Using the LANCA® Model to Account for Soil Quality Within LCA: First Application and Approach Comparison in Two Contrasted Tropical Case Studies

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Abstract:

Assessing the effect of land management on soil quality is nowadays a key environmental concern, as the soil system is linked to major ecosystem services. There is a strong methodological shortage to integrate the impact of anthropogenic pressure on the soil system within large scale environmental frameworks, such as the Life Cycle Assessment. The LANCA® method was proposed to meet this need, integrating five impact categories of soil functions and directly applicable within the Life Cycle Assessment framework. Although the most recent 2016-LANCA® version shows readiness to be integrated in this large scale environmental framework to meet the demand, it has not yet been applied and validated on case studies. This study proposes a first application of the LANCA® model on two contrasted agricultural-based case studies to share experience in implementing the model through both background and foreground approaches, to analyze the first model outputs and to provide tracks for further model improvements. The results proved that both LANCA® approaches were poorly sensitive to the agricultural land managements tested. The foreground approach was difficult to implement due to the lack of transparency of the targeted characterization factors calculation procedure. Further global sensitivity and redundancy analysis should also be proposed in order to validate the consistency of the global model.

Key Words: *LANCA®, Land Use, Land Management, Life Cycle Assessment, Soil Quality, Case studies*.

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1. INTRODUCTION

Soils provide multiple services encompassing i) provisioning services (e.g., food/fiber), ii) regulating services (e.g., air quality/water purification), iii) cultural services and iv) supporting services (e.g., nutrient cycling/habitat) [1][2]. Human society deeply relies on those soil ecosystem services (Sustainable Development Goals, 2015), but also directly affects these through an increasing anthropogenic pressure on soils [3][4]. In order to understand and regulate the impact of anthropogenic perturbations on the soil system, there is a strong need to develop and apply methods to assess these impacts on soil quality, *i.e.* its ability to provide multiple ecosystem services [5].

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 [6][7]. In relation to this framework or in parallel, several methods were developed to account for the impact of Land Use and Land Use Change (LULUC) on soil carbon sequestration and release in relation to the climate change impact category [8][9][10], or on various soil properties or functions [11][12][13]. Nevertheless, there is still no scientific consensus on the best method to assess the holistic impact of LULUC on soil quality within LCA, as highlighted in a recent review on the topic by Vidal Legaz et al., [14]. In this review, the authors highlighted the relevance of LANCA® given its adaptation to the land use framework in LCA, its multi-criteria approach and its available data tables for a worldwide application. However, they also stressed that the lack of transparency of some calculation details as well as the lack of application of the model might hamper its wide application [14].

LANCA® is a method specifically developed for soil quality assessment within LCA. It gathers five midpoint indicators to assess the impact of land use on soil quality: 1) erosion resistance, 2) physicochemical filtration, 3) groundwater regeneration, 4) mechanical filtration and 5) biotic production. LANCA® is specifically built to be used within the conceptual framework of land use impacts assessment within LCA [6][7], *i.e.* the impacts on those five midpoint categories are calculated based on inventory flows in terms of land occupation and land transformation from an initial/to a final state. The impacts are characterized with the help of semi-qualitative models through the use of decision trees and weighting factors, which can be parameterized more easily than process-based models. To our knowledge, the only application of the LANCA® model was proposed by Saad et al., [15][16], based on the LANCA® 2010 version [17] integrating only three of the five impact categories. In these studies, the model was applied on seven very contrasted land uses to raise the importance of implementing regionalized characterization factors (CFs). The new updated LANCA® version [11] integrates regionalized CFs, and proposes two approaches to apply LANCA®: either the user has access to information of a studied system at a local scale and can apply the five different models within the foreground approach; or in the absence of available data, the user cannot run the models and uses the background characterization factors provided in the LANCA® database defined at the country level within the background approach.

In this context, the objective of this study was to test the applicability of LANCA® [11] through both approaches in data-limited agricultural conditions, such as tropical ones. Through these applications of LANCA®, we aimed to share the experience and potential difficulties any LCA practitioners might face.

To answer this objective, the two case studies and the parameterization of the LANCA® method through the background and foreground approaches will firstly be described. Then, the CFs obtained for both background and foreground approaches will be presented for each of the five LANCA® impact categories. Finally a critical review of the LANCA® method will be proposed, highlighting the strengths and the points which need further developments for LANCA® wide application in LCA.

2. MATERIALS AND METHODS

2.1 Case studies

In order to study a contrasted range of agricultural land managements and pedo-climatic conditions, two case studies were selected in different tropical regions, one in Thailand and one in Brazil. The pedo-climatic context of each of the case study is presented in table 1. The input data were directly extracted from the case studies without investigating any depth factor, as no requirement on the soil studied depth was specified in LANCA®.

