Environmental benefits of compost use on land through LCA – a review of the current gaps

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ABSTRACT

The use of biowaste compost on land can have beneficial effects on the plant–soil system. While the environmental impacts associated with compost production have been successfully assessed in previous studies, the assessment of the benefits of compost on plant and soil has been only partially included in few published works. In the present study, we reviewed the recent progresses made in the quantification of the effects associated to biowaste compost use on land by using life cycle assessment (LCA). Different research efforts are required for a full assessment of the potential benefits, apart from nutrient supply and carbon sequestration; additional impact categories – dealing with phosphorus resources, biodiversity, soil losses, and water depletion – may be needed for a comprehensive assessment of compost application. Several of the natural mechanisms identified and the LCA procedures discussed in the paper could be extensible to other organic fertilizers and compost from other feedstocks.

Keywords: sustainable agriculture, organic fertilizer, biowaste, soil organic matter, soil quality, biodiversity, carbon sequestration

1. Introduction

There is increasing concern about soil interrelated environmental problems such as soil degradation, desertification, erosion, and loss of fertility (European Commission 2006). These problems are partially consequence of the decline in organic matter content in soils. An estimated 45% of European soils have low soil organic matter (SOM) content, principally in southern regions (European Commission 2006). A parallel concern is the massive generation of organic waste by human activities in urban areas. Composting is one of the best-known and well-established processes to recycle organic waste. Composting allows the stabilization and sanitation of organic waste through accelerated aerobic decomposition under controlled conditions, resulting in a product called compost.

Several studies indicate that the use of compost on land may improve several plant and soil parameters, thereby making compost an interesting option for soil restoration purposes, while taking advantage of its fertilizer properties. On the other hand, the application of compost may also potentially result in environmental and agronomic drawbacks, such as gaseous and leachate emissions, and increase in salt and heavy metals content in soil (Hargreaves et al. 2008). Nevertheless, these issues are in general directly associated with the quality of the final compost and agronomic management.

Life Cycle Assessment (LCA) was promoted in different European directives as a robust quantitative tool and has been widely used for the environmental assessment of waste and agricultural sectors. The negative environmental impacts associated with compost production and transport, particularly in the case of compost produced from municipal solid waste, have been successfully assessed in previous studies (ROU 2007; Boldrin et al. 2009; Martínez-Blanco et al. 2010; Colón et al. 2012). However, assessment of most of the potential environmental benefits of compost on plant and soil has not been carried out yet. Several recent studies address the inclusion of compost benefits in a qualitative manner, recommending that further research should be undertaken on the subject (Boldrin et al. 2009; Favoino and Hogg 2008; Hansen et al. 2006; Martínez-Blanco et al. 2011). Nevertheless, carbon sequestration and nutrient supply are, to date, the only environmental benefits taken into account in these studies. Because of the modeling complexity, ROU (2007) is, to our knowledge, the only study that attempted including most of the abovementioned benefits within LCA of two Australian case studies. The results were however only presented at the inventory stage.

The main goal of this review paper is to quantitatively address LCA modeling of the positive potential effects traditionally associated with land application of biowaste compost produced from organic municipal solid waste and garden waste. Here we have focused only on the implications of compost application to the soil and plant without considering the full life cycle (i.e. production process and transport are not discussed here).

2. Methodology

A comprehensive review of the literature dealing with the potential benefits of compost application and the current situation of the inclusion of each of these benefits in LCA studies was carried out. First, the most relevant benefits of compost on soil properties and plant growth were identified and the inventory data was collected. Subsequently, 90 articles (including both reviews and case studies) published later than 1990 were selected. Although similar environmental and agronomical benefits could be observed in compost produced from other types of feedstock and in other organic fertilizers, in this review field studies considering compost from organic municipal solid waste and green waste (from now on called biowaste) were taken into account when possible. The potential benefits were grouped into nine categories (Table 1). According to the literature review, the benefits were classified into short-term (1 year), mid-term (1–10 years), and long-term (10–100 years), depending on the time perspective of the agronomic effects.

Later on, the potential benefits studied were reviewed, through an LCA perspective, according to: (1) the existing evidences for the effects on soil, plant, environment, farmer or harvest and the main factors affecting the results for each of them; (2) the possibility of quantification of the substituted or saved process (i.e. the availability of data that can be later included in an inventory); and, finally, (3) the current availability of tools for their inclusion in LCA, together with the current status of new assessment methodologies.

