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Delivering food security without increasing pressure on land

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ABSTRACT

The challenge of feeding 9 to 10 Billion people by 2050 may seem like a big enough challenge in itself, but we also need to achieve this feat whilst, at the same time, reducing adverse impacts of food production on a whole range of ecosystem services. One suggested response is "sustainable intensification" which entails delivering safer, nutritious food from the same area whilst maintaining ecosystem service provision. In this review, I examine sustainable intensification and consider alternatives such as management of food demand and waste reduction. I conclude that sustainable intensification has a role to play, but this must be accompanied by fundamental change in global food systems.

1. Introduction

The challenge of feeding 9 to 10 Billion people by 2050 is enormous (Godfray et al., 2010). A number of options have been proposed to help address the food security challenge, including closing the yield gap (making the difference between the attainable yield and that actually realised smaller), increasing the production potential of crops (largely through use of new technologies and investment in research), reduced waste, changing diets and expanded aquaculture, which all need to be coordinated in a multifaceted and linked global strategy to ensure sustainable and equitable food security (Godfray et al., 2010).

At the same time as delivering food security, we also need to significantly decrease the climate impact of food production (Smith et al., 2008), improve the resilience of food production to future environmental change (Nelson et al., 2009), protect biodiversity (FAO, 2010a), protect our freshwater resource (Frenken and Kiersch, 2011), move to healthier diets (WHO, 2004), and reduce the adverse impacts of food production on the whole range of ecosystem services (Firbank et al., 2011). Historical expansion of agriculture into forests and natural ecosystems (Bruinsma, 2003) has contributed significantly to the loss of ecosystem services listed above. This has led to the suggestion that future increases in food supply need to be met without increasing the agricultural area, i.e. to derive more agricultural product from the same area (Godfray et al., 2010; Smith et al., 2010). Since this must be done sustainably, this process has been termed "sustainable intensification" (Garnett and Godfray, 2012; Tilman et al., 2011). Sustainable intensification can be regarded as an enhancement of current "business as usual", in which agricultural systems remain largely unchanged, and demand follows current projections, but in which agricultural production becomes more efficient. The need for sustainable intensification could be reduced if either demand patterns were radically changed relative to projected demand, or if global agricultural systems were changed fundamentally.

In the sections below I examine the challenge posed by sustainable intensification, such that food security could be delivered without increasing the pressure on land, and then briefly examine if more systemic changes in global food production and consumption patterns could provide an alternative, or complementary response, to sustainable intensification. I must first, however, offer a definition of sustainable intensification.

2. Sustainable intensification

2.1. A working definition of sustainable intensification

A whole paper could be written on suggested definitions for sustainable intensification, including the economic, social and environmental aspects of sustainability, and the different spatial and temporal scales at which different definitions will play out. For the purposes of this paper, I will offer a simple working definition.

I define intensification here as the process of delivering more safe, nutritious food (e.g. tonnes of cereal, tonnes of meat, litres of milk, kilocalorie of food energy, gram protein, nutrients etc.) per

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unit of input resource (e.g. land area, energy input, fertiliser input, other agrochemical input etc.). It is recognised that more production does not always equate to higher quantities of necessary dietary components (e.g. energy, protein, nutrient), which is why the definition does not include not just bulk agricultural product, but also includes the delivery of nutritious food. I use a definition of sustainability which borrows heavily from the Brundtland definition of sustainable development: "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). Combining the two, I arrive at a definition of sustainable intensification as:

> "The process of delivering more safe, nutritious food per unit of input resource, whilst allowing the current generation to meet its needs without compromising the ability of future generations to meet their own needs".

