

The debate over sustainable intensification

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Abstract Sustainable intensification is a process designed to achieve higher agricultural yields whilst simultaneously reducing the negative impact of farming on the environment. It is an idea that has had much prominence over the last decade, but which has also raised considerable concerns among a number of different stakeholders. In particular, there are worries that it might be used to justify intensification per se and the accelerated adoption of particular forms of high-input and hi-tech agriculture. Here, some of the issues surrounding the concept of sustainable intensification are explored including: how the term itself has become a centre of debate, how it has been appropriated to support different worldviews, and how it might evolve to help the food system respond to the environmental and food security challenges ahead.

Keywords Sustainable intensification · Agriculture · Yields · Environment · Ecosystem services · Genetic modification · Animal welfare

Introduction

Global food prices have declined throughout the last hundred years. This decline has been punctuated by periods of higher prices and higher price volatility, in particular during the two World Wars, the oil price crisis of the 1970s, and most recently over the last 6 years beginning in 2008 (Baldos and Hertel 2014; Piesse and Thirtle 2009). The causes of the food price rises in 2008 are still debated but include a series of bad har-

vests at a time of historically low stock to use ratios. More controversially, food prices may have been affected by higher oil prices and biofuel subsidies (To and Grafton, this issue), and possibly the flight of capital from mortgage and other markets into commodities at the time of the banking and financial crisis (Piesse and Thirtle 2009). The immediate effect of higher prices was civil disturbance in a number of countries, and tension over food was a contributing cause of the civil unrest that led to the Arab Spring (Lagi et al. 2011; Harrigan 2014). A second consequence was that food moved dramatically up the political agenda, and several different governments and other organisations commissioned studies of threats to future food security through to mid century and beyond (e.g., Paillard et al. 2009; Royal Society 2009; Searchinger 2014; Nellemann et al. 2009; IAASTD 2008).

The Foresight project on the Future of Food and Farming, commissioned by the United Kingdom's Government Office for Science (Foresight 2011), was an example of a project set up in the wake of the increases in food prices. As did several other studies, it concluded that there was a significant threat that a combination of secular increases in demand due to rising population and increasing wealth, combined with supply-side pressures such as increasing competition for land, water and other agricultural inputs, might lead to rises in global food prices. These increases could be of such a magnitude that they would lead to markedly increased hunger in developing countries, and possibly social and political unrest. Moreover, such problems were likely to be exacerbated by the effects of climate change that would become increasingly manifest during the course of the 21st century (Nelson et al. 2014; Nelson 2014; Wheeler and von Braun 2013; Schmidhuber and Tubiello 2007). Although precise predictions of the magnitude of the problem are impossible, the Report concluded that the likely threats were such that action was justified throughout the food system: on making food production more efficient, on moderating demand, on

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reducing waste, and on global food system governance (Godfray et al. 2010; Foley et al. 2011). In addition, the Report argued, all policy interventions should be seen through the twin prisms of environmental sustainability and the needs of the world's poorest.

Precisely what should be the supply-side response to the potential threat of global food insecurity? The Foresight Report, again in common with a number of other studies, highlighted the concept of 'sustainable intensification' (Royal Society 2009; Foresight 2011; FAO 2011). This was interpreted as producing more food from the same amount of land but with less impact on the environment. In the last 5 years a number of different governments and national and international organisations have adopted sustainable intensification as an organising principle to consider how agriculture might contribute to future food and environmental security. However, the prominence given to sustainable intensification has raised concerns amongst several stakeholders. In particular, a number NGOs have worried about whether it might be used to justify intensification per se and the accelerated adoption of particular forms of high-input or hi-tech agriculture (e.g., Collins and Chandrasekaran 2012). In some forums the debate has become highly polarised, and even politicised.

