How to cope best with field emissions of nitrate in a food LCA?

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Abstract

When performing a LCA of food products and bio-fuels the question about how to quantify direct field emissions arises. Since the agricultural production phase is crucial for eutrophication of water bodies, the selection of an appropriate model for quantifying nitrate leaching is an important task for LCA-researchers. The aim of this presentation is to break the deadlock: we discuss possible approaches to estimate nitrate leaching in a LCA and compare their performance from the point of view of scientific soundness, feasibility and usefulness.

LCA practitioners urge to have one single approach for the whole world. This demand is typical for streamlined LCAs [2]. For such a rapid assessment, a regression model based on field experiments can be applied. Yet the advantage of a unique and basic equation is counterbalanced by the fact that this approach should be solely applied inside the limits the model has been developed for. The approach chosen in Ecoinvent Report No 17 [6] for crops like palm based on fixed emission factors, is surely user-friendly. But the general assumption of an emission factor of 30% of fertiliser input for arable crops is arbitrary and has the enormous disadvantage of neglecting effects of crop rotation, soil, fertilizer characteristics and other relevant parameters. It does not allow a comparison of different cultivation practices and improvement options meant at limiting nitrate leaching.

On the other extreme, simulation models may consider basically all relevant parameters and lead to accurate results but require time consuming data collections and are still only valid for the region and crop types they have been developed for. [13] shows how simulation models can be used in a LCA context: Coefficients derived from long-term simulations with the model SUNDIAL are used in conjunction with crop husbandry data and allow the prediction of nitrate leaching for a given input of N. Yet for each crop rotation, soil characteristics and rain regime new simulations are necessary.

The empirical model SALCA-NO3 [14] is tested for use in central Europe and requires only well accessible data. This model, based on an input-output nitrogen balance, includes crops and vegetables and accounts for mineral and organic fertilising, soil characteristics and related mineralization rates. Furthermore the underlying crop-specific uptake curves are modelled with the N model STICS [16]. The leaching rate of mineral nitrogen is based on expert knowledge. Detailed analyses of the agricultural processes are possible because whole crop rotations including improvement options are modelled.

This analysis shows that a single accurate approach for the whole world does not exist since the variation of relevant parameters is too large. The approach has to be adapted to the scope of the study and the available input data .Regression models or emission factors are adequate for streamlined LCAs or when little knowledge about the crop or the site is on-hand. Detailed emission modelling is required for full LCAs in order to allow a comparison of different production conditions.

Introduction

LCA results of food or feedstock for bio-fuel production are dominated by the agricultural phase. For a chicken meal more than 90% of the emissions regarding eutrophication originate from agriculture [1]. Nutrient leaching, mainly responsible for it, is induced by agricultural activities [2], [3]. Therefore accurate methods to estimate the relevant nutrient emissions are crucial. This paper analyses possible approaches for the calculation of nitrate leaching in a LCA framework and compares them from various points of view: scientific soundness, feasibility and usefulness.

Nitrate emissions depend on soil characteristics (e.g. texture, field capacity), climatic conditions (drainage water rate or mineralization rate) and agricultural management (nitrogen balance, nitrogen leaching reducing management practices). All these parameters can be estimated, but the more precise they should be the more complicated it becomes.

Literature review

A literature review shows that nitrate emissions are very sensitive to the model used for their determination [4]. Simplifications have to be well considered, since leaching depends on the actual situation in the field. Therefore estimating field emissions poses major problems in LCAs of agricultural goods. Three methods are proposed for the quantification of field emissions in LCAs [5]:

- measuring actual emission rates caused by the system under consideration,
- using values derived from literature in a case-by-case procedure, or
- estimating potential emission rates using structured estimation methods.

Measurements under real conditions are difficult and for an LCA study generally not possible. A very high number of measurements would be necessary to estimate reliable average emissions. Literature data can be used as rough approximations, mainly as constant emission rates. This approach is used for some bio-energy crops in Ecoinvent [6]. Most studies opt for the third method, namely, using models able to calculate emission rates depending on the actual situation (soil, climate, management) [7]. In consideration of the fact that the dominant factors influencing nitrate leaching are highly site-dependent, a single model for the whole world would have many drawbacks. But it has to be kept in mind that accurate modelling of nitrate leaching requires simulations of both soil hydrological and biogeochemical processes [8].

The models used in literature range from simple farm gate N balances to complex simulation models. When estimating leaching as the difference between farm gate N surplus and gaseous N emissions any errors within these values are propagated in the nitrate emission estimate [9]. Farm N surplus can be seen as an expression of the long-term potential N loss. By multiplying the nitrogen balance with the exchange frequency of drainage water per year (Rate of drainage water / field capacity), the most dominant factor for leaching can be considered in a simple manner [5].

