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System-level approach needed to evaluate the transition to more sustainable agriculture

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We disagree with Leifeld fundamentally on the purpose of our agricultural system—our goal should be to produce nutritious, affordable and accessible food in a socially and environmentally sustainable manner and not just 'keeping prices low'. So-called low-cost food produced by industrialized, conventional agriculture comes at a great price to our soils, water, biodiversity, atmosphere and worker health [1]. In turn, low calories also contribute to a rise in obesity, which is associated with increased risks of diabetes and heart diseases, and paradoxically is often accompanied by various types of malnutrition [2]. Thus, the price of food does not reflect these costs [1]. Arguably, the people that pay the highest price for this 'low-cost food' are the farm workers who sacrifice their health, living conditions and sometimes even lives, although they may not be able to afford food for their own tables. Accessible, affordable, nutritious food is not synonymous with 'low-cost food', and low-income families should not have to choose between whether to eat, versus accepting harms to their own families, as well as the environmental consequences and exploitation of farm workers. Needing food to be 'low-cost' to feed people results from low wages and the inequitable distribution of wealth [3], issues that need to be tackled in order to attain a sustainable food system.

Further, the negative consequences of large-scale, industrialized conventional agriculture undermine the earth's capacity to continue producing food [4]. In deciding the future trajectory of agriculture, we must balance the known harm caused by our current, high-input agriculture system with the potential costs and benefits associated with a transition to alternatives. Yield is only one factor within a set of complex socio-economic forces that determine what management practices growers adopt, how much land is dedicated to agricultural production, and how much food is available and accessible for the hungry [5–8]. Yield, however, has continued to be a focus in the debate surrounding the adoption of alternative, less environmentally and socially damaging agriculture practices [9]. A focus solely on increasing yields will not solve the problem of world hunger; this is clearly the case, because two billion people today are either chronically hungry or malnourished despite the fact that we produce more than enough food to feed the current population [7]. Instead, all aspects of a farming system, including ecosystem services, production and livelihoods, must be evaluated in considering the future of agriculture. Leifeld argues for larger-scale studies to examine conventional and organic agriculture, but simply increasing the scale does not equate to a systems approach, although it may be an important component. We must instead invest in research aimed at understanding the full social–ecological consequences of transitioning or not transitioning to more sustainable food systems [10,11].

Responding to Leifeld's four specific points, we note that Leifeld, in focusing on how consideration of large scales might reveal negative consequences of transitioning to alternative agriculture practices, overlooks the potential positive implications of this transition at large scales.

1a. Leifeld states that broad-scale adoption of organic practices could result in decreased yields in organic system because of reduced nitrogen deposition from conventional farms. This is an interesting hypothetical; however, there is absolutely no evidence in the published literature. Further, it is difficult to argue that hypothetical yield decreases in organic farms caused by the loss of nutrient spillover from conventional systems could offset the well-established negative impacts of nitrogen runoff, which include dead zones in the ocean and soil acidification [12].

There is, however, growing evidence from landscape-scale studies that greater proportions of land devoted to organic and diversified techniques enhance ecosystem services such as pest control and pollination on farms. Across hundreds of cereal fields and nine regions in Europe, the potential for pest control was positively associated with the proportion of the landscape using organic and diversified farming techniques and negatively related to the amount of pesticide application [13]. Similarly, in wheat fields across three regions in Germany, increasing the proportion of organic fields in the landscape from 5% to 20% more than doubled the richness and abundance of pollinators, on both organic and conventional farms [14,15]. Increasing the use of diversified and organic agriculture in a landscape thus has the potential to improve yields, both through reducing pest damage [13,16] and increasing pollination services [17]. This would also contribute to the profitability of these systems by reducing the costs of inputs such as pesticides [18] or managed honeybees [19]. Expanding organic and diversified practices may also enhance food security by reducing reliance on fossil fuels owing to higher energy efficiency [20] and managed honeybees through promoting wild pollinator populations [21]. At the same time, organic soils also have higher water storage and infiltration, leading to higher resilience to severe weather conditions than in conventional systems [22]. The next step is to understand when the enhanced provision of ecosystem services in diversified systems translates to improvements in human health and livelihoods [23,24].

1b. As landscapes transition to organic, it will also be interesting to study how the supply chain for supplemental external inputs evolves. Because organic agriculture is currently only a small proportion of the land in production, it relies on inputs like manure from conventional systems, but as the landscape changes, so will the source of inputs. Alternative, under exploited sources of nutrient inputs include municipal composting, and livestock integration may help eliminate the need for importing manure [25].

2. Leifeld points out that we do not know whether pest control services promoted by diversification practices will be sufficient for stable production at a large scale. We also rarely study the effects of pesticides at a landscape scale [26].

We agree with Leifeld that integrated pest management (IPM) where organic or synthetic pesticides are used only as a last resort, is a key component of sustainable agricultural systems. Only in organic systems, however, is IPM encoded into the best management practices. In conventional systems, no such guidelines exist. IPM is mentioned in the FAO's International Code of Conduct on the Distribution and Use of Pesticides, but this is simply a recommendation with a purely voluntary agreement and only 15% of countries have signed onto it. In fact, worldwide the use of IPM is diminishing as systemic pesticides, such as neonicotinoids, are increasingly applied prophylactically as seed treatments [27], protecting against pest pressures that may never materialize [28]. Pesticide use is associated with extreme negative impacts on human health and wildlife [29,30]. Simplified landscapes and high pesticide use are strongly associated with increased pest pressure, not pest control [16]. Instead, we need to promote pest control through diversification, using methods of conservation biological control. Strong policies to promote IPM are needed to protect humans and the environment.

3. Leifeld argues that alternative forms of agriculture such as organic should not be considered more sustainable because they may require more land for production. However, there is no simple relationship between yields and amounts of land used for production [8]—often, yield intensification leads to agricultural expansion and conversion of natural habitats in a phenomenon known as the Jevon's paradox [31]. Further, alternative systems are not always less productive or profitable. In fact, our results suggest that further investment in research into diversification techniques has the potential to improve productivity of sustainable agricultural methods to equal conventional yields. Encouragingly, the few long-term studies that have been conducted have demonstrated that diversification techniques enhance yields while enhancing ecosystem services, profitability and stability [18,23,32–35].

4. Leifeld's last point that organic agriculture will lead to more greenhouse gas emissions suffer from various fallacies that we have already addressed, including that increasing yield is needed to relieve hunger, that alternative to conventional agriculture cannot produce comparable yields and that yield is the sole determinant of the amount of land in production. Further, he fails to take a large-scale, systems perspective in his assertion that organic farms create more greenhouse gas emissions per unit of yield, because he considers only the gas fluxes from soils. When the entire system is considered, organic farming systems have on average higher energy efficiency and lower greenhouse gas emissions per farm product than conventional farms [20]. The lower-energy efficiency in conventional farms is primarily owing to nitrogen fertilizers, which are highly energy intensive to produce [36].

Despite the fact that research into refining organic and diversified farming techniques has been severely underfunded relative to conventional [10,37], these alternative forms of agriculture outperform conventional systems in terms of promoting environmental and social sustainability [38,39]. We believe it is time to invest in rigorous, systems-based research oriented at eliminating yield gaps between organic and conventional agriculture (when they occur), and elucidating the links between farming techniques, ecosystem services and livelihoods.

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