In Thailand, we selected different land uses and in Brazil different management practices under the same land use, *i.e.* soybean cultivation. Those land managements were representative of the main cropping systems of the studied regions. In Thailand, three land uses were studied: an intensive cash crop (cassava – *Manihot esculent*), a mature rubber tree plantation (*Heveabrasiliensis*), and a degraded secondary forest, the latter being taken as the reference system. In Brazil, two soybean (*Glycine max*) management practices were studied with contrasted tillage and crop residues practices: a soybean alternating with cotton under conventional plow-based tillage with a carbon input of 1.01 $Mg.ha^{-1}.yr^{-1}$, and a continuous no-till soybean followed by millet (*Pennisetumglaucum*) or maize (*Zea mays L.*)

+ *Brachiariaruziziensis* as a second crop (carbon input = 7.41 $Mg.ha^{-1}.yr^{-1}$) [21]. A cerrado natural forest was taken as a reference in this case study.

Table 1: Pedo-climatic context of the two studied sites.

Case Study	Brazil		Thailand
Literature reference	Moraes Sá et al., 2013;		Peerawat et al., 2018;
	Tivet et al., 2013		Thoumazeau et al., 2019b
Regional localization	Mato Grosso		Chachoengsao Province
	Lucas do Rio Verde Site		
GPS position	13°00'S – 55°58'W		13°34'N – 101°27'E
Climate (Köppen-Geiger classification, Rubel and Kottek, 2010)	Equatorial Fully Humid		Equatorial Winter Dry
Mean Annual Precipitation (mm)	1950		1328
Studied depth (cm)	0-40		0-10
Soil texture (%)	Clay	40	21
	Silt	10	21
	Sand	50	58

The two sites were also different in terms of data availability and site expertise. For the site in Thailand, the authors of the study had implemented multiple field experiments and had a fine expertise of the soil studied [18][19][20]. On the contrary, in Brazil, the specific available data originated from a soil science paper focused on the characterization of soil carbonate the field scale [21][22]. No further site expertise was available in this Brazil case study.

2.2 Application of the background approach

For the background approach, the updated version of the characterization factors (www.lbp-gabi.de/90-0-LANCA.html, extracted the 6th of June 2018) was used and directly computed for each of the five impact categories. The country-specific data were used (*i.e.* Brazil and Thailand) and the LANCA® land use types corresponding to the land management in the two case studies are described in table 2. The land use selected as a reference for the two sites from the literature were very close to the natural vegetation reference assumed in LANCA® guideline, as their background CF values were equal to 0 in most of the case. The cerrado natural system was defined as a "forest natural" according to Moraes Sá et al., [21] system definition. The non-tilled system in Brazil was considered as an extensive treatment, due to its lower impact on soil health [5].

2.3 Application of the background approach

2.3.1 Calculation of the quality levels

When applying the foreground approach for the calculation of the CFs, LCA practitioners first need to calculate the quality (Q) levels for each land use (LU) and for each of the five impact categories. We applied the foreground approach by strictly following the procedures from both versions of LANCA® 2010[17] and LANCA® 2016 [11].

Table 2. LANCA® land use types corresponding to the two case studies.

Case Study	Land Use Description	Land Use Type
Brazil	Cerrado - (NV)	Forest, natural - Reference
	Soybean with tillage (CT)	Arable, non-irrigated, intensive
	Soybean without tillage and high C-input (NT6)	Arable, non-irrigated, extensive
Thailand	Secondary degraded forest	Forest, secondary - Reference
	Rubber plantation	Permanent Crops, non-irrigated
	Cassava	Arable, non-irrigated

For the erosion resistance, the physicochemical filtration and the groundwater regeneration impact categories, the updated version of LANCA® [11] was used. However, for the mechanical filtration and biotic production impact categories, as no update was provided in the 2016 version, the LANCA 2010 version was used [17].

For the two latter impact categories, the units shift between the 2010 and the 2016 version was not clearly explained in the guidelines [11]. We, therefore, needed to make two assumptions; we applied a coefficient of 100/365 (converting $cm.d^{-1}$ into $m^3.m^{-2}.a^{-1}$) for the mechanical filtration impact category and a coefficient of 1000 (converting $g.m^{-2}.a^{-1}$ into $kg.m^{-2}.a^{-1}$) for the biotic production impact category.

In some cases, the available data were not sufficient to follow the decision tree structure within the five different models. In those cases, we relied on the default classes or assumptions which are further described (see "NO" in table 3).

