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How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030?

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ABSTRACT

Growing global population figures and per-capita incomes imply an increase in food demand and pressure to expand agricultural land. Agricultural expansion into natural ecosystems affects biodiversity and leads to substantial carbon dioxide emissions.

Considerable attention has been paid to prospects for increasing food availability, and limiting agricultural expansion, through higher yields on cropland. In contrast, prospects for efficiency improvements in the entire food-chain and dietary changes toward less land-demanding food have not been explored as extensively. In this study, we present model-based scenarios of global agricultural land use in 2030, as a basis for investigating the potential for land-minimized growth of world food supply through: (i) faster growth in feed-to-food efficiency in animal food production; (ii) decreased food wastage; and (iii) dietary changes in favor of vegetable food and less land-demanding meat. The scenarios are based in part on projections of global food agriculture for 2030 by the Food and Agriculture Organization of the United Nations, FAO. The scenario calculations were carried out by means of a physical model of the global food and agriculture system that calculates the land area and crops/pasture production necessary to provide for a given level of food consumption.

In the reference scenario – developed to represent the FAO projections – global agricultural area expands from the current 5.1 billion ha to 5.4 billion ha in 2030. In the faster-yet-feasible livestock productivity growth scenario, global agricultural land use decreases to 4.8 billion ha. In a third scenario, combining the higher productivity growth with a substitution of pork and/or poultry for 20% of ruminant meat, land use drops further, to 4.4 billion ha. In a fourth scenario, applied mainly to high-income regions, that assumes a minor transition towards vegetarian food (25% decrease in meat consumption) and a somewhat lower food wastage rate, land use in these regions decreases further, by about 15%.

1. Introduction

According to the Millennium Ecosystem Assessment (MEA, 2005), the most important direct driver of terrestrial ecosystem change during the past 50 years has been land cover change, in particular the conversion of ecosystems to agricultural land. Together with the adoption of new technologies and increased agricultural inputs, the expansion of agricultural land has enabled an extraordinary progress in nutrition levels and food security. Despite this, however, undernourishment still affects about 920 million people in low and medium-income regions (FAO, 2008).

Still-growing global population figures and per-capita incomes and the need to decrease undernourishment imply increased pressure on the global food supply system. This amplifies the risk of further expansion of agricultural land into forests and other land with high biodiversity values. In addition, if stringent policies aimed at curbing climatic change are implemented – by substantially increasing the cost of emitting carbon dioxide (CO_2) through taxes or emissions cap and trade schemes – demand for biomass for energy purposes is likely to increase dramatically (Gielen et al., 2003; van Vuuren et al., 2004).

Clearly, curbing food and bioenergy-driven agricultural expansion is critical to conserving natural ecosystems and global biodiversity. Limiting expansion, particularly conversion of forests into cropland and pastures, is also essential for mitigating global CO_2 emissions (Gitz and Ciais, 2004; Fargione et al., 2008; Burneya et al., 2010). Limiting the land area used for livestock production – which currently accounts for about 80% of total agricultural land use – is consequently considered a key approach in reducing livestock's environmental impact (Steinfeld et al., 2006).

There is considerable agreement that increasing yields on existing agricultural land, especially cropland, is a key component for minimizing further expansion (Waggoner, 1994; Goklany, 1998; Ausubel, 2000; Tilman et al., 2002; Cassman et al., 2003; Evans,

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2003; Balmford et al., 2005; Green et al., 2005; Lee et al., 2006; The Royal Society, 2009). There are, however, limitations and negative aspects of further intensification of the use of cropland. The potential for further sustained growth in crop yields is gradually diminishing in several main producer countries, mainly because the exploitable gap between average farm yields and the genetic yield potential is closing. Raising the genetic yield potential of major crops further appears difficult, and even maintaining current yield potentials may prove to be a challenge, as there are signs of intensification-induced declines of the yield potentials over time, related to subtle and complex forms of soil degradation (Cassman, 1999; Pingali and Heisey, 1999). Also, high crop yields depend on large inputs of nutrients, fresh water, and pesticides, and contribute to negative ecosystem effects, such as eutrophication (Tilman et al., 2002).

Besides intensification of cropland use, there are other major – but hitherto less investigated – options, including: (i) increasing the efficiency of the entire food-chain from ‘‘field to fork”, (ii) changing diets toward food commodities requiring less land, and iii) incrasing the yields and nutritive quality of permanent pastures, which globally amount to 3.5 billion ha – more than twice the area of the global croplands.

