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The nitrogen footprint of food products and general consumption patterns in Austria

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ABSTRACT

In this paper we use nitrogen (N) footprints as indicators of potential environmental impacts of food production in Austria. These footprints trace the losses of reactive nitrogen (Nr), i.e. N compounds that are generally accessible to biota, in connection to the chain of food production and consumption. While necessary for food production, Nr is known for its negative environmental impacts. The N footprints presented here describe Nr losses but do not link to effects directly. In deriving N footprints, Nr lost along the production chain needs to be quantified, expressed as "virtual nitrogen factors" (VNF). We calculated specific VNF for Austrian production conditions for a set of eight broad food categories (poultry, pork, beef, milk, vegetables & fruit, potatoes, legumes, cereals). The life-cycle oriented nitrogen footprints for the respective food groups were replenished by assessing Nr losses related to energy needs and to food consumption. The results demonstrate that in general, animal based products are less nitrogen-efficient than plant based products. For meat, footprints range from 64 g N per kg (pork) to 134 g N per kg (beef). For vegetable products, footprints are between 5 g N per kg (potatoes) and 22 g N per kg (legumes). The detailed ranking of food products is different when relating nitrogen footprints to either simple mass of food, or protein content. Vegetables & fruit cause only 9 g N per kg, but 740 g N per kg protein, which is even higher than pork (616 g N per kg protein) or poultry (449 g N per kg protein). These differences clearly show that taking into account protein and other aspects of food quality may be crucial for a proper assessment of dietary choices. The total N footprint per Austrian inhabitant is dominated by food production and consumption (85%) but also includes other activities linked to fixing nitrogen from the atmosphere (notably combustion). The average N footprint is 19.8 kg N per year per Austrian inhabitant, which is on the lower end of a range of industrialized countries.

Introduction

Nitrogen (N) is crucial for life on our planet. As a key element of proteins, it is needed for many metabolic functions and especially for growth activities which can be hampered by a lack of N. Thus fertilizers – the basis for global food production – provide the essential nutrient N to the food production process. Its molecular form N_2, which constitutes the major part of the earth's atmosphere, is only accessible to very distinct organisms. Most plants (and animals) rely on certain chemical N compounds, generally subsumed as reactive nitrogen or Nr (Galloway et al., 2002). Nr comprises all forms of biologically, chemically, and radiatively active nitrogen compounds (e.g., NH_3, NO, NO_2, HNO_3, N_2O, and NO_3^-, urea, amines, proteins, and nucleic acids), but excludes the unreactive N_2 (UNEP and WHRC, 2007).

As humans today artificially create amounts of Nr (e.g. as fertilizer for food production, but also as by-products in combustion processes) that far exceed natural terrestrial creation by biological nitrogen fixation (BNF), the natural nitrogen cycle has been modified substantially (Vitousek et al., 2013). Excess nitrogen accumulates in the environment, causing significant effects on humans and ecosystems (Sutton et al., 2011). Different Nr species act as greenhouse gases and deplete stratospheric ozone (N_2O), they are air pollutants and precursors of tropospheric ozone (NO_x), and contribute to the formation of particulate matter, the acidification of soils and water bodies and the eutrophication of ecosystems (NH_x, NO_3) (Galloway et al., 2002; UNEP and WHRC, 2007). The environmental behavior of Nr has been described as a cascade in which Nr moves between different environmental pools in the form of various Nr species, contributing to a number of different

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adverse effects (Galloway, 1998; Galloway et al., 2003; Sutton et al., 2013). Thus, whereas nitrogen is crucial to sustain life on our planet, it is imperative to use it as efficiently as possible in order to prevent losses to the environment and the resulting negative impacts.

Enhanced research activities in the last years have aimed to find ways to decrease those negative impacts of agricultural production by a more efficient use of Nr (Dalgaard et al., 2011; Halberg et al., 2005; Kumm, 2003). The focus on agriculture highlights the key role of this sector. In light of the substantial increases in yields and agricultural area that will be needed to provide food for the growing world population in the decades to come (see e.g. Ray et al., 2013), a more nitrogen-efficient agricultural production is crucial for keeping losses of Nr as small as possible.

In order to solve the "food security challenge" (Ericksen et al., 2009), the human demand and consumption sides require consideration as well, as the potential for further advancements in production efficiency is limited (Meier and Christen, 2013). Dietary requirements can be met using different types and combinations of food, which can have distinctly different nitrogen efficiencies (e.g. Smil, 2002). Therefore appropriate food consumption habits will have to be an issue. Tukker et al. (2006) assume that 20–30% of combined environmental impacts (and more than 50% of eutrophication impacts) of private consumption in the EU-25 are due to food and drinks consumption, thus pointing to the key role of consumers in this matter. By deliberately choosing more N efficient food products (i.e., consuming less meat), the overall impact could be reduced (Leach et al., 2012). But this is not only true for nitrogen. Livestock consumption is responsible for 18% of global GHG emissions, and its production requires 80% of global agricultural land (Steinfeld et al., 2006). In general, it has been demonstrated that, with respect to a "Western" developed world diet very rich in animal proteins, moving away from animal products and towards more vegetable products is not only beneficial for health, but also for the environment in many aspects (González et al., 2011; Stehfest et al., 2013; Zessner et al., 2010). Overall, animal products are evaluated as being less environmentally efficient than plant-based products as a consequence of the losses in the additional production step needed, animal husbandry. This step follows the production of feed crops that alone is largely comparable to food crops.

