Proceedings of the Nutrition Society (2015), **74**, 187–190 doi:10.1017/S0029665114001517

First published online 16 October 2014

The Nutrition Society Summer Meeting 2014 was held at the University of Glasgow on 14–17 July 2014

Conference on 'Carbohydrates in health: friends or foes'
Plenary Lecture 1: Boyd Orr Lecture

Malthus is still wrong: we can feed a world of 9–10 billion, but only by reducing food demand

Pete Smith
Scottish Food Security Alliance-Crops & Institute of Biological and Environmental Sciences, University of Aberdeen, 23 St Machar Drive, Aberdeen AB24 3UU, UK

In 1798, Thomas Robert Malthus published 'An essay on the principle of population' in which he concluded that: 'The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race.' Over the following century he was criticised for underestimating the potential for scientific and technological innovation to provide positive change. Since then, he has been proved wrong, with a number of papers published during the past few decades pointing out why he has been proved wrong so many times. In the present paper, I briefly review the main changes in food production in the past that have allowed us to continue to meet ever growing demand for food, and I examine the possibility of these same innovations delivering food security in the future. On the basis of recent studies, I conclude that technological innovation can no longer be relied upon to prove Malthus wrong as we strive to feed 9–10 billion people by 2050. Unless we are prepared to accept a wide range of significant, undesirable environmental consequences, technology alone cannot provide food security in 2050. Food demand, particularly the demand for livestock products, will need to be managed if we are to continue to prove Malthus wrong into the future.

Food security: Food production: Dietary change: Food demand: Agriculture

'An essay on the principle of population' was published in 1798 by Thomas Robert Malthus. In that essay, Malthus concluded that: 'The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race'[1]. Over the following century this conclusion was criticised, with Karl Marx one of his notable critics[2], and was further criticised for underestimating the potential for scientific and technological innovation to provide positive change. 'Malthus bashing' has been a popular sport ever since, with a number of papers published during recent decades pointing out why he has been proved wrong so many times, e.g.[3]. In this short paper, I briefly review the main changes in food production in the past that have allowed us to continue to meet ever growing demand for food, before examining the possibility of similar innovations delivering food security in the future.

The challenge of feeding 9–10 billion people by 2050

Feeding 9 billion people by 2050 presents an enormous challenge[4]. A number of options have been proposed, making the difference between the attainable yield and that actually realised smaller (i.e. including closing the yield gap), increasing the production potential of crops through investment in research and the use of new technologies), expanding aquaculture, reducing waste or changing diets, all of which would need to be coordinated globally[4].

As outlined by Smith & Gregory[5], at the same time as delivering food security, there is a pressing need to

Corresponding author: Professor Pete Smith, fax +44 (0)1224 272703, email pete.smith@abdn.ac.uk

decrease the climate impact of food production[6], and to improve the resilience of food production to future environmental change[7]. Non-climate-related needs include the need to protect our freshwater resource[8], protect biodiversity[9], move towards healthier diets[10], and to reduce the adverse impacts of food production on a whole range of ecosystem services[11]. In the following sections, I briefly outline how food production has increased to meet demand in the past, before examining how this might be achieved in the future.

How food production has increased to meet increasing demand in the past

Historically, in the era before industrial fertilisers, producing more food largely meant converting more land to agriculture. Historically, the expansion of agriculture into forests and natural ecosystems[12] has contributed significantly to the loss of ecosystem services. Much of this loss of forest and other natural systems had occurred many centuries ago in Europe, East Asia, South Asia and parts of Africa, but has occurred more recently in North America and the populated parts of Oceania. Ramankutty & Foley[13] produced maps showing the expansion of cropland area from 1700 to 1992, showing both the spread of cropland (the spread from east to west in North America is particularly apparent) and its intensification in all regions. Before about 1900, agricultural expansion was the most prominent way to increase food production, but after the advent of industrial mineral fertilisers[14], it was possible to also dramatically increase productivity on the same land. Even with productivity (output per unit area) increasing, the spread of agricultural land onto native ecosystems was still clearly visible across North America and South America in 1900–1940, in the former Soviet Union 1940–1960 and South East Asia 1980–1990. Expansion in some regions, particularly South East Asia continues to this day. Despite this expansion of agricultural land, the main increase in production since 1960 has been through increased yields per unit area, characterised by the 'Green Revolution' in the USA in the 1940s followed in developing countries over the following decades[15]. Cereal production (wheat, maize and rice) has increased from 877 million t in 1961 to 2342 million t in 2007, the world average cereal yield has increased from 1·35 t/ha in 1961 to 3·35 t/ha in 2007, and is projected to be about 4·8 t/ha in 2040. Simultaneously, per-capita arable land area has decreased from 0·415 ha in 1961 to 0·214 ha in 2007[16]. Had the increases in yield of the last 60–70 years not been achieved, almost three times more land would have been required to produce crops to sustain the present population; this is land that simply does not exist or that is unsuitable for cropping[5].

