

# Representing soil function in agriculture LCA in the Australian context

Marguerite Renouf<sup>1,2,\*</sup>, Sandra Eady<sup>3</sup>, Tim Grant<sup>1</sup>, Mike Grundy<sup>4</sup>, Miguel Brandão<sup>5</sup>

<sup>1</sup> Life Cycle Strategies Pty Ltd., Melbourne, Australia

<sup>2</sup> University of Queensland, School of Geography Planning and Environmental Management, Brisbane, Australia

<sup>3</sup> CSIRO, Agriculture Flagship, Armidale, Australia

<sup>4</sup> CSIRO, Agriculture Flagship, Brisbane, Australia

<sup>5</sup> Massey University, Palmerston North, New Zealand

\* Corresponding author. E-mail: [m.renouf@uq.edu.au](mailto:m.renouf@uq.edu.au)

## ABSTRACT

Soils function is an important environmental value in Australia particularly for agriculture. However it has not been considered in life cycle assessment (LCA) studies to date in Australia, which has precluded its consideration alongside other environmental impacts. The agriculture sector and LCA community in Australia desire that soil function be captured in national life cycle inventory (LCI) and impact assessment frameworks. CSIRO has commenced a project to this end, with the first step being a workshop that brought together prominent soil scientists and LCA researchers to lay some groundwork for the project by i) prioritising the soil function and quality parameters of most importance and relevance for Australia, ii) considering how soil-related indicators can assign with evolving land use impact assessment frameworks, and iii) exploring the utilisation of spatial datasets to generate LCI for flows related to soil function to allow for more regionally-specific assessment of soil-related impacts.

Keywords: soil, LCI, LCIA, Australia, national inventory databases, agriculture, soil carbon, erosion, acidification

## 1. Introduction

This paper describes the outcomes from an Australian workshop, at which a proposed approach for integrating indicators of soil function and quality into the Australian national life cycle inventory database was developed.

Soil function and qualities and their influence on productivity and ecosystem services have been under-represented in LCA to date. Recent efforts by the UNEP SETAC Life Cycle Initiative have devised an impact assessment framework that captures the eco-system service functions of land, including soil functions (Koellner et al. 2013). However this has yet to translate into the representation of soil-related impacts in life cycle studies.

Soil-related impacts are pertinent to many production systems that involve transformation of land. However interest in soil impacts has been expressed most keenly by those working on agriculture-based production systems. This is because soil function is inherently linked to agricultural productivity, and the long-term sustainability of agriculture relies on protecting and enhancing it. Hence there is more incentive to influence the protection of soil in agriculture than in any other sector.

The absence of soil function considerations in LCA to date is in contrast to the recognition of soil-related problems by the agriculture sector. Compared to soils on other continents, Australia's soils are very old, highly weathered and relatively infertile (DAFF, 2014). While there are areas of highly fertile soil, Australia's soils often have poor structure with low levels of organic matter and are affected by salinity, sodicity, and acidification, and in some regions are subject to wind and water erosion. So, for Australia in particular, declining soil quality is a major concern. The level of investment by the agriculture sector and governments to rectify soil-related impacts in Australia (estimated at A\$124 million in 2011; DAFF 2014) is higher than for other environmental impacts such as eutrophication and pesticide impacts on sensitive environments and global warming.

Therefore the agriculture sector and LCA community in Australia desire that soil function and qualities be captured in national inventory and impact assessment frameworks. The Commonwealth Scientific and Industrial Research Organization (CSIRO) commenced a project to this end, with the first step being a workshop that brought together soil scientists and LCA researchers to lay some groundwork for the project.

This project follows on from a prior program of work completed in 2013 to establish a national life cycle inventory (LCI) dataset for Australian agricultural processes (AusAgLCI) (Eady et al. 2013) which is available within the AusLCI database ([alcas.asn.au/AusLCI](http://alcas.asn.au/AusLCI)). The developed data sets currently contain inventory that allows for the assessment of resource depletion, global warming, eutrophication, acidification, and human- and eco-toxicity. The current project aims to extend the inventory to enable the assessment of soil-related impacts.

