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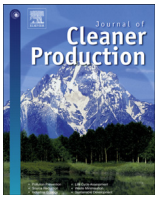

Nutrient footprint as a tool to evaluate the nutrient balance of a food chain

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ABSTRACT

The unsustainable use of nutrients such as nitrogen (N) and phosphorus (P) has resulted in the straining of the environment to excess. To improve this situation, a better knowledge of the nutrient flows is necessary. Even though nutrient balances and emissions have been calculated, an illustrative calculation method for the efficient use of nutrients use is still lacking.

This article presents a novel methodology for a nutrient footprint, which takes into account 1) the amount of nutrients taken into use as virgin or recycled nutrients and 2) the efficiency of these nutrients utilized in that particular production chain. At the same time, nutrient losses at each life cycle phase are identified. Hence, the nutrient footprint is an indicator which combines the amount of captured nutrients [kg of N and P] for use in the production chain and the share of nutrients utilized [%] either in the product itself or in the entire production chain, accounting also for side-products.

The nutrient footprint method is tested using oat flakes and porridge as a case product. The case calculation results reveal a relatively efficient use of the nutrients, as the nutrient use efficiency (NUE) of the production chain for N is 71% and for P 99%. When examining only the NUE of the oat flakes and porridge and excluding the side-products, the nutrient use efficiency is 55% for both N and P. The case calculation also reveals the hotspots for nutrient losses, which were located in the wastewater and food waste treatment.

The nutrient footprint methodology seems to have potential in assessing the nutrient balances of food chains as well as other bio-based production chains. It offers information about the nutrient usage and utilization efficiency in a simple and comparable form. This information can not only be used in improving the production chains but also in communicating the importance of the sustainable use of nutrients to decision makers.

1. Introduction

The need for different kind of methods for measuring, managing, and mitigating environmental impacts has grown. Footprint tools already exist for many issues regarding sustainability (Čuček et al., 2012). Perhaps the most widely used footprint tool is the carbon footprint, which accounts for the greenhouse gases and assesses the global warming potential, and the water footprint (Hoekstra et al., 2011) concentrating on water scarcity issues. These footprint tools assess different substance flows with different kind of cycles in the biosphere. Therefore, various approaches are also needed when constructing these footprints. One area needing this kind of attention is the nutrient cycles.

Secure food production relies on the use of nutrients such as nitrogen (N), phosphorus (P) and potassium (K). However, our current industrialized practices in agriculture, the change towards more meat-intensive diets and the population growth have resulted in an increase in the nutrients in the cycle (Antikainen, 2007; Metson et al., 2012; Webeck et al., 2014). The existing nutrients are flowing in a one-way direction and the losses in nutrient cycles

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cause serious environmental impacts such as eutrophication, acidification, and global warming. At the same time, resources such as land, water, and minerals are limited (Garnett, 2014). Consequently, capturing nutrients into the cycle has its challenges: Phosphate rock is a diminishing and non-renewable mineral (Steen, 1998; Smil, 2000; Smit, 2009; Fixen, 2009) and located only in certain parts in the world (Schröder et al., 2010). Nitrogen, on the other hand, is abundant in the atmosphere, but converting it to its reactive form is a highly energy intensive process (Galloway, 2008). It has been estimated that the amount of N_2 removed from the atmosphere and converted for human use has already exceeded the safe operating limit for human development and wellbeing (Rockström et al., 2009).

The overall nutrient use efficiency is very low: on average, over 80% of N and 25–75% of P taken into use in the full chain are lost to the environment (Sutton, 2013). The nitrogen and phosphorus flows are mostly linked to the production of fertilizers, food production, and consumption chains, with the share of the global nutrient flows in the agrifood systems for nitrogen being 74% and for phosphorus 80% (e.g. Antikainen, 2007; Kahiluoto et al., 2014). Less than 20% of the mined phosphate used in fertilizers end up as human nutrition (Cordell et al., 2009). In Europe, it is assumed that only 36% of the nitrogen inputs in the food chain are bound into the food products (Erisman, 2011). Therefore, it is relevant to assume that this efficiency will further decline when the rest of the food chain, for example food waste, is taken into account. These large amounts of nutrients used, as well as the low nutrient use efficiencies, indicate that the efforts to reduce the use of new nutrients and to increase the recycling of nutrients should be especially focused on food chains.