In this article I explore some of the issues surrounding the concept of sustainable intensification. I examine how the term itself has become the centre of debate, and how it has been appropriated to support particular worldviews including doing nothing – business-as-usual – or used to act as a focus to organise opposition in support of different worldviews. I argue that while genuine disagreements about how agriculture should respond to food security do exist, the gulf is less than appears from the ferocity of the debate. This leads to an exploration of whether sustainable intensification is still a useful concept, whether it is defined appropriately, and whether it should, or can, be replaced by a different term.

Sustainable intensification

In this section I describe what I believe the groups that originated the term sustainable intensification meant by the concept, and the logic that led to its formulation.

The argument for sustainable intensification begins with the observation that demand for food will increase markedly over the next 50 years. There are two main drivers underlying this trend. The first is population growth; because of demographic inertia we can be certain that total population numbers will increase over the next 40 years though the rate of growth is declining, and most studies project that human population numbers will peak sometime in the second half of this century (United Nations 2013; Lutz and Samir 2010; Bongaarts 2009). Population growth is concentrated in the least developed countries, in particular in sub-Saharan Africa. Recent

revisions of population projections have suggested that the demographic transition is occurring at a slightly slower rate than previously thought, and global peak population may be nearer 10 billion people rather than 9 billion (United Nations 2011, 2013). The second driver, which is tied to the first, is increasing income and wealth. People with greater income demand more varied diets, and typically ones that are richer in meat and other food types that require more resources to produce (Drewnowski and Popkin 1997; Popkin 1998). But because richer people tend to be more financially secure and have better access to education and reproductive healthcare, they also tend to have fewer children (Bongaarts 2009). Bringing people out of poverty is not only a good thing in itself, but also has a demographic dividend and important beneficial consequences for food demand in the long term (Ezeh et al. 2012).

There is concern that the increase in the demand for food will coincide with greater supply-side pressures on agriculture. Growing populations will require more land for cities and other habitations (Satterthwaite et al. 2010) and lead to greater competition for water, a resource source that is already under great pressure in many places (Strzepek and Boehlert 2010). In addition, climate change will, on balance, reduce the area of land suitable for agriculture, with land in the tropics coming out of food production while areas at high latitude are farmed for the first time (Challinor et al. 2014; Gornall et al. 2010). There will also be an increase in the frequency of extreme events such as droughts and floods that will have a uniformly detrimental influence (Gornall et al. 2010). While agricultural productivity has increased steadily over the 21st century, there is some evidence of a reduction in yield growth over recent decades (Piesse and Thirtle 2010; Ludena et al. 2007; Ray et al. 2013). One explanation for this growth decline is that at a time of historically low food prices investment in agricultural research has been low, and hence yield growth restricted. Alternatively, we may be approaching biophysical ceilings that represent absolute limits on yields.

Proponents of sustainable intensification do not argue that increased demand and threats to supply will necessarily result in problems for global food security. What they do argue is that the threats ahead are sufficiently real that they justify action throughout the food system to help reduce the probability of food insecurity. On the demand side this entails action on population, in particular promoting the idea that putting in place measures that help reduce population growth has economic benefits that lead to a virtuous cycle of income growth and fertility reduction (Ezeh et al. 2012). It also involves action on consumption, for example stressing the multiple health, environmental and food security benefits of reducing consumption of certain food types (Friel et al. 2009), as well as reducing waste at all points along the food chain from the farm to the fork (Gustavsson et al. 2011; WRAP 2008; HLP 2014). Finally, it requires reform of international and national

food governance: asking questions about whether which developed-world trade and tariff barriers negatively affect global food security, and whether the structure of the global commodity industry bolsters or reduces resilience to perturbations (Foresight 2011; Aksoy and Beghin 2005).