## 2. Methods

A two-day workshop was held in Canberra on the 8 and 9 April, 2014, which was attended by around 50 soil scientists, LCA researchers and, government and research investment managers (25 in person and 25 by webinar) (see [www.alcas.asn.au/events/roundtables](http://www.alcas.asn.au/events/roundtables)). The aim of the workshop was to connect LCA researchers with Australian soil scientists, for the purpose of reviewing the latest science related to soil processes in Australia and considering how best to characterise soil-related impacts in LCA in the Australian context.

After some introductory sessions on LCA and international developments in land use impact assessment, the forum heard presentations from prominent Australian soil scientists about notable soil characterization developments in Australia. The forum also connected via webinar with overseas LCA researchers (from Europe, North America and New Zealand) to gain insights into international developments and interest in this field.

The soil issues covered in the workshop were those for which there is active and significant research taking place in Australia, and which have been identified as the key soil condition indicators (Australian Government, 2011). They were compaction, soil organic carbon, erosion, contamination, soil biota and acidification. While not covered in the structured presentations, the additional issues of soil salinization and structural decline were also discussed.

Based on the structured discussion at the workshop it was possible to i) nominate the soil function and quality parameters of most importance and relevance for Australia, ii) propose how soil-related indicators of interest in Australia can align with evolving impact assessment frameworks, and iii) identify how Australian spatial datasets can be utilised to generate LCI for soil-related flows to allow for more regionally-specific assessment of soil-related impacts.

## 3. Results and discussion

### 3.1. Priority soil function and quality parameters for Australia

The geochemical processes that influence soil characteristics vary in different parts of the world, with a general distinction drawn between the high latitude countries where glacial weathering has a significant renewal effect on soil quality or those areas where significant volcanism or annual flooding has rejuvenated landscapes, and continents such as Australia where under the influence of flat topography and long periods of weathering, low rainfall and wind erosion, most soils have lower resilience and are more vulnerable to degradation. This means there may be differences in the way soil-related impacts are best represented in Australia (and other similar geological regions e.g. parts of Africa) compared with Europe, which has been the context for life cycle impact assessment development to date. Therefore, it was worth considering the soil function and quality parameters that are of relevance and importance for Australia, to ascertain if they can be adequately captured in evolving land use impact assessment frameworks. Furthermore, the practicality of collecting data for these parameters for inventory development needs to be considered.

Participating soil scientists were asked to rank the soil characteristics according to their environmental importance in Australia and the expected difficulty of inventory development. The results of participant feedback are shown in Figure 1.

The priority soil attribute raised at the workshop (those in the top left-hand quadrant of Figure 1) were consistent with those identified in Australia's State of the Environment reporting (Australian Government 2011) and the national soil R&D strategy (DAFF 2014). The leading challenges are acidification, erosion and loss of soil carbon. This degradation will increasingly affect Australia's agriculture unless carefully managed, and in some cases ameliorated. Assessment of soil condition for regions with cropping and/or intensively managed grazing systems (approximately 75 million hectares) showed that for:

- **acidification**—50 per cent of regions were in very poor or poor condition, while 95 per cent of regions showed a deterioration in soil pH
- wind and water **erosion**—53 per cent of regions were assessed as in poor condition, while soil cover in 11 per cent of regions was deteriorating
- **soil carbon**—33 per cent of regions had very poor or poor soil carbon content, while 85 per cent of regions had ongoing deterioration in soil carbon content.