For the erosion resistance impact category, very fine sand was assumed to be 20% of the sand percentage [23]. In the Brazil study case, as the structure and stoniness were not identified, the attributed classes were respectively "medium" and "factor=1". The C_{factor} based on European crops was not adapted for the site in Thailand because the studied tropical crops do not figure in Panagos et al. [24] study. The C_{crop} for rubber and cassava were respectively assumed to be equal to 0.5 and 0.34. Furthermore, both the no-till conservation agriculture in Brazil and the rubber plantation were assigned with a $C_{tillage}$ factor equal to 0.25 and a $C_{residues}$ equal to 0.8 [24]. The two other land managements (*i.e.* conventional practices in Brazil and cassava in Thailand) had a $C_{tillage}$ and a $C_{residues}$ equal to 1 [24]. Concerning the physicochemical filtration impact category, the %humus content was assumed to be the percentage of soil organic matter content. For the groundwater regeneration impact category, the distance to groundwater class was not known in the two studies. We used the default 0.8-10 m class.

Table 3. Proportion of uncertain input parameters computed in the LANCA® model over the two case studies. YES = the variable could be computed with the available site knowledge. NO = the variable was integrated with LANCA® default values or assumptions. Violet input parameters are sensitive to Land Management and blue input parameters are rather sensitive to inherent pedo-climatic conditions.

Impact Category	Input Parameter	Brazil	Thailand	Comm.
Erosion resistance	Mean annual precipitation	YES	YES	
	Texture	YES	YES	
	Soil structure class	NO	YES	
	Permeability class	YES	YES	
	Stoniness factor	NO	YES	
	Slope	NO	YES	
	C_{factor}	NO	NO	
	P_{factor}	NO	NO	
Mechanical filtration	Texture	YES	YES	
	Distance to groundwater	NO	NO	
	Sealing factor	YES	YES	
Physicochemical filtration	Texture	YES	YES	
	Humus content	NO	NO	
	pH	YES	YES	
	Sealing factor	YES	YES	
Groundwater regeneration	Mean annual precipitation	YES	YES	
	Evapotranspiration	NO	NO	
	Runoff coefficient	NO	YES	Slope missing in Brazil
Biotic production	NPP	YES	YES	
	Sealing factor	YES	YES	
% of uncertain variables		**45%**	**25%**	

Additional literature was needed to implement the model for the groundwater regeneration impact category. The evapotranspiration for the two sites were extracted from two regional studies. For the Brazilian case study, we took the regional mean annual evapotranspiration of Mato Grosso from Dias et al. [25]. As the study provided detailed evapotranspiration data for soybean and for cerrado, we used in this case differentiated values for the two land uses. For the case study in Thailand, we took the data from Chachoengsao region from Vudhivanich [26] for all the land uses, as no differentiated data were available. The C factor of the model was extracted from the table provided by McCuen [27] to fit with the rational method. This factor was compiled for the Precipitation-Evapotranspiration difference.

In the 2016 LANCA® version [11], the sealing factor was sometimes not clearly integrated in the calculation procedure. To keep consistency in the analysis, we followed the calculation structure decision tree of the guidelines for each impact category, *i.e.* multiplying by the sealing factor when it was specified in the decision tree even when this was not detailed in the calculation procedure. Table 4 synthetizes the type and the number of input parameters needed to calculate the different impact categories proposed by LANCA® [11].

2.3.2. Calculation of the characterization factor for occupation impact

The characterization factors (CF) are calculated as the differences between the soil quality levels of two land uses. For the occupation impact, the difference is calculated between the land use under study and a reference land use (Eq. 1).

$$CF_{Occupation} = -(Q_{LU_{current}} - Q_{LU_{reference}}) \qquad \text{(Eq. 1)}$$

This study aimed at testing the foreground approach and analyzing the results against the background method. We thus limited our study to the analysis of the occupation impact. However, further characterization factors for “transformation to” and “transformation from” can also be derived from the quality levels calculated in the present study according to the equations provided in the guidelines [11].

For the transformation impact, changes in quality levels are calculated with a marginal approach, *i.e.* levels depend on the land use type over a year and do not represent equilibrium states over several years (as it is done for instance with soil organic carbon stocks used as a proxy for soil quality in Milà i Canals et al., [28]. With this approach, there is no regeneration time included in the CF calculation. This is a notable difference when comparing LANCA® with the other models developed to assess land use impact on soil quality within LCA.

