Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

Minimizing the ecological footprint of food: closing yield and efficiency gaps simultaneously?

Meine van Noordwijk[1,2] and Lijbert Brussaard[3]

Agriculture as a source of food has a substantial spillover that affects the Earth's ecosystems. This results in an 'ecological footprint' of food: negative environmental impacts per capita. The footprint depends on the dietary choice of types and amounts of food, on the non-consumed part of product flows and its fate ('waste' or 'reused'), on transport and processing along the value chain, on the environmental impacts of production per unit area, and on the area needed per unit product. Yield gaps indicate inefficiency in this last aspect: resource-use efficiency gaps for water and nutrients indicate that environmental impacts per unit area are higher than desirable. Ecological intensification aimed at simultaneously closing these two gaps requires process-level understanding and system-level quantification of current efficiency of the use of land and other production factors at multiple scales (field, farm, landscape, regional and global economy). Contrary to common opinion, yield and efficiency gaps are partially independent in the empirical evidence. Synergy in gap closure is possible in many contexts where efforts are made but are not automatic. With Good Agricultural Practice (GAP), enforceable in world trade to control hidden subsidies, there is scope for incremental improvement towards food systems that are efficient at global, yet sustainable at local, scales.

Addresses
[1] World Agroforestry Centre (ICRAF), Bogor, Indonesia
[2] Plant Production Systems group, Wageningen University, Wageningen, The Netherlands
[3] Department of Soil Quality, Wageningen University, Wageningen, The Netherlands

Corresponding author: Brussaard, Lijbert (lijbert.brussaard@wur.nl)

Current Opinion in Environmental Sustainability 2014, **8**:62–70

This review comes from a themed issue on **Sustainability governance and transformation**

Edited by **Paul C Struik** and **Thom W Kuyper**

For a complete overview see the Issue and the Editorial

Received 26 May 2013; Accepted 12 August 2014

Available online 29th August 2014

http://dx.doi.org/10.1016/j.cosust.2014.08.008

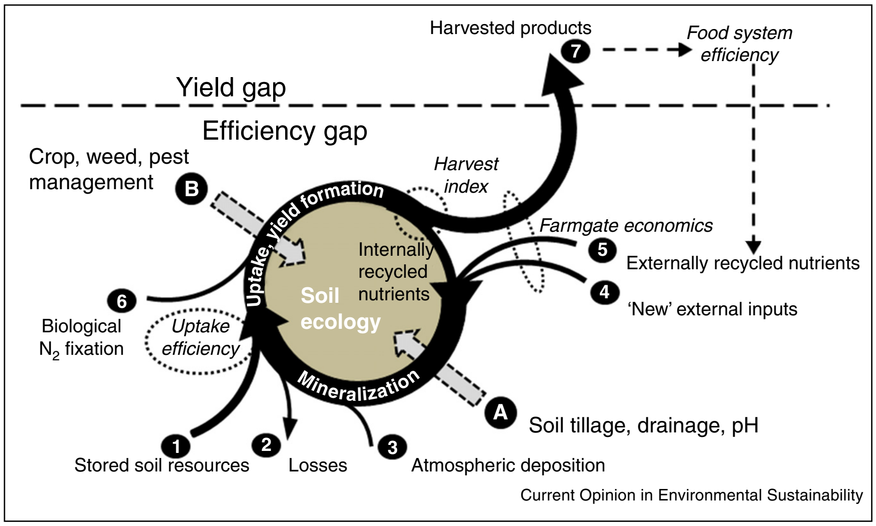
Introduction

Progress in seeing agriculture as the basis of complex value–chain interactions in 'food systems' [1] currently interacts with perspectives on agriculture as an important category of land use competing with other land functions [2], as a source of employment and livelihoods for a decreasing part of the rural population [3], as an important part of cultural heritage and identity[4], as modifier and storehouse of genetic resources [5•,6], as threat to environmental integrity and biodiversity at landscape scales [7], as source of greenhouse-gas emissions [8], and as a sector in the national and global economy [9]. Each of these interactions is a potential source of unsustainability [10•] and lack of sustainagility [5•]. From the consumer end of the chain, the concept of footprints [11] has become a useful integrative metric: the footprint of food depends on the dietary choice of types and amounts of food, on the non-consumed part of product flows (waste), on transport and processing along the value chain, on the environmental impacts of production per unit area and on the area needed per unit product. The latter two aspects are summarized in the related concepts of resource-use efficiency gap and yield gap and are the focus of this review.