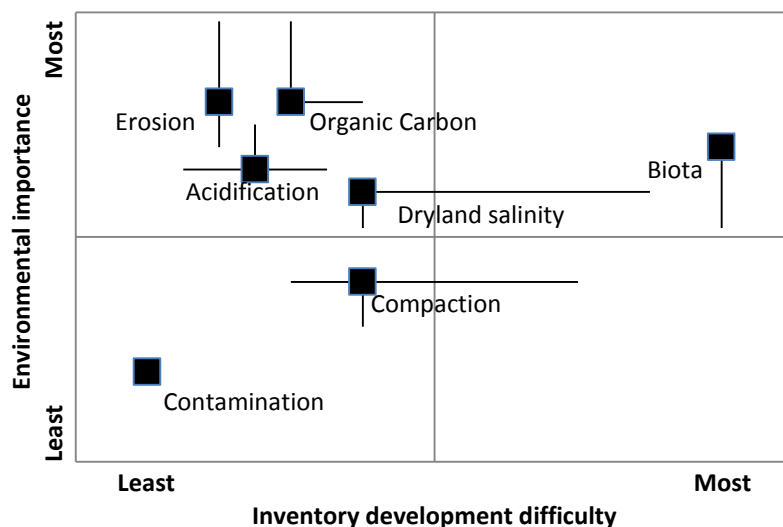


Figure 1. Ranking of environmental importance and difficulty of inventory development (with the horizontal and vertical bars indicating spread in opinion).

Dryland salinity has also been identified as an ongoing threat, although the millennium drought may have slowed its spread temporarily. However, salinity is less easily linked to on-site agricultural management. While its expression (in contaminated soil or near-surface groundwater) can adversely impact on agricultural production, its cause may be substantially removed in space and time (e.g. clearing or irrigation elsewhere in the catchment at other times) and the risk components are complex (Grundy et al. 2007). Compaction was assessed to be of lesser overall importance while diverse and high populations of soil biota were considered to be important but difficult to quantify. Soil contamination was also thought to be less of an issue as it is mostly related to point source pollutant emissions and hence quite localized, and impacts can be adequately captured in existing inventory and impact assessment (e.g. heavy metals in fertilizers).

In relation to the practicality of inventory development, it was considered that datasets of sufficient representativeness exist for soil organic carbon, erosion and acidification. For organic carbon, data on stocks and flows are available from cropping systems models such as APSIM, continent scale models such as FullCAM, and geospatial modeling (Viscarra Rossel et al. 2014). For erosion, there are model data assimilation approaches such as those used by Chappell et al. (2013) to estimate net rates of erosion. For acidification, data are available from the Australian Soil Resource Information Systems ([www.asris.csiro.au](http://www.asris.csiro.au)). For salinity and compaction more work may be required to adapt existing datasets; detailed data are available for areas of salinity high risk e.g. the south-west cropping lands (Furby et al. 2009). There is a considerable paucity of measurement methods available for soil biota at the spatial scale required for national inventory making it impractical at this time to consider including biota-related inventory.

It was noted that in the Australian context the sustainability objectives for soil function and quality were both the maintenance of eco-systems services and the maintenance of the soil resource itself. As will be discussed further in the next section, existing LCA frameworks are mostly concerned with the eco-system services function of soils. Soil is not captured by resource depletion indicators in LCA as fossil fuels and minerals are. In the Australian context avoiding the depletion of soil resources is important. This is because the natural reference state for land in Australia is already highly eroded with very shallow soil profiles and high propensity for ongoing erosion. Consequently it is easy for tipping points to be reached.

In summary, the set of characteristics considered to be important because they significantly influence the productivity, the soil resource base, and ecosystem services, they are related to land management in the agricultural system and for which there are reasonable data available, are soil organic carbon, erosion and acidification. These will become the priorities for further investigation in the CSIRO project.

### 3.2 Alignment with land use impact assessment frameworks

The alignment of inventory with impact assessment is an important consideration in developing regional inventory datasets. The authors appreciate the challenges of regionalized impact assessment and the need to harmonize impact indicators (Saad et al. 2013), and acknowledge that Australia-specific inventory needs to enable impact assessment using internationally consistent indicators and impact assessment methods.

A good starting point is the guideline for land use impact assessment developed under the UNEP/SETAC Life Cycle Initiative (Brandão and Canals 2013; Koellner et al. 2013; Saad et al. 2013). It is the most developed model relating to land use to date, and proposes a characterization model that links land characteristics with indicators of eco-system services. Figure 2 presents an extract from this model showing the cause and effect chains related to soil characteristics and including the midpoint indicators proposed to date.

Overlaid on this model are the priority soil characteristics identified for the Australian context (shaded in light grey in Figure 2). Two of these, soil organic carbon and erosion, are already captured in the land use impact assessment model (light grey). Soil organic carbon (tC/ha) is proposed in the model as a proxy for fertility, influencing biotic production (Brandão and Canals 2013). It is also the indicator used to quantify soil carbon sequestration. Erosion regulation potential is captured in the model, with the proposed proxy indicator being erosion resistance potential (t soil/ha/yr) (Saad et al. 2013).