Were demand for food to begin to outpace supply, the inevitable consequence would be an increase in food prices. This, in turn, would stimulate production, exactly as we have seen in the response of world agriculture to the 2008 food price rises (Baldos and Hertel 2014). This raises the question of whether there is a need for policy intervention that might, it could be argued, distort the efficient endogenous response of the market. However, there are a number of inevitable or potential market failures that policymakers will want to address. The first is that the new equilibrium food prices may be sufficiently high to lead to hunger or food poverty, both in developing countries and among the poorest sectors of developed countries (Nelson et al. 2010). The second is that the agricultural sector may be slow at responding to price signals, and the response may require innovation that, in its turn, is based on basic research that can only be publicly funded (Piesse and Thirtle 2010). Finally, the food system may respond by increasing production in ways that are environmentally unsustainable and that lead to negative externalities, such as higher greenhouse gas emissions and increased fertiliser pollution. Calls for sustainable intensification in middle and high income countries where agriculture is embedded in a market economy are calls for interventions that help ensure the food system responds efficiently, in the economic sense, and sustainably, in the environmental sense, to price signals reflecting increased demands. These are not calls for interventions to increase food supply now, for example by the imposition or re-imposition of direct or indirect production subsidies.

The situation in least-developed countries, where many smallholder farmers that are not properly connected to national, let alone international, markets and where much of the food is consumed locally, will be rather different (Conway 2012; Pretty et al. 2011). Here, there may be strong arguments for direct interventions to help increase both production and productivity. Higher food production can directly alleviate hunger as well as increase rural incomes. In addition, in poor countries women and disadvantaged sectors of society typically constitute a large fraction of the agricultural workforce so bolstering agriculture can be a very efficient way of improving their living conditions (FAO 2012). Inevitably, difficult decisions will have to be made about when interventions in the market become counter-productive, but the lack of human capital and an enabling economic environment, as well as the physical infrastructure needed for agriculture, all argue for the value of direct intervention in food production in these circumstances.

Logically the food system could respond to increased demand by bringing more land into agriculture or by raising

productivity within the existing agricultural footprint. There are major negative externalities associated with the former. Land conversion for agriculture is estimated to be responsible for somewhere between 10 and 15 % of all anthropogenic greenhouse gas emissions (Stern 2007). It also has major effects on biodiversity and the ecosystem services provided by natural environments (TEEB 2011). Calls for sustainable intensification are based on the premise that the damage to the public good through extensification outweighs any benefits of the extra food produced on new lands (Burney et al. 2010; Tilman et al. 2011). Moreover, developing sustainable ways of increasing productivity from the majority of existing agricultural land might provide a buffer in food supplies to enable some elements of the farmed environment to be managed in ways that result in lower yields (Phalan et al. 2011b). Thus, certain agricultural environments that produce other important services, such as flood protection, carbon sequestration, or habitats for biodiversity, could be managed in ways that optimise multiple goals in a multifunctional landscape. Some agricultural land might even be taken out of farming for other environmental or social purposes. Sustainable intensification should not be taken to imply that yields would increase uniformly everywhere (Foresight 2011).

Sustainable intensification specifies a goal, but not a trajectory (Royal Society 2009; Foresight 2011; Conway 2012; Godfray and Garnett 2014): it is neutral about how economically efficient and environmentally sustainable responses to price signals might be arrived at, or how sustainable increases in productivity may be encouraged in developing countries. Indeed, most proponents have stressed the importance of taking an evidence-based approach to distinguish amongst a broad set of potential strategies, and also that the best approach will be context specific: no single set of solutions will work in all environmental and economic types of agriculture. Thus, in some circumstances, the most appropriate strategies may involve high-tech bioscience and the most sophisticated precision agriculture that harnesses cutting-edge ICT; in others what may be needed is the sharing of existing agronomic insights and the application of relatively straightforward measures that require little capital investment. Scaling up and translating insights about sustainable practices that have been developed in the organic farming community will, for some problems, be just as critical as the research outputs of major university and private sector animal and plant science laboratories. There are of course, boundaries to the set of possible strategies that are politically and socially acceptable, an issue I return to below.

