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# Incorporating denitrification-decomposition method to estimate field emissions for Life Cycle Assessment

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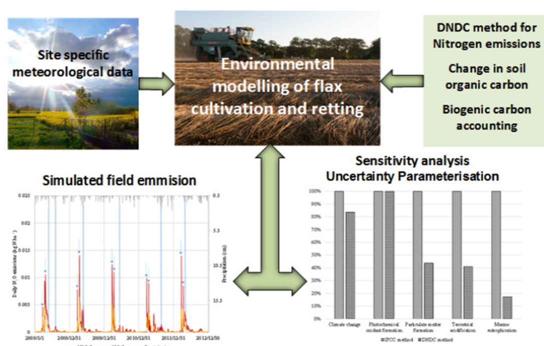
## HIGHLIGHTS

- The DeNitrification-DeComposition (DNDC) model is incorporated into the life cycle assessment.
- Impact assessment results from the DNDC model is compared to IPCC method.
- It shows that the two methods exhibit significant differences regarding environmental impacts.
- Guideline for the selection of agrochemical models for field emissions is provided.

## GRAPHICAL ABSTRACT

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## ABSTRACT

This study focuses on a detailed Life Cycle Assessment (LCA) for flax cultivation in Northern France. Nitrogen related field emissions are derived both from a process-oriented DeNitrification-DeComposition (DNDC) method and the generic Intergovernmental Panel on Climate Change (IPCC) method. Since the IPCC method is synthesised from field measurements at sites with various soil types, climate conditions, and crops, it contains significant uncertainties. In contrast, the outputs from the DNDC method are considered as more site specific as it is built according to complex models of soil science. As it is demonstrated in this paper the emission factors from the DNDC method and the recommended values from the IPCC method exhibit significant variations for the case of flax cultivation. The DNDC based emission factor for direct $N_2O$ emission, which is a strong greenhouse gas, is 0.25–0.5%, significantly lower than the recommend 1% level derived from the IPCC method. The DNDC method leads to a reduction of 17% in the impact category of climate change per kg retted flax straw production from the level obtained from the IPCC method. Much higher reductions are recorded for particulate matter formation, terrestrial acidification, and marine eutrophication impact categories. Meanwhile, based on the DNDC and IPCC methods, a comparative LCA per kg flax straw is presented. For both methods sensitivity analysis as well as comparison of uncertainties parameterisation of the $N_2O$ estimates via Monte-Carlo analysis are performed. The DNDC method incorporates more relevant field emissions from the agricultural life cycle phase, which can also improve the quality of the Life Cycle Inventory as well as allow more precise uncertainty calibration in the LCA inventory.



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## 1. Introduction

The increasing concern on global warming due to greenhouse gases (GHGs) emissions triggers a gradual paradigm shift from fossil-fuel based resources towards biobased products. Biobased products embody the solar energy into exploitable sources while contributing to carbon neutral products. Among biobased products, flax fibres, which are extracted from the straw of flax, have been explored in replacing of traditional glass fibres as composite reinforcement (Shah, 2013; Yan et al., 2014). Currently, the use of flax fibres has already entered into the commercial stage since it has gained widespread acceptance in the automotive sector (Shah, 2013). Flax fibres, as the biobased substitute of glass fibres, have a lower density, and thus contribute to lightweighting (Shah, 2013).

Flax cultivation is concentrated on Northern France meanwhile France is the largest producer of the flax fibre in the world (FAO Statistics, 2016). The use of flax fibres, however, raise environmental concerns associated with its cultivation stage to obtain the flax straw where nitrogen, potassium, and phosphate fertilisers are required to allow straw growth. Therefore, cultivation of flax involves nitrogen and phosphate cycles, which may yield various gaseous emissions and leaching. Nitrogen, a base macronutrient in agriculture, it is actively transposed through the entire ecological system consisting of plants, soil, water, and air (Bernhard, 2012; Li et al., 2006). Nitrogen sources mainly include atmospheric deposition, biological fixation, and fertilisation. Nitrogen needs to be transformed into its mineral forms ($NH_4^+$ and $NO_3^-$) before it can be harvested by plants and microbes etc. (Li et al., 2006). When organisms excrete waste or die, the embodied organic nitrogen content will be decomposed into inorganic nitrogen, as ammonium, through a process known as ammonification (Bernhard, 2012). Part of the ammonium can be emitted as ammonia due to its high volatility. Under aerobic condition, ammonium is further oxidised into nitrate via the nitrification process (IPCC, 2006) while under anaerobic condition, denitrification occurs converting nitrate to atmospheric nitrogen gas. Both the nitrification and denitrification processes can trigger $N_2O$ emission along their courses, which is a strong GHG. Global statistics suggest that the agriculture sector is accounted for 10–12% of the total anthropogenic greenhouse gas emissions for 2005 (Metz and Davidson, 2007). In particular, agriculture is the most significant global contributor of $N_2O$ (representing 60%) emissions. Moreover, since nitrate is a highly soluble substance, part of nitrate will be leached into the water causing an eutrophication problem.