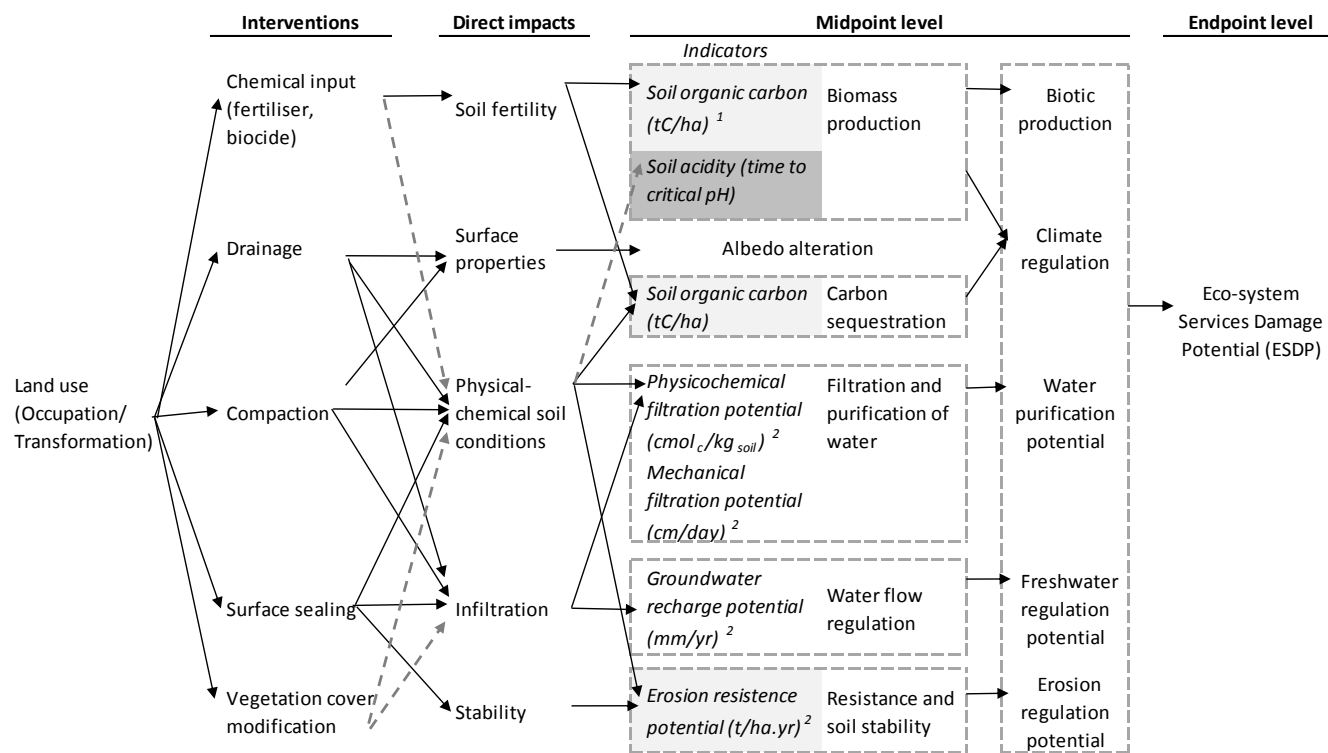


Figure 2. Extract from the land use impact assessment model developed under the UNEP/SETAC Life Cycle Initiative (Koellner et al. 2013), and incorporating the midpoint indicators proposed for biomass production (1) (Brandão and Canals 2013), and other eco-system services (2) (Saad et al. 2013). The shaded indicators are those identified as important in the Australian context.

Soil acidity is not captured in the model (dark grey in Figure 2). It adversely influences agricultural productivity in Australia (Australian Government 2011) and could be considered as a moderator of biotic production along with soil organic carbon. Some consideration may need to be given to how it can be integrated into the model.

