How to use the global land bank to both produce food and conserve nature: examining extensive vs intensive agriculture

TG Benton, AJ Dougill, EDG Fraser[1] & DJB Howlett

Africa College Partnership

Faculty of Biological Sciences

University of Leeds

LS2 9JT

t.g.benton@leeds.ac.uk

[1] Current address:
Department Geography
University of Guelph
Guelph, ON, N1G 2W1
Canada

Summary

The world is facing unprecedented long term pressures on food and agricultural systems. Increasing production will be necessary to help meet demand but this must be undertaken sustainably, with a minimum of environmental and social impacts. "Sustainable" farming is often equated with less intensive (i.e. extensive or organic) approaches that can be locally beneficial to the environment but typically also reduce yields and, therefore, make the challenge of increasing production more acute. To explore this we can conceptualise agricultural landscapes as systems that produce two products: agricultural yield and ecosystem services (which may relate to biodiversity, water, carbon storage or environmental health). Assuming that food production needs to be increased, and that extensive farming yields less, but has a lower local environmental impact, leads to two strategies: farm extensively over a large area to produce both food and ecosystem services on the same land ("land sharing"), or farm intensively over a smaller area and use the excess land to provide ecosystem services and conserve biodiversity ("land sparing"). Recent research indicates when the extra land needed to maintain yields under extensive systems is taken into account, land sparing involving intensive systems may be the best way to produce both food, maintain ecosystem services and reduce environmental impact. This conclusion is reinforced by research that suggests intensive agriculture will need to reduce net green house gas emissions by using more ecological practices as we move to a low carbon world. This should reduce the conflict between intensive and extensive systems and help align production and environmental goals to achieve sustainable agriculture.

Introduction

The world's population is predicted to increase by 35% by 2050 (UNDP 2008), and, at the same time per capita food demand is raising, partly because as individual wealth increases consumption increases especially of meat and dairy products leading to increased demand for land and water resources. These two factors, population growth and increased consumption, mean that globally demand for food will increase at a greater rate than population growth. Although there are uncertainties in these projections, the most widely cited prediction comes from the FAO who calculated that 70% more food will be required by 2050 (Bruinsma 2009).

Currently, pests, diseases and post-harvest losses account for a significant waste of the global harvest and although Parfitt et al. (2010) conclude that while there is little useful data on actual post-harvest losses the amount of food wasted is likely to be high. For example, they estimate that 15% of China's rice harvest is lost due to poor storage and inefficient processing. As a result, many suggest there is scope for a considerable part of the solution to come from improving efficiency (Smil 2001). Furthermore, any behavioural change (e.g. reduced consumption of meat and dairy: see Godfray et al. 2010) will also reduce demand. Nonetheless, many argue that to meet projected demand, global food production will need to continue to increase at rates similar to those of the last two decades (Foresight 2011).

As demand is increasing, three factors limit productivity: land use change, climate change, and the need to reduce fossil fuel based inputs in farming. Land use change arises from a number of causes (Holmgren et al., 2006): urbanisation is changing the relationship between society and the land, not least as rural populations are often decreasing, reducing access to labour capital and transport and leading to changes in agricultural practice. In particular, many in African rural societies are asking "where is the life in farming?" and are shifting their livelihood choices away from food production. Land is also increasingly used for non-food crops such as cotton, oil palm and other biofuels. Environmental degradation such as soil erosion and salinisation has led to abandonment of agricultural land (Smith, Gregory et al., 2010). Climate change is likely to have major impacts on agricultural productivity and practices ((Lobell, Burke et al., 2008; Battisti and Naylor, 2009), Challinor et al. 2010): on average by 2050 yields in sub-Saharan African agriculture will decrease between 7 and 27%, with higher productivity areas being more directly affected (Schlenker and Lobell, 2010). Finally, movement towards a low carbon economy, coupled with tighter environmental regulation means that agriculture will have to both reduce use of agrochemicals and mitigate against direct GHG emissions, and sequester and maintain carbon in soils and biomass This suggests that the historical growth of productivity, which is largely based on energy intensive agricultural inputs in the developed world and parts of the developing world, will become more difficult. Indeed if low- or no-input agriculture is required, unit area yields in many productive farming systems may drop. Thus, on the one hand demand is increasing, and on the other hand, production growth may become more difficult.