3. Results

The following two sections provide an overview of the results. Occurrence of individual benefits is discussed in the first part, while the second part deals with quantification of the benefits in a life cycle perspective.

3.1. Compost potential benefits

An outline of the literature review dealing with the nine potential benefits resulting from compost application is provided in Table 1. The full review is available in Martínez-Blanco et al. (2013) where, for each of the agronomic benefits, a discussion of the main factors affecting the performance of individual benefits, the degree of proof and the range of the benefits measured were included.

Regarding the supply of plant nutrients, carbon sequestration, soil erosion and soil workability, the positive effects of compost application were demonstrated in most of the reviewed studies, and their magnitude was quantifiable. Although we were also able to state the magnitude of the effect, for the following three benefits the share of studies with non-significant results was relevant: crop nutritional quality was not relevantly different for a third of the case studies included; for crop yield, more than 60% of the case studies did not report differences when compost was applied; and finally, non-significant benefits were detected for soil moisture content for low rates of compost. These were also the benefits with higher disparity in the measured effects among the results.

For the benefits pest and disease suppression and crop nutritional quality, although they were proved, it was not feasible to summarize the benefit in a unique data range. These benefits involve several concurring indicators at the same time and the intensity of the effect is different for each of them due to several factors. Regarding weed suppression, this effect was not proved when compost is used as a soil amendment. Finally, data regarding effects of compost application on soil biological properties and biodiversity are scarce and restricted to microorganisms. Table 1 shows the results of the review for three of the most used microbial indicators.

On average, positive effects due to compost application were found for all the potential benefits, except for weed suppression. Benefits in the long-term were only reported for nutrient supply, carbon sequestration, soil biodiversity and soil workability, whereas for the other potential benefits only mid- or short-term data were found. In addition, quantification of the potential benefits yielded broad ranges in most of the cases.

During literature review the variables having the largest influence on the magnitude of compost benefits were identified. The original feedstock material, management of the composting process, compost maturity, and crop management are some of the main factors that determine the occurrence of environmental and agronomic benefits. For instance, Boldrin et al. (2009) reported that the typical contents of nutrients in biowaste compost can vary depending on the initial raw waste material. Susceptibility of these nutrients to mineralization and release might depend on the degree of stability and/or maturity of the compost as well as on the prevailing climatic conditions due to the large influence of temperature and moisture in decomposition and nutrient release (Sikora and Szmidt 2004).

Regarding the impacts of compost on soil moisture, workability and erosion, several authors reported large positive effects with high-rate compost application on soils with initially low SOC content. Compost quality is the most important factor determining the impacts on soil biological properties and biodiversity, together with the dose applied (Hargreaves et al. 2008; Diacono and Montemurro 2010). Increases in crop nutritional quality when compost is employed largely depend on crop management and climate conditions (e.g. better results were observed when a lag of time between compost application and crop existed and nutrient mineralization rates tend to be higher in warm climates).

3.2. Quantification of benefits

Depending on the nutrient content and availability of the compost, the use of mineral fertilizers can be avoided and therefore their industrial production and transport. Final utilization efficiencies for N, P and K are in the order of 20–60% for N, 90–100% for P, and 100% for K (Boldrin et al. 2009). Using the nutrient contents presented in Table 1, the potential amount of inorganic fertilizers replaced may be within the range of 1–13 kg of N, 1–5 kg of P, and 5–14 kg of K per ton of compost applied. A life cycle inventory (LCI) for fertilizer production include use of materials and energy, and emissions to different compartments, which would typically result in potential impacts on Resource Depletion, Global Warming, Human- and Ecotoxicity, and Eutrophication impact categories (Figure 1). Inventory datasets for N-P-K fertilizers are reported in different sources. In addition, the use of a renewable P source rather than inorganic non-renewable supply is of great importance and this reduced raw resource consumption might be quantified during impact quantification.

