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Drivers for global agricultural land use change: The nexus of diet, population, yield and bioenergy

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ABSTRACT

The nexus of population growth and changing diets has increased the demands placed on agriculture to supply food for human consumption, animal feed and fuel. Rising incomes lead to dietary changes, from staple crops, towards commodities with greater land requirements, e.g. meat and dairy products. Despite yield improvements partially offsetting increases in demand, agricultural land has still been expanding, causing potential harm to ecosystems, e.g. through deforestation. We use country-level panel data (1961–2011) to allocate the land areas used to produce food for human consumption, waste and biofuels, and to attribute the food production area changes to diet, population and yields drivers. The results show that the production of animal products dominates agricultural land use and land use change over the 50-year period, accounting for 65% of land use change. The rate of extensification of animal production was found to have reduced more recently, principally due to the smaller effect of population growth. The area used for bioenergy was shown to be relatively small, but formed a substantial contribution (36%) to net agricultural expansion in the most recent period. Nevertheless, in comparison to dietary shifts in animal products, bioenergy accounted for less than a tenth of the increase in demand for agricultural land. Population expansion has been the largest driver for agricultural land use change, but dietary changes are a significant and growing driver. China was a notable exception, where dietary transitions dominate food consumption changes, due to rapidly rising incomes. This suggests that future dietary changes will become the principal driver for land use change, pointing to the potential need for demand-side measures to regulate agricultural expansion.

1. Introduction

A growing global population increases the need for food, fuel and shelter (Foley et al., 2011), whilst increasing wealth is resulting in changing food consumption patterns towards commodities that are more land intensive to supply (Delgado et al., 1999; Godfray et al., 2010; Kearney, 2010; Keyzer et al., 2005; Tilman et al., 2011 Weinzettel et al., 2013). The location of food production is changing, due to the globalisation of food supply and increasing international trade in agricultural commodities (D'Odorico et al., 2014; Erb et al., 2009; Fader et al., 2013; Meyfroidt et al., 2013). Demands for land unrelated to food production are also increasing, for example from bioenergy feedstock supply, urbanisation and non-provisioning ecosystem services, e.g. through protected areas (Lambin and Meyfroidt, 2011; Schröter et al., 2005). Greater demands for agricultural commodities can be met by intensification (improved yield by greater inputs, such as fertiliser, pesticides or water, and or changes to management practices), agricultural expansion, or both (Cassman, 1999; Johnson et al., 2014; Tilman et al., 2011). Improvements in agricultural yield have helped to mitigate the impact on these demands (Foley et al., 2011), but still land use change has occurred (FAOSTAT, 2014a). Negative environmental impacts can result from land use change or agricultural intensification, including greenhouse gas emissions, deteriorating soil quality, use of scarce water resources, and biodiversity loss (Smith et al., 2013). For example, since 1990 land

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use change is believed to be responsible for 10–20% of global CO_2 emissions (Houghton et al., 2012; Le Quéré et al., 2009).

Pasture forms the largest component of agricultural land globally, but, to date, research on agricultural land use—environment-food security nexus has focused disproportionately on the role of arable crops (Wirsenius et al., 2010). Permanent pasture accounted for 69% of agricultural land (26% of total land) in 2011, while arable was 28% of agricultural land (11% of total land) (FAOSTAT, 2014a). Permanent pasture is land used for five years or more to grow herbaceous forage crops, either cultivated or growing wild (FAOSTAT, 2014a), and therefore ranges from intensively managed grassland through to savannahs and prairies. In addition to pasture, land used in the production of animal products (meat, milk and eggs) is further increased by the use of crops for animal feed. Due to the lower efficiency of animal products compared to vegetal crops (Fairlie, 2010; Smil, 2002), 90% of food calories are supplied from cropland (Kastner et al., 2012). Attempts have been made to quantify the impact of closing the crop 'yield gap' (Foley et al., 2011; Kastner et al., 2014; West et al., 2014), the use of crops for animal feed (Kastner et al., 2012), and the potential increase in available food supply if the latter were diverted for human consumption (Cassidy et al., 2013; Foley et al., 2011). But, the entire food-chain including animal products and dietary changes have received less attention (Wirsenius et al., 2010), although more recently the need for food demand management has been suggested (Bajželj et al., 2014; Tilman and Clark, 2014). There is also considerable debate about the true impact of the emerging demand for agricultural commodities as a bioenergy feedstock on food prices and volatility (Eide, 2008; Mitchell, 2008; Rathmann et al., 2010; Slade et al., 2011), and the level of indirect land use change (Haberl et al., 2012; Searchinger et al., 2008). However, work has not been conducted to investigate and compare the impact on the agricultural land use, including pasture, from additional demand, due to population and dietary change and from demand from bioenergy feedstocks.

