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Current Opinion in Environmental Sustainability

Deconstructing and unpacking scientific controversies in intensification and sustainability: why the tensions in concepts and values?

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Assuming 'ceteris paribus' in terms of the viability of the planet during the coming half-century or so, the rising needs of a burgeoning, but also increasingly rich and demanding world population will drastically change agriculture. Crop yields and animal productivity will have to increase substantially, with the risk of further depleting the resource base and degrading the environment, making food production both the culprit and the victim. Future food security therefore depends on development of technologies that increase the efficiency of resource use and prevent externalization of costs. The current trend is towards intensification, especially more output per production unit so as to increase input efficiency. Whether that trend is sustainable is a matter of strong debate among scientists and policy-makers alike. The big question is how to produce more food with much fewer resources. Sustainable intensification (i.e., increasing agricultural output while keeping the ecological footprint as small as possible) for some is an oxymoron, unless real progress can be made in ecological intensification, that is, increasing agricultural output by capitalizing on ecological processes in agro-ecosystems. Definitions of intensification and sustainability vary greatly. The way these concepts are being used in different disciplines causes tensions and hides trade-offs instead of making them explicit. Inter-disciplinarity and boundary-crossing in terminology and concepts are needed. Implicitly, the operationalization of intensification and sustainability implies appreciation of and choices for values, an issue that is often overlooked and sometimes even denied in the natural sciences. The multidimensional nature of intensification needs to be linked to the various notions of sustainability, acknowledging a hierarchy of considerations underlying decision-making on trade-offs, thus allowing political and moral arguments to play a proper role in the strategy towards sustainable intensification. We make a plea to create clarity in assumptions, norms and values in that decision-making process. Acknowledging that win-win situations are rare and that (some) choices have to be made on non-scientific grounds makes the debate more transparent and its outcome more acceptable both to the scientific community and society at large.

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Current Opinion in Environmental Sustainability 2014, **8**:80–88

This review comes from a themed issue on **Sustainability governance and transformation**

Edited by **Paul C Struik** and **Thom W Kuyper**

For a complete overview see the Issue and the Editorial

Received 23 July 2014; Accepted 01 October 2014

Available online 30th October 2014

http://dx.doi.org/10.1016/j.cosust.2014.10.002

Introduction

The majority of the world's population is affected by poor nutrition. During the period 2011–2013, 0.84 billion people were chronically hungry [1]. Most recent data show that over 2 billion suffer from micronutrient deficiencies [2], while 1.4 billion adults are over-nourished [3]. More people are obese than chronically hungry, but those with micronutrient deficiencies equal the sum of those who eat too much or too little. In total, over half of all deaths worldwide are associated with malnutrition. Poor quantity and quality of food production and nutrition have very high societal costs.

The societal costs of current ways of using technology for producing food also are substantial. From an agronomic and environmental perspective these include depletion and spillage of resources such as water, degradation of agro-ecosystems and natural ecosystems, decline in ecosystem services, loss of biodiversity, emission of greenhouse gases and toxic waste, post-harvest loss, among others, all contributing to agriculture's ecological footprint.

Future trends are unclear: although population growth might level off by 2050, in some parts of the world the population will age rapidly inducing large changes in diets, irreversible climate change and sea level rise will affect agriculture in many densely populated countries, degradation of natural resources might accelerate in fragile environments, among others. Although some of the worrying trends will slow down or come to a halt, the processes described will give even inveterate optimists gloomy moments.

These trends make it necessary to put much more efforts into the analysis of trade-offs and bring this analysis into the complex societal debate on decision making towards sustainable agro-ecosystems. Trade-offs, that is, compromises between desirable but incompatible features, are ubiquitous in agriculture, under a wide range of resource availabilities. They are also present at different hierarchical levels and across temporal and spatial scales. Therefore they also have moral dimensions and political consequences.

