Accounting for land use contribution to climate change in agricultural LCA: Which methods? Which impacts?

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Abstract

Soil organic carbon (SOC) plays a key role in soil functioning, i.e. soil quality. Land use affects SOC and soil quality. However, despite various methodological developments, there is still no scientific consensus on the best method to assess the holistic impact of land use and land use change within LCA. The SOCLE project aimed to review how SOC is accounted for in LCA and to test the feasibility and sensitivity of best methodological options. In total, five crop products (annual/perennial, temperate/tropical) and two livestock products were investigated through 32 scenarios of land use changes (LUC) and agricultural land management changes (LMC). Three methodologies were applied, IPCC Tier 1-2 (2006), Müller-Wenk & Brandaõ (2010) and Levasseur et al. (2012). The accounting of LUC and LMC influences greatly the results on the climate change impact category. Based on the project results, we recommend accounting systematically for the impact of LULUC on climate change by applying, *a minima*, the comprehensive IPCC Tier 1 approach (2006). When available, site-specific data should be used (e.g. Tier 2) for SOC stocks but also C:N ratio and in order to model the digressive impact over 90% of the time period needed to reach equilibrium.

Keywords: *Soil carbon, Climate change, Land use, Agricultural practices.*

1. Introduction

More than 57% of global greenhouse gas emissions from agriculture, forestry, land use and land use change (LULUC) are due to the release of soil organic carbon (SOC) (Lal, 2004). Moreover, SOC plays a key role in the soil functioning, i.e. the capacity of the soil to provide various ecosystem services such as fertility, erosion resistance, etc. (Arrouays et al., 2002; Lal, 2004). This capacity to function, defined as the soil quality (Karlen et al. 1997), highlights the great importance of soil for agroecosystems. Nevertheless, the impact of agricultural practices on soil quality is still poorly accounted for in agricultural life cycle assessments (LCA).

For the last 10 years, methodological developments in life cycle assessment (LCA) have led to the development of a conceptual framework to start accounting for the impact of land use on soil quality (Milà i Canals et al., 2007; Koellner et al., 2013). In relation with this framework or in parallel, several methods were developed to account better for the impact of LULUC on i) soil carbon sequestration and release in relation to the climate change impact category (e.g. Müller-Wenk & Brandão, 2010; Levasseur et al., 2012; Benoist & Cornillier, 2016), or on ii) various soil properties or functions (Oberholzer et al., 2012; Núñez et al., 2012; Garrigues et al., 2013; Bos et al., 2016). Nevertheless, there is still no scientific consensus on the best method to assess the holistic impact of land use and land use change within LCA (Vidal-Legaz et al., 2016).

The objectives of the ADEME SOCLE project – Soil Organic Carbon changes in LCA, which Evaluations to improve environmental assessments? – were i) to review the methods developed to account for SOC within LCA with a focus on the links with the climate change impact category; and ii) to apply best methodological options to various agricultural LCA in order to test the feasibility of the methods and their sensitivity to land use and agricultural management changes, and to carry out a sensitivity analysis on the most influential factors. We selected contrasted case studies in order to span various contexts of data limitations and applicability.

2. Material and methods

In total, five crop products (annual/perennial, temperate/tropical) and two livestock products were investigated through 32 scenarios of land use changes (LUC) and agricultural land management changes (LMC). Three methodologies were applied, IPCC Tier 1-2 (2006), Müller-Wenk & Brandaõ (2010) and Levasseur et al. (2012).

In a sensitivity analysis, we tested the influence of data sources for assessing LULUC and quantifying SOC stocks and dynamics (including SOC modelling work), as well as the influence of various parameters such as the reference state, regeneration rates or time allocation of the transformation impact. We also looked at the related nitrogen emissions due to the loss of SOC through LULUC depending on the C:N ratio, following IPCC (2006) guidelines.

