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Review

Flaws and criteria for design and evaluation of comparative organic and conventional cropping systems

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ABSTRACT

In this review, comparisons between organic and conventional cropping systems are discussed. Publications from four topics, crop yields, carbon sequestration, biological diversity and nitrogen leaching were selected as examples to point out pitfalls and shortcomings in comparative analysis that can weaken or even disqualify evaluations. Inconsistent results between different comparative studies were found to be pseudo-contradictions. As the experimental design of comparative organic and conventional cropping systems often is biased in some aspects, suitable denominators for comparative assessment are discussed (ratios per area, per product and per land demand for the same amount of product). Conditions for equitable evaluations are outlined in order to avoid biased design, inappropriate interpretations and flawed conclusions. We stress that respecting at least three stringency criteria will help to ensure the scientific quality of data interpretation of comparative studies: similar soil fertility status at start, comparable type of crop production, and quantification of off-farm organic and nutrient input.

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1. Introduction

Organic agriculture is one of the methods frequently proposed for reducing the impact of agriculture on the environment (Seufert et al., 2012). Whereas rules exist for reasonably classifying production systems as 'organic' (IFOAM, 2005), corresponding standards are missing for other methods such as integrated farming, conservation agriculture, ecological intensified agriculture and others, all of which are classified as 'conventional'. Although exclusion of mineral fertilizers, synthetic pesticides and GMO is the principal difference between organic and conventional farming, organic and conventional cropping systems can differ far more—in terms of crop rotation, nutrient supply from manure or other organic amendments, weed control, soil management and crop protection. These differences can determine results of comparative studies to a large extent. Consequently, evaluations of comparative organic and conventional systems require that major differences in addition to mineral fertilizers and synthetic pesticides are also considered in the analysis. Only field experiments where each intervention is considered as a separate factor in the interpretation and rigorous boundary condition are observed can be correctly evaluated. In other words, all major system differences—temporal and spatial scales as well as indirect effects should be considered in a holistic analysis of results. A system that is sustainable at an experimental scale may not be so at a larger scale.

In previous articles, conflicting conclusions and difficulties evaluating comparative studies were pointed out (e.g. Kirchmann and Bergström, 2001; Kirchmann et al., 2008; Kätterer et al., 2012). In this paper, a more complete approach to address failures when evaluating comparative cropping systems is described and discussed. We argue that contradicting results are mainly due to inconsistencies in scale and boundary conditions. A common problem in the literature is that measurements made on individual crops are erroneously extended to discussion of productivity of entire farms or agricultural systems (e.g. Badgley et al., 2007; Seufert et al., 2012). Crop yields represent the field scale and comparative yields of crops grown with organic manures or mineral fertilizer do not represent cropping system productivity. Productivity of systems is defined as the ration of outputs to inputs used (Connor, 2013). Thus, upscaling organic yields to productivity of organic systems must include, for example, import of organic fertilizers and composts from other systems including conventional agriculture, extra land required for green manure crops, impact of frequent biological N-fixing crops on total yields over a crop rotation, differences in water use etc.

When attention is given to all the essential differences between systems affecting yields, conflicting results often become explainable and a better understanding of differences between farming systems can be gained.

The aim of this paper was to use published papers to (i) illustrate how differences in the design and scale can lead to incorrect conclusions; (ii) point out common pitfalls to be avoided, and (iii) define appropriate standards that are necessary to make scientific comparison of organic and conventional agricultural systems valuable. We hope that this paper can help readers to identify weaknesses of published and planned papers and improve the scientific understanding of comparative studies being free from ideological bias, political correctness, preconceived environmental opinions or confusing incentives.

2. Critical review of comparative organic and conventional studies—definition of stringent boundary conditions

Publications within four topics—crop yields, carbon sequestration, biological diversity and nitrogen leaching—were used to demonstrate frequent limitations in scientific evaluations of comparative studies. We focus on organic *vs* conventional farming systems but many of the concepts and the rationale developed here also applies to other system comparisons.

2.1. How large are yield gaps between organic and conventional crop production?

The central task of agriculture is to produce sufficient food with a minimum negative environmental impact. In a previous review on organic crop yields, Kirchmann et al. (2008) found organic crop yields being 25 to 50% lower than conventional ones and main factors limiting organic yields were lower nutrient availability, poorer weed control and limited possibilities to improve the nutrient status of soils. Opposite opinions exist whether organic farming can sufficiently feed the world (e.g. Badgley and Perfecto, 2007) or not (e.g. Cassman, 2007; Connor, 2008; Goulding et al., 2009). Thorough and detailed analyses of organic and conventional yields are necessary to be able to foresee whether organic methods can be a realistic option to provide sufficient food in the future (e.g. UN Millenium Project, 2005; FAO, 2012). According to official crop production records from Statistics Sweden (SCB, 2014), organic yields are generally lower for most crops grown in Sweden. Meta-analyses of yield differences between organic and conventional agriculture (e.g. Badgley et al., 2007; De Ponti et al., 2012; Ponisio et al., 2014) show that organic crops can match conventional yields in some studies, whereas in others it cannot. However, in these reviews, no or insufficient information is provided about reasons for why yield gaps can be small or large. In other words, yield determining factors such as number of legumes in rotation, rates of nutrient supplied, amount of manure transferred from conventional agriculture, soil fertility status, etc. are so far seldom taken into account in the evaluation. Meta-analysis is only meaningful when properly used. Philibert et al. (2012) showed that there is clearly a need to improve systematic reviews in agronomy; none of the 73 meta-analyses they reviewed satisfied all the recommended quality criteria. Selecting only years with highest organic yields for a comparison with conventional yields is not scientifically sound (Badgley et al., 2007). A review by Seufert et al. (2012) showed that gaps between organic and conventional crop yields widened from 20 to 34% when organic studies applying manure originating from conventional systems were excluded. Overlooking nutrient input to organic systems originating from conventional agriculture will