The demand-supply shortfall cannot simply be met by taking more land into agriculture, although theoretically the area of cultivated land could double (Fischer et al. 2002). Firstly, some of the land that could be cultivated is forested, and deforestation is a major driver of current climate change (Smith et al. 2010), so liberating carbon to bring land into agriculture becomes counter-productive as it increases the rate of climate change and therefore will require more costly mitigation, whilst simultaneously impacting on the world's most biodiverse habitat. Secondly, the most productive land is already cultivated and diminishing returns are likely if marginal land is taken into production, and production (or increased grazing) on marginal land that may lead further to land degradation. Thirdly, non-cropped land has other uses for tourism, conservation of natural resources, habitation, production of fuel, cultural significance, carbon storage and water quality regulation that currently have not been fully valued (TEEB, 2010), but their importance is increasingly recognised and incorporated into environmental policies.

Are we therefore facing a global "perfect storm" of needing to increase productivity in the face of adapting agriculture to climate change (and its mitigation via reducing GHG emissions), whilst not increasing the global footprint of agricultural land?

The sustainability challenge

The growth in global productivity must be sustainable, in that any environmental degradation due to agriculture should not impact on future generations' ability to utilise natural resources for their livelihoods (WCED, 1987). One key reason why agricultural practices threaten both current and future generations is that ecological services have not been sufficiently recognised for their value (TEEB, 2010; Costanza et al. 1997). For example, pollination services contribute to yields of plants accounting for some 15-20% of total crop production (Klein, Vaissiere et al., 2007), amounting to a direct contribution of about 10% of all food production at a value of $153bn (Gallai, Salles et al., 2009). Similarly, "natural enemy" services provided by, for example, small wasps are directly responsible for suppressing harmful pest outbreaks; a recent study suggests control of the soy bean aphid by natural enemies in just 4 US states has an annuals value of $239 million (Landis, Gardiner et al., 2008). Furthermore, work on dryland soils by Elbert et al., (2009) estimate that globally a petagrams of carbon (1 billion metric tonnes) is taken up by autotrophic micro-organisms in biological soil crusts each year in dryland regions, contributing directly to soil fertility. The annual dryland soil C uptake equates to a monetary value of *c*. $20 billion. Thus, there are clear indications that ecology on a range of scales has a direct value to production systems, and conserving ecology may become ever more important for future agriculture, especially when chemical inputs and mechanisation may be restricted due to carbon costs.

Sparing vs sharing

Thus, demand for global food production is rising, and the solution cannot be in taking more land for the reasons already discussed. At the same time, there is an increased awareness that agricultural management must become more sustainable but this exposes a very serious tension. Typically "sustainable" farming is often equated with organic or more extensive[2] and less productive farming systems (Connor, 2008). Logically, therefore, if farmers adopted more of these types of management, then at a global scale agriculture would need to expand to maintain production. We examine this tension in detail, concentrating on recent agro-ecological work that examines the productivity of different types of farming systems. The key to resolving this tension lies in not thinking of a farmer's field in isolation, but thinking of a field within a landscapes.

Ecosystems the service they provide on a farm or in a field reflect the organisms present in the landscape around the agricultural land (Weibull, Ostman et al., 2003; Gabriel, Roschewitz et al., 2006; Carre, Roche et al., 2009; Batary, Matthiesen et al., 2010; Chamberlain, Joys et al., 2010; Diekotter, Wamser et al., 2010). Recognising that a farm's ecology is landscape-dependent suggests that one can consider biodiversity (or ecology or ecosystem services[3]) as a property of both the broader landscape as well as the field or farm, and that management of ecosystem services requires consideration of the field, farm and landscape context. This landscape view

---

[2] We use the terms extensive vs intensive as simple labels, whilst recognising that they are relative terms. Our sense is that extensive farms yield less food because production methodologies are less intense. We note that organic farming may be intensive (e.g. with high application rates of green manure, large fields etc) or extensive and organic and extensive are not necessarily synonyms

[3] The following argument broadly applies for whatever ecological currency, so we'll use "biodiversity" as a generic term for ecosystem service or ecology

implies that a landscape can be multifunctional in that it produces both agricultural produce and biodiversity; society demands both products and so the conceptual question becomes "what is the optimal way to deliver both products from the same landscape?"