3. Results

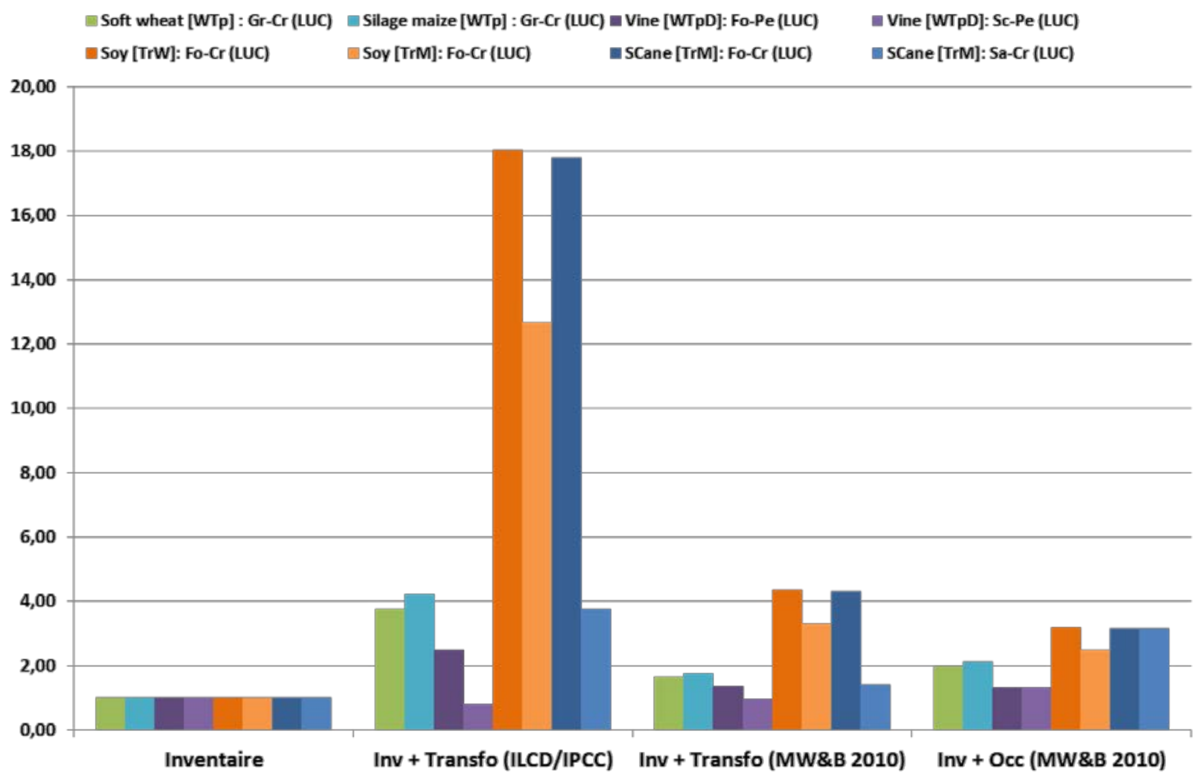
As showed in Figure 1, results highlight the importance to account for the contribution of LUC and LMC to the climate change impact category for 7 scenarios of LUC and 14 scenarios of LMC, with an increase by up to 18 fold the baseline inventory emissions across the LUC scenarios and variations from -130% up to +215% across LMC scenarios. Although both methodologies, IPCC (2006) and Müller-Wenk & Brandaõ (2010) (i.e. MW&B 2010) were applied using the same data sets for carbon stocks, results varied sensibly with a lower magnitude with MW&B 2010. Besides the transformation impact, the MW&B 2010 method introduces an occupation impact as based on the land use framework proposed by Milà i Canals et al. (2007) and Koellner et al. (2013). On top of the data on stocks, MW&B 2010 also relies on parameters such as the reference land use and the regeneration time that explain the differences between the methods. The sensitivity analysis on the regeneration time (+10% for either the previous or the current land uses) showed a high sensitivity of the results to this parameter (variation range -5 folds up to 7 folds).

With both IPCC and MW&B 2010, impacts are very sensitive to the used stock data. Variations are generally more critical in the case of LMC than for LUC. By default, data on stock variations due to management changes are constrained by the weighting factors provided by IPCC (0.6 – 1.6). Variations can be small and hence more sensitive to small changes, whereas stock differences between land uses may be much more severe and hence less sensitive to small changes.

The way the transformation impact is allocated over time also influences the final results. The linear distribution over 20 years is the default approach in IPCC. When the impact is allocated in a digressive way over 20 years, which is recommended in ILCD guidelines, the impact is logically higher. This is, however, not true for perennial crops, when the whole cropping cycle is accounted for and longer than the allocation time period. On the contrary, when the distribution is based on a more dynamic modelling of the carbon stock evolution, which is usually slow and then longer than 20 years, the impacts are generally lower.

