat soils by dairy cows, an extra number of people can be fed potentially.

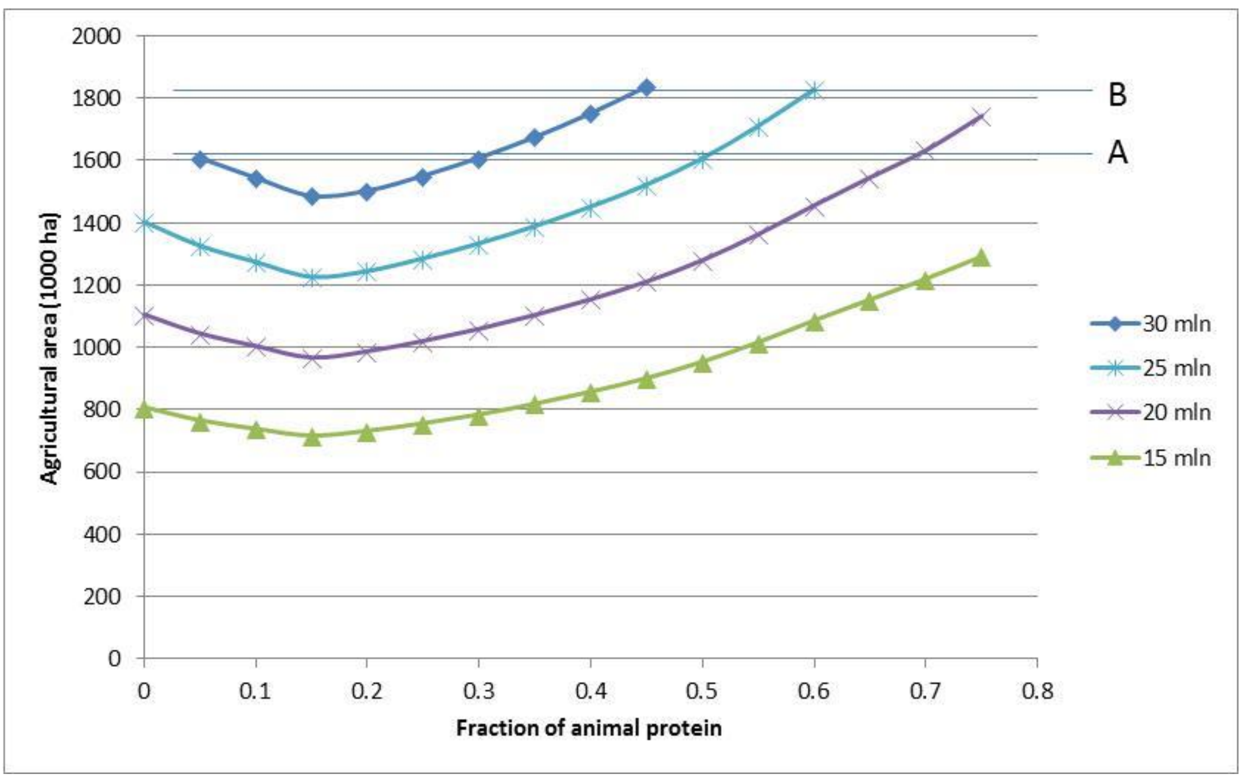

Figure 1. Agricultural land use (ha) in the Netherlands with increasing population, for diets differing in the amount of animal protein. The current Dutch population is 17 million. The Netherlands has around 1.8 x 10^6 hectares of agricultural land; we assumed no import of food. A: total agricultural area on clay and sandy soils. B: total agricultural area on clay, sand and peat soils.

4. Discussion

Our analysis was limited to land use. We did not consider economic effects of dietary choices. Besides, land area requirement is only one of many impact categories that should be accounted for when assessing overall sustainability of human diets. In the Netherlands, high crop yields partly result from high levels of inputs, which may reduce required land area at the cost of long-term sustainability in relation to, e.g., ecosystem services (Foley et al. 2005). Western diets contain in the order of 70% animal protein (Van Kernebeek et al. 2014). A reduction of animal consumption in affluent diets could help reducing land use, as well as greenhouse gas emissions (Hedenus et al. 2014).

Because we do not use allocation in our optimization model, it was not possible to express land use per kg of product or per kg of protein, as is often seen in literature (De Vries & De Boer 2010). However, we were able to compare land use of the diets with results from literature (Meier & Christen 2013, Terluin et al. 2013). Land use required for diets reported by Terluin et al. (2013) varied between 470 and 1000 m^2/capita/year. Land use required for diets reported by Meier and Christen (2013) varied between 1000 and more than 2000 m^2/capita/year. Land use required for diets in our study varied between about 500 and 1000 m^2/capita/year.

5. Conclusion

The ability of animals to utilize products that cannot be consumed by humans can help to reduce land use for food production. Moreover, utilization of land unsuitable for crop production, in our case peat soils, provides the opportunity to sustain a larger population compared to a situation in which these soils are not used to produce food.

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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