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Can soil-less crop production be a sustainable option for soil conservation and future agriculture?

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ABSTRACT

Agriculture faces huge challenges regarding sustainable use of soils and its sustainability performance in general. There are three different approaches to sustainable agricultural production commonly proposed, namely intensification, agro-ecological approaches and high-tech industrial approaches. Often, some propose that only agro-ecological approaches are truly sustainable options, with particular benefits for soil protection, while others argue that intensification or high-tech performs better through land sparing. In this viewpoint, we scrutinize the notion of "sustainable agricultural production" and the role these approaches may play for such, in particular addressing the controversy of "naturalness" versus "artificiality" in production systems. Consumers often perceive agriculture as "natural", but agriculture today thrives always on strong human intervention. We posit that agriculture *is* linked to soils and natural processes, but that this provides little guidance on what sustainable agriculture *should* be. Being "natural" need not be an aspect of being sustainable. If it is, arguments for this need to be provided. Furthermore, revealed consumer preferences may much less frequently posit being "natural" as a central criterion for food consumed than usually assumed. By all this, we do not want to promote any of those three approaches uncritically. We rather argue for enlarging the option space for sustainable agriculture in an unprejudiced way.

1. Introduction

Agriculture has huge environmental impacts. Providing food for an ever-increasing population, up to 10 billion in 2050, threatens to increase those impacts further (Evenson and Gollin, 2003; Pingali, 2012; Smith et al., 2013). One key challenge is soil conservation and the maintenance of associated ecosystem services.

Three general approaches are proposed to face this challenge. Firstly, agro-ecology approaches focus on aligning agriculture with ecosystem dynamics and natural cycles, thus promoting food production that is less environmentally disruptive (Tomich et al., 2011). Secondly, intensification strategies focus on producing more output per unit of input (e.g. land, fertilizer) and on reducing environmental impacts per unit of food. Thirdly, high-tech industrial-engineering approaches such as algae protein bio-reactors, cultured meat or vertical farming focus on manageability of production processes, thus rather delinking food production from natural ecosystem dynamics and soils. Such approaches aim at minimising impacts by maximal control of the processes and environments involved. Controversies on which approach is best for soil conservation and environmental sustainability in agriculture emerge especially along the lines of yields and land use, agricultural production vs. other ecosystem services, health and nutritional value of the products, and the "naturalness" or "artificiality" of production systems. In this contribution, we scrutinize this aspect of being "natural" or "artificial" in different agricultural production systems. We critically discuss the merits of increasing the option space for

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sustainable food production in general and for soil conservation in particular with high-tech, soil-less production systems. This relates to the "artificiality" of conventional agricultural production; the "naturalistic fallacy" of resistance against high-tech solutions; and the revealed preference of people on "natural food".

We do not want to uncritically promote high-tech systems, but we want to support an objective discussion on the arguments in favour and against those, and on their potential advantages and drawbacks. Thereby, we put the environmental component of sustainability at the centre of our analysis. "Sustainable agriculture" or "sustainable food systems" are highly complex and value loaded concepts and clearly cover much more than environmental aspects. Food security, animal welfare, labour rights, social well-being, for example, are central and can also conflict with environmental goals. Environmental aspects however play a key role in all notions of sustainable food systems and sustainable agricultural production in particular.

2. Agro-ecology, intensive production systems, high-tech solutions

Agro-ecological approaches, intensive production systems and high-tech industrial-engineering solutions address soil conservation and the maintenance of associated ecosystem services from two different angles.

High-tech approaches and intensification support soil conservation via land sparing, agro-ecology approaches rather preserve soils and their ecosystem services via land sharing. For illustration, Table 1 provides some indicative values for key indicators for these systems. Another key difference between these production systems is the intensity of financial capital and land in producing one unit of food. While the first and the third approach substitute land and partly labour with capital, agro-ecology tends to use more land with lower capital input and rather more labour. Fig. 1 shows a schematic representation of the three approaches and associated (soil) ecosystem services.