Simple models based on regression or mechanistic equations do also exist [10], [11], [12], yet they should only be applied in the same ranges of the data used for their setup. For example the regression model described in [11] has been used for a nitrogen balance assessment in the whole Sub-Saharan Africa [12].

On the other extreme, simulation models may consider all relevant parameters and lead to accurate results but require time consuming data collections and are still only valid for the region and crop types they have been developed for. Researchers of the Cranfield University (www.agrilca.org) show how such models can be used in an LCA context: Coefficients are derived from long-term simulations with the model SUNDIAL. For that purpose different rotations were simulated for nine combinations of soil textures and rainfall (clay, loam and sandy soil with low, medium and high rainfall, in the context of arable crops) until they were in steady state. This means that the soil organic N (SON) fraction was the same at the start and the end of a simulated rotation. The yields used in these simulations were taken from national averages or standard texts [13]. The derived coefficients are used in conjunction with crop husbandry data and allow the prediction of nitrate leaching for a given input of nitrogen. With this approach, new simulations are necessary every time the crop rotation, soil characteristics or rain regime is modified.

Presentation of SALCA-NO3

For modelling nitrate emissions of food and fodder crops in Switzerland and adjacent regions, we use our own, recently improved tool SALCA (Swiss Agricultural Life Cycle Assessment). The tool allows also estimates of the impacts of animal husbandry on nitrate leaching which are not discussed in detail in this paper. Nitrate losses are calculated in SALCA in function of the crop rotation, the nitrogen fertiliser regime, the management practices and the soil characteristics. This LCI method aims at allowing a comparison of the impacts of different crops and cultivation types on nitrate leaching based on in Switzerland easily available input data [14]. Minor adaptations based on local expertise allow also an application in a broader European context [15].

The main model components are the mineralization of the soil organic matter, the nitrogen uptake by plants, the input of mineral and organic nitrogen fertiliser and seasonal water drainage potential. All of these components are based on time course of temperature and precipitation according to long term weather data. The rate of mineralization is based on a standard soil with 2% organic matter content and 15% clay content and assumes a regular input of manure to the soil, as it is usual in Switzerland. This net nitrogen mineralization is adapted to a specific soil with other characteristics, taking into account its clay and organic matter contents, the manure input intensity (live stock units), the intensity and time of tillage and the crops cultivated before and after. The nitrogen uptake by crops is modelled with help of a temperature-depending N-uptake function. The plant N-uptake functions have been developed using the simulation model STICS [16] based on the standard N-uptake rates and yields of crops given in the Swiss fertilization recommendations [17] as important input data.

Nitrate leaching is calculated on a monthly basis as the difference between the available soil mineral nitrogen and the amount taken up by the considered crop in the given month. This difference results in the portion of mineral nitrogen prone to leaching. No leaching is assumed during the period of intensive growth of crops, because then soil water balance (precipitation minus evapotranspiration) is negative. The leaching directly following an application of mineral fertiliser is modelled based on the seasonal leaching risk, the amount and the date of the nitrogen application as well as the soil characteristics.

SALCA-NO3 allows calculating likely amounts of nitrate leaching. Yet, it neglects the variation of leaching rates caused by actual (weather) conditions and does not directly consider neither the immobilisation of nitrogen in the soil nor denitrification losses. In order to consider the abovementioned effects, dynamic simulation models like for example STICS [16] or MINERVA [18] would have to be applied, but they require data which are rarely available in a LCA context.

For taking into account crop rotation effects, the nitrate leaching attributed to a crop is calculated for the period from the harvest date of the preceding crop until the harvest of the investigated crop. Moreover, nitrate leaching of whole crop rotations can be assessed with SALCA-NO3, which is important when farming systems like organic farming or low-input strategies have to be assessed.

Model evaluation

Three evaluation axes have been chosen for the model assessment: scientific soundness, feasibility and usefulness [19]. The first axis is related to the transparency of the documentation (peer review paper, report), the coverage of agricultural production branches and management practises as well as site specific parameters (e.g. soil characteristics, precipitations). The second one is related to the accessibility of data required, the integration in software and the required qualification of the user. The last one expresses the clearness of conclusions that includes for example the ability to distinguish different cultivation intensities or techniques. The indicators listed in Table 1 are used to characterise four selected approaches (fixed emission factors, regression models and empirical as well as site specific modelling) to estimate nitrate leaching as described above and represented by the following methods: Ecoinvent report 17 [6], De Willigen [11], SALCA-NO3 [14] and AgriLCA [13].

Regarding the scientific soundness, Table 1 shows that all approaches are well documented in reports but their scope does differ form one to another. Whereas in Ecoinvent report 17 emission factors are explicitly given only for the selected bio-energy crops oil palm, sweet sorghum, sugar cane and soy beans, the regression model [11] is applicable for basically all crops. The method SALCA-NO3 has a very broad scope of production branches including arable crops, pasture, vegetables and selected permanent crops like vine or short rotation coppice of salix. The model AgriLCA as described in [13] is developed for selected crops and vegetables as well as animal husbandry. This shows that the selection of an approach can also be driven by the product that needs to be investigated.

