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Spatialised fate factors for nitrate in catchments: Modelling approach and implication for LCA results

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Abstract

The challenge for environmental assessment tools, such as Life Cycle Assessment (LCA) is to provide a holistic picture of the environmental impacts of a given system, while being relevant both at a global scale, i.e., for global impact categories such as climate change, and at a smaller scale, i.e., for regional impact categories such as aquatic eutrophication. To this end, the environmental mechanisms between emission and impact should be taken into account. For eutrophication in particular, which is one of the main impacts of farming systems, the fate factor of eutrophying pollutants in catchments, and particularly of nitrate, reflects one of these important and complex environmental mechanisms. We define this fate factor as: the ratio of the amount of nitrate at the outlet of the catchment over the nitrate emitted from the catchment's soils. In LCA, this fate factor is most often assumed equal to 1, while the observed fate factor is generally less than 1. A generic approach for estimating the range of variation of nitrate fate factors in a region of intensive agriculture was proposed. This approach was based on the analysis of different catchment scenarios combining different catchment types and different effective rainfalls. The evolution over time of the nitrate fate factor as well as the steady state fate factor for each catchment scenario was obtained using the INCA simulation model. In line with the general LCA model, the implications of the steady state fate factors for nitrate were investigated for the eutrophication impact result in the framework of an LCA of pig production. A sensitivity analysis to the fraction of nitrate lost as N_2O was presented for the climate change impact category. This study highlighted the difference between the observed fate factor at a given time, which aggregates both storage and transformation processes and a "steady state fate factor", specific to the system considered. The range of steady state fate factors obtained for the study region was wide, from 0.44 to 0.86, depending primarily on the catchment type and secondarily on the effective rainfall. The sensitivity of the LCA of pig production to the fate factors was significant concerning eutrophication, but potentially much larger concerning climate change. The potential for producing improved eutrophication results by using spatially differentiated fate factors was demonstrated. Additionally, the urgent need for quantitative studies on the N_2O/N_2 ratio in riparian zones denitrification was highlighted.

Keywords: Eutrophication; Environmental assessment; Life cycle assessment; Climate change; INCA; Denitrification; Riparian zone; Catchment hydrology

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1. Introduction

In regions of intensive agriculture, the contribution of farming systems to the degradation of the environment is increasingly investigated, especially concerning water quality. However, assessing the sustainability of such farming systems considering water pollution only can be misleading, because of possible trade-offs between their different impacts on the environment. More complete environmental assessment tools have been developed, to provide a holistic picture of the environmental impacts of a given system. The challenge of such tools is to be relevant both at a global scale, i.e., for global impact categories such as climate change, and at a smaller scale, i.e., for regional impact categories such as aquatic eutrophication.

Among those, the Life Cycle Assessment (LCA) approach, which considers the whole product life cycle, is recommended by the European Union (Anonymous, 2003) and UNEP (UNEP, 1996). The recent EU communication on Integrated Product Policy (IPP; Anonymous, 2003) states that "All products cause environmental degradation in some way, whether from their manufacturing, use or disposal. Integrated Product Policy (IPP) seeks to minimise these impacts by looking at all phases of a product's life cycle and taking action where it is most effective".

LCA has proved a valuable tool for the environmental evaluation of farming systems (Van der Werf and Petit, 2002). This methodology consists of four stages: the definition of the goal and scope of the study, the inventory analysis, the impact assessment (LCIA) and the interpretation. In the inventory analysis the resources consumed and the emissions to the environment are quantified at all stages of the life cycle of the product studied—from the extraction of resources, through the production of materials, product parts and the product itself, and the use of the product, to its reuse, recycling or final disposal (Guinée et al., 2002). For each environmental impact in the LCIA stage, a characterisation model is used to convert the inventory data contributing to this impact, into impact results. This is done by multiplying the emissions of each substance with a characterisation factor for each impact category to which it may potentially contribute. Characterisation factors are substance-specific, quantitative representations of the additional environmental pressure per unit emission of a substance.

To reach the general objective of taking all the impacts of a given system over time and space into account, in the general LCA model, the impacts are integrated over all the emission/impact locations (world) and over time (infinite horizon) in an assumed steady state (Guinée et al., 2002, p. 413). This situation generally corresponds to ignoring most of the environmental mechanisms between emission and impact as formalised by Heijungs and Wegener Sleeswijk (1999): emission, fate and effect, in each specific context of emission. The *emission* is defined as the output of pollutant from the system studied. The *fate of a pollutant* consists of its transport, its transformation and its accumulation or dilution in a compartment of the environment. The *sensitivity* of the ecosystem describes the way the ecosystem reacts to one dose of pollutant, for example through dose/effect curves.

For regional impact categories such as eutrophication, the simplifications of this generic model are considered excessive (Finnveden et al., 1992; Potting and Blok, 1994; Nichols et al., 1996; Potting and Hauschild, 1997; Finnveden and Potting, 1999; Udo de Haes et al., 1999b; Heijungs et al., 2003) especially when these categories dominate the system studied. SETAC (Society of Environmental Toxicology and Chemistry) now recommends to consider the cause and effect chain between emission and impact and to develop spatially differentiated characterisation factors (Udo de Haes et al., 1999a,b; Potting, 2000). The time differentiation of the characterisation factors is even harder to develop, due to a lack of data and because of the different time scales of each stage of the cause and effect chain.

Concerning the eutrophication characterisation factors, the spatial differentiation has rarely been implemented, or the results obtained still present much uncertainty (Seppälä et al., 2004). Some work has however been done on the fate of eutrophying pollutants in air (NH_3 and NO_x) by using the EMEP model (Potting et al., 1998; Huijbregts et al., 2001; Huijbregts and Seppälä, 2000; Seppälä et al., 2004). Huijbregts and Seppälä (2001) also proposed, on the basis of empirical data from the literature, fate factors for eutrophying pollutants reaching water via the soil. However, their approach is highly questionable for an application of LCA to farming systems. First of all, the system does not include the soil, which leads to defining the emissions as the rates of N and P applied to the soil and the fate factors for these emissions as the fractions of N and P which leave the soil by leaching or runoff. This is not in line with the actual definitions both of the system limits, the emissions and consequently the fate factors, in LCA studies of farming systems (Audsley et al., 1997; Cowell and Clift, 2000; Gosse et al., 2000; Brentrup et al., 2001; Sandars et al., 2003). In these studies, the soil is considered as being part of the studied