Finally, sustainable intensification if treated seriously is genuinely radical. It is not a smorgasbord of interventions that can be chosen at will to justify different farming methods and philosophies. It is a coherent program that seeks radical change in the way food is produced and which places as much weight on improving environmental sustainability, as on

economic efficiency. It should not be seen as business-as-usual with marginal improvements that benefit the environment, nor as a call for a purely environmental agenda that fails to acknowledge the need to meet people's expectations for affordable, nutritious and varied food.

The meaning of the term

Natural scientists are often perplexed at the attention given to particular words when concepts move outside academic debate into the political and public arena. This is particularly true concerning debates over what is exactly meant by sustainable intensification. But when real-life applications are being considered, it is understandable that different interest groups look carefully at a term and how it might be interpreted, or even hijacked by stakeholders that have different aims or have different values. How has the term sustainable intensification been interpreted and might the words have even hindered the introduction of the radical new type of agriculture its originators advocate?

One of the original motivations for introducing the term sustainable intensification was that it posed dual challenges and call-to-arms for groups concerned with the environment and with food production. The word sustainable, in the environmental sense of its meaning, stressed the need to develop to a far greater extent than previously a more environmentally benign form of agriculture. The word intensification underlined the need and importance of supply-side responses to the future challenges of food security. It challenged the environmental community to accept that, without food security, progress on the environment was going to be much more difficult if not impossible to achieve, and it challenged the agriculture community to accept their role in mitigating global environmental deterioration. To an extent, the debate over the meaning of sustainable intensification has shown that it has successfully focused attention on these two joint issues. On the other hand, both words have become problematic.

First, consider the word intensification. As discussed in the last section there are logically two ways in which the agricultural system can respond to increased demand for food: increasing yields from existing farmland and extensification – bringing more land into agriculture. Extensification has major negative consequences to the public good and thus the former is the far better strategy and the use of the word intensification, in the sense of the opposite of extensification, underlines this view. Sustainable intensification is thus, shorthand, for the more accurate but less snappy “sustainable increases in productivity from existing agricultural land in response to price signals”.

The problem is that intensification is used not only as the opposite of extensification, but also to represent modern Western-style farming in contradistinction to low input, small

scale farming, often as practised by smallholders in developing countries. Thus, sustainable intensification is more often linked to “ecological intensification” than it is to “agroecology”. The former is a set of ideas associated in particular with Ken Cassman (Cassman 1999) concerned with how yields in temperate arable crops can be enhanced by considering ecological processes. Agroecology (de Schutter 2011) is a way of farming that places huge importance on sustainability and many of its proponents would argue that the way to achieve this is through agroecosystems that mimic their natural counterparts. Such ideas apply much more naturally to small-scale farming enterprises, and the agroecology movement includes a normative element which sees this approach to be an intrinsically more equitable and just solution to food production than alternatives. Supporters of sustainable intensification would argue that it applies both to modern Western agriculture and to the poorest farms in developing countries. They would also argue that insights from the explicit consideration of ecology, from the organic and agroecological movements, as well as from the experiences of smallholder farmers growing food in circumstances critically influenced by challenging environments, may help transform conventional agriculture so that it is more sustainable (Foresight 2011). The word intensification gets in the way of this process.

If intensification implies to many high input Western-style arable farming, to those concerned with animal welfare it is often considered synonymous with high density livestock rearing where little concern is paid to the wellbeing of the animals (CIWF 2012). Of course, there is not a simple relationship between stocking density, production system, and animal welfare. Animals can suffer greatly on highly extensive very poor quality grazing or on smallholder farms where the owner has neither the resources nor sometimes the expertise to provide high quality care. At the other extreme, large rearing units can be designed in such a way that, at least by objective measures of stress and other physiological processes, the animals they house appear to enjoy a high state of wellbeing (Dawkins 2011). Again, the word intensification gets in the way of discussing these important nuances.