However, for a specific product, there is significant variation in the range of environmental impacts, depending among others on the production methods used. For instance, the energy use for tomatoes produced in heated greenhouses can be as high as 51 MJ/kg in Sweden and 130 MJ/kg in the UK, whereas open field tomatoes produced in Spain only need 3 MJ/kg. In consequence, while Swedish and UK greenhouse tomatoes cause 3.7 and 9.4 kg CO_2-eq/kg, respectively, the Spanish open field tomatoes only account for 0.37 kg CO_2-eq/kg (González et al., 2011). In a review of 15 studies, Nijdam et al. (2012) found carbon footprints of beef ranging between 9 and 129 kg CO_2-eq/kg, and land requirements between 7 and 420 m^2 y/kg.

In order to make environmentally-conscious decisions, consumers need to have information about the consequences of their consumption choices and sustainable alternatives. In this context, a large body of literature has evolved. There are a range of studies on environmental impacts of food and sustainable nutrition, including scenario studies on shifting overall food consumption patterns, footprint or Life Cycle Assessment (LCA) studies on different food products, and meta-studies (de Vries and de Boer, 2010; González et al., 2011; Nijdam et al., 2012). Most prominently, such studies investigate the emissions of CO_2 equivalents related to food. But there are also studies considering energy consumption, land use, water use (Herath et al., 2013; Milà i Canals et al., 2010) or the eutrophication and acidification potential of diet choices (Martínez-Blanco et al., 2011; Meier and Christen 2013). In a remarkable publication, Röös et al. (2013) attempt to integrate various impacts, arguing that carbon footprints of meat production can in most cases also serve as indicators of eutrophication and acidification, as well as a proxy for land use. While this is an interesting approach, carbon footprints cannot fully substitute the investigation of other environmental indicators, as there still might be trade-offs in many forms. Xue and Landis (2010) for instance highlight that carbon footprints do not necessarily match N footprints in ranking products by their environmental effects. Also, a relatively low water footprint of a food product might be accompanied by a relatively high CO_2 footprint (see for instance Page et al., 2012; Stoessel et al., 2012).

While it has been argued that the analysis of sustainable consumption options should include more pollutants (Hertwich, 2005), nitrogen is only rarely considered explicitly in these studies. Leach et al. (2012) have done some pioneer work in this field in providing a consistent methodology. Xue and Landis (2010) conducted some kind of N footprint analysis by investigating the eutrophication potential of food consumption patterns (considering both nitrogen and phosphorus) in a systematic way. Other studies explore N use efficiencies of diets from an N budget approach, analyzing N flows for entire countries (e.g. Bleken and Bakken, 1997; Isermann and Isermann, 1998; Lassaletta et al., 2013; Thaler et al., 2011). However, these studies do not explicitly look at different food products, and usually focus on animal production. Most recently, Chatzimpiros and Barles (2013) presented N "food-prints" for meat and dairy consumption in France, but also did not include any vegetable products. Leip et al. (2013) thoroughly assess the N footprints of a broad range of food products, including a set of vegetable foods, for the EU27. In contrast to the study at hand, however, Leip et al. (2013) present a "farm-gate" footprint and do not include energy use, or the processing, retail, and preparation phases.

With this study, we intend to contribute to a more complete and widespread assessment of the environmental performance of food, taking into account specific characteristics of Austrian production and consumption. Based on the approach by Leach et al. (2012), we estimate Austrian "virtual N" factors[1] (VNF) for a set of food categories. Adapting these factors allows us to derive product-specific N footprints that give an indication of how much Nr is used for the production of 1 kg food product and of 1 kg protein from a food product. Specifically, we do not only investigate animal products, but also look at different vegetable food categories, which are often neglected in other studies. The N footprint adds to existing food product footprints (carbon, water, energy, land use) and provides the basis for an assessment of impacts related to losses of Nr. Furthermore, the consideration of specific Austrian production conditions helps identify the importance of food production systems when evaluating dietary choices. Finally, we apply the Austrian VNF to calculate an average per capita N footprint that includes average food consumption patterns in Austria, as well as combustion-related nitrogen due to energy and goods & services consumption.

Methods

Boundaries and definitions

The N footprint of a food product is defined as the amount of Nr released to the environment along the entire production and consumption chain of a certain product. We calculate such footprints

[1] Virtual N is defined as all the Nr released to the environment during the production chain that is not contained in the final food product. See Section 'Virtual N factors (VNF)' for a detailed definition.