Assessing the land use impacts of agricultural practices on ecosystems

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ABSTRACT

In Life Cycle Assessment, agricultural fields have been defined as part of the technosphere. In order to cover environmental damage to fields during crop occupation and assess their reversibility, the different agricultural practices need to be covered by the land use impact category. The main goal of our contribution is to test the applicability of ongoing land use methods to assess agricultural practices, as well as provide recommendations for further research. Among existing complementary proposals of impact characterization models, we have chosen those, which could provide spatially explicit information on biodiversity damage expressed as species richness (relative or absolute number) and ecosystem services represented by net primary production depletion or biotic production potential. We have applied them in a case study of corn production comparing extensive and intensive management. Improvement of characterization factors for different land use intensity types and better definition of boundaries are main needs for further research.

Keywords: Biodiversity, Biotic Production Potential, Erosion, Organic matter, Technosphere

1. Introduction

In Life Cycle Assessment (LCA) agricultural studies, cropland is usually defined as part of the technosphere, and agricultural practices are assessed in relation to their effects on the surrounding environment (e.g. ecotoxicity, eutrophication). However, crop management affects the cropland itself as a natural resource. It can be argued that good management is reflected in the yields obtained, the quality of the crop and of subsequent ones. But a longer term vision, as well as the recognition of the importance of soil as provider of ecosystem services is necessary. Therefore, damage to the technosphere by the different agricultural practices needs to be covered by the land use impact category (or reconsider agricultural fields as part of ecosphere).

Land use impact assessment is a complex issue due to region specificities as well as the different nature of damages involved. The International Reference Life Cycle Data System Handbook (EU-JRC-IES 2011) and the ENVIFOOD Protocol (Food SCP-RT 2013) recommend cautiously (level III) the method that considers soil organic matter (SOM) (Milà i Canals et al. 2007a), because it is the most appropriate soil-quality indicator among the existing approaches to assess land-use impacts at midpoint level. No method was recommended for use at endpoint level; ReCiPe method can be used as an interim method.

Nowadays a lot of work is being developed in order to provide operational and globally-applicable methods to asses land use impacts in the framework of LCA. Milà i Canals et al (2007b), proposed that land use impact category should be assessed in terms of impact on biodiversity, impact of biotic production and impact on the regulating functions of natural environment. Within the framework of UNEP/SETAC Life Cycle Initiative a flagship project has been launched in 2012 to provide guidance and create consensus for assessing, among other LCIA indicators, land use impacts on biodiversity (Jolliet et al., 2014).

An updated version of the soil organic matter approach allows to use the change in soil organic carbon as an indicator for impacts on biotic production potential (BPP) (Brandão and Milà i Canals 2013), which in fact can also be considered as a measure of supporting services of ecosystems. Similarly Núñez et al (2013) developed a method using a growth-based value potential: net primary production depletion (NPPD) to assess the effect of soil erosion on ecosystem quality.

De Baan et al (2013) developed regional Characterization Factors (CFs) for land-use occupation and transformation using the species-area relationship model to assess the number of species that might be driven to extinction due to different land use types including agriculture.

More recently Elshout et al (2014) derived CFs based on findings of previous studies to assess agricultural land occupation on relative species richness. They provided midpoint CFs for different crops and differentiated between conventionally and low-input managed crops.

The main goal of our contribution is to test the applicability of ongoing methods to assess different agricultural practices focusing on endpoint damage, as well as provide recommendations for further research. We have applied them in a case study developed in the frame of a European LIFE project (F4F 2013-17), conducted in order to reduce the environmental consequences of manure livestock management.