From the end of the Second World War until about 1980, agricultural research in the developed world focused on increasing productivity per unit of land or labour, whereas from 1980 until 2000 that focus shifted to limiting the ecological footprint of agriculture [4]. During the latter period, agriculture became unpopular among donors and policy-makers. In the wealthy First and Second Worlds, further investment in an economic activity that produced in excess to requirement at the cost of a large ecological footprint was considered unnecessary. In the poorer Third World, with the exception of Africa, the Green Revolution was considered a success. The period from 1980 until 2000 was marked by the common notion that hunger was no longer caused by a combination of poverty and lack of production — as in the past [5] — but by a combination of poverty, poor governance of resources, speculation, and competition between food, feed and fuel. Agriculture only regained prominence in the international political agenda after the United Nations Millennium Development Goals had been agreed upon [6], and after the food crises in the periods 2007–2011 [7,8]. Influential publications by Beddington *et al.* [9,10] helped to put agriculture on the climate change agenda of the United Nations Framework Convention on Climate Change.

As a result, food and agriculture are definitely back on the societal and political agenda. Renewed donor attention to persistent hunger and malnutrition and political cognizance of the global drivers that create or reinforce food crises reframed the case of food security as an urgent and highly complex problem with technical, economic, and social dimensions that affect world trade and geopolitics. The urgency is underlined by population growth which increases demand, political realities that undermine production in key production areas, and increasing competing claims on natural resources. The re-emergence of food and nutrition on the political agenda is strengthened by climate change [11,12], resource depletion (e.g., phosphorus [13]; water [14]; energy [15] and the loss of agro-biodiversity [16•]), questioning the sustainability of current trajectories [17••]. A common response from scientists to such threats is to plead for paradigm shifts and scientific revolutions, or at least (and perhaps a bit more realistic and devoid of empty rhetoric) to call for changes in scientific concepts, practices and approaches, as well as new research agendas.

This response has come in different appearances. Cassman [18] coined the term ecological intensification to frame the challenge of increasing attainable yield and narrowing yield gaps by implementing new insights in precision agriculture, plant and crop physiology, and soil science, acknowledging that approaches and strategies should be different for favourable and unfavourable agricultural conditions. Meinke *et al.* [11] made a plea for 'adaptation science' to develop climate-robust agriculture and management of natural resources. Keating *et al.* [19] suggested options for making agriculture more 'eco-efficient': based on the simple notion that efficiency refers to output per unit of input, 'eco-efficiency' is the output of food and fibre relative to the input of ecological resources, including land, water, nutrients, energy, and biological diversity. Brussaard *et al.* [20•] made a case for a science that develops the best ecological means for food production with less negative or even positive impacts on biodiversity and ecosystem services. They proposed that trait-based ecology offers opportunities to design agro-ecosystems that contribute to both biodiversity conservation and food security. In the social realm, Khoury *et al.* [16•] noted that over the past 50 years considerable change has occurred in the composition of national food supplies, whereas diets around the world have become more similar. This resulted in several pleas to pay more attention to crops that are less favoured in terms of international research funding ('orphan crops'), for example towards the Consultative Group on International Agricultural Research (CGIAR) [21]. Recognizing that the concept of ecological intensification has been adopted, but also adapted over the last decade, Tittonell and Giller [22] re-defined the concept as "a means of increasing agricultural output, while reducing the use and need for external inputs, and capitalizing on ecological processes that support and regulate primary productivity in agro-ecosystems". Finally, it has been emphasized that new directions towards food and nutrition security require simultaneous change at the level of formal and informal social rules and incentive systems (i.e., institutions) that orient human interaction and behaviour, and hence that 'institutional innovation' should be a key entry point to addressing threats [23–25]. This is important for science to be able to contribute to international policies for food security and protection of natural resources that appear to rest on three pillars: right to food, intensification of agriculture, and sustainability. The three pillars are briefly described in the next section. Following that section we describe the need for intensification, how to evaluate intensification, the need for sustainability, which problems are encountered on the way towards sustainable intensification, and the nature of these problems and possible solutions. We also stress the importance of thorough analysis of trade-offs in agro-ecosystems.