So intensification has been essential, but has resulted in many undesirable outcomes, including air, water and soil pollution[17] with agrochemicals and surplus nutrients, increased climate forcing[18], resources depletion[19], high fossil energy inputs[14] and habitat/biodiversity loss[11].

During the past century, then, while agricultural area expansion has continued, the emphasis for increasing food production has shifted towards intensification, i.e. the increased production of agricultural products per unit area, but this intensification has come at a cost to the environment. The environmental costs of future intensification, if implemented in the same way, would be too great, meaning that future intensification needs to be sustainable[20,21]. In the next section, I examine if sustainable intensification could, by itself, again prove Malthus wrong, as agricultural expansion has done over centuries, and intensification did over the past 7–8 decades.

Can sustainable intensification deliver food security by 2050?

As noted in the section 'Can sustainable intensification deliver food security by 2050?', increased income and changes in diet have been accompanied by substantial increases in crop and animal production (2·7-fold for cereals, 1·6-fold for roots and tubers and 4·0-fold for meat[22]). Bruinsma[12] estimated that 78 % of the increase in crop production between 1961 and 1999 was attributable to yield increases, and 22 % to expansion of harvested area. Of the world's 13·4 billion ha land surface, about 3 billion ha is suitable for crop production[12] and about one-half of this is already cultivated (1·4 billion ha in 2008). The remaining, potentially cultivatable, land is currently beneath tropical forests, so conversion to agriculture is highly undesirable because of the effects on biodiversity conservation, greenhouse gas emissions, regional climate and hydrological changes, and because of the high costs of providing the requisite infrastructure[16,23]. According to these projections[12], expansion of agricultural area will still contribute significantly to crop production in Sub-Saharan Africa (27 %) and Latin America and the Caribbean (33 %), but there is practically no land available for expansion of agriculture in South and East Asia and the Near East/North Africa sustainable intensification is expected to be the main means of increasing production in these regions[5]. Smith[21] provided an overview of the options for sustainable intensification, and concluded that it had an essential role to play, but speculated that alone, it could not deliver food security by 2050. Studies have shown the importance of demand-side measures[24–26]. Recently, a new study has quantified the potential role of sustainable intensification in meeting global food requirements, and it showed that sustainable intensification alone cannot deliver food security; demand management appears to be essential[27]. Bajželj *et al.*[27] found that delivering more food for 2050 by sustainable intensification, through yield gap closure, could reduce baseline cropland area, forest area loss, total greenhouse gas emissions and water use relative to a baseline of current yield trend, but would still lead to expanded agricultural area. The addition of demand-side options (healthy diet, plus waste reduction by 50 %) could deliver enough food but also allowed a decrease

https://doi.org/10.1017/S0029665114001517 Published online by Cambridge University Press