This issue is highlighted in a landmark paper (Green, Cornell et al., 2005) where the authors contrasted alternative hypothetical strategies when a set level of food was required from a single landscape. The first scenario was where the whole area was farmed extensively, in a way that yielded less food but consequently gained more biodiversity (so called "land sharing"). The contrasting scenario was where some of the land was farmed intensively thus allowing “spare land” to be managed for biodiversity ("land sparing"). The paper analyzed “optimal land management” as a function of the costs and benefits to both yield and biodiversity.

The arguments about the merits of land sparing and sharing have been addressed in a recent study that compared organic and non-organic farms in the UK as models for extensive and intensive farming systems (Gabriel, Carver et al., 2009; Gabriel, Sait et al., 2010; Hodgson, Kunin et al., 2010). On a like-for-like comparison, organic farms were better for biodiversity (though the effect varied across different plant and animal groups) with biodiversity increasing by about 12% on average (Gabriel, Sait et al., 2010), but also in a like-for-like comparison of the field yields, yields of organic winter cereals in each field were about 45% of the conventional paired field. For a single animal group (butterflies, which had a positive uplift of ~40% on organic farms), this study also assessed biodiversity on spared land in local nature reserves. The butterfly biodiversity data was used to model the optimal landscape configuration to maintain food production and maximise biodiversity. This optimality approach indicated that if organic yields were greater than 87% of the conventional yields, organic farming produced more biodiversity whilst retaining food yields across the landscape (Hodgson, Kunin et al., 2010). Alternatively, when organic yields were below this threshold, biodiversity was maximised by farming intensively to maximise production in some places, allowing the nominal production threshold to be passed without using all the land, such that some land could be spared for "farming" biodiversity. As the observed yields were below the critical threshold, it implied that in lowland UK farming, a land sparing strategy had both greater food and biodiversity production potentials.

The optimality framework indicates that the optimal strategy will be context dependent, and so the optimal solution will vary from place to place. Studies of production of the biofuel crop *Jatropha curcas* in the developing world highlight that small-scale and community-led developments are able to produce reasonable yields, make a meaningful contribution to local livelihoods, and retain landscape heterogeneity better than large scale operations (see Achten et al., 2010). This result is confirmed by studies from rural Malawi that demonstrate that ecological problems make large scale plantations less attractive than small scale and local-level projects (Dyer et al., submitted).Together these studies suggest that for *Jatropha curcas* production in Africa a land sharing strategy is the best optionl.

The conclusion of this research is that the critical ratio of intensive:extensive yields that makes land-sparing or land-sharing optimal depends crucially on the place. For instance, regions with small fields, steep valleys, or large amounts of non-cropped habitat impose constraints on intensive production. In such regions, yields will be lower, biodiversity may be higher due to the greater habitat heterogeneity (Benton, Vickery et al., 2003) and land sharing strategies optimal. Conversely, a flat landscape with fertile soil will naturally suit large scale production. In such regions, the landscape may naturally be low in biodiversity and optimal management would be to farm more intensively thus sparing land elsewhere for biodiversity conservation.

The land sparing vs sharing arguments indicate that the optimal strategy for maintaining biodiversity and production may be intensive farming plus land sparing. In addition to biodiversity benefits, extensive farming is often seen as "environmentally friendly" due to their lower inputs[4]. A recent study developed a full carbon-account for 17 years of a corn-soybean rotation systems in Michigan (Gelfand, Snapp et al., 2010) . This study showed that the efficiency (the outputs per unit input) were almost identical for organic and conventional approaches. This was because

[4] Extensive farming, with lower or zero inputs of synthetic products, does not necessarily equate to a lower environmental impact. Green fertiliser, if over-applied, can lead to eutrophication of water courses; and permitted organic chemical uses include some high-impact toxic chemicals such as copper and natural pyrethroids for pest control. Furthermore, organic methods of weed control may require greater fuel use, contributing to GHG emission.

