Global Food Security xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Could consumption of insects, cultured meat or imitation meat reduce global agricultural land use?

Peter Alexander[a,b,*], Calum Brown[a], Almut Arneth[c], Clare Dias[a], John Finnigan[d], Dominic Moran[b,e], Mark D.A. Rounsevell[a]

[a] School of Geosciences, University of Edinburgh, Drummond Street, Edinburgh EH8 9XP, UK
[b] Land Economy and Environment Research Group, SRUC, West Mains Road, Edinburgh EH9 3JG, UK
[c] Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU), Kreuzeckbahnstr. 19, 82467 Garmisch-Partenkirchen, Germany
[d] The Centre for Australian Weather and Climate Research – A partnership between CSIRO and the Bureau of Meteorology, CSIRO Marine and Atmospheric Research, Canberra, Australia
[e] Environment Department, University of York, York YO10 5NG, UK

A R T I C L E I N F O

Keywords:
Land use
Animal products
Livestock
Dietary change
Entomophagy
Cultured meat

A B S T R A C T

Animal products, i.e. meat, milk and eggs, provide an important component in global diets, but livestock dominate agricultural land use by area and are a major source of greenhouse gases. Cultural and personal associations with animal product consumption create barriers to moderating consumption, and hence reduced environmental impacts. Here we review alternatives to conventional animal products, including cultured meat, imitation meat and insects (i.e. entomophagy), and explore the potential change in global agricultural land requirements associated with each alternative. Stylised transformative consumption scenarios where half of current conventional animal products are substituted to provide at least equal protein and calories are considered. The analysis also considers and compares the agricultural land area given shifts between conventional animal product consumption. The results suggest that imitation meat and insects have the highest land use efficiency, but the land use requirements are only slightly greater for eggs and poultry meat. The efficiency of insects and their ability to convert agricultural by-products and food waste into food, suggests further research into insect production is warranted. Cultured meat does not appear to offer substantial benefits over poultry meat or eggs, with similar conversion efficiency, but higher direct energy requirements. Comparison with the land use savings from reduced consumer waste, including over-consumption, suggests greater benefits could be achieved from alternative dietary transformations considered. We conclude that although a diet with lower rates of animal product consumption is likely to create the greatest reduction in agricultural land, a mix of smaller changes in consumer behaviour, such as replacing beef with chicken, reducing food waste and potentially introducing insects more commonly into diets, would also achieve land savings and a more sustainable food system.

1. Introduction

Livestock provides a quarter of all the protein (and 15% of energy) consumed in food, but also creates substantial environmental impacts (FAO, 2012; Herrero et al., 2016). The area of global pasture is more than twice that of cropland, with livestock animals additionally consuming around a third of the crops harvested as feed (FAO, 2006). Despite rises in crop yields and in the efficiency of livestock production, global agricultural land area has been expanding, increasing by 464 Mha between 1961 and 2011 (Alexander et al., 2015). Land use change in recent decades has accounted for 10–12% of total anthropogenic carbon dioxide emissions, and a third since 1850 (Houghton et al., 2012; Le Quéré et al., 2015). Livestock production also contributes to atmospheric greenhouse-gas (GHG) emissions, due to methane from enteric fermentation (presently 2.1 Gt CO_2 eq year^{-1} (Gerber et al., 2013)), and nitrous oxide emissions from fertiliser use on pasture and croplands in fodder production (Smith et al., 2014). In total, livestock is responsible for 12% of global anthropogenic GHG emissions (Havlík et al., 2014). A larger global population consuming a diet richer in meat, eggs and dairy (Kearney, 2010; Keyzer et al., 2005; Popkin et al.,

* Corresponding author at: School of Geosciences, University of Edinburgh, Drummond Street, Edinburgh EH8 9XP, UK.
E-mail address: peter.alexander@ed.ac.uk (P. Alexander).

http://dx.doi.org/10.1016/j.gfs.2017.04.001
Received 13 January 2017; Received in revised form 29 March 2017; Accepted 8 April 2017

1999; Tilman et al., 2011) has meant that agricultural land use change in the past 50 years has been dominated by the expansion of livestock production (Alexander et al., 2015). Besides the direct GHG emissions, agriculture also has large indirect emissions (e.g. from agrochemicals production and fossil fuel used) (Smith and Gregory, 2013). The combination of land use change and other emissions increases the share of agriculture in all global anthropogenic GHG emissions to between 17% and 32% (Smith and Gregory, 2013). Therefore, changing demands on agricultural production, and in particular for animal products (i.e. meat, milk and eggs), has the potential to substantially alter GHG emissions (Bustamante et al., 2014; Havlík et al., 2014). Additionally, the sparing of agricultural land provides options for further climate change mitigation measures, including afforestation or bioenergy (Humpenöder et al., 2014).

The projected rise in global population and higher per capita rates of animal product consumption, arising from higher incomes and urbanisation, suggests that livestock production will continue to increase (Tilman et al., 2011). Changes in production practices and animal genetics that increase efficiencies may help to offset some of the potential land use and associated environmental impacts (Havlík et al., 2014; Le Cotty and Dorin, 2012). Nevertheless, demand-side measures to reduce animal product consumption may be necessary to meet climate change targets (UNFCC, 2015), while helping to achieve food security (Bajželj et al., 2014; Lamb et al., 2016; Meadu et al., 2015; Smil, 2013). High levels of meat consumption are also detrimental to human health, with links to obesity, cardiovascular diseases and cancer (Bouvard et al., 2015; Hu, 2011; NCD Risk Factor Collaboration, 2016; Popkin and Gordon-Larsen, 2004). Despite both the health and environmental benefits, changing consumer preferences towards a low meat diet is difficult because of cultural, social and personal associations with meat consumption (Graça et al., 2015; Macdiarmid et al., 2016). Although there is some evidence for increasing rates of vegetarianism and reduced meat diets in western countries (Leahy et al., 2011; Vinnari et al., 2010), the global average per capita rate of animal product consumption has continued to increase (FAOSTAT, 2015a).