The hierarchy of the transformation impacts with the dynamic LCA (Levasseur et al. 2012) is quite similar to that obtained with the IPCC/ILCD method with a digressive impact allocation over 90% of the time period needed to reach the equilibrium. This digressive allocation may be a good option to approximate a more dynamic modelling in a simple way, although in this case, like for the dynamic LCA, some dynamic data on carbon evolution are needed.

(a)



(b)

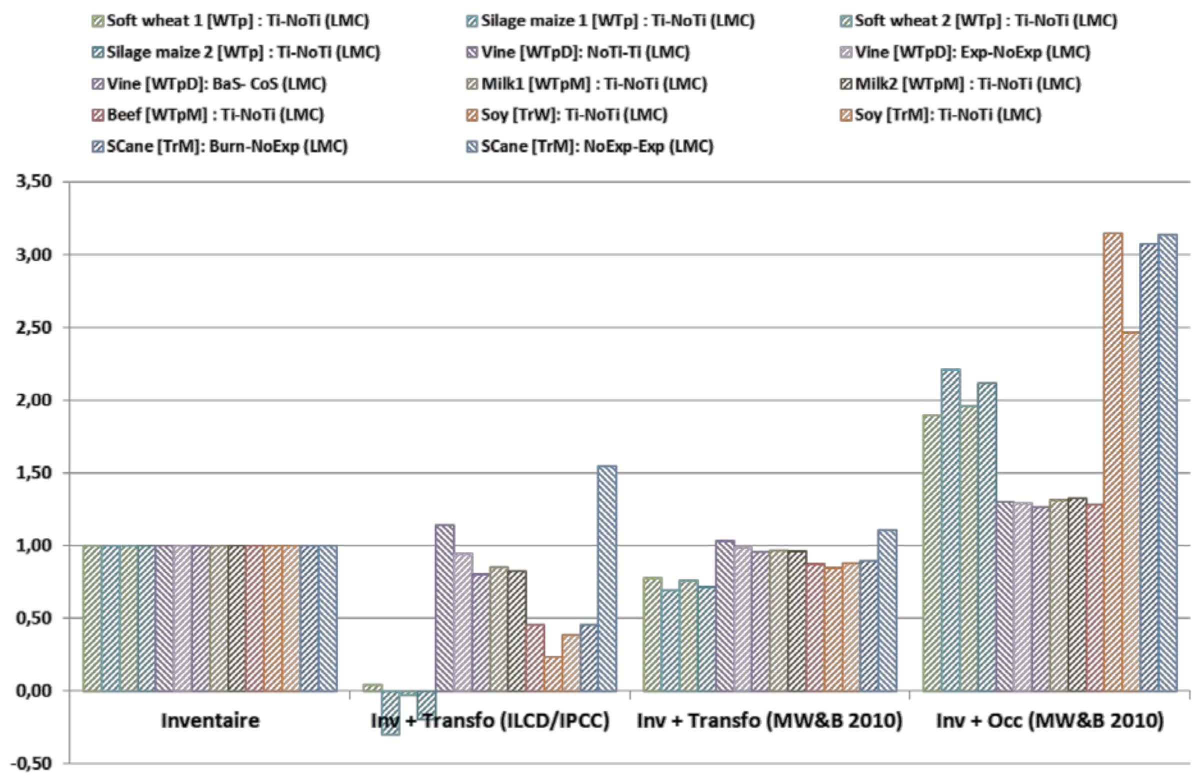


Figure 1: Influence of considering LUC (a) and LMC (b) contributions to climate change in relative terms to the baseline impact due to the rest of the supply chain processes (Inv = inventory impact = 1) and depending on the scenario and the method tested. LUC : Gr = grass ; Cr = Anuual crop ; Fo = Forest ; Pe = Perennial crop ; Sa = Savanah; Scan = Sugar cane; LMC : Ti/NoTi = Tillage/NoTillage; Exp/NoExp = Exported residues/No export ; BaS = Bare soil ; CoS = Covered soils ; Burn = Burnt residues.