although organic methods "saved" energy costs by not using synthetic chemicals, they "spent more" on the greater mechanised costs of farming (requiring more passes with machinery during weed control for example, plus a winter cover crop of clover). Therefore, extensive farming in the guise of organic production may have environmental benefits in locally raising biodiversity, it doesn't necessarily reduce the carbon cost of farming (per unit of production) and it requires more land to produce the same outputs. The Gelfand study also explored the relative efficiencies of "no till" systems (i.e. without deep ploughing but maintaining chemical inputs) and "low input" systems (i.e. ones where there is low chemical input coupled with mechanised weed control). Both of these “alternative management” strategies provided demonstrated greater production efficiencies than either conventional or organic, and the no-till system had a greater average yield than the conventional system. No-till systems both maintain soil carbon stocks (West and Post, 2002) and require less energy due to reduction in the fuel costs of mechanisation. Thus, rather than creating a misleading contrast by dividing farming systems into either organic/extensive and conventional/intensive there needs to be greater recognition that future farming has the potential to maintain yield whilst becoming "greener" by further optimising inputs and practices to reduce environmental impacts. We return to this issue below.

The spatial scale of sparing vs sharing

Landscapes produce both agricultural products and biodiversity and ecosystem services. The theory underpinning the results discussed above (Green, Cornell et al., 2005; Hodgson, Kunin et al., 2010) shows that the optimal solution to maximising biodiversity whilst producing food depends on the amount of biodiversity that would be gained from farming extensively versus the amount of yield would be lost.

The key point is that costs and benefits of different land management strategies must be *assessed across all affected land.* If a fixed level of production is required, a particular area (farm, landscape or region) converting to extensive farming implies that elsewhere farming will need to intensify (e.g. by converting extensive into intensive, or converting semi-natural land to farmland) and so the net landscape-scale effect needs to be considered. The best solution is place-dependent (as discussed above) but it is also scale independent. For example, within a country if costs and benefits vary regionally, a higher productivity in one region will go a greater distance towards meeting production needs, thus allowing other regions to be relatively spared. Hence, one can imagine hierarchical applications of this argument: comparing landscapes within a region, land sparing in some, land sharing in others; comparing regions, with greater proportions intensive production plus spared land in the higher production regions, and more sharing in the lower production regions and so on.

To extend this argument, consider the case for organic farming within the EU. Organic farms tend to be locally ecologically friendly as farming practices promote landscape heterogeneity (through a diversity of crops and rotations), in addition to the reduction in synthetic applications of fertilisers and pesticides. This extensification also usually leads to lower yields. All things being equal, if a larger percentage of European farmers adopted organic farming practices, we might expect a reduction in European production, and this would necessitate more food imports from other regions such as Asia and sub-Saharan Africa. To increase production to meet both their growing home markets (where demand is growing faster than in EU) and to supply extra EU demand, we would expect to see either an increase in intensification or more land being brought into production in these regions. These options carry both environmental and economic implications. Adding further complexity the EU has much tighter environmental regulations relative to other regions, so greater intensification elsewhere may result in greater environmental damage than in Europe. Finally, since biodiversity is typically richer in warmer parts of the world the environmental damage caused by an expansion of organic farming in Europe may add additional stress to vulnerable and ecologically valuable parts of the world. This issue has been quantified and it has recently been estimated that European imports of food already account for a virtual land grab of the equivalent area of Germany (34 million ha). If Europe increased the proportion of its land devoted to organic farming to 20%, then it is likely that an additional >10m ha, an area equivalent to the size of Portugal, would need to be devoted to export crops in the developing world (von Witzke, 2010; von Witzke & Noleppa, 2010). Hence, organic farming in Europe may help conserve European environments, but only through the potential export (and magnification) of the environmental costs to elsewhere in the globe.

Global markets and equity under climate change.