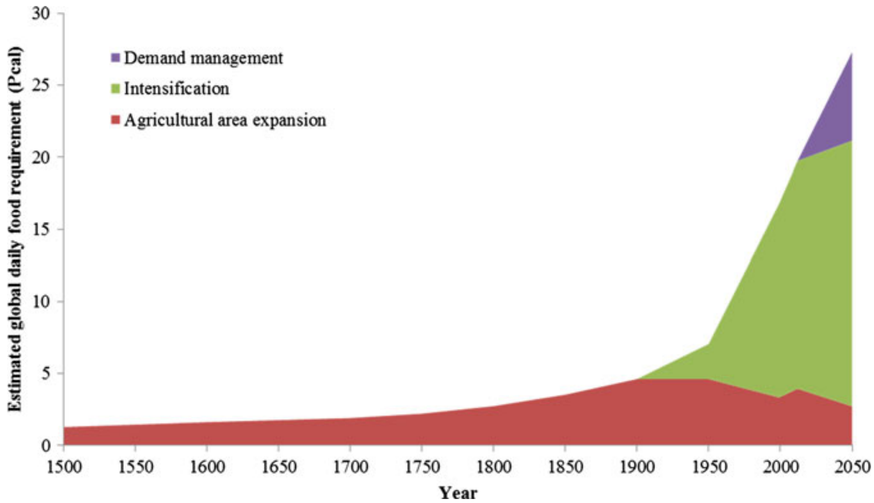

Fig. 1. Schematic representation of how agricultural area expansion, intensification and demand change have contributed to increased global daily food requirement in the past, and might do so in the future. Approximate global daily food requirement was calculated by multiplying total global population[29] (linear interpolation between dates; 1500, 1600, 1700, 1750, 1800, 1850, 1900, 1950, 1999, 2008, 2010, 2012, 2050) by the mean global per-capita food consumption for 1997–1999 of ~11715·2 kJ (2800 kcal) per capita per d[30]. Estimated global daily food requirement values are shown in Peta calories (Pcal = 10^{15} cal). Agricultural expansion was assumed to be responsible for meeting additional demand until industrial fertilisers became available, with the relative contribution of expansion assumed to decline to 22 % by 1999[12], and intensification through industrial fertilisation, irrigation and mechanisation becoming the dominant means to meet growing demand. The future failure of intensification to meet increasing food demand to 2050 is demonstrated by Bajželj *et al.*[27], but the relative contribution of demand management and intensification in the future remains unquantified, and should be viewed as schematic rather than quantitative.

of cropland and pasture area, an increase in forest area and a reduction in greenhouse gas emissions, not just relative to the baseline, but also in absolute terms compared with the present. The addition of demand-side options provided better environmental outcomes across all indicators (except for a light increase in fertiliser use) relative to the current yield trend baseline. They concluded that improved diets and decreases in food waste are essential to deliver emissions reductions and to provide enough food for the global population of 2050[27].

Conclusions

Malthus has been proved wrong many times since his essay in 1798. Between the time of his essay and the advent of industrial fertilisers, the predominant means of increasing food production was to expand the agricultural area. In some regions, this expansion continues, though its contribution to increased food supply accounted for only about 22 % between 1961 and 1999[12]. Since industrial fertilisers became available in about 1900, increasing per-area productivity allowed agricultural intensification, providing more agricultural output per unit area. Coupled with increased mechanisation and other scientific and technological developments, intensification became the dominant force in increasing food supply, particularly after the Second World War. That intensification came at the cost of a range of adverse environmental outcomes, and future increases in agricultural output will need to be through sustainable intensification. Sustainable intensification will be able to deliver a portion of the increased food supply required by 2050, but recent studies suggest that, by itself, will not be able to deliver food security. Instead, food demand will need to be managed, particularly with respect to the consumption of livestock products, and through reduced waste. We will prove Malthus wrong again and feed 9–10 billion people by 2050, but this time it will not be technology alone that allows us to do so. This time we will need to manage demand, as we are already pushing at the limits of a number of planetary boundaries, which we cannot sustainably exceed[28]. Fig. 1 provides a schematic representation of the different means by which we have proved Malthus wrong in the past, and a projection of how we might do so in the future.

We are leaving the era where technology can deliver our ever increasing levels of consumption, and are entering one where will need to start managing our demand. This will no doubt be politically and socially more challenging than developing techno-fixes, but is essential if we are to continue to prove Malthus wrong without wrecking our planet for future generations.

Acknowledgements

The paper was prepared for The Nutrition Society Annual Meeting: 'Carbohydrates in Health: Friends or Foes' held at the University of Glasgow in July 2014. This work contributes to the Scottish Food Security Alliance-Crops, the University of Aberdeen's Environment and Food Security Theme, and to Scotland's ClimateXChange.

Financial Support

This paper was prepared for the Nutrition Society Annual Meeting 2014 and travel and subsistence support was provided by the Nutrition Society.

Conflicts of Interest

None.