Most of the high-tech approaches are still far from being mainstreamed and are implemented in a few pilot trials, if at all. Most advanced towards larger-scale implementation are soil-less crop-production and crop-aquaculture systems such as vertical farms or hydroponics and aquaponics. Soil-less production systems are discussed very critically, in particular by proponents of agro-ecology approaches, e.g. organic agriculture (NOSB, 2010). However, such production could be promising for soil protection, because it has minimal soil use, correspondingly reduces demand for soil for agricultural production and thus spares soils and their services elsewhere. Under soil-less production, the soil no longer functions as part of the agro-ecological processes, but only as area for support of infrastructure needed for the soil-less systems. Such production can thus be established on any area, even sealed or highly unproductive soils, or also stacked in vertical farms, thus minimising area use. Unless organic material such as peat is used as substrate, these systems can fully delink agricultural production from fertile soils. This is one key aspect for their potential environmental sustainability, as many environmental impacts scale with acreage and soil input management. Being soil-less is also one key aspect why these systems are criticised and opposed for not being "natural" (e.g. NOSB, 2010).

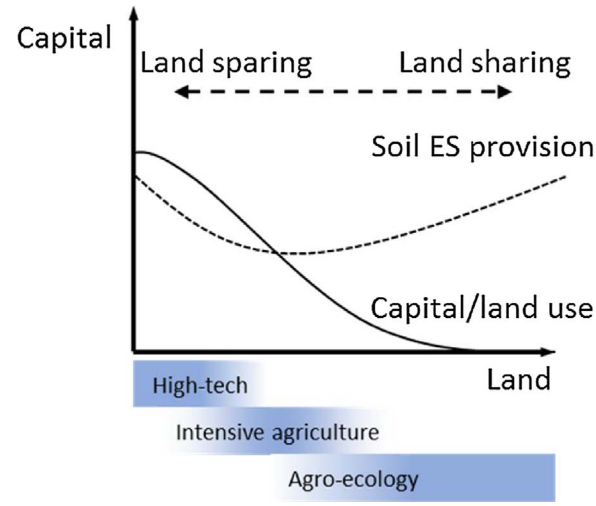

Fig. 1. Schematic representation of the capital-land ratio (solid line) in agricultural production systems to produce one unit of food and the provision of (soil) ecosystem services (ES; dotted line) through land sparing and land sharing approaches (see e.g. (Fischer et al., 2011; Law and Wilson, 2015; Tscharntke et al., 2012)).

3. Challenging "naturalness"

3.1. *Artificiality*

Agriculture is already detached from natural conditions and takes place in managed up to artificial environments not only when being delinked from soils. Even traditional monocropping or breeding are not natural, as they would not occur without human intervention. Current agricultural production relies on human-modified environments regarding water and nutrient supply from irrigation and fertilization, and regarding temperature and humidity via greenhouses and plastic tunnels, for example. Todays' agriculture and food production in developed countries is an industrialised production sector and far from being "natural". This is reflected in huge greenhouse-based vegetable production facilities; in industrial chicken production with ten thousands of animals in huge buildings; in the use of lysine or phytase to improve animal digestive capabilities; in the importance of imports and off-season products in daily diets; or in the industrial processes involved in the making of the final product.

Thus, current agriculture is far from the images many people may have of agriculture. With less people working in agriculture, the image

Table 1
Illustrative comparison of high-tech, intensive, and agro-ecology approaches along a range of key-indicators. Data for organic and intensive conventional systems stems from recent meta-analyses; data for vertical farming stem from case studies, in lack of reviews. Agro-ecology covers more than organic production and the latter can also be intensive. However, organic production can serve as a well-researched and established case for agro-ecological approaches. Sources: (Crowder and Reganold, 2015; Gattinger et al., 2012; Lorenz and Lal, 2016; Meier et al., 2015; Reganold and Wachter, 2016; Seufert et al., 2012; Touliatos et al., 2016; Tuomisto and Teixeira de Mattos, 2011; Westhoek et al., 2014).