Table 4. Summary of the input parameters needed to implement the LANCA® model.
*One of this parameter is the sealing factor

Impact Category	Erosion Resistance	Mechanical Filtration	Physicochemical Filtration	Groundwater Regeneration	Biotic Production
LANCA® version	LANCA® 2016	LANCA®, 2010	LANCA®, 2016	LANCA®, 2016	LANCA®, 2010
Pedo-climatic input parameter	6	2	1	2	-
Land Management input parameter	2	1*	3*	1	2*
Total n=20	**8**	**3**	**4**	**3**	**2**

3. RESULTS

3.1. Erosion Potential Occupation Impact

The results for the erosion potential occupation impact calculation in the contrasted land managements studied are represented in Figure 1. Results were very different when comparing the background and the foreground characterization factors. In all cases, across case studies and land managements, background impacts were always greater than the foreground ones. The CF values of the background approach were globally higher in Thailand than in Brazil. On the contrary, when comparing foreground results, the contrast between sites was less clear and discrepancies across land uses were bigger than those across sites. In Brazil, the impact of tillage practices on the soil erosion was higher than the one of no-till conservation practices soybean cultivation, both with background and foreground approaches. On the contrary, in Thailand, two different trends were observed for the background and the foreground approaches. The background did not raise any difference between the two land uses. However, the foreground approach highlighted differences between the two land uses, with a higher erosion potential for intensive cash crop compared to the perennial rubber plantation. Hence, the strong differentiating factor for erosion potential impacts was the site effect for the background calculations, and land management for the foreground calculations.

3.2. Infiltration Reduction Potential Occupation Impact

The results for the infiltration reduction occupation impact calculation in the contrasted land management studied are presented in Figure 2.

The CF values between the background and the foreground approaches strongly differed in Thailand, whereas they were relatively close in Brazil. Following the background approach, the impacts were identical for the two sites and the two land uses. However, following the foreground approach, the infiltration reduction potential occupation impact was more than five times higher in Brazil than in Thailand. In Brazil, tillage practices and residues incorporation did not have any impact on infiltration reduction potential with either background or foreground approaches. In Thailand, the resulting CF values were identical for the two land uses with both background and foreground approaches. However, in that case study, the foreground absolute data were lower than the background one. The impacts were thus never differentiated against site effect or land management with the background approach, but were only sensitive to site effect with the foreground approach.

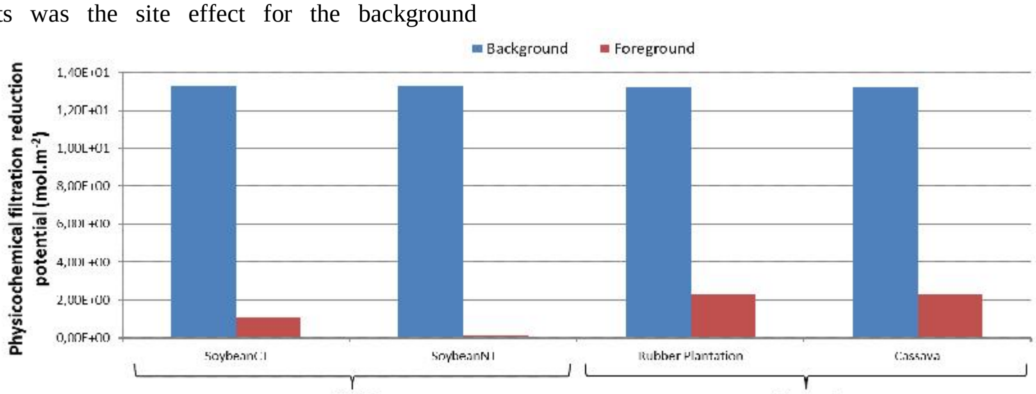

Figure 1. Characterization factor values for erosion potential occupation impact.

3.3. Physicochemical Filtration Reduction Potential Occupation Impact

The results for the physicochemical filtration reduction potential occupation impact calculation, in the contrasted land management studied are presented in Figure 3.

The background values were globally much higher than the foreground values, with a factor of around six. The CF values were identical for the two sites with the background approach and they were different under the different land managements of the two sites with the foreground approach. In Brazil, under the foreground approach, the physicochemical filtration reduction potential was higher in conventional soybean cropping system than in no-till conservation agriculture with a net difference of around 1 mol.m^{-2}. In Thailand, with the foreground approach, the physicochemical filtration reduction potential occupation impact was identical under the rubber plantation and the cassava cropping systems. The results of the physicochemical filtration reduction potential impact category revealed undifferentiated results under the background approach over the land management tested. The foreground approach allowed highlighting small value differences among different Brazil site land management practices.

3.4. Groundwater Regeneration Reduction Potential Occupation Impact

The results for the groundwater regeneration reduction potential occupation impact calculation are presented in Figure 4.

The results highlighted a strong gap between the background and the foreground values, with at least a factor of 100 between the two approaches. The results of the background approach were positive, and always higher than the negative foreground values. The foreground approach provided negative values. Analyzing the site effect, the groundwater regeneration reduction potential was higher in Thailand than in Brazil. In Brazil, the background and the foreground models were not sensitive to changes in management practices. This result was also noticed in Thailand, where the same value of characterization factor was observed between the perennial and the annual cropping systems.