In summary, soil-related inventory developed for Australia for soil organic carbon and erosion could align with the emerging land use impact assessment framework. Even though compaction is not currently a priority for inventory development, it could also be accommodated at a later date as midpoint indicators reflecting the impacts of compaction have been proposed (physicochemical and mechanical filtration potentials and groundwater recharge potentials) (Saad et al. 2013). An adaptation to the impact assessment framework to accommodate Australian conditions, could be the inclusion soil acidity as a moderator of biotic production. Furthermore, including soil within abiotic resource depletion impact categories would allow for consideration of Australia's soil resource conservation objective.

### 3.3 Utilisation of spatial datasets to generate LCI for flows related to soil function

The spatial scale of the agricultural LCI datasets (AusAgLCI) is at the level of agro-ecological regions (Williams et al. 2002). To enable cost effective inventory development across the breadth of Australia's agricultural regions, GIS-enabled spatial data are utilized. As previously noted, spatially-linked data for soil organic carbon, erosion and acidification are available, and it is proposed that these be used to supply soil-related inventory (see an example in Figure 3).

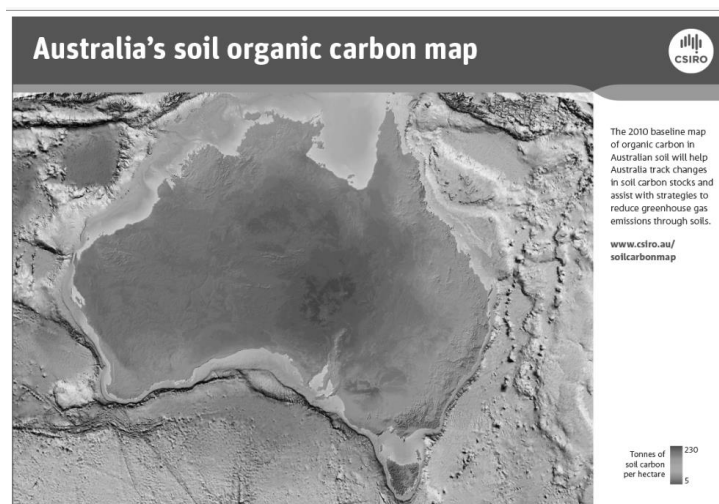


Figure 3. The 2010 baseline map of soil organic carbon in Australian soil; a base to track changes in soil carbon stocks and assist with strategies to reduce greenhouse gas emissions through soils (Viscarra Rossel et al. 2014).

As part of the UNEP/SETAC land use impact assessment framework generic characterization factors for global application have been developed, which characterize the mid-point indicator per unit of land, based on regionally-disaggregated modeled estimates (Brandão and Canals 2013; Saad et al. 2013). For the purposes of extending Australian agricultural inventory, region- and production system-specific inventory flows derived from the spatial data are proposed to be employed rather than defaulting to the generic characterization factors. These will give a more robust and representative estimate of the key soil-related impacts in the Australian context. Spatial data for soil organic carbon, acidity (pH) and net soil erosion already exist, and are represented as 'stocks'. The challenge will be to couple these estimates of 'stocks' with a means of estimating 'flows' (stock changes), and to link flows to management practices and interventions.

A similar approach was taken in the previous inventory development project (Eady et al. 2013) to generate region- and production system-specific pesticide flows by using PestLCI to partition flows between soil, air and water compartments. This meant that more robust regional inventory is possible, rather than relying on generic characterization factors embodied within the impact assessment methods, that do not account for the climate and

soils of the region. Hence, we propose to take a similar approach for soil attributes and use the best existing data to describe mid-points indicators.

#### 4. Conclusion

An approach for extending Australian agricultural LCI datasets to include soil-related flows has been proposed, which can be consistent with evolving international frameworks for land use impact assessment. Spatially-linked data for soil organic carbon and erosion are available to generate inventory flows that align with proposed midpoint indicators for biotic production and erosion regulation. Acidification is a major constraint to soil function in the Australian context, and a way of adapting the biotic production mid-point indicator to be moderated for acidification may need to be considered. The tasks for the project will be to convert the 'stock' information available from the datasets into 'flows' (stock changes) for the inventory, and to link the flows to management practices and interventions. The inclusion of soil resources within adiabatic resource depletion impact categories would also allow for consideration of Australia's particular soil resource conservation objectives.

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