Can the neutral sense of the word intensification be reclaimed? One possible way is through the decomposition of the term suggested by Gordon Conway into genetic, ecological, and market intensification (Conway 2012). Genetic intensification includes plant and animal breeding, in his view both conventional and where appropriate through genetic modification. Ecological intensification includes the much more efficient uses of resources and the application of ideas from the organic and agroecological movements to improve productivity. Market intensification represents the creation of the enabling economic environment that provides farmers with access to investment capital and to markets for their produce to incentivise increased productivity. Conway developed these ideas with smallholder sub-Saharan agriculture

particularly in mind, but with variations they can be applied to any farming system; they are helpful in stressing the multiple ways in which higher productivity can be achieved, not just through the application of Western-style agriculture.

There are also issues with the word sustainability, though these are subtly different from those concerning intensification. What does sustainable mean and how should it be defined? And while everyone agrees sustainability applies to environmental questions should it also be extended to include economic, nutritional, social and even cultural sustainability?

Environmental sustainability implies farming in a way that does not undermine the future capacity of the land to produce food and other ecosystem services (Pretty 2008). It also implies maintaining the natural capital embodied in the soil, and the farming ecosystem in general, so that the flows of goods and services they provide can continue unimpaired. When non-renewable resources are employed, for example water in underground fossil aquifers, sustainability means that the profits of their use should be invested into providing equivalent flows of goods and services from other sources into the future (Collier 2011). There are numerous complexities with applying this definition in practice. For example, exactly how should biodiversity in farmland be considered within this framework? Some biodiversity provides direct economic benefits through pollination and pest control, but much has just cultural significance whose value is difficult or impossible to capture or value by markets. It can even be argued that the mere act of valuation can change its worth (Sandel 2012). A second issue is the spatial scale at which an agroecosystem is adjudged sustainable. Consider biodiversity again. Should wild plants and animals be maintained on agricultural land even at the cost of reduced yields, or should the aim be higher productivity so that land can be spared from agriculture as biodiversity reserves (Phalan et al. 2011b).

A further question is whether sustainability can be taken to mean economic sustainability in addition to environmental sustainability? This can be answered in two ways: economic sustainability as a means of achieving environmental and possibly other sustainability goals, or economic sustainability as a goal in itself. The former, economic sustainability in pursuit of environmental goals, might involve the state intervening in food and agricultural markets to correct market failures or avoid unwelcome market consequences that would otherwise occur. Market failures include the negative externalities of food production such as greenhouse gas emissions, and unwelcome market consequences might include pressure to reduce animal welfare standards because of economic competition from other countries with poorer standards, leading to lower production costs. Achieving the goals of this type of economic sustainability might involve, in high-income countries, the restructuring of support for rural economies to incentivise more sustainable or higher welfare food production practices. In low-income countries, measures to improve

economic sustainability might include the ideas that Conway (2012) discusses within his concept of sustainable economic intensification (see above).

Economic sustainability can also be interpreted as farming that is profitable and maintains farmers' income and returns on investment in agriculture. Such a narrow economic interpretation could be used to support production subsidies or direct farm payments, or to allow more negative environmental externalities if it could be justified by the financial benefits that would accrue to the industry. There is a legitimate political argument to be had about the health of agriculture and the rural economy in high-wage countries subject to competition from countries with lower costs. But this is surely distinct from sustainable intensification. The suspicion that sustainable intensification is either explicitly or implicitly being used as an argument to subsidise, or in other ways support the farming and agricultural industry at the expense of the environmental and other dimensions of sustainability is at the root of much of the disquiet about the concept by environmental NGOs.

A viable and persistent agricultural system needs also to be socially sustainable in the sense that young people enter the industry at a sufficient rate to replace those that retire. Both in the developed and developing world there has been a trend for the farming workforce to age at rates that are not viable in the long-term. Making the industry more attractive to young people is clearly important but many would argue best approached outside the concept of sustainable intensification.