2. Methods

2.1. Case Study

An LCA was carried out to compare intensive and extensive corn production. Crops were grown at the Mas Badia experimental station (La Tallada d'Empordà, Girona, north-east Spain) under different agricultural practices. Intensive corn production includes the use of chemical fertilizers and pesticides. Extensive corn production includes organic manure application and the use of catch crops as an intermediate crop to catch excess nitrogen and posterior treatment as a co-substrate in a biogas plant. In addition, growing catch crops are considered as a service to prevent erosion. We performed an attributional simplified LCA, where the functional unit was 1 ha. The life cycle stages included until farm-gate were: seeds production, manure, inorganic fertilizers, diesel consumption in labor operations and pesticide treatment. Livestock farming and posterior treatment for biogas plant are out of the scope of this study (they will be included in a subsequent step). In this paper we just focused on the land use assessment of foreground crops. A year period with one (intensive) or two annual crops, ryegrass and corn (extensive) are set as examples. Ryegrass was used as a catch crop previous to silage corn production. Table 1 shows relevant inventory flows of agricultural practices for each crop.

Table 1. Relevant inventory flows for ray-grass and corn.

LCI	catch crop	corn extensive	corn intensive
Seeds	26.70 kg·ha^{-1}	80000 u·ha^{-1}	80000 u·ha^{-1}
Date of sowing	Sept, 30th	Apr, 2nd	Apr, 2nd
Date of harvesting	Mar, 20th	Set,15th	Set,15th
Moisture content at harvesting	79.4%	78%	78%
Irrigation	--	2833 m^{3}·ha^{-1}	2833 m^{3}·ha^{-1}
Manure		170 kg·ha^{-1}	
N fertilizer	--		250 kg·ha^{-1}
P fertilizer	--		100 kg·ha^{-1}
K fertilizer	--		100 kg·ha^{-1}
Herbicide treatment	--		3.5 L·ha^{-1}
Tractor hours for different operations	7.7 h·ha^{-1}	12.6 h·ha^{-1}	12.6 h·ha^{-1}

2.2. Impact methods

Among existing complementary proposals of LCIA, we have chosen those for which inventory information was available and impact assessment provides information about agricultural impacts close to endpoint level for our specific area of study.

Following ILCD and Envifood protocol we used soil organic carbon (SOC), as a midpoint indicator and applied an updated approach (Brandao and Milà i Canals 2013) where the change in SOC is used as an indicator for impacts on BPP. Our area of study is located, according to this method, on the warm temperate dry climate region.

The effect of soil erosion on ecosystem quality is expressed using a growth-based value potential: net primary production depletion (NPPD). Indicator for soil erosion impacts was defined at the endpoint level for ecosystem quality in two steps: first relating soil loss to SOC loss and then relating SOC loss to ecosystem biomass productivity drop, NPPD. CFs are at a spatial resolution of 5 arcmin (Núñez et al 2013)

For biodiversity assessment the approach and CF for occupation and transformation provided by De Baan et al (2013) has been used. These authors calculated the total number of regional and non-endemic species lost per five different taxonomic groups (mammals, birds, plants, reptiles and amphibians) choosing biome units to derive CFs. This total regional damage was then allocated to the different land-use types according to the area share they occupied and their habitat quality. We applied the agricultural land use CFs for, Northeastern Spain and Southern France Mediterranean forest ecoregion, PA1215, (De Baan et al. 2013) for our case study.

In fact the area of study corresponds to. Climatically, the ecoregion experiences very hot and dry summers, and relatively temperate winters. Forests are mainly composed of mixed evergreen and deciduous broadleaf and conifer species. Endemism rate in the ecoregion ranges between 10-20% of the total vascular plants. Large mammals are not particularly prominent in this ecoregion. Most of the ecoregion has been intensively transformed into agricultural land or coastal urbanization for tourism.

Land use type according to Koellner et al (2013) corresponds to Arable Land, 5.1, differentiating between Arable, irrigated, intensive plus chemical–synthetic and organic fertilizer as well as pesticides use for corn (5.1.3.2) and Arable, irrigated extensive without use of chemical–synthetic or pesticides but indirect use of organic fertilizer and catch crop (5.1.3.1).

Table 2 shows main geographical characteristics of crop location relevant for the land use impact assessment methods applied.

Table 2. Geographical characteristics corresponding to location and each crop assessed.