There are some methods available to analyze the nutrient flows and environmental impacts arising from nutrients, but they have some limitations. Material flow analysis (MFA) or substance flow analysis (SFA) accounts for the incoming and outgoing nutrient flows, but neglects to further classify or value them. Life cycle assessment (LCA) also characterizes the different inputs and outputs of the production chain and allows different environmental impact categories such as eutrophication, acidification, and global warming potential to be examined. However, the results of the LCA might be hard to interpret for anyone other than LCA practitioners. An aggregated indicator, which incorporates the information about the amount of used nutrients and the nutrient use efficiency, might be more easily understood and communicated.

Sutton (2013) take a step in this direction by introducing a nutrient use efficiency ratio, which presents the nutrients contained in the product in relation to the new nutrients captured by the chain, such as mineral fertilizers and biological nitrogen fixation. However, this boundary setting can be seen as slightly limited. It would also be relevant to include the recycled nutrients, especially manure and its nutrients, and also communicate the different nature of the new and the recycled nutrients. Secondly, there can be other means to exploit the nutrients besides the product. The benefit of recycling the secondary or by-products and their nutrient contents, for example, back to fertilizers or nutrition of animals, could also be allocated to the production chain of the product.

Another method in this field is the N-Print tool which calculates the nitrogen losses caused during consumption (Leach et al., 2012). Nitrogen released to the atmosphere as N_2 is not considered as a loss in this method. Nitrogen in its non-reactive form is not harmful to the environment, but the released N_2 is no longer part of the nutrient cycle and a great amount of energy is required to acquire it back with current conversion techniques. Therefore, nitrogen released as N_2 could also be considered as a loss. Secondly, the all-important resource use is not evident in the N-Print approach, as it concentrates on the losses. Thirdly, nutrients other than nitrogen are not taken into consideration in this tool. The Metson et al. (2012) method to calculate the phosphorus footprint of an annual average diet per capita offer valuable information on P demand. We still indicate a need to investigate individual food products to gain more detailed information on nutrient use efficiency including all losses throughout the life cycle of a food product. In order to improve food chains, it is relevant to know what the NUE is in each of the life cycle phases.

The methods presented above fulfill their purposes, but to overcome their limitations, we propose a novel method which would 1) focus both on the amount of captured nutrients and the nutrient use efficiency, 2) would take into account the entire life cycle of a product and 3) would be relatively easy to use and understand. The aim of this article is to present such a method for calculating a nutrient's footprint, which would allow examining and intensifying the nutrient use efficiency in production chains. The nutrient footprint, as with other footprints such as carbon or water, aims to communicate knowledge of the nutrient economy of a product to decision makers. This article presents the nutrient footprint method and demonstrates its use and utility through a case calculation conducted on oat flakes and porridge.

2. Material and methods

2.1. The nutrient footprint methodology

Our proposal for the nutrient footprint is a combined indicator for nutrient intake and nutrient use efficiency during the whole life cycle of a product. The nutrients that are currently included in our calculations are nitrogen and phosphorus, due to the environmental challenges that are evidently linked to them. Other nutrients can also be examined with this method. The third main nutrient, potassium, is important in nutrient economy, but the potassium reserves are substantially more long-lasting than for phosphorus (Sutton, 2013) and manufacturing potassium fertilizer is far less energy-intensive than producing nitrogen fertilizer (Galloway, 2008), hence potassium is currently excluded.

The functional unit of the study is based on the mass or the volume of a product under investigation, which is customary when examining food items (Roy et al., 2009; Schau and Fet, 2008). It has also been suggested that the nutritional value of the food could be used as a basis for functional units in LCA studies (Cederberg and Mattsson, 2000; van Kernebeek et al., 2014). In order to reduce the complexity when introducing a new method, we chose to use mass as the basis of our functional unit. In addition, mass as a functional unit is more applicable when examining other products than foodstuffs.

Fig. 1 presents the principle of the nutrient footprint.

The nutrient footprint method follows the normal life cycle perspective, where the entire life cycle of a product is taken into account including: the raw material extraction and acquisition, energy and material production and manufacturing, the use and end-of life treatment and disposal. The arrows in Fig. 1 represent different nutrient flows during the product's life cycle. The amounts of nutrients are examined throughout the life cycle as in a traditional life cycle inventory, but the amounts are not characterized to represent different environmental impact categories as done in the life cycle impact assessment.

On the left hand side of Fig. 1, there are two different nutrient flows that the examined chain uses as input nutrients. Virgin nutrients are captured nutrients that are extracted from nature and converted into a reactive form (for human exploitation) for this particular production chain. Typically, virgin nutrients enter into