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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).

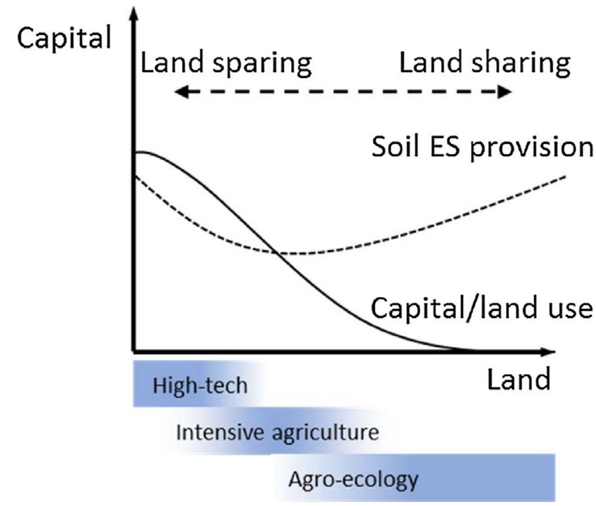

Fig. 1. Schematic representation of the capital-land ratio (solid line) in agricultural production systems to produce one unit of food and the provision of (soil) ecosystem services (ES; dotted line) through land sparing and land sharing approaches (see e.g. (Fischer et al., 2011; Law and Wilson, 2015;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