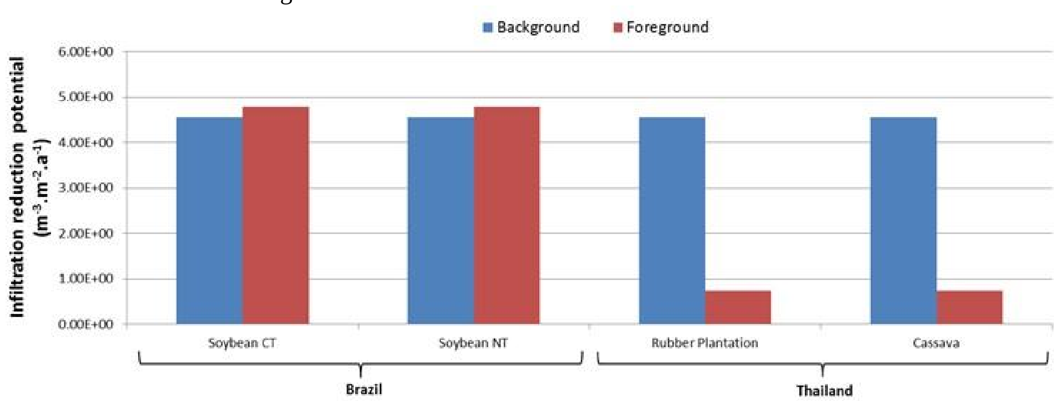

Figure 2. Characterization factor values for infiltration reduction potential occupation impact.

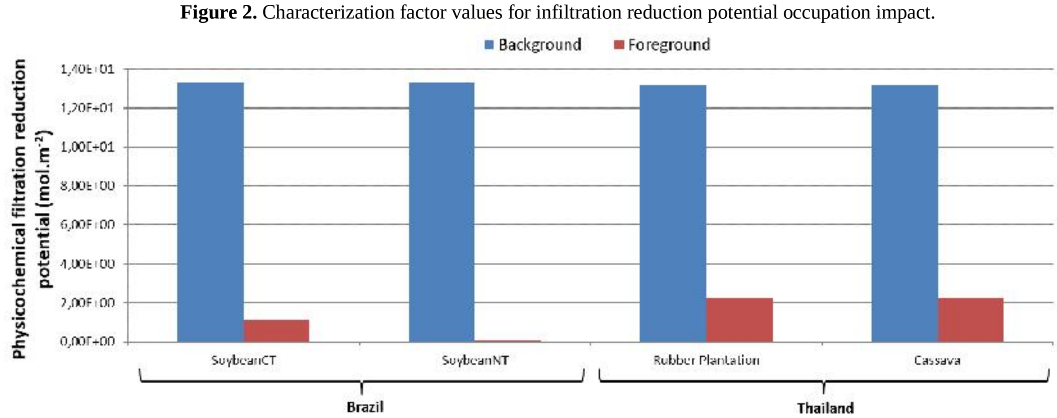

Figure 3. Characterization factor values for physicochemical filtration reduction potential occupation impact.

To summarize the results of this impact category, very different CF values were observed between the background and foreground approaches. Also, those differences were rather due to a site effect than a land management effect.

3.5. *Biotic Production Loss Potential Occupation Impact*

Finally, the results for the biotic production loss potential occupation impact calculation are presented in Figure 5. A gap between background and foreground values was highlighted, with higher values following the foreground approach. The results were not affected by the site effect both for the background and the foreground approaches. In Brazil, the CFs with the foreground approach was identical for the two land managements studied. However, the extensive annual crop represented with the no-tillage system had a slightly lower biotic production loss potential than the more intensive conventional system following the background approach. In Thailand, the results following the background or foreground approach were identical, no impact of the land uses on soil biotic production loss potential was thus observed. The biotic production loss potential was affected by the calculation approach and some land management changes but not by pedo-climatic differences.

4. DISCUSSION

4.1. Critical Analysis of the Results Obtained in the Two Case Studies

4.1.1. Comparison of background vs foreground results

The analysis of the characterization factors absolute values highlighted sharp differences between the background and foreground approaches. Moreover, those differences followed different trends across the five impact categories. For the erosion resistance, the physicochemical filtration and the groundwater regeneration impact categories, the background values were higher than the foreground values. For the biotic production, the foreground values were higher than the background values. Finally, for the mechanical filtration impact category, the differences depended on the site considered. In most cases, the scale of the analysis may explain this result. The background CFs are indeed averaged at the country level whereas foreground CFs integrate site-specific conditions. However, the gap between the values of the two approaches raises questions on the interpretation of the results that may strongly differ following one approach or another. Also, the results for the groundwater regeneration impact category seemed especially dubious. Indeed, very strong differences were observed between the background and foreground approaches absolute values. Also, the negative values of the foreground approach in Thailand would mean a groundwater regeneration increase compared to the reference secondary forest. This result remains questionable and we strongly advocate to further study this impact category to check if the results obtained in our two case studies are isolated cases.