Besides carbon emissions due to LULUC, it is also important to account for N_2O emissions related to the mineralization of nitrogen associated to the decomposition of SOC. Across the scenarios tested, the accounting for those direct emissions of N_2O, related to carbon losses through the C:N ratio, increased the final climate change impact by +1% to +18%. This added impact is not negligible and requires the LCA practitioner to care for both site specific SOC stocks and C:N ratios, when available.

Based on the project results, we recommend accounting systematically for the impact of LULUC on climate change by applying, *a minima*, the comprehensive IPCC Tier 1 approach (2006). When available, site-specific data should be used (e.g. Tier 2) for SOC stocks but also C:N ratio and in order to model the digressive impact over 90% of the time period needed to reach equilibrium. Depending on the LCA objectives, MW&B 2010 and the dynamic LCA may bring further information providing that results are interpreted in light of transparent choices regarding the key parameters such as the reference state and the regeneration time.

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References

Arrouays D., Balesdent J., Germon J.C., Jayet P.A., Soussana J.F., Stengel P. (Eds) (2002) Mitigation of the greenhouse effect Increasing carbon stocks in French agricultural soils? Scientific Assessment Unit for Expertise. Synthesis of an Assessment Report by the French Institute for Agriculture Research (INRA) on request of the French Ministry for Ecology and Sustainable Development. October 2002, 33 p.

Benoist, A., Cornillier, C., 2016. Towards a consensual method to assess climate change impacts from bio-based systems, in: 26th SETAC Europe Annual Meeting - Environmental Contaminants from Land to Sea: Continuities and Interface in Environmental Toxicology and Chemistry. Nantes, France.

Bos, U., Horn, R., Beck, T., 2016. LANCA - Characterization Factors for Life Cycle Impact Assessment - Version 2.0. Stuttgart, Germany.

Garrigues, E., M.S. Corson, D.A. Angers, H.M.G. van der Werf, and C. Walter. 2013. Development of a soil compaction indicator in life cycle assessment. Int. J. Life Cycle Assess. 18(7): 1316–1324.

Karlen D.L., Mausbach M.J., Doran J.W., Cline R.G., Harris R.F. and Schuman G.E. 1997. Soil quality: a concept, definition, and framework for evaluation. Soil Science Society of America Journal 61(1), 4–10.

Koellner, T., L. de Baan, T. Beck, M. Brandão, B. Civit, M. Margni, L.M. i Canals, R. Saad, D.M. de Souza, and R. Müller-Wenk. 2013. UNEP-SETAC guideline on global land use impact assessment on biodiversity and ecosystem services in LCA. . Int. J. Life Cycle Assess 18(6): 1188–1202.

Lal, R. 2004. Agricultural activities and the global carbon cycle. Nutr. Cycl. Agroecosystems 70(2): 103–116.

Levasseur, A., P. Lesage, M. Margni, M. Brandão, and R. Samson. 2012. Assessing temporary carbon sequestration and storage projects through land use, land-use change and forestry: comparison of dynamic life cycle assessment with ton-year approaches. Clim. Change 115(3–4): 759–776.

Lindeijer, E. 2000. Review of land use impact methodologies. J. Clean. Prod. 8(4): 273–281.

Milà i Canals, L., J. Romanyà, and S.J. Cowell. 2007. Method for assessing impacts on life support functions (LSF) related to the use of "fertile land" in Life Cycle Assessment (LCA). J. Clean. Prod. 15(15): 1426–1440.

Müller-Wenk, R., and M. Brandão. 2010. Climatic impact of land use in LCA—carbon transfers between vegetation/soil and air. Int. J. Life Cycle Assess. 15(2): 172–182.

Núñez, M., A. Antón, P. Muñoz, and J. Rieradevall. 2012. Inclusion of soil erosion impacts in life cycle assessment on a global scale: application to energy crops in Spain. Int. J. Life Cycle Assess. 18(4): 755–767.

Oberholzer, H.-R., R. Freiermuth Knuchel, P. Weisskopf, and G. Gaillard. 2012. A novel method for soil quality in life cycle assessment using several soil indicators. Agron. Sustain. Dev. 32(3): 639–649.

Vidal-Legaz, B., A. Antón, D. Maia De Souza, S. Sala, M. Nocita, B. Putman, R.F.M. Teixeira, European Commission, and Joint Research Centre. 2016. Land-use related environmental indicators for life cycle assessment: analysis of key aspects in land use modelling. Publications Office, Luxembourg.