There are many arguments surrounding the issues of poverty and hunger in the developing world and how the developed world can help or hinder. Despite food exports from Latin America, Africa and SE Asia to the developed world providing much needed hard currency for poverty ridden economies, one of the arguments from this paper is that rich nations may risk under-producing many crops and that importing produce from poor nations undermines food security in the global south. In addition, the arguments made here raise the real possibility that an increased dependence on imports from the Global South is unsustainable and can lead to environmental degradation. In other words, for some developing countries, exporting to developed countries will, over the next decades, impact increasingly on their local food security (von Witzke 2010) and that to ensure long term food security global food supply has to be met by productive areas continuing to produce (Foresight, 2011).

The future

A world where extensive farming dominates is possible to imagine, in that extensive agricultural systems can potentially provide sufficient calories to maintain a healthy life for the growing population. However, this future would require such considerable change in individual and societal behaviour that in our opinion this is unlikely to happen in the short term. Our pessimism is born out of our observation about how society has responded to climate change: despite the threat of, and evidence for, climate change, behavioural change to date has been relatively small. It is also not clear that an "organic world" is the most sustainable solution because moving to organic production will intensify pressure on landscapes and likely lead to greater deforestation, greater release of carbon into the atmospheres and greater long term climatic effects.

Despite our pessimism about the likelihood of shifting behaviour, we take from our analysis of the literature that farming has unnecessarily been polarised into an intensive vs extensive debate (in any of the many variants of this debate). High-production systems are by definition intensive, but this need not equate to "industrial farming" or "high environmental cost" farming. Greening of "conventional" agriculture is already underway, partly driven by consumer demand, tighter environmental regulation and recognition of the rising cost of oil driving up input costs. Furthermore, research demonstrates that no-till and low-input agriculture can maintain production, increase efficiency and have lower environmental impacts than "conventional" farming (and perhaps also lower environmental impacts than organic farming, if one accounts for the extra land need for production). Increasingly, both policy makers and producers are valuing the ecosystem services that contribute to yields and, therefore, ensuring operations have minimal impact on local biodiversity. Hence, we believe that the weight of the evidence suggests that ecological, or green, agriculture can exist without wholesale adoption of extensive or other organic practice. In the developed world, greener intensive agriculture may manifest itself in an increase in no-till, low-input and other agronomic systems, plus further development of precision agriculture using remote-sensed data to produce high-resolution maps of fields to target inputs (Bongiovanni and Lowenberg-Deboer, 2004). Clearly, plant-breeding technologies (including gene tilling, for identifying new variants, and also genetically modified crops) are potential partial solutions for maintaining or growing yield in a "greener" way in that they may require less input (in terms of fertiliser, or water by changing root architecture or b modifying drought resistance, or pesticides by modifying resistance).

In the developing world, organic farming often represents good farming practice, in that management is necessary to avoid loss of yield to pests and diseases. However, there is widespread acknowledgement that some external inputs can radically improve yields (Foresight 2011, (Vitousek, Naylor et al., 2009), which can both reduce poverty and enhance food security. Low-input systems can then create radical increases in yield and can be managed in a sustainable way.

To balance competing needs for both food production and nature conservation, landscapes need to be actively managed for both outputs. In the land sharing scenarios, much of the biodiversity will exist in the background landscape. In land sparing scenarios, the spared land needs to be actively managed for biodiversity (and not simply left fallow). In the discussions above, we have not addressed how the spared land could be laid out. Given that agricultural land may increasingly require ecosystem services for which non-cropped areas may be prime sources (e.g. spared land may provide habitat for predator insect or bird species that reduce pest damage in cropped areas), then we must not think of spared land solely as being in blocks or "nature reserves". Rather, an optimal arrangement might be where spared land becomes a network of linked patches across the landscape. So, even highly productive landscapes may have high biodiversity provided across the landscape via this network. The management of this spared land may evolve from the considerable ongoing research on the efficacy of agri-environment schemes linked with input by the land managers in specific localities. High production, land sparing landscapes, need not be the "green desert of industrialised farming" that people often imagine. They may, due to the greening of conventional farming and proper management of spared land, be home to considerably more wildlife friendly land uses than has been true of conventional farming landscapes in the last few decades.

Conclusions

Extensification will not be the answer to global issues of food security due to the two major barriers of having insufficient land to expand into, and the need for considerable change in dietary habits. A recent study (Smith, Gregory et al., 2010) concludes: "Given the need to feed 9 billion people by the middle of this century, and increasing competition for land to deliver non-food ecosystem services, it is clear that per-area agricultural productivity needs to be maintained where it is already close to optimal, or increased in the large proportion of the world where it is suboptimal" (p2955).