4.1.2. Focus on background results

The background results of the different impact categories made it possible to observe an effect of the pedo-climatic properties of the site (Brazil vs Thailand) in three out of five impact categories. Concerning the land use effect, the sensitivity of the factors to land management was very low. In Thailand, even under contrasted land uses (rubber plantation and cassava), the background approach never allowed to highlight differences in soil functioning. In Brazil, on the contrary, the background approach showed the positive effect of extensive conservation practices on erosion potential reduction and biotic production potential. Those results are in line with the literature, on the effect of tillage reduction and residues incorporation on

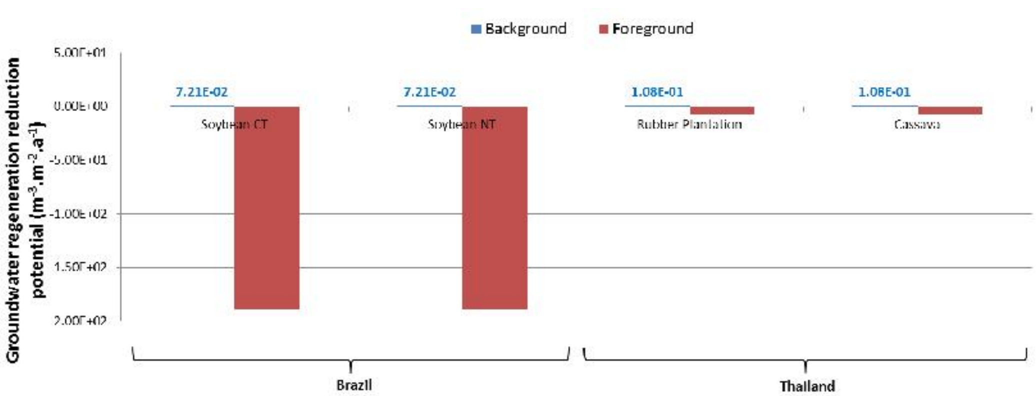

Figure 4. Characterization factor values for groundwater regeneration reduction occupation impact

erosion reduction [29]. Also, residues incorporation under the conservative agriculture may be a process to increase the biotic production potential with a spare biomass available at the soil surface [22]. To conclude, the land use classes for the background methods seem too numerous and specific. One option to overcome this global very poor sensitivity of the background factors to agricultural management practices may be to include new parameters in the empirical equation.

4.1.3. Focus on foreground results

Foreground results may provide finer information, as they are based on site-specific input parameters. The approach was very sensitive to the pedo-climatic conditions met in the two case studies. The biotic production impact category was the only impact category which was not sensitive to the site effect. This observation can be explained by the inherent structure and the input parameters needed for this model (Table 3). The foreground approach was however only very poorly sensitive to change in land management. The only impact category that stressed differences between land management practices in each site was the erosion potential (the slight difference between Soybean CT and Soybean NT for physicochemical filtration reduction seemed to rather be caused by pH class boundaries than a true management practice effect). In Brazil, the trends between the two tested land management practices were in accordance with the background results. The erosion potential was lower under the conservation agriculture system compared to the conventional soybean cultivation. In Thailand, this indicator was sensitive to the two tested land uses. The intensive cassava cash-crop had a higher erosion potential compared to the mature rubber plantation. This may be explained by the lower soil mechanical perturbation in mature rubber plantations, which is favorable to preserve soil structure maintenance [20].

Considering the results within the other four impact categories, it does not seem relevant to keep the precision level of the land use classes if the changes in CFs are only sensitive to country pedo-climatic conditions, or improvement of the models would be needed to be more sensitive to management practices.

4.2. LANCA® method input parameters and site-expertise requirements

The two case studies were different in terms of site expertise in order to test the influence of this expertise while implementing the foreground approach. In Thailand, the authors had a very fine field knowledge [19][20]; the case study in Brazil originated from a literature paper focused on soil carbon characterization [21][22]. This contrast enabled to define the scope of needed expertise to apply the foreground approach and which problems could be faced, since both study cases required additional data for the foreground implementation.

For the case study in Brazil, with data derived from the literature, the foreground method was difficult to apply. Many assumptions, complementary literature analysis or default factors were applied with a lot of embedded uncertainty, which may have a strong influence on the final results. The exact proportion of those uncertain parameters amounted for 45% of the total input parameters of the LANCA® method in Brazil (Table 3).