Finally, there is an intimate connection between nutrition and agriculture (Hawkes and Ruel 2006; Hawkesworth et al. 2010; Garnett et al. 2013) and it has been argued that sustainability should also incorporate notions of nutritional sustainability, that people's diets should be varied and nutritionally balanced. This has been partly motivated by the observation that while in many countries progress on reducing hunger has been highly successful, measures to improve nutrition have often been less so. Might sustainable intensification with its concentration on higher yields lead to monocultures of a few crops and a reduction in the availability of vegetables, fruit and other food types that improve nutritional outcomes? In part these concerns reflect, yet again, the worry that sustainable intensification implies one type of high-input agriculture. A different interpretation is that better nutrition should be incentivised by both demand-side and supply-side measures, and where these require the cultivation of particular crops, then how this may be done in such a way that yields are high and environmental impacts reduced is part of what is meant by sustainable intensification.

Criticisms

We have already seen some of the criticisms of sustainable intensification in the debate over what the two words actually

mean. In this section I try to crystallise the main criticisms and sketch the response of defenders of the concept.

Productionism

The food system today is highly globalised and future food security requires attention to all aspects of the food system (Foresight 2011). Yet it is typically politically more straightforward for governments to concentrate on supply-side solutions than to address issues on the demand side and those involving governance. Agricultural constituencies are often large and nearly always politically influential; successful interventions can generate wealth and contribute to GDP. Demand-side measures, on the other hand, are often politically highly sensitive (e.g., population) or unpopular with the electorate (e.g., measures to change consumption). Improving governance often involves confronting entrenched vested interests or grappling with interminable and seemingly intractable international negotiations. Does a concentration on sustainable intensification encourage the view that food security is a supply-side issue and provides governments and other actors an excuse not to engage with the full food system?

Some critics go further and argue that the problem with sustainable intensification is not only that it overemphasises one component of what should be a multi-pronged response to the potential threat to food and security, but that it is unnecessary. They argue that the world already produces enough food to feed everyone and that the solution is to improve distribution and reduce waste rather than to increase production (Soil Association 2010).

It is hard to judge whether support for sustainable intensification induces a sort of policy moral hazard, an excuse not to confront important other issues. Most of the authors that framed the concept of sustainable intensification have stressed the importance of taking a food system perspective, while an emphasis on it being an efficient and sustainable response to price signals in developed countries helps address the argument that it is not just a return to support for production subsidies.

While arguments about the optimal distribution of food make popular polemics, they ignore the realities of political economy. Most people are hungry because they cannot afford food, not because there is not enough food in the world (Sen 1981). Extreme weather events, wars and civil unrest cause episodic famines, but the majority of food security crises arise because food prices rise to unaffordable levels. The need for famine contingency plans will, unfortunately, remain essential, but sustainable intensification aims to reduce global hunger by increasing food supply in low income countries and helping the global food system maintain affordable food prices and reduce volatility in global commodity markets. While it is possible to construct scenarios where dramatic changes in diet and reductions in waste enable a population

of 10 billion people to be fed on the area of land currently in agriculture using existing or more extensive farming methods and practices, the likelihood of this occurring in the real world is vanishingly small. Using these arguments to justify not thinking about production side responses as one of the portfolio of measures to ensure future food security risks imperilling the access to food of large numbers of people.

Farming worldviews

Some critics of sustainable intensification accept the need for increases in productivity, and for this to be done sustainably, but believe that this should be achieved in a particular way. Thus, they reject the positivism of sustainable intensification and its agnosticism about how to achieve its goal. The specific approach normally advocated is a variant of organic farming, agroecology, or other production systems that put a premium on reducing the input of fertilisers and other agrochemicals. The approach is often, but not always, coupled with a view of how farming should be structured. Typically, this stresses the value of small farms, often family owned and run, and places less emphasis on larger more capital-intensive farming operations. Critics vary in whether they see the catholicism of sustainable intensification as bad in itself, or because they view it as well-motivated, but liable to exploitation by commercial interests that will concentrate on increasing yields and pay little attention to making food production more sustainable.