Local extensification only becomes possible if somewhere else intensifies, and it becomes a matter of assessing the costs and benefits of regional, country and local strategies to minimise environmental impact whilst maintaining the necessary food production. In naturally productive areas, it is likely that land sparing strategies gives the optimal mix of ecology and food; whereas in naturally less productive areas, land sharing becomes optimal. This argument applies to a degree at whatever spatial scale.

Extensification is "not the answer" but suggestions to the answer can be found in the greening of existing methodologies to reduce climate impacts and synthetic inputs, coupled with management contextualised by the local landscape and local users as well as considering the farming landscape holistically. This landscape view contributes to a reconciliation of "conservation" or "production" because recognising that landscapes produce two outputs allows at least a conceptual optimisation of the landscape design to produce the most of both.

Sometimes, the optimal landscape design will look like a traditional extensive landscape, other times it will look more like an intensively farmed landscape, but with specific areas of land managed very actively to maximise ecosystem service production, biodiversity or conservation. This spared and managed land will most likely be required as a network crossing the agricultural landscape, allowing the provision of ecosystem services (the likely scale of many natural enemies into cropped land from non-cropped land is a few hundred metres). Linked together a greening of agriculture that couples agronomy, information technology and remote sensing, low-input, low-environmental impact farming can continue to push productivity in areas where conditions are suitable. It is perfectly possible for there not to be a societal choice between producing sufficient food with high environmental impact OR producing insufficient food in a sustainable way, but to BOTH produce enough food and to do it sustainably. The landscape view of farming is a tool towards aligning the traditionally opposing camps, and moving towards more sustainable agriculture that helps provide food security for an expanding population, the livelihoods for hundreds of millions of people and a way out of poverty for many in the developing world.

References.

Achten, W.M.J., Maes, W.H., Aerts, R., Verchot, L., Trabucco, A., Mathijs, E., Singh, V.P. & Muys, B., 2010. *Jatropha*: From global hype to local opportunity. *Journal of Arid Environments*. **74,** 164-165.

Batary, P., T. Matthiesen, et al. (2010). Landscape-moderated importance of hedges in conserving farmland bird diversity of organic vs. conventional croplands and grasslands. *Biological Conservation* **143**(9): 2020-2027.

Battisti, D. S. and R. L. Naylor (2009). Historical Warnings of Future Food Insecurity with Unprecedented Seasonal Heat. *Science* **323**(5911): 240-244.

Benton, T. G., J. A. Vickery, et al. (2003). Farmland biodiversity: is habitat heterogeneity the key? *Trends in Ecology & Evolution* **18**(4): 182-188.

Bongiovanni, R. and J. Lowenberg-Deboer (2004). Precision Agriculture and Sustainability. *Precision Agriculture* **5**(4): 359-387.

Bruinsma, J. (2009). The resource outlook to 2050: by how much do land, water and crop yields need to increase by 2050? *Expert Meeting on How to Feed the World in 2050.* Rome, FAO.

Carre, G., P. Roche, et al. (2009). Landscape context and habitat type as drivers of bee diversity in European annual crops. *Agriculture Ecosystems & Environment* **133**(1-2): 40-47.

Challinor, A. Simelton, E., Fraser, E.D.G., Hemming, D., Collins, M. (2010) Increased crop failure due to climate change: assessing adaptation options

