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Biotic resource loss beyond food waste: Agriculture leaks worst

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ABSTRACT

Enhancing the efficiency of biotic resource use by avoiding losses and boosting circular economy is one key in agrifood systems to ensuring food security and the functioning of the Earth system. The aims of this study were to first identify the greatest prospects for improving the biotic resource use efficiency and, second, to design methods to assess this efficiency. We assessed biotic resource use efficiencies (outputs/inputs) and biotic residue ratios (residues/inputs) in terms of dry matter, energy (LHV_d), nitrogen and phosphorus for two Finnish case regions. We identified the greatest biotic resource use inefficiency as occurring in animal production, followed by crop production. The resource use efficiency in animal production is unavoidably low, but in crop production, the utilization of recycled nutrients, i.e., animal and green manures, and the rejection of the use of spare mineral fertiliser can enhance efficiency. In addition, the agrifood system efficiency was 3.4–21% higher according to the circular use of biotic resources compared to the exclusion of these. The losses from the agrifood system represent 52–76% of the current biotic inputs of the studied elements in crop production, which highlights the importance of efficient resource use in terms of food security. We conclude that substituting the external resources in favour of the circular use of biotic resources as well as the avoidance of losses are the keys to enhancing the system's efficiency. The determination of the biotic resource use efficiency and biotic residue ratio applying the introduced generic assessments serves boosting of circular economy.

1. Introduction

Resource scarcity, environmental changes and rapidly increasing food demand are challenging agrifood systems around the globe. The primary function of an agrifood system is to generate biotic resources for food, fodder, fibre and fuel, but these systems also play a key role in many environmental changes, such as eutrophication, biodiversity loss and climate change, while also having great potential for ameliorating these problems. For example, agrifood systems in Finland are responsible for 69% of the conversion of atmospheric nitrogen (N_2) to reactive nitrogen and for 81% of phosphorus (P) load to aquatic systems (Kahiluoto et al., 2015). In addition, biomass extraction is constantly increasing (Franconi et al., 2016), so the efficiency of agrifood systems in the production and use of biotic resources is important. Circular economy is a way forward to more sustainable resource use by avoiding losses, enhancing efficiency and sustaining and increasing the value chain, i.e., enhancing the interplay between the economy and the Earth system (Ghisellini et al., 2016).

Food waste is a debated (Smil, 2004; Godfray et al., 2010; Foley et al., 2011) and studied (Parfitt et al., 2010; Gustavsson et al., 2011) example of inefficient resource use and loss. Although biotic residues from agrifood systems are not entirely edible to humans, a large share of residues is a manifestation of inefficient biotic resource use, which impairs food security and environmental performance. Assessments of biotic residue potentials from agrifood systems have revealed major differences in residue generation among the various sectors (Kahiluoto et al., 2011). The residue potential of the agriculture sector appears to be dominant, but residues from the food processing sector also possess remarkable nutrient and energy potential, depending on the local circumstances. However, agrifood residue potential does not reveal the resource use efficiency because (1) efficiency depends on the ratio of residues to products or inputs, not on the absolute amounts of residues, (2) in addition to residues, there are also gaseous and leaching losses from a system and stock changes, e.g. in field soil, and (3) residues can be utilized as inputs in agrifood systems or other production systems. Relating residue generation to biotic resource use is, therefore, an important complementary means that can be used to reveal the efficiency of agrifood systems.

Resource use efficiency is one application of the efficiency concept, which has a thermodynamic origin, i.e., it is the ratio of useful outputs to inputs (Jollands and Patterson, 2004). Resource use efficiency has been analyzed to indicate performance in various systems, such as crop

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production (e.g., Brooker et al., 2015) and the chemical industry (e.g., Ma et al., 2016), and assessment of resource use efficiency can assist in describing the efficiency of biotic resource use (Jensen and Bonnichsen, 2015). Here, the biotic resources also include natural and industrial biomass as well as residue biomass (Huysman et al., 2015). Biotic resource use efficiency reveals the production efficiency in agrifood systems that might be due to, e.g., the typical characteristics of a production line, technological or logistical choices, or market conditions, which also are the causes of food losses and waste (e.g., HLPE, 2014).

A consistent analysis of biotic resource use efficiency can be used to reveal the sectors of a system on which to focus efforts, i.e., where the most can be gained and the types of actions that are needed. The material flow and input-output analyses that have been performed have not revealed the biotic resource use efficiency of agrifood sectors (Risku-Norja and Mäenpää, 2007; Seppälä et al., 2011), or they have not included quality parameters other than dry matter (Kalt, 2015). The losses of the various sectors of agrifood systems were studied, e.g., in terms of fresh and dry matter, energy and protein (Alexander et al., 2017) and use of freshwater, cropland and fertilizers (Kummu et al., 2012). However, biotic resource use efficiencies have only been conversely stated (Alexander et al., 2017; Kummu et al., 2012) but not directly explored, and the role of circularity has not been assessed. Tools to assess the biotic resource use efficiency in various sectors to enlighten the potential of and enable the transformation to circular economy are urgently needed, especially because the theoretical underpinnings of circular economy remain narrow and disconnected (see, e.g., Murray et al., 2015; Ghisellini et al., 2016). Considering the indicators of circular economy, the biotic resources have not been covered (e.g., Geng et al., 2012) or indicators have been integrated (e.g., Geng et al., 2013).