Geographical characteristics	**Common to location**	**Extensive**	**Intensive**
Geographical coordinates	42º08’ N; 2º99’ E		
Climate region	Warm temperate		
Moisture regime	Dry		
Reference Ecoregion (De Baan et 2013)	Northeastern Spain and Southern France Mediterranean forests PA1215		
Land Use type (Koellner et al 2013)		5.1.3.1 Arable, irrigated, extensive	5.1.3.2 Arable, irrigated, intensive
Rainfall (mm y^{-1})	670.6	386.5	284.1
Sand (%)	64		
Silt (%)	23		
Clay (%)	13		
C org (%)		1.74	1.45
Land slope (%)	2		
Slope length (m)	100		
USLE ΔR-factor (MJ mm ha^{-1} h^{-1})	2360		
USLE K-factor (t ha h MJ^{-1} ha^{-1} mm^{-1})		0.026	0.027
USLE LS-factor (-)	0.285		
USLE C-factor (-)		0.475	0.755
USLE P-factor (-)	1		
Soil loss mass due to Erosion (t soil)		8.3	13.7

In addition, we provided the climate change impact for the same scope and reference period (one year of crop production to farm gate) expressed as kg CO_2 eq and in species·y following ReCiPe methodology to provide a reference to compare natural environment damage importance.

In order to have a detailed explanation of the methods, we invite readers to consult the corresponding references.

3. Results

The results shown in table 3 were calculated for the different approaches per ha and year. Despite the difficulties encountered to identify damage of the different land use intensity type, extensive production appeared to have lower impacts than their intensive counterparts. This is clear when applying BPP method, for which extensive practice did not report any impact. Considering uncertainty of results, none of the other methods can differentiate between different practices, regarding biodiversity damage (de Baan et al 2013), because there are common CFs for all agriculture types.

The use of catch crop helps to reduce soil loss in extensive systems and although the loss of organic matter is higher in intensive systems, there is not final difference in erosion ecosystem quality impact due to method applied to convert SOC loss in NPPD.

Transformation impacts are higher than occupation impacts. Land transformation impacts on BPP are one order of magnitude higher than land occupation impact on BPP. Biodiversity impacts due to land transformation were one or two orders of magnitude higher than occupation depending on the taxa.

Table 3. Results for the different impact categories are expressed in the respective units per ha and yr and show the geographical reference unit of CFs applied. Climate change is the full life cycle for an annual catch crop plus silage corn crops. Rest of the impact categories are related to one ha of land use for the foreground crops.

Damage Nature	**Units·** $ha^{-1}·yr^{-1}$	**Results** Extensive	Intensive	**Geographical unit**	**CF source**
Climate Change	kg CO_2 eq	1730	5300	Global	Goedkoop et al.2009
Climate Change	Species·yr	$1.37·10^{-5}$	$4.20·10^{-5}$	Global	Goedkoop et al.2009
Occupation					
SOC loss mass due to Erosion	kg SOC	144	199	Local	Núñez et al 2013
Erosion ecosystem quality	NPPD	2.66	2.66		Núñez et al 2013
Biotic Potential Production	kg C	no impact	$5.8·10^{3}$	Warm temperate dry region	Brandaö and Milà i Canals 2013
Biodiversity, Mammals	PLNE	$3.38·10^{-6}$	$3.38·10^{-6}$	Ecoregion PA1215	De Baan et al 2013
Biodiversity, Birds	PLNE	$1.19·10^{-5}$	$1.19·10^{-5}$	Ecoregion PA1215	De Baan et al 2013
Biodiversity, Plants	PLNE	$1.20·10^{-4}$	$1.20·10^{-4}$	Ecoregion PA1215	De Baan et al 2013
Biodiversity, Amphibians	PLNE	$1.03·10^{-6}$	$1.03·10^{-6}$	Ecoregion PA1215	De Baan et al 2013
Biodiversity, Reptiles	PLNE	$1.50·10^{-6}$	$1.50·10^{-6}$	Ecoregion PA1215	De Baan et al 2013
Transformation					
Biotic Potential Production	kg C	no impact	$4.5·10^{4}$	Warm temperate dry region	Brandaö and Milà i Canals 2013
Biodiversity, Mammals	PLNE	$1.82·10^{-4}$	$1.82·10^{-4}$	Ecoregion PA1215	De Baan et al 2013
Biodiversity, Birds	PLNE	$7.51·10^{-4}$	$7.51·10^{-4}$	Ecoregion PA1215	De Baan et al 2013
Biodiversity, Plants	PLNE	$4.34·10^{-3}$	$4.34·10^{-3}$	Ecoregion PA1215	De Baan et al 2013
Biodiversity, Amphibians	PLNE	$7.59·10^{-5}$	$7.59·10^{-5}$	Ecoregion PA1215	De Baan et al 2013
Biodiversity, Reptiles	PLNE	$1.11·10^{-4}$	$1.11·10^{-4}$	Ecoregion PA1215	De Baan et al 2013