using models and socio-economic data for wheat in China . *Environmental Research Letters*. 5(3) (1-8).
Chamberlain, D. E., A. Joys, et al. (2010). Does organic farming benefit farmland birds in winter? *Biology Letters* **6**(1): 82-84.
Connor, D. (2008). Organic Agriculture Cannot Feed the World. *Field Crops Research* **106**: 187-190.
Costanza, R., R. d'Arge, et al. (1997). The value of the world's ecosystem services and natural capital. *Nature* **387**(6630): 253-260.
Diekotter, T., S. Wamser, et al. (2010). Landscape and management effects on structure and function of soil arthropod communities in winter wheat. *Agriculture Ecosystems & Environment* **137**(1-2): 108-112.
Dyer, J.C., Stringer, L.C. and Dougill, A.J. (submitted). *Jatropha curcas*: Sowing local seeds of success in Malawi. Submitted to *Journal of Arid Environments*.
Elbert, W., Weber, B., Büdel, B., Andreae, M.O. and Pöschl, U. 2009. 'Microbiotic crusts on soil, rock and plants: neglected major players in the global cycles of carbon and nitrogen'. *Biogeosciences* 6:6983-7015
FISCHER, G., VAN VELTHUIZEN, H., SHAH, M. & NACHTERGAELE, F. 2002. Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and results. Laxenburg: IIASA.
Foresight (2011). *Foresight. The Future of Food and Farming, Final Project Report.* The Government Office for Science, London. http://www.bis.gov.uk/Foresight
Gabriel, D., S. J. Carver, et al. (2009). The spatial aggregation of organic farming in England and its underlying environmental correlates. *Journal of Applied Ecology* **46**(2): 323-333.
Gabriel, D., I. Roschewitz, et al. (2006). Beta diversity at different spatial scales: Plant communities in organic and conventional agriculture. *Ecological Applications* **16**(5): 2011-2021.
Gabriel, D., S. M. Sait, et al. (2010). Scale matters: the impact of organic farming on biodiversity at different spatial scales. *Ecology Letters* **13**(7): 858-869.
Gallai, N., J. M. Salles, et al. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics* **68**(3): 810-821.
Gelfand, I., S. S. Snapp, et al. (2010). Energy Efficiency of Conventional, Organic, and Alternative Cropping Systems for Food and Fuel at a Site in the US Midwest. *Environmental Science & Technology* **44**(10): 4006-4011.
Godfray, H. C. J., J. R. Beddington, et al. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science* **327**(5967): 812-818.
Green, R. E., S. J. Cornell, et al. (2005). Farming and the fate of wild nature. *Science* **307**(5709): 550-555.
Hodgson, J. A., W. E. Kunin, et al. (2010). Comparing organic farming and land sparing: optimizing yield and butterfly populations at a landscape scale. *Ecology Letters* **13**(11): 1358-1367.
HOLMGREN, P. 2006. Global land use area change matrix. *Forest Resources Assessment Working Paper* **134**. Rome: FAO
Klein, A. M., B. E. Vaissiere, et al. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B-Biological Sciences* **274**(1608): 303-313.
Landis, D. A., M. M. Gardiner, et al. (2008). Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes. *Proceedings of the*

National Academy of Sciences of the United States of America **105**(51): 20552-20557.
Lobell, D. B., M. B. Burke, et al. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science* **319**(5863): 607-610.
Parfitt, J., M. Barthel, et al. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B: Biological Sciences* **365**(1554): 3065-3081.
Schlenker, W. and D. B. Lobell (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters* **5**(1).
Smil, V., 2001: *Feeding the World.* Cambridge, MA: MIT Press.
Smith, P., P. J. Gregory, et al. (2010). Competition for land. *Philosophical Transactions of the Royal Society B-Biological Sciences* **365**(1554): 2941-2957.
Vitousek, P. M., R. Naylor, et al. (2009). Nutrient Imbalances in Agricultural Development. *Science* **324**(5934): 1519-1520.
von Witzke, H**.** (2010), *Towards the Third Green Revolution: World Agriculture - a Key Industry of the 21st Century*. Augsburg
von Witzke, H**.** and S. Noleppa (2010)**,** EU agricultural production and trade: Can more efficiency prevent increasing land-grabbing outside of Europe? *Research Report, University of Piacenca* (http://www.appgagscience.org.uk/linkedfiles/Final_Report_Opera.pdf)
Weibull, A. C., O. Ostman, et al. (2003). Species richness in agroecosystems: the effect of landscape, habitat and farm management. *Biodiversity and Conservation* **12**(7): 1335-1355.
WCED, 1987 *World Commission on Environment and Development, WCED, 1987, Our Common Future*, United Nations**.**
West, T. O. and W. M. Post (2002). Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. *Soil Science Society of America Journal* **66**(6): 1930-1946.