Yield, defined as the harvested part of crop growth or animal production, is the result of complex processes of nutrient uptake, nutrient availability, soil ecological functioning, soil-and-crop management practices and input use, with the latter including crop residue, within farm nutrient cycling, inputs recycled from manure and waste within the regional economy, and new external nutrient inputs in the form of chemical fertilizer. The yield gap measures only the result of these interactions while resource-use efficiency gaps require a more detailed account of the underlying processes (Figure 1). Efficiency of the overall food system includes possible recycling of 'waste' back into the primary production process.

After defining yield and efficiency gap concepts and their relationships, this contribution to the debate reviews the scale dependency of yield and efficiency gaps and the consequences for internalizing externalities of farm-level decision making. A review of recent literature documents that both decreases and increases in efficiency gap occur in farming practice, as part of current efforts to close yield gaps. Finally, the opportunity is considered that articulation of Good Agricultural Practice (GAP) and its enforcement in global trade agreements, such as those in the

Figure 1



Food system efficiency perspective on soil **(A)** and crop **(B)** management as modifying factors of field-level interactions between soil (1), losses to atmosphere or water (2), nutrient inputs (3–6), and crop growth, leading to harvested products (7).

context of the World Trade Organization, can help in closing the two gaps simultaneously in the context of a debate on hidden subsidies implied by loss of natural capital.

Yield and efficiency gaps

Yield gaps, the difference in production per unit area between what is deemed to be feasible and what is achieved in terms of crop yield, indicate inefficient use of land [12•]. This can be formulated as: 'Yield gap = 1 − Achieved_yield/Potential_yield'. While Achieved_yield can be measured, Potential_yield is based on inferences drawn from models (especially ones that consider radiation and temperature of the actual location but assume that water and nutrient supply are non-limiting) or highest-observed local yield record [12•].

Resource-use efficiency is generically defined as the amount of targeted output achieved per unit input. If we see the production factor land as input — or as proxy for the way light, water and nutrients are accessible to crops — then the yield of harvestable products per unit area of land is a special case of resource-use efficiency. Different metrics are obtained for other types of resource-use efficiency if the same amount of harvested product is quantified relative to other types of inputs (e.g. fertilizer, agrochemicals, labour, total economic factor input). If negative consequences of production (non-targeted outputs), such as area of natural habitat converted or greenhouse-gas emissions, are used as denominator, a 'footprint' is calculated similarly.

Across various production systems the yield gap is not necessarily aligned with other efficiency gaps. A classical result of agricultural economics, challenged by some (see below), is that 'economic optimum' input levels do not achieve maximum yield and thus do not fully close the yield gap or, conversely, that fully closing yield gaps is not (micro)economically efficient and justifiable. There is a long tradition in publicly financed subsidies to inputs, such as fertilizer or irrigation where the micro-economic rationality does not match perceived macro-economic goals. There is a countervailing discussion on the relevance of taxing use of fertilizer and irrigation water where the microeconomic decisions tend to lead to low resource-use efficiency, loss of natural capital and increased environmental issues.

Yield gaps are most commonly discussed for one crop at a time but the Land Equivalent Ratio (LER), a common metric in mixed and multiple cropping systems [13], is similarly based on the sum of yields of various components relative to their potential value in reference systems. As it is quite possible for an LER to be above 1.0, however, the yield gap (interpreted as $1 - \Sigma_i(\text{Achieved\_yield}_i/\text{Potential\_yield}_i)$) can be negative for intercropping, which may appear to be a *contradictio in terminis*. It implies that the same amount of yield currently obtained in separate fields could have been achieved in intercropping with a smaller allocation of land.

For any steps towards closing yield gaps, there is a conceptually simple link to statements that land is being "spared" from agricultural use and may serve other functions. The value of these other functions can be high if land spared was left in a natural state and conversion was prevented. In the more common scenario where land