The management practices highly influence nitrate leaching. Most important is the amount of fertiliser applied which is taken into account by all four approaches. But crop rotation and soil tillage have an effect on the potential leaching rate too. These influence factors can only be found in more complex methods. Site specific parameters are neglected in the factors given by [6], but are considered by the other approaches.

Looking at feasibility, data accessibility plays a dominant role. The simpler the approach the better is this accessibility. For SALCA-NO3 the contact to the farmer or a profound knowledge about the site and the production processes are necessary. The approach of AgriLCA requires simulations with the model SUNDIAL, when new crops or new site conditions are investigated. For such approaches the user needs a higher qualification. The regression model of "De Willigen" is implemented in the web-Tool of the project SQCB [2]. It is simple to use but the user should bring a good knowledge about the site conditions in order to evaluate the applicability of the model to his needs.

The usefulness of an approach depends on the scope of the investigation. Whereas streamlined LCAs urge to give fast results and accept a limited accuracy, a full LCA needs to be based on a method with a higher clearness of conclusions in order to avoid wrong statements. Table 1 shows that the usefulness of an approach is directly linked to data accessibility, which means that site specific parameters are indispensable for a sound differentiated conclusion. Furthermore it reveals that the range of crops is very different for the four methods analysed.

Table 1: Model evaluation

	Model Type	**Fixed emission factors**	**Regression model**	**Empirical simulation model**	**Site specific modelling**
Axes	**Indicators**	**Ecoinvent report 17 [6]**	**"De Willigen" [11]**	**SALCA-NO3**	**AgriLCA**
Scientific soundness	Documentation	Report	Report	Internal report	Report
	Production branches	Selected bio-energy crops	Arable crops	40 Crops, vegetables and animal husbandry	Selected crops and vegetables; animal husbandry
	Management practices	Fertiliser input	Fertiliser input, yield	Crop rotation, fertiliser input, soil working, yield	Crop rotation, fertiliser input, yield
	Site specific parameters	None	Clay, organic nitrogen in soil, rooting depth, precipitation	Clay, organic nitrogen in soil, rooting depth, production zone (valley, hill, mountain)	Soil texture, precipitation
feasibility	Data accessibility	Simple	Moderate	Detailed farming knowledge required	Detailed farming knowledge required. Simulation data needs to be generated.
	Software	Not required	Web-Tool in SQCB	Excel-Tool	Simulation model
	Qualification of the user	Basic	Academic	Academic	Academic, advanced
Usefulness	Clearness of conclusion	Limited	Limited	High	High

Conclusions

One worldwide applicable method for estimating nitrate leaching under crops and pastures may correspond to a need of LCA practitioners. But to draw clear conclusions about nitrate leaching, site-specific parameters are indispensable. Constant emission rates from literature are in most cases not available and are hardly reflecting the situation under study. Therefore constant emission rates are under most conditions inappropriate and cannot reflect the influence of the farmers' management practises. The latter is a prerequisite for the improvement of production processes and could only be neglected if the agricultural step would play a minor role, what is not the case as stated in the introduction. The risk of inaccuracy of the resulting food or bio-energy productions, consequently of drawing false conclusions, is high. However, nitrate leaching has not been investigated for all crops with field experiments until now, and the parameterisation of complex models is therefore impossible. This is the case of exotic crops like oil palm. From this point of view, the approach chosen in Ecoinvent [7] is justified, but it reveals that basic agricultural research is needed to improve modelling.

Regression models can be used in order to get a glimpse of the potential emissions, as used for example in the sustainability quick scan tool for bio-fuels SQCB [2], but not for an accurate quantification of nitrate leaching needed for political decision-making, legal processes or academic research. The risk for wrong conclusions would be too high. Nevertheless the large application range and the considerable literature review used in order to setup the model "De Willigen" [11] supports its appropriateness for a quick assessment with only very basic input data. For streamlined LCA with the goal to give a first insight to stakeholders, simple approaches have the advantage of being easy to apply without demanding time consuming data research. On the contrary, for extensive LCA studies of food or feedstock for bio-fuel production, nitrate leaching has to be estimated with models that allow considering site-specific parameters. They have to account for the most influencing parameters like soil texture, climatic conditions and agricultural management in order to guarantee well-founded conclusions. The variation of the mentioned parameters is very high from site to site and therefore the model needs to be adapted to the region under investigation.

Ultimately the selection of a model for estimating field emissions in general is first of all dependent on the scope of the study (detailed vs. streamlined LCA) and the availability of site-specific models for the products under investigation.

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