Studies of the food system that include the impact of dietary change typically assume the continuation of existing consumption patterns and income and price elasticity relationships (e.g. Engström et al., 2016a, 2016b; Schmitz et al., 2014; Tilman et al., 2011), implicitly discounting the possibility of major shocks or transformative changes in diets. There has also been an increasing number of studies considering the impact of alternative assumptions regarding future diets, such as lower animal product consumption, healthy diets, vegetarianism or veganism, e.g. (Bajželj et al., 2014; Erb et al., 2016; Haberl et al., 2011; Mora et al., 2016; Popp et al., 2010; Stehfest et al., 2009).

However, technology changes or radical alteration of consumer preferences, which could be transformative for the food system, remain unexplored. New technologies raise the possibility of supplying high quality food from novel sources, e.g. cultured meat, also known as in vitro meat (Thornton, 2010). Also, behaviour, preferences and social norms change over time, such that food previously considered unacceptable or undesirable (e.g. insects, in western countries) could become a more common part of future diets (van Huis, 2013). There are historical precedents for foods becoming acceptable after long periods of rejection; for example, tomatoes in Britain were widely viewed with suspicion and dismissed for over 200 years (Bir, 2014; K. A. Smith, 2013). Similarly, lobster in America was initially a poverty food eaten by slaves and prisoners, and used as fertiliser and fish bait, due to their abundance (Dembosky, 2006). It wasn't until the late nineteenth century that lobster developed a status as a luxury food, supported by the expansion of the US railway network giving access to new markets (Townsend, 2012). But while alternative food sources may become technologically feasible or publically acceptable in the future, their potential contributions to sustainability remains unclear.

This study addresses this research gap by reviewing and comparing the potentially transformative alternatives to conventional animal products, including cultured meat, imitation meat and insects, and consider the implications for global agricultural land use requirements given widespread adoption. The approach is explorative, rather than predictive, and assumes half of existing animal products are substituted by each alternative food, to provide at least equal energy and protein. The objective is to compare the alternatives on an equal basis and to assess their potential to reduce agricultural land requirements, and contribute to food system sustainability. To allow comparison with more typical dietary change, several other scenarios were also included using the same methodology. These scenarios include shifts in conventional animal product consumption, changes to high and low animal product diets (based on average consumption in India and the USA), and reductions in consumer waste. The focus is on animal products due to their dominance in the food system for land use and environmental impacts (Herrero et al., 2016), and because of their relative inefficiency in converting inputs into human-edible food (FAO, 2006; Mottet et al., 2017). The premise is that due to the cultural and personal associations with animal product consumption (Graça et al., 2015; Macdiarmid et al., 2016), consumers with higher incomes continue to eat large quantities of animal products and consumers currently eating at lower rates will increase their consumption as incomes increase. This assumption combined with population growth, also underlies the projections of substantial increases (from 76% to 133%) in global animal product demand (Alexandratos and Bruinsma, 2012; Bodirsky et al., 2015). Therefore, alternatives that mimic aspects of these products in a manner that is acceptable to consumers need to be explored for environmental sustainability.

2. Alternatives to current animal products

There are several alternatives to existing animal products as food protein and energy sources:

2.1. Insects

Edible insects have the potential to become a major source of human nutrition, and can be produced more efficiently than conventional livestock, i.e. in terms of converting biomass into protein or calories (Tabassum-Abbasi and Abbasi, 2016; van Huis, 2013). They are high in fat, protein and micronutrients (Persijn and Charrondiere, 2014; Rumpold and Schlüter, 2013), and can be produced with lower levels of GHG emissions and water consumption (van Huis, 2013). The efficiency of insects to convert feed into edible food is in part due to the higher fraction of insect consumed (up to 100%), compared to conventional meat (e.g. 40% of live animal weight is consumed with cattle). Insects are poikilothermic, so they do not use their metabolism to heat or cool themselves, reducing energy usage. They tend to have higher fecundity than conventional livestock, potentially producing thousands of offspring (Premalatha et al., 2011). Efficiency is also increased by rapid growth rates and the ability of insects to reach maturity in days rather than months or years.

Isotope analysis of bones indicates that insectivorous diets are entrenched in human evolution (De-Magistris et al., 2015; Ramos-Elorduy, 2009), and a variety of species are currently consumed (> 2000 species (Rumpold and Schlüter, 2013)) across many regions of the world (119 countries (Rumpold and Schlüter, 2013)). But issue of limited consumer acceptability is prevalent particularly in western countries. These are also the countries with high animal product consumption rates per capita, and are therefore where a switch from animal product to insect consumption would have the greatest impact. There are already signs that consumer attitudes in developed countries such as the USA and the UK may be starting to change (Jamieson, 2015), and there may be less of a barrier to including insect-derived materials in other products, for example in powdered form (Little, 2015). However, in some jurisdictions, there are legal barriers. For