Here, we address the lack of analysis by quantifying the impact from the consumption of animal products relative to other drivers of land use change, including bioenergy. We attempt to answer the following questions: How much land and land use change has been associated with the production of animal products and vegetal crops for human consumption, waste and biofuels? What has been the relative importance of population, diet and yield as drivers for agricultural land use change? How does land use change and its drivers differ between countries and regions? The methodology followed is similar to Kastner et al. (2012), with a number of important advances including; consideration of the pasture area, identifying bioenergy and waste uses, and a more spatially disaggregated analysis. Perhaps most notably is the inclusion of pasture area, which provides a far more comprehensive insight into the agricultural sector as a whole, the importance of which is emphasised by the pivotal role of animal products in the results.

2. Materials and methods

The analysis uses FAO data from 1961 to 2011 to determine the land used to produce each commodity consumed, including land displacement through international trade, i.e. the domestic area used to produce a commodity consumed is notionally increased for net importing countries, or decreased for net exporting countries. The land used for animal products includes both pasture for grazing, and the area harvested to cultivate the animal feed consumed. Land displacement was considered in both the supply of animal feed, and in the trade of animal products. A decomposition analysis was performed to investigate the impact of population, diet and yield as drivers for change in land allocated to food production, for each commodity and country.

2.1. Data sources

The primary data source used was FAO data on agricultural production, commodity balance, and land use between 1961 and 2011 at a country level (FAOSTAT, 2014a,b,c,d,e, 2013). The unprocessed data covers 219 countries in 2011, and provides production values for 182 crop plus 57 livestock types. The commodity balance data provides an itemisation of the consumption of each item, and as well as the quantity of production, stock variation, imports and exports that provide that supply. The animal feed conversion ratio, i.e. the efficiency of the production of animal products, was estimated from various sources (FAO, 2014, 2009; Little, 2014; SAC Consulting, 2013; Smil, 2002). The analysis was conducted at country level, in R (R Core Team, 2014) with Rworldmap used to produce global maps of results using associated geographic data (South, 2011).

2.2. Joining production and consumption data

The dataset for crop production and consumption use different categorisation for crops and commodities. Consumption categories were mapped onto the agricultural commodity used, to allow them to be associated with the harvested areas. A few products were a trivial one-to-one mapping, e.g. bananas and oats; some others required multiple production categories to be mapped onto one category of consumption. For example consumption of "Oranges Mandarines" were mapped onto two items of production, "Oranges" and "Tangerines mandarins clementines satsumas". In the case of the "Vegetables Other" consumption was mapped onto the production of 34 crops. Rice was handled in paddy equivalent terms, and sugarcane in unrefined form, as consumption data was given in multiple unit (e.g. refine, unrefined and raw equivalent). The outcome was 51 consumption types, mapping onto one or more crop production items.

2.3. Displacement of land

To understand the full extent of land used in the production of commodities consumed, the import and export of goods needs to be considered. Land displacement has been defined as the migration of activities to another place, causing land change in the other location (Lambin and Meyfroidt, 2011, Weinzettel et al., 2013). Here we follow an approach similar to Yu et al. (2013), where the consumption of embodied land used to produce a commodity is used to measure land displacement. The imported or exported land area is then combined with the area for domestic production, to obtain a net land use, for that commodity, country and year. When calculating the displaced land, the areas associated with net imports are considered to occur at the global mean yield of exports, weighed by net export quantity. Net exports are taken as domestically produced, to reduce that country's land allocation on a proportional basis.

2.4. Crop consumption types

The category of consumption, for each crop commodity and country, was allocated between four categories; food for human consumption, animal feed, bioenergy and waste, based on FAO data (FAOSTAT, 2014b,c). The four categories were mapped from the 6 types of consumption in the FAO data, i.e. food, feed, waste, processing, seed and other. The FAO defines the food, as the quantity available for human consumption, feed as the amount fed to animals, and waste as the losses in transport and storage prior to reaching the consumer. Theses were allocated to the categories used for food for human consumption, animal feed and waste, respectively. The processing type is also assumed to be used for