Very few studies have been undertaken that consistently address several of these topics. Studies addressing food wastage at the household and retail level are few, examples include Bender (1994), Kantor et al. (1997), Engström and Carlsson-Kanyama (2004) and WRAP (2008). Recent global studies of long-term development of animal food production and feed use include CAST (1999), Delgado et al. (1999), Bouwman et al. (2005), Keyzer et al. (2005), Steinfeld et al. (2006). Numerous studies have stressed the environmentally beneficial effects of changes in food consumption patterns, primarily in substituting vegetable for animal food – recent examples include Gerbens-Leenes and Nonhebel (2002), Smil (2002), Carlsson-Kanyama et al. (2003), de Boer et al. (2006), Elferink and Nonhebel (2007) and Stehfest et al. (2009).

The scenarios in the current study were developed to complement the projections to 2030 in the FAO's ‘‘World Agriculture: towards 2015/2030” (Bruinsma, 2003). The FAO study included comprehensive analyses of the prospects for increasing yields and production of cereals and other edible-type crops (sugar crops, oil crops, etc.). However, the FAO study did not include any projections of yield increases and production of permanent pasture and animal forage crops (grasses, etc.), nor of the total use and supply of livestock feed – only feed use of cereals and other edible-type crops was included.

The purpose of this study is to:

I. Complement the FAO projections for the year 2030 by estimating total feed and land requirements implicit in the projections, including estimates of feed supply from by-products/residues, forage crops, and permanent pastures, as well as area and yield of permanent pastures.
II. Estimate the potential until the year 2030 for minimizing agricultural expansion through means other than further intensification in cultivation:
   (a) accelerated growth in feed-to-food efficiency in animal food production
   (b) dietary changes toward less land-demanding animal and vegetable food
   (c) decreased wastage of food at retail and household levels.

In the following section, the model used for creating the scenarios is briefly described. In Section 3, we describe the foundations of the scenarios and the data and methodology used in creating them. Principal results from the scenarios are presented and considered in Section 4, and in Sections 5–6 we discuss the accuracy and relevance of the results, and what conclusions may be drawn from them.

2. Model description

The methodological basis for constructing the scenarios was a physical model of the global food and agriculture system, the ALBIO (Agricultural Land use and BIOmass) model. From a prescribed food consumption level, the ALBIO model calculates the land area and crops/pasture production necessary to provide for that level of food consumption. Major exogenous variables are food consumption, productivity in livestock and crop production, efficiency in food industry, trade, and use of by-products and residues for purposes of animal feeding, bedding, etc. Major endogenous variables are land use and crops and pasture production, as well as production of by-products and residues (e.g. straw, oil cakes, etc.) generated within the food and agriculture system. For each geographical region described, the model contains about 1700 parameters and about 170 physical flows.

There are in total eight regions in the model: West Europe, East Europe (including Russia), North America and Oceania, South and Central Asia, East Asia, Sub-Saharan Africa, Latin America and the Caribbean, and North Africa and West Asia. Trade of food and feedstuffs between these regions is represented in the model. Global trade flows are balanced, i.e. a net import to one region is met by an equally large net export from the other regions combined.

The representation of the plant biomass production comprises all major categories of terrestrial biomass used in the food system. In total about 30 crops and pasture systems are included, with separate descriptions of rainfed and irrigated production. Exogenous parameters in crop systems include yield and cropping intensity, and in pasture systems, yield and pasture utilization.

Production of animal food is represented by nine animal systems (cattle and buffalo milk and meat, sheep meat, goat meat, pork, eggs, and chicken meat). Feed energy requirements are calculated endogenously using standardized bio-energetic equations with basic biological parameters, such as live weight, live-weight gain, reproduction rate, mortality rate and milk/egg production rate, as exogenous parameters. The estimated feed energy requirements are fully met by feed matter intake. The model calculates the feed dry matter intake with feed ration specification (the share of each feedstuff in the ration) and energy content of each feedstuff used as exogenous parameters. The number of individual feedstuffs included in the specification varies from about 20 (chickens) to roughly 45 (pigs and ruminants).

Production of processed vegetable food is represented by 12 separate systems, including major cereal products (flours, rice, etc.), sugars, vegetable oils, and alcoholic beverages. Food use is represented by about 40 separate food commodities, and includes all principal food commodities consumed in each of the world regions.

For further details on the ALBIO model, see Wirsenius (2003a,b, 2008). A comprehensive description can be found in Wirsenius (2000, pp. 13–54). Please note that the model described in those publications refers to a previous and less comprehensive version, named the Food Phytomass Demand model. The major difference between the model versions is that, in contrast to the previous ones, the version used in this study includes explicit representation of land use.

3. Scenario rationale, data and methodological approach

3.1. Overview of scenarios and methodological approach

This section describes the scenarios and their rationale, with details on parameter values, data sources, and modeling