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Review

Evaluating agricultural trade-offs in the age of sustainable development☆

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ABSTRACT

A vibrant, resilient and productive agricultural sector is fundamental to achieving the Sustainable Development Goals. Bringing about such a transformation requires optimizing a range of agronomic, environmental and socio-economic outcomes from agricultural systems – from crop yields, to biodiversity, to human nutrition. However, these outcomes are not independent of each other – they interact in both positive and negative ways, creating the potential for synergies and trade-offs. Consequently, transforming the agricultural sector for the age of sustainable development requires tracking these interactions, assessing if objectives are being achieved and allowing for adaptive management within the diverse agricultural systems that make up global agriculture. This paper reviews the field of agricultural trade-off analysis, which has emerged to better understand these interactions – from field to farm, region to continent. Taking a "cradle-to-grave" approach, we distill agricultural trade-off analysis into four steps: 1) characterizing the decision setting and identifying the context-specific indicators needed to assess agricultural sustainability, 2) selecting the methods for generating indicator values across different scales, 3) deciding on the means of evaluating and communicating the trade-off options with stakeholders and decision-makers, and 4) improving uptake of trade-off analysis outputs by decision-makers. Given the breadth of the Sustainable Development Goals and the importance of agriculture to many of them, we assess notions of human well-being beyond income or direct health concerns (e.g. related to gender, equality, nutrition), as well as diverse environmental indicators ranging from soil health to biodiversity to climate forcing. Looking forward, areas of future work include integrating the four steps into a single modeling platform and connecting tools across scales and disciplines to facilitate trade-off analysis. Likewise, enhancing the policy relevance of agricultural trade-off analysis requires improving scientist-stakeholder engagement in the research process. Only then can this field proactively address trade-off issues that are integral to sustainably intensifying local and global agriculture – a critical step toward successfully implementing the Sustainable Development Goals.

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Contents

1. Introduction

Agriculture plays a central role in sustainable development. Its fundamental position as the supplier of human nutrition shapes the global economy and society's relationship with the natural world. It is thus central to achieving a suite of Sustainable Development Goals (SDGs) agreed to by the United Nations in 2015 (United Nations, 2015), ranging from ending hunger and poverty, to improving human well-being and reducing environmental impacts (United Nations Economic and Social Council, 2016). Already, over a third of the world's land surface and nearly three quarters of its freshwater resources are devoted to agriculture (Dobermann et al., 2013; HLPE, 2013; Pretty et al., 2006). It is both an important driver of global climate change, as a result of land-use change and greenhouse gas emissions (Smith et al., 2014), and one of the sectors most vulnerable to its impacts (Vermeulen et al., 2012). Moreover, approximately three quarters of the world's poorest people live in rural areas, where farming is the main source of employment and income (World Bank, 2007; IFAD, 2011). With growing global population and affluence, the pressure on agricultural and natural systems increases. As a result of these growing pressures, humans now expect agriculture to supply not only nutritious food but also employment, energy resources, clean water, biodiversity conservation and more. This situation makes it essential to navigate and manage the trade-offs between potential benefits and negative impacts that can arise as food production interacts with other aspects of sustainable agricultural systems (Millenium Ecosystem Assessment, 2005; Tilman et al., 2009; Godfray et al., 2010; Tilman and Clark, 2014).

Concepts such as sustainable agricultural intensification (Garnett and Godfray, 2012) and climate-smart agriculture (Lipper et al., 2014) are rallying cries to the challenge of achieving the multiple goals of increasing agricultural productivity and rural livelihoods while minimizing negative environmental effects. As pointed out by Garnett and Godfray (2012), sustainable agricultural intensification is not a particular set of practices but instead provides a conceptual framework for guiding discussions on achieving balanced outcomes of intensification. Thus, there can be multiple alternative pathways to sustainable agricultural systems whose suitability and outcomes vary depending on agro-ecological zone, farming system, cultural preferences, institutions and policies, among other factors. Each of these pathways results in a different suite and/or degree of environment and socioeconomic trade-offs and synergies that must be recognized and addressed.

The successful transformation of the agricultural sector to meet these multiple goals, therefore, requires the ability to track multiple outcomes, assess whether identified goals are being met or compromised, and allow for guided course corrections. In an effort to make these interactions explicit, trade-off analysis for agricultural systems has emerged as an increasingly important field of study. This paper attempts to synthesize the central components of the literature on agricultural trade-off analysis and provide guidance on next steps for research in this area.

Trade-off analysis developed out of cost-benefit-analysis (CBA) and was first applied to agriculture during the Green Revolution in the 1970s to evaluate the economic impacts of emerging agricultural technologies (Alston et al., 1995). These approaches focused on maximizing financial margins in agriculture. As researchers began to broaden their focus to issues of sustainability in the 1980s and 1990s, it became apparent that the CBA paradigm was insufficient to address the multiple monetary and non-monetary goals of sustainability. Early applications of trade-off analysis in agricultural sustainability assessments coupled biophysical data and models with economic models to generate a more inclusive approach to evaluating agricultural sustainability (Antle and Capalbo, 1991; Antle and Pingali, 1994; Pingali and Rosegrant, 1995; Crissman et al., 1998). These early studies assessed the economic, environmental and health trade-offs of pesticide use. Since then, the use of trade-off analysis to assess agricultural sustainability has steadily grown as a field of study, expanding beyond agronomic and economic outcomes at the field and farm level, to incorporate environmental and social outcomes at regional and continental scales (e.g. Weersink et al., 2002; Chen et al., 2008).

A range of tools provide means to assess the trade-offs and synergies that arise from agricultural intensification. This review builds on previous introductions to trade-off analysis in agricultural systems by moving beyond considerations of any one specific technique (e.g. Crissman et al., 2001) or scale of analysis (Dale et al., 2013; Klapwijk et al., 2014). The scope of this review encompasses more inclusive notions of human well-being beyond income or direct health concerns (e.g. to gender, equality, nutrition), as well as extending consideration of environmental aspects from a historic focus on soil health to issues of biodiversity, climate forcing and landscape-level processes. Moreover, we consider how information derived from trade-off analysis can be visualized and communicated effectively to guide agricultural development – a key challenge of making this research relevant at the science-policy interface. In short, we attempt to provide a comprehensive review of the parameters, tools, and outreach methods that constitute the various stages of trade-off analysis. With the international community now focused on how to implement the SDGs across local, national and global scales, it is more important than ever to understand how trade-off analysis can help decision-makers develop balanced approaches that take the links between the SDGs into account (Le Blanc, 2015). This integrated approach is particularly relevant for agriculture, as efforts to make this sector more economically, environmentally and socially sustainable are critical to the success of a majority of the SDGs (Canavan et al., 2016).

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