For the case study in Thailand, the choices of the classes used to define the calculation parameters were done in a more secure and precise way, since the authors had a field experience and a comprehensive knowledge of the study site [19][20]. However, 25% of the classes were still impossible to fill without preliminary hypotheses, even with a strong expertise on the soil quality of the site [20].

The various hypotheses and complementary literature data were difficult to integrate in the models, as the precision level of these input parameters may

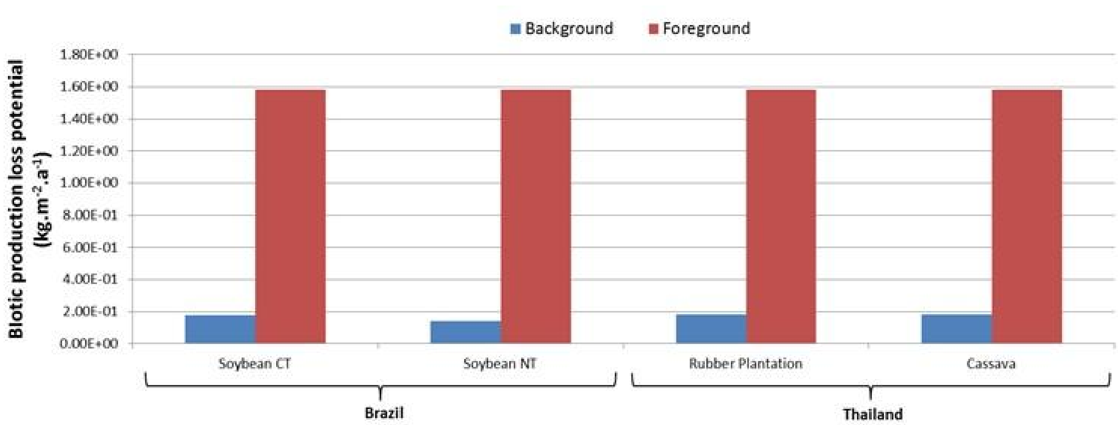

Figure 5. Characterization factor values for biotic production loss potential occupation impact

not be appropriate to the general foreground model structure of LANCA®. For example, evapotranspiration data were integrated with different levels of precision in the Brazil and Thailand sites, based on data availability, since no requirements on the data precision were mentioned in the guidelines.

Similarly, as the studied depth was not specified in LANCA® guidelines, we might have had discrepancies between background and foreground calculations in each case study. We did not know what was the depth used to calculate the background CFs. We chose to use the site-specific data for the foreground calculations using the actual investigated soil depth. This soil depth was different in both case studies. When comparing different management practices in one site, the soil depth was kept consistent. The soil depth may be influential mostly for the soil organic matter parameter used in the erosion and physicochemical filtration CF calculations. In the case of soybean, we observed a decreasing gradient of organic matter from 0 to 40 cm in the primary data set. Depending on the soil depth accounted for, the foreground erosion values may potentially be 10% reduced both in NT and CT land management when considering 0-10 cm depth (instead of 0-40cm). For physico-chemical filtration reduction potential, a change of class would also be observed, but only for the natural vegetation. For this reference land use, working at 0-10cm would result to 10% increase of physico-chemical filtration reduction potential, compared to considerations at 0-40 cm layer. The magnitude of observed differences between foreground and background results might also be influenced if soil depths considered are different, which add to the overall uncertainty linked to some unclear parameter settings. Soil depth should thus be further specified in LANCA® guidelines.

At this stage, LANCA® seems very difficult to implement, or need a lot of preliminary hypotheses on variables that may have a strong impact on the CF results and conclusions. A further sensitivity analysis of the factors may be implemented to quantitatively address the need for improving the modelling of land management impacts.

4.3. LANCA® Method Practitioner Accessibility

The two case studies confirmed the capacity of the LANCA® method to assess several soil functions, with the two different approaches. The background approach allows the practitioner for computing directly the difference of country-average characterization factors, previously calculated in Bos et al., [11]. These country-specific factors, following the Land Use classification of the IPCC, provide very operational calculations. Under the current demand to find a global and efficient model to be implemented within the Life Cycle Assessment framework, the background LANCA® method may be a relevant baseline [14]. The foreground approach also allows the practitioner for computing the available soil data and taking into account more local site-specific conditions. The background and foreground approaches thus make it possible to work at various scales, depending on data availability and input parameters.

However, despite the wish of LANCA® to provide a consistent and user-friendly foreground method, our first attempt to apply the different impact categories raised many difficulties. The first problem that may easily be overcome is the shift from the 2010 version to the 2016 version and the foreground approach procedure description in the guidelines. As an example, the changes in the units of two impact categories between the two versions remains hazardous and wrong CF values maybe integrated with a strong impact on the final LCA result. Also, some models such as the one used for the groundwater regeneration impact category are not detailed enough in the guideline to understand how to implement the model [11].