Thus, a well-established LCA study on flax fibres must properly address and simulate field emissions during cultivation, taking into account the environmental issues related to the nitrogen cycle. This includes gaseous fluxes: ammonia, $N_2O$, NO and $NO_3^-$ leachate. However, according to the survey on the LCA studies of flax fibres, the field emissions are not systematically and accurately documented and modelled. Among studies providing detailed inventory data on flax fibres (Deng et al., 2016; Dissanayake et al., 2009; Le Duigou et al., 2011; Le Duigou et al., 2012; Turunen and Werf, 2006), some of them neglected the field emissions from flax cultivation while two studies (Deng et al., 2016; Turunen and Werf, 2006) provide information on the flax agroecosystem modelling, based on an empirical method, the IPCC tier 1 method (the IPCC method hereafter) (IPCC, 2006). However, this method, as an easy-to-calculate model, considers direct nitrogen in the form of $N_2O$ emission ($N_2O$-N) is linearly related to the added N amount. Complex soil physical and chemical processes are neglected. This may be a considerable issue for flax fibres, as France is the dominant producer of flax products and flax cultivation is highly concentrated in Northern France. Therefore, a site-specific field emission modelling will contribute to improving the available LCI.

For this reason, a process-oriented method can be applied to provide more site-specific simulated outputs, by incorporating both climate and soil factors involved in the agricultural nitrogen cycle. Among the currently available process-oriented methods, e.g., DNDC (Li, 2000), Daycent (Parton et al., 1998), Roth-C 26.3 (Coleman et al., 1997), and Ceres (Gabrielle et al., 2006b); Guo et al. (2011) identified the Denitrification-Decomposition model as one of the most widely validated methods, demonstrating that the results simulated using the DNDC method are in very good agreement with the field-measured $N_2O$, $CH_4$, $NO_3^-$ for cropland and seasonal emissions. Thus, they applied the DNDC method to simulate field emissions during wheat cultivation in the UK (Guo et al., 2011). The authors identified that the DNDC is a better method compared to the IPCC method providing a more reliable simulation of the greenhouse gases emissions for agro-ecosystem. Moreover, the DNDC method has also been applied and verified for agricultural emission simulations for spring wheat cultivation in loamy soil in Germany (Ludwig et al., 2011), spring barley field in Ireland (Abdalla et al., 2009), winter wheat cultivation across a tile-drained field in Central France (Gu et al., 2013), 2500 counties with various crops and agricultural management in China (Li et al., 2001), rice cultivation in paddy fields in India (Babu et al., 2006), maize cultivation in matured-amended loamy soil in Canada (Smith et al., 2002), and multiple agricultural systems in Europe (Butterbach-Bahl et al., 2009). Currently, the DNDC method has been used to optimize the crop management to reduce the greenhouse gases emissions (Goglio et al., 2014; Abalos et al., 2016).

Thus, this study aims to incorporate the process-oriented DNDC method for inventory construction of flax cultivation. The DNDC method is chosen for the purpose of providing more accurate and representative inventory data. Moreover, the IPCC method is also applied for the purpose of comparison. The uncertainties of the final results through the two approaches are also investigated.

## 2. Material and method

### 2.1. Goal and scope definition

The goal of this study is to perform an LCA on flax cultivation. Flax cultivation is highly concentrated in a region of northern France (Le Duigou et al., 2011). Thus the functional unit is set to be 1 kg retted flax straw harvested in northern France.

### 2.2. System boundary

The cradle-to-gate LCA covers the main steps in flax cultivation, harvesting and retting (Fig. 1). The temporal scope of this analysis covers the period 2008–2012, reflecting the recent French flax cultivation situation.

The flax cultivation is modelled following the scenario presented in figure. It presents a standard intensity of agricultural machinery (Labouze et al., 2007). In flax cultivation, ploughing is implemented twice for soil preparation. The first run is to encourage weed germination. The second ploughing is performed just prior sowing to remove the weeds. Rotary power harrowing is recommended in between ploughings to maintain soil texture. The P and K fertilisers serve as a fertiliser bed. Moreover, N fertiliser is spread twice during the growing period (Labouze et al., 2007). Pesticides are applied in four occasions, i.e., twice with herbicides and twice with insecticides (Labouze et al., 2007). Fibrous flax plants are generally pulled to maximise the length of flax fibres.

Following, the pulled flax straws are left on the field for retting at beginning of maturity (beginning of august) when weather conditions are warm and misty to allow a moderate speed of retting. Retting leads to decomposition of the pectin, which is the binder between the flax fibre skin and woody core and thus facilitates the subsequent extraction process. To ensure a uniform retting among flax straws, a turning process is needed as the top layers of flax swaths ret. faster than the bottom layers. After retting, flax straws are baled and transported around 40 km to fibre extraction factories by truck (Labouze et al., 2007). To avoid over-retting, the moisture content of the retted flax straws must remain