	High-tech (e.g. vertical farming, cultured meat)	Intensive agriculture	Agro-ecology (e.g. organic agriculture)
Yields (index: 1 for intensive agriculture)	10–100 (i.e. highest yields, lowest area use)	1	0.65–0.95 (i.e. lower yields, higher area use)
Soil carbon (t/ha)	soil sealed (but low area use)	low	medium (1 t CO_2e/ha/y for closed systems)
Energy use (MJ/ha)	very high (but may use waste heat)	high	low (considerably less energy per area; per product unit from −50% to +50%)
Nitrogen loss (tN/ha)	zero (if well designed)	high	lower
Biodiversity	spare	spare/share	share; increased biodiversity, but high heterogeneity
Capital requirements ($/ha)	high	Low-medium	Low

of agriculture among consumers in developed countries may mainly be driven by retailers', industries' and farmers organizations' ads and by children's books promoting a version of agriculture from a century ago that is hardly found today. These everyday images are partly counteracted by media reports on scandals, e.g. on livestock housing; nevertheless, the positive images remain. These positive images may result in the assumption that agricultural production today is or should be "natural", triggering reservations against high-tech approaches.

3.2. Naturalistic fallacy

It is legitimate to hold convictions that agriculture should be "natural", and many people support a central role for soils within this. This is, for example, reflected in the recommendation of the National Organic Standards Board (NOSB) against including soil-less crop production practices in organic standards, as one key aspect of organic agriculture is the close link to natural processes and to fertile and "living" soils in particular (NOSB, 2010). NOSB acknowledges the potential of soil-less production but emphasizes its incompatibility with current organic regulations.

It is, however important to scrutinize the arguments why agriculture should not be high-tech, industrial or soil-less. Arguments for example refer to the necessity to establish a "natural" situation, where the link of agriculture to the soil is essential, as in most of current agriculture, and particularly emphasized in organic agriculture (IFOAM, 2016). Also important is the role of living organisms in agriculture and of food for survival and in religious contexts, again relating to agriculture as somehow being "natural".

This is, however, a problematic argument, related to the "naturalistic fallacy" where characteristics of how something "is" are used to conclude how it "should be" (Frankena, 1939). What sustainable agriculture "should be" has to be identified in relation to criteria of sustainability. Thereby, one can argue that "natural" food production should be an essential aspect of a sustainable food production, e.g. based on the precautionary principle. However, "naturalness" need not *a priori* coincide with key sustainability criteria for food production. High-tech solutions that do not link to natural environments (while they still link to natural processes) can be designed to perform well regarding environmental sustainability, e.g. in nutrient recycling and closed nutrient management. Aquaponics is a prime example, where aquaculture excrements fertilise plant production and nutrient loss is minimised (Godek et al., 2015).

3.3. Consumer preferences

Much information on food production is available to consumers. However, revealed preferences are still not for products that fulfil additional standards, as can be seen from the shares of organic and otherwise labelled products in total consumption and from the acceptance of e.g. artificial cheese not based on milk on ready-made pizza, albeit stated preferences may tell otherwise (Vringer et al., 2015). We thus ask whether or to which extent people at all want to eat "natural" food. It needs at least to be scrutinized what is meant by "natural" and why action and stated preferences may differ. There clearly are those people that care for the authentic, traditional, regional production. Those will always get their products from niche markets, irrespective of how mainstream food production looks like. Whether we like it or not, however, many people may not be that interested in how the food they eat has been produced. In this case, why producing only "naturally" if many people may not care about the relation of agriculture and nature? Anecdotal evidence from our daily work suggests that researchers and activists on food are biased here, as they tend to be interested in food, paying attention to good and characteristic taste and quality more than the average consumer. But they then implicitly and wrongly derive that all other people should adopt or already have the same preferences.

4. Challenging soil-less production systems

The arguments provided above do not mean that anything goes. The environmental problems demand solutions, animal welfare needs to play a key role, and working conditions need to be human in any agricultural production system, be it more natural or technologically driven. Soil-less solutions can be used, but not at the expense of these other aspects.

The sustainability performance of soil-less production needs further investigation. Such systems allow for multiple use of resources (e.g. several vertically stacked production levels) and are independent of weather and climate variability. They can be optimised regarding resource use and recycling and are thus very resource efficient and minimise nutrient runoff to the environment (Specht et al., 2014). These systems fully delink agricultural production from fertile soils, which is one key aspect for their potential environmental sustainability.