Authorship

P. S. is the sole author.

References

1. Malthus TR (1798) *An Essay on the Principle of Population*. London: J. Johnson. 125 pp. Available at: http://www.esp.org/books/malthus/population/malthus.pdf (accessed 27 August 2014).
2. Marx K (1867) *Capital. Volume 1*. First English edition from 1887. Available at: https://www.marxists.org/archive/marx/works/download/pdf/Capital-Volume-I.pdf (accessed 27 August 2014).
3. Trewavas A (2002) Malthus foiled again and again. *Nature* **418**, 668–670.
4. Godfray HCJ, Beddington JR, Crute IR *et al*. (2010) Food security: the challenge of feeding 9 billion people. *Science* **327**, 812–818.
5. Smith P, Gregory PJ (2013) Climate change and sustainable food production. *Proc Nutr Soc* **72**, 21–28.
6. Smith P, Martino D, Cai Z *et al*. (2008) Greenhouse gas mitigation in agriculture. *Phil Trans R Soc B* **363**, 789–813.
7. Smith P, Haberl H, Popp A *et al*. (2013) How much land based greenhouse gas mitigation can be achieved without compromising food security and environmental goals?. *Glob Change Biol* **19**, 2285–2302.
8. Frenken K & Kiersch B (2011) *Monitoring agricultural water use at country level. Experiences of a pilot project in Benin and Ethiopia*. FAO Land & Water Discussion Paper 9. Rome: Food and Agriculture Organisation, Rome. Available at: http://www.fao.org/nr/water/docs/FAO_LW_Discussion_Paper_9.pdf (accessed 27 August 2014).
9. Food and Agriculture Organisation (2010) *Final document: International Scientific Symposium Biodiversity and Sustainable Diets: United against Hunger*. 3–5 November 2010, Rome: Food and Agriculture Organisation.
10. World Health Organization (2004) *Global Strategy on Diet, Physical Activity and Health*. Rome: World Health Organization. Available at: http://www.who.int/dietphysicalactivity/strategy/eb11344/en/ index.html (accessed 27 August 2012).
11. Firbank L, Bradbury R, Jenkins A *et al*. (2011) Enclosed farmland [chapter 7]. In: *UK National Ecosystem Assessment. Understanding nature's value to society. Technical Report*, pp. 197–239. Cambridge: UNEP-WCMC.
12. Bruinsma J (editor) (2003) *World Agriculture: Towards 2015/2030, an FAO Perspective*. London: Earthscan Publications.
13. Ramankutty N, Foley JA (1999) Estimating historical changes in global land cover: croplands from 1700 to 1992. *Glob Biogeochem Cycles* **13**, 997–1027.
14. Erisman JW, Sutton MA, Galloway J *et al*. (2008) How a century of ammonia synthesis changed the world. *Nat Geosci* **1**, 636–639.
15. Brown LR (1969) *Seeds of Change. The Green Revolution and Development in the 1970's*. London: Pall Mall Press. 205pp.
16. Smith P, Gregory PJ, van Vuuren D *et al*. (2010) Competition for land. *Phil Trans R Soc B* **365**, 2941–2957.
17. Smith P, Ashmore M, Black H *et al*. (2013) The role of ecosystems and their management in regulating climate, and soil, water and air quality. *J Appl Ecol* **50**, 812–829.
18. Reay D, Davidson EA, Smith K *et al*. (2012) Global agriculture and nitrous oxide emissions: challenges of estimation, projection and mitigation. *Nat Clim Change* **2**, 410–416.
19. Cordell D, Drangert J-O, White S (2009) The story of phosphorus: global food security and food for thought. *Glob Environ Change* **19**, 292–305.
20. Garnett T, Appleby MC, Balmford A *et al*. (2013) Sustainable intensification in agriculture. *Science* **341**, 33–34.
21. Smith P (2013) Delivering food security without increasing pressure on land. *Glob Food Secur* **2**, 18–23.
22. Foresight (2011) *The Future of Food and Farming. Final Project Report*. London: The Government Office for Science.
23. Gregory PJ, George TS (2011) Feeding nine billion: the challenge to sustainable crop production. *J Exp Bot* **62**, 5233–5239.
24. Stehfest E & Bouwmann L, van Vuuren D *et al*. (2009) Climate benefits of changing diet. *Clim Change* **95**, 83–102.
25. Wirsenius S, Azar C & Berndes G (2010) How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? *Agric Syst* **103**, 621–638.
26. Popp A, Lotze-Campen H & Bodirsky B (2010) Food consumption, diet shifts and associated non-CO_2 greenhouse gases from agricultural production. *Glob Environ. Change* **20**, 451–462.
27. Bajželj B, Richards KS, Allwood JM *et al*. (2014) Importance of food-demand management for climate mitigation. *Nat Clim Change* **4**, 924–929. doi:10.1038/nclimate2353.
28. Rockström J, Steffen W, Noone K *et al*. (2009) A safe operating space for humanity. *Nature* **461**, 472–475.
29. United Nations (2008) *World Population Prospects. The 2008 Revision. Highlights*. Available at: http://www.un.org/esa/population/publications/wpp2008/wpp2008_highlights.pdf (accessed 27 August 2014).
30. World Health Organization (2014) *Global and Regional Food Consumption Patterns and Trends*. Available at: http://www.who.int/nutrition/topics/3_foodconsumption/en/ (accessed 27 August 2014).

https://doi.org/10.1017/S0029665114001517 Published online by Cambridge University Press