NPPD: net primary production depletion; PLNE: potentially lost non-endemic species;

4. Discussion

The different methods provide CFs based on homogeneous areas such as climate region (BPP) or biome (biodiversity damage). However, they are still large areas, which, depending on final goals of LCA, application can make comparisons difficult. From an applicability point of view, it is clear that more site-specific CFs for land use offer a better approach to grasping the local specificities of crop production.

On the other hand, it is necessary to develop CFs for more specific agricultural practice types (e.g., extensive, intensive, irrigated, greenhouse, organic agriculture) instead of generic ones (agriculture).

Main differences between both agricultural systems, extensive and intensive management are found in BPP land use impact assessment, because this category is using management factors from IPCC (2006), which give special importance to the carbon sequestration through the incorporation of manure (management factor 1.37 with manure vs 1.04 without manure). The use of management land use factors similar to those included in land use change could be potentially a good approach to consider the different agricultural practices.

Similarly, current erosion impact are applying different management factors related to agricultural practices and can provide information on long-term effects on soil resources but the revision and inclusion of more soil archetypes and conversion to biodiversity damage units are recommended.

Regarding biodiversity damage, vascular plants were shown to be the most sensitive group, followed by birds. This makes sense because usually plants are considered competitors of crops and removed from agricultural fields. These results are in agreement with the CFs derived by Elshout et al (2014). These authors differentiated between conventionally and low-input managed crops giving the respective CFs of 0.42 and 0.05 expressed as relative value of potentially disappeared fractions. Despite these results agree with previous studies, they shows different ratios depending on crops and area of study, which can confirm a tendency of lower impact for extensive systems but also the need for more accurate assessment methods.

Also according to the study of Elshout et al (2014), arthropods do not appear to be significantly impacted upon; however, we presume that the different management practices especially those related to pesticides use may have a large effect on them and therefore arthropods may serve as a good indicator for the impacts of differentiate practices.

Although regeneration times applied according to SOC indicator are lower than for biodiversity indicators, differences in importance between methods for transformation related to occupation can be explained because while de Baan et al (2013) calculated the transformation impact as a multiplication of occupation CF with half the regeneration time, Brandão and Milà i Canals (2013) included in this impact, the deficit of SOC due to the postponed regeneration of the system.

In this paper we have focused on crops (foreground system), issues related to land use on background processes have already been established in Milà i Canals et al (2013) and De Baan et al (2013).

5. Conclusion

Although it seems that extensive agricultural practices should mean lower impact when compared to more intensive practices, currently we have not enough developed impact characterization methods to assess and compare different agriculture intensities.

Among the different needs for further research, from our case study in particular, and agriculture in general, special attention should be paid to developing CFs for different land use agricultural types, as well as a better knowledge of relevance of the different taxa affected.

Together with the development and improvement of methods we would like to highlight the importance of testing them in practical and different case studies.

And last but not least a clear definition of boundaries, not only between technosphere and ecosphere, especially important in agriculture, but also which level of detail could/need to be covered by LCA. That means assuming the degree of implicit uncertainty, or otherwise the need to advise that environmental damage may/should/shall be assessed by other tools.

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