The expertise and insights on how to reduce the environmental impact of farming and how to use inputs more efficiently that have come out of the organic and agroecological movements are immensely valuable, and there are great opportunities for these to be adopted at scale in conventional agriculture (IAASTD 2008; Foresight 2011). Codes of practice such as those that underlie organic farming also have the advantage that uniform better environmental practices can be incentivised and enforced across the whole sector, and those who adopt them can be rewarded by the consumer through a price premium, at least in higher income countries. However, most organic and related systems of agriculture have lower yields than conventional farms (Seufert et al. 2012), for arable crops chiefly because of the reduced use of industrial fertilisers, and in livestock because of the more extensive rearing systems with little use of concentrates. Can one defend lower-yield agriculture were population and food demand to rise and prices to increase so threatening access to food by the poorest?

One response is to point out that some forms of organic farming have yields comparable to conventional approaches, and to make the very fair argument that if as much research went into improving the productivity of organic as conventional farming then higher yields almost certainly would be achieved (Seufert et al. 2012). Nevertheless, most data and arguments from biophysical first principles suggest a yield

gap will remain. Another response is to explicitly or implicitly argue that agroecology is such an intrinsically superior way of producing food, for environmental, equitable, social justice or other reasons, that any diminution of yield should be accepted and adjustments made elsewhere in the food system. Often this implies reducing consumption and major structural readjustment to farming in developed countries. The problem with this response is that it is part of a much broader discussion of competing economic and political worldviews (Kershen 2013). There can be a disjunction in the discourse on sustainable intensification when different participants in the same conversation are on the one hand making technical agronomic points and, on the other, probing the limits of modern market economies. Supporters of sustainable intensification might respond in two ways: first, we live in the world we live in and progress is most likely to be made at the margin; second, debates about political worldviews are obviously worth having, but need to be framed within their own context and not fought through proxies such as competing farming philosophies.

Finally, consider the argument that sustainable intensification is well intentioned although naïve; that it will allow greater adoption of high-input forms of agriculture under the guise of simultaneously improving yields and environmental performance, but that the latter will quickly be abandoned, in part because agriculture will become more profitable and attract more investment. This is a sort of agricultural version of Jevon's paradox (Alcott 2005), the 19th century demonstration that improving the efficiency with which coal is used does not necessarily lead to reduced demand, but by lowering prices and increasing the profitability of coal-using industries does exactly the opposite. Jevon's paradoxes have been intensively explored in natural resource and environmental economics, and different ways of countering it have been investigated, for example through regulation or by taxes on externalities. Proponents of sustainable intensification would acknowledge these difficulties and then seek to find the most efficient and easiest way to implement solutions.

The discussion over how sustainable intensification can contribute to the maintenance of sustainable levels of biodiversity brings these issues starkly to the fore (Norris et al. 2010; Phalan et al. 2011a, b; Garnett et al. 2013; Hodgson et al. 2010). It can be shown that in some agricultural environments the twin aims of producing food and maintaining biodiversity can best be achieved by sacrificing some yield in order to farm in a way that allows a rich community of plants and animals to persist: what is called 'land sharing'. In other environments, most biodiversity is lost with even the most modest land conversion and sustainable conservation requires the creation of protected reserves. Will investment in more productive agriculture provide the buffer in food supply that allows land to be set aside for nature (land sparing) as well as allow some farming environments to be managed in ways

that retain rich biodiversity at the expense of lower yields (land sharing)? Quantitative analysis demonstrates that land sparing can work in theory (Phalan et al. 2011b), but in practice it requires a mature and robust regulatory system to ensure protective land is in fact protected, especially if local investment in roads and other infrastructure increases the profitability of agriculture. There is a vigorous debate on 'land sharing' versus 'land sparing', which on occasion becomes fractious as competing worldviews collide.