This study proved that the transparency of impact category calculation needs to be improved. For example, the links between the background CF values and the foreground calculation were difficult to handle and understand. Empirical models are easy to implement but their scope of validity needs to be more precisely indicated to avoid misleading conclusions. To be transparent, there is a critical need for a publication of a clear description of the calculations of the background CFs. The literature references of the guidelines proposed by Bos et al. [11] are also hardly accessible and most of the references are under restricted access. The CFs from the background approach are currently being applied in large environmental assessment programs and we strongly advocate a more transparent procedure description of the LANCA® method before this large scale application.

4.4. The Need to Improve the Empirical Equations

4.4.1. Consistency and necessity of the five indicators

The method is based on numerous empirical equations for the five impact categories. This multi-parameter assessment of soil quality meets the expected demand to integrate soil complexity in the LCA framework with the use of accessible parameters rather than process-based modelling. It makes it possible to have a better understanding of the impacts on soil functioning. This consistent analysis of the soil system is conceptually relevant. However, the add-on of each category on the final assessment should be statistically tested. Indeed, some correlation analysis between CFs factors [11] proved to show a very strong correlation on the CFs provided by LANCA® background data table at a global scale, using the 75 land use classes (Table 4).

Globally, the background values for the infiltration reduction potential, the physicochemical filtration reduction potential and the groundwater regeneration reduction potential CFs values were strongly correlated, with a $r_{pearson}> 0.79$. The infiltration reduction potential and the physicochemical filtration reduction potential factors were even completely correlated with a $r_{pearson}=1$. Hence, in studies where land use is in the background processes and the location not specified, the calculation of these two categories at the world scale level is completely redundant. Such a correlation raises the question of the model structure beyond the coarseness of the data grain and hence of the representativeness of the soil functioning as characterized by the model. With the foreground calculations, these two impact categories were not fully correlated in our two case studies (Figure 2 and 3). A redundancy analysis at the country level could not be carried out due to lack of data accessibility in Excel format. Such a finer redundancy analysis would be needed to identify better the limits of the model and improve its structure.

4.4.2. Toward a proposition to fill the gap between soil science and LCA models

Finally, the quality of the proposed models within each impact category is very heterogeneous. The most detailed and robust model is for the erosion potential CF, based on the RUSLE model. RUSLE is widely applied in the literature and some improvements are constantly proposed in the scientific literature [23][30][31][32][33]. The models used for the four other impact categories are less, or even not at all, applied in other soil science studies and cannot take the advantage of the scientific improvement dynamics. Some calculation parameters are based on very site specific data, such as the estimation of the potential CEC of the humus content, which were calibrated for German soils only [11][34] and may not be robust enough to compute a global assessment of the soil quality. Soil science papers, based on pedo-transfer functions for example, provide a large range of functions assessment (e.g. water flows, solute transport, heat exchange, biochemical processes, vegetation parameter) with limited input parameters [35]. Those models are continuously discussed in the literature and constantly improved with new field calibrations and applications. Such pedo-transfer functions might provide a relevant basis to improve the reliability of the equations within each of the five impact categories in the LANCA® method.

5. CONCLUSION

The LANCA® method is a first attempt to integrate a consistent evaluation of land management impacts on soil quality within the existing LCA framework. On the one hand, the model is ready to be integrated in large-scale environmental assessments, as the background calculated characterization factors allow for implementing the model rapidly and globally. On the other hand, the foreground approach allows the practitioner for integrating primary data to get a site-specific assessment. However, the two case studies stressed the need to further investigate some LANCA® impact categories before its large-scale application. The main issue raised is the lack of transparency of the methods and calculations that should be enhanced to allow further implementation and scientific dynamic on the empirical model used.

Table 5. Pearson correlation matrix on the characterization factor of the various Land Use based on world average data. The Characterization factors were uploaded from the website: www.lbp-gabi.de/90-0-LANCA.html in June 2018.

	Erosion Potential	Infiltration Red. Pot.	Physicochemical Filtration Red. Pot.	Groundwater Regeneration Red. Pot.	Biotic Production Loss Pot.
Erosion potential		0.12	0.12	-0.02	0.18
Infiltration reduction potential	0.12		1	0.79	0.61
Physicochemical filtration reduction potential	0.12	1		0.79	0.61
Groundwater regeneration reduction potential	-0.02	0.79	0.79		0.39
Biotic production loss potential	0.18	0.61	0.61	0.39	

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Note

The authors will provide the Excel spreadsheets with all the calculations upon request to the following email: alexis.thoumazeau@cirad.fr

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