If we apply this definition within the food production system, it would mean increasing production of safe, nutritious food whilst maintaining the capability for production in the future, but the definition needs to be applied more widely. The needs of humans are not met only through food production; there are a range of ecosystem services supporting human health and well-being that exist outside food production (Millennium Ecosystem Assessment, 2005; UKNEA, 2011), including other provisioning services (e.g. fibre, water supply, wild species diversity), regulating services (e.g. climate regulation, pollination, disease and pest regulation, purification of air, water and soil), cultural services (e.g. recreation, tourism, spiritual/ religious value) and the supporting services that underpin them (e.g. primary production, nutrient cycling, water cycling, soil formation). Indeed, there is a feedback, with a number of ecosystems services (such as pollination) being extremely important for agricultural production. The UN Food and Agriculture Organisation (FAO, 2010b) have already advocated taking an ecosystem services approach to sustainable intensification. So sustainable intensification must deliver more product per unit of input resource, whilst preventing damage to the ecosystem services that underpin human health and wellbeing both now and in the future.

Whilst there will be "win–win" options that co-deliver on increased food production and one or more other ecosystem services (e.g. intensification to reduce agricultural GHG emissions; Burney et al., 2010), there will also be many trade-offs (e.g. eutrophication of water courses from agrochemical pollution, loss of biodiversity when land is cleared for agriculture or use of monoculture, loss of local air quality from manure application; Smith et al., 2012). Given these trade-offs between different ecosystem services, it is clear that sustainable intensification could never be achieved in absolute terms (i.e. not all ecosystem services can be enhanced simultaneously in all cases), so instead sustainable intensification can be regarded as a guiding principle in decisions about land use, rather than as an end-point.

2.2. How have historical increases in food demand been met?

The growth in the human population from about 3 billion in 1960 to 6.8 billion in 2010, coupled with increased income and changes in diet, has 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; Foresight, 2011). This increase will need to be maintained if the projected population of 9 billion by 2050 is to be sustained and if demand for different dietary components develops as projected (but see Section 3 on changes in demand). Past increases in crop production have occurred as a result of both extensification (altering natural ecosystems to produce products) and intensification (producing more of the desired products per unit area of land already used for agriculture or forestry). Bruinsma (2003) suggests 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 (Bruinsma, 2003) 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 (Smith et al., 2010). Therefore, increased yield and a higher cropping intensity will need to be the main driver behind future growth in food production (Bruinsma, 2003). Table 1 shows that, according to the projection of Bruinsma, extensification will still contribute significantly to crop production in Sub-Saharan Africa (27%), Latin America and the Caribbean (33%). There is almost no land available for expansion of agriculture in South and East Asia and the Near East/North Africa (and there may be loss of agricultural land to urban development) so sustainable intensification (see definition in the previous section) is expected to be the main means of increasing production in these regions (Gregory et al., 2002; Bruinsma, 2003; Gregory and George, 2011).

Table 1
Projected contributions (%) to increased crop production between 1997/99 and 2030 (derived from Bruinsma, 2003).

	Land area expansion	Increase in cropping intensity[a]	Yield increase
All developing countries	21	12	67
Sub-Saharan Africa	27	12	61
Near East/North Africa	13	19	68
Latin America and Caribbean	33	21	46
South Asia	6	13	81
East Asia	5	14	81

[a] More crops per unit time, e.g. double/ triple cropping within a year.

The main means to intensify crop production will be through increased yields per unit area together with a smaller contribution from an increased number of crops grown in a seasonal cycle. As 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^{-1} in 1961, to 3.35 t ha^{-1} in 2007. Simultaneously, per capita arable land area has decreased from 0.415 ha in 1961 to 0.214 ha in 2007 (Foresight, 2011). Had the increases in yield of the last 40–50 years not been achieved, almost three times more land would have been required to produce crops to sustain the present population; land that does not exist.

There have also been substantial changes in human food consumption reflected in dietary and nutritional changes over recent decades (Schmidhuber and Tubiello, 2007). There is an increasing demand for livestock products, particularly in developing countries (Smith et al., 2007) and given the lower efficiency of livestock products compared to the direct consumption of vegetal matter (Stehfest et al., 2009), an increasing proportion of livestock products in the diet is expected to increase the pressure on agricultural land.

Since 1960, agricultural area has increased from just under 4.5 billion ha to just over 4.9 billion ha in 2007 (FAOSTAT, 2012). During the last 20 years, there has been an overall increase in agricultural area from 4.86 billion ha in 1990, but showing some