High-tech solutions are hardly an option when land (as a production factor) is not scarce and financial capital is not abundant or not available to farmers (cf. Fig. 1). High-tech solutions may be most feasible in the developed world. The relevance of soil-less production as a solution to address the global food crisis thus may be limited, especially because regions mostly affected by food insecurities have rather an abundance of land and a scarcity of capital.

Further challenges are energy use, as areas of soil-less production are small and capturing solar energy is thus not possible within the system. On the other hand, such systems can utilize waste heat from other infrastructure such as buildings, power plants or gas-pipeline pressure stations. Due to high capital demand, economic viability can be challenging, at least as long as agriculture does not internalise its external costs.

Special focus should be on the vulnerability of such high-tech operations and the resilience of agricultural production when high-tech approaches play a significant role. If it cannot be assured that resilience is high and vulnerability low, e.g. regarding pest outbreaks, energy price increases or nutrient supply, precautionary detention may be indicated. Finally, social aspects such as impact on community structures, and in particular power relations and power inequalities need to be evaluated before promoting such high-tech systems, where initial investment is high and where small-scale operations often will not be viable.

Further aspects can be critical, as well. Relevant differences regarding taste and nutritional quality and health aspects may derive from crops being exposed to natural soils, soil organisms as well as climate and weather influences. For humans, being exposed to soil likely goes along with lower allergic deposition, for example (Wall et al., 2015). This is, however, no argument against soil-less production, as this exposure is not achieved via food but via adequate areas of natural soils and animals in vicinity to where people live. For some production, natural soils may be essential, though. Wine production, for example, strongly emphasizes the importance of soil characteristics, i.e. "terroir" for the quality and character of the final product (while vineyards, in fact, are quite "artificial" and far from "natural" conditions).

It is also important to ask who the "farmer" is in high-tech agriculture (Walter et al., 2017). Social consequences from the adoption of such techniques also need to be addressed. Employment opportunities and self-esteem of producers are important. With soil-less production systems, the manager of operations may rather be an engineer than a farmer and his/her role would thus change thoroughly. In industrialised societies, where only a low percentage of the work force is in agriculture, and structural change is still leading to larger enterprises, this may fit to the future development, although it would lead to a break with still common perceptions on how agriculture is and should be done. In countries where agricultural workforce is a high percentage of total population, the situation is different, which adds to the challenges high-tech approaches face there (cf. above). However, structural change in agriculture is possible also in these contexts. If agricultural workforce declines and alternative job opportunities become available, such high-tech agriculture may become relevant there as well. Providing decent working conditions and livelihoods in agriculture is in any case of key importance. In this regard, high-tech solutions need not fare worse – or better – than traditional agriculture.

5. Conclusions

We argue that consumers may perceive agriculture as natural, due to the increasingly weak link between consumers and agricultural production, and supported by the representation of agriculture in our society via advertisements, children's books, lobbying, etc. We lined out that agriculture today is not natural and thrives always on strong human intervention. We also hypothesized that consumer preferences may not be such that being natural is a central criterion for food consumed and that "naturalness" as such is not a good indicator for sustainable agricultural production systems. Thus, whether agriculture should be natural is consequently a further topic. Being natural need not be an aspect of being sustainable, albeit it clearly can. But if so, arguments for this need to be provided. Some of the research and activist community working on sustainable agriculture may have a biased view on that, construed from their own convictions and values. We do not want to promote soil-less food production uncritically. Much research is still needed on these production systems, from their detailed environmental and economic performance, to social and societal topics related to consumer attitudes towards these systems, farmers' self-esteem and to power relations. The performance of different production approaches also depends on the spatial and regional context, and what may work well for one region and institutional setting may not work for another. We rather argue for enlarging the option space for sustainable food systems in an unprejudiced way by including high-tech production approaches in the portfolio of options to be considered and by asking for evaluating all arguments in favour or against such solutions and their potential contribution to sustainable food systems and soil protection. No single solution can solve all problems and different approaches need to complement each other, each one contributing a significant part, be it organic agriculture with its focus on fertile soils or vertical farming.

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