The efficiency of a system is not solely a sum of the efficiencies of its sectors, which means that partial (i.e., component) optimization does not necessarily maximize system efficiency (Jensen and Bonnichsen, 2015). For example, in agrifood systems, manure is a valuable output of animal production along with animal products and therefore manure output as such improves the efficiency of animal production. However, if mineral fertilizers are utilized as the primary nutrient source in crop production, manure nutrients may be excessive relative to crop uptake, and the efficiency of manure use therefore remains poor (Nesme et al., 2011). Since manure is an unavoidable by-product of animal husbandry, omitting or reducing mineral fertiliser use rather than use of manure would improve the resource use efficiency of crop production and of entire food systems. Another example of partial efficiency in agrifood systems is the quality requirements for vegetables, e.g., size and shape criteria, posed by retailers with the result of somewhat less residues in retail stores but much more residue generation in the supply sector (Mena et al., 2011). Therefore, it is essential to analyze the interactions among the efficiencies of the agrifood system and its sectors to benefit the most from the resources.

The aim of this study was to develop the understanding of biotic resource use efficiency and its determination in agrifood systems, with a particular attention to circular economy. We posed the following research questions:

(1) Where in the agrifood systems are the biotic resource use efficiencies particularly low thus with high potential for improvement?
(2) How does maximizing the sector-specific biotic resource use efficiency affect the efficiency of the entire agrifood system?
(3) How can the biotic resource use efficiency of an agrifood system be determined?

Determinants of biotic resource use efficiency were also discussed, and two contrasting case regions in Finland were studied to reveal the ranges in efficiency.

2. Materials and methods

2.1. Case regions

The case study was performed in Finland in the industrialized agrifood systems of the regions of South-Savo and Satakunta, which contrast in terms of population density, the main agricultural production line and the extent of the food processing industry. In South-Savo, the total agricultural field area is only 53% of the corresponding area in Satakunta, but animal density is higher (0.5 Finnish animal units (AU) per ha vs. 0.3 in Satakunta; 1 AU = dairy cow, suckling cow, bull, steer or other cattle over 2 years of age). Agriculture is dominated by grass and ruminants in South-Savo and by grain and monogastrics in Satakunta, and there are fewer large food processors in South Savo (4 vs. 12 in Satakunta) (see the more detailed description in Kahiluoto et al., 2011). The agrifood systems of the case regions are open, i.e., exchange between other regions occurs both nationally and globally, as is typical of current globalized food systems.

2.2. System borders

Agriculture (crop production, animal production and fish farming),

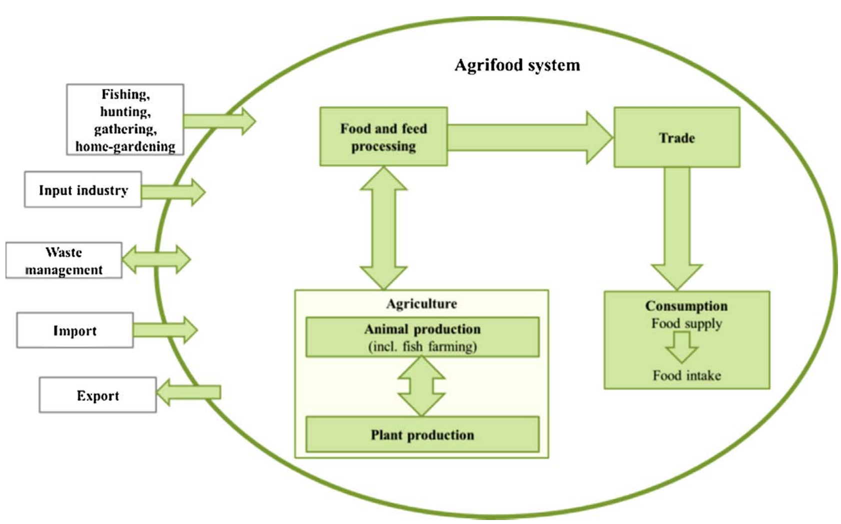

Fig. 1. A model of the agrifood system and its subsystems addressed by the study (ellipse) including biotic resource flows (arrows), and biotic resource flows from and to other systems (arrows).