Boundaries

Proponents of sustainable intensification take a broad, catholic view of how high yields with less impact on the environment may be achieved, stressing the goal rather than the trajectory. Most would include the use of genetically modified organisms (GMOs) within the potential strategy set, though all would stress that they are far from being a panacea and are just one of a broad range of possible interventions, both high-tech and low tech. The use of GMOs is one of the most divisive and contentious issues in current discussions of farming, and sustainable intensification has been placed on one side of this grand fault line because of its willingness to countenance genetic engineering. Indeed, one critique of sustainable intensification is in effect one long argument against genetic engineering (Collins and Chandrasekaran 2012).

Arguing that sustainable intensification is neutral with regard to strategy is somewhat misleading. It would be more accurate to say that it is neutral within bounds. To take a *reducto ad absurdum* example, if the best way to achieve sustainable pest management was through corralling child labour to pick individual locusts off the crop from dawn to dusk no one would argue that it should seriously be considered within the set of possible strategies. It may be more helpful to have a debate about what should be the boundaries of the permissible strategy rather than about whether sustainable intensification is, or is not, a good thing. Thus, one might decide, for whatever reason, that GMOs should be excluded from the permissible set and then go on to explore how best to achieve sustainable intensification using the remaining tools available. I should add this is not my view.

A boundaries approach might also help reconcile sustainable intensification with concerns about animal welfare (CIWF 2012). For instance, only those production methods that achieve a certain standard of animal welfare might be considered within the bounds of possible strategies (Garnett et al. 2013).

Being explicit about what are the boundaries of the permissible strategy set would be helpful in advancing the debate about sustainable intensification. Important and legitimate discussions about genetic modification and animal welfare, for example, would not be conflated with broader goals of improving productivity sustainably. But sustainable

intensification would cease to have any utility if the boundaries were set too narrowly; for example, if only agroecological interventions were allowed, or if only western-style high-input techniques were considered useful.

A major advantage of the notion of sustainable intensification, at least in my view, is its willingness to adopt methods from very different farming systems. Further, tightening the boundary does not come for free: reducing the strategy set will mean that in some circumstances yields will be constrained or environmental benefits not realised. Thus, though it may be useful to separate arguments about what should be permissible strategies and how best to achieve the goal, they interact and cannot be considered completely in isolation.

Conclusions

My view is that sustainable intensification is an important and valuable concept to help achieve the hugely challenging task of providing affordable food for ten billion people without destroying the natural environment and our capacity to produce food in the future. Yet the debate over the last 10 years has revealed complex issues over the framing and application of the idea, issues that were not apparent, or not anticipated, by the groups of largely natural scientists who formulated the idea. I finish with four broad conclusions that I think arise from this debate.

First, words matter. “Sustainable” means different things to different people and can be appropriated by different interest groups. “Intensification” is a red rag to many bulls. Is it worth abandoning the label and reframing sustainable intensification using more neutral terminology? I am not sure there is an obvious alternative, and any new term would almost certainly come with its own baggage; and with all its faults, sustainable intensification does highlight the real tension between improving environmental performance and yields simultaneously.

Second, responding to food insecurity involves making hard decisions on consumption and governance, as well as food production and productivity. Always placing discussions about sustainable intensification within this broader food system context will be helpful in allaying concerns that it is a purely ‘productionist’ agenda.

Third, being clear about what sustainable intensification means for production stimuli in different contexts is critical. In low-income countries there are strong arguments for direct stimulation of production. There is suspicion that such arguments might be used to justify production subsidies in high-income countries, a return to the bad old days of production-oriented Farm Bills and Common Agricultural Policies. Stressing that in

developed-countries sustainable intensification involves the economically efficient and environmentally sustainable response to price signals may help to allay these concerns.

Finally, arguments about sustainable intensification have become conflated with arguments about economic and social worldviews, GMOs, animal welfare and other topics. This leads to confusion and lack of clarity. Restricting the term sustainable in sustainable intensification to its environmental aspect and making clear that this in no way reduces the importance of acting on other agendas in the food system (nutrition, social structure of the workforce, poverty reduction etc.) seems a sensible way forward. It is also important to have discussions about the tool box available for sustainable intensification, and the best ways to employ it in different contexts.

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