The amount of C sequestered into soil by compost application, can be translated into saved CO_2 emissions by using a conversion factor of 44/12, based on molar relation, and then entered into the LCI. A time frame of 100 years is considered to be relevant for estimating contributions to Global Warming (Favoino and Hogg 2008). Boldrin et al. (2009) reported that the benefits from C retained in soil 100 years after the addition of biowaste compost is between 2 and 79 kg CO_2-eq. t^{-1}. Higher values, 279 kg CO_2-eq. t^{-1}, were reported by ICF (2005). Most likely, this large variability is due to the synergetic effect of the different environmental and site-specific factors, meaning that estimations should be done on a case-to-case basis.

When the application of compost results in pest suppressive effects, the use of pesticides can be reduced or avoided. However, compost benefits on plant health are so case-specific that it is not possible to provide any general figures for the amount and the type of pesticides saved. The avoided use can be credited to the system as an environmental saving associated to both the avoided production/transportation and to the avoided release of these products to the environment. Inventory data covering emissions modelling, production and transport of pesticides can be found in different databases such as PestLCI, Ecoinvent, and GEMIS. Potential environment impacts from production/transportation and use of pesticides can be assessed using existing impact categories, the most relevant being the Toxicity categories, both Human- and Ecotoxicity (Figure 1).

Increased yield as a consequence of compost application could result in avoided additional agricultural production, and thus all the associated environmental burdens. If arable land is not constrained, the benefit is linked to theoretical avoided use of material and energy needed for the crop production (of the yield increased). In the most likely regime of constrained arable land, the increased yield would have an effect on both intensification and expansion of agricultural production, and ultimately will prevent indirect land use changes (ILUCs), which are for instance a major source of GHG emissions (Thamsiriroj and Murphy 2010). Depending on the specific area and crop, most of the impact categories are influenced when agricultural production is involved (Figure 1).

Table 1. Summary of the potential benefits of compost use-on-land in the short-, mid- and long-term retrieved from the literature review (adapted from Martínez-Blanco et al. 2013).

Benefit	Indicator (Unit)	Short-term (<1 yr)		mid-term (<10yr)		long-term (<100yr)	
		Min.	Max.	Min.	Max.	Min.	Max.
Nutrient supply	N mineralized (% of N applied)	5	22	40	50	20	60
	P mineralized (% of P applied)	35	38	90	100	90	100
	K mineralized (% of K applied)	75	80	100		100	
Carbon sequestration	C sequestered in soil (% of C applied)	40	53		30	2	16
Weed, pest and disease suppression	Weed suppression (-)	ns	ns	-	-	-	-
	Pest and disease suppression (-)	nad	nad	-	-	-	-
Crop yield	Δ Crop yield (% from mineral fertilization) [1]	-138	0	-71	52	-	-
Soil erosion	ΔSoil loss (%)[1]	-	-	-5	-36	-	-
	Δ Soil structural or aggregate stability (%)	29	41	0	63	-	-
Soil moisture content	Δ WHC (%)	0	50	-	-	-	-
	Δ PAW (%)	0	34	-	-	-	-
Soil workability	Δ Soil bulk density (%)[1]	-2.5	-21	-0.7	-23		-20
Soil biological properties and biodiversity[2]	Δ Microbial diversity (%)[1]	-	-	-	-	-2	4
	Δ Microbial biomass (%)	22	116	10	242	3.2	100
	Δ Microbial activity (%)	0	344	-	264	0	43
Crop nutritional quality	Crop nutritional quality (-)	nad	nad	-	-	-	-

Δ, change in the indicator; WHC, water holding capacity; PAW, plant available water; ns, no significant differences; nad, no average data because of complexity of available dataset; "-", no reported benefits.

[1] Negative value indicates a decrease in the indicator.

[2] The ranges of benefit for three of the more used indicators are presented.

As shown in Table 1, losses of soil could be decreased by 5 to 36% with the application of compost, depending on the time horizon considered. A more precise quantification is possible for specific local conditions taking into account for instance climate, application rate, and type of soil. Avoided soil losses can be modelled within traditional LCA impact categories; here the consequential modelling should identify the agricultural production affected by the losses of arable land. Assuming a constrained agricultural production at a system level, the modelling is then done similarly to "crop yield", meaning that the consequences of intensification and/or land expansion are included in the assessment. Another alternative is to consider soil as a resource, thus either including loss of soil in the inventory as 'resource depletion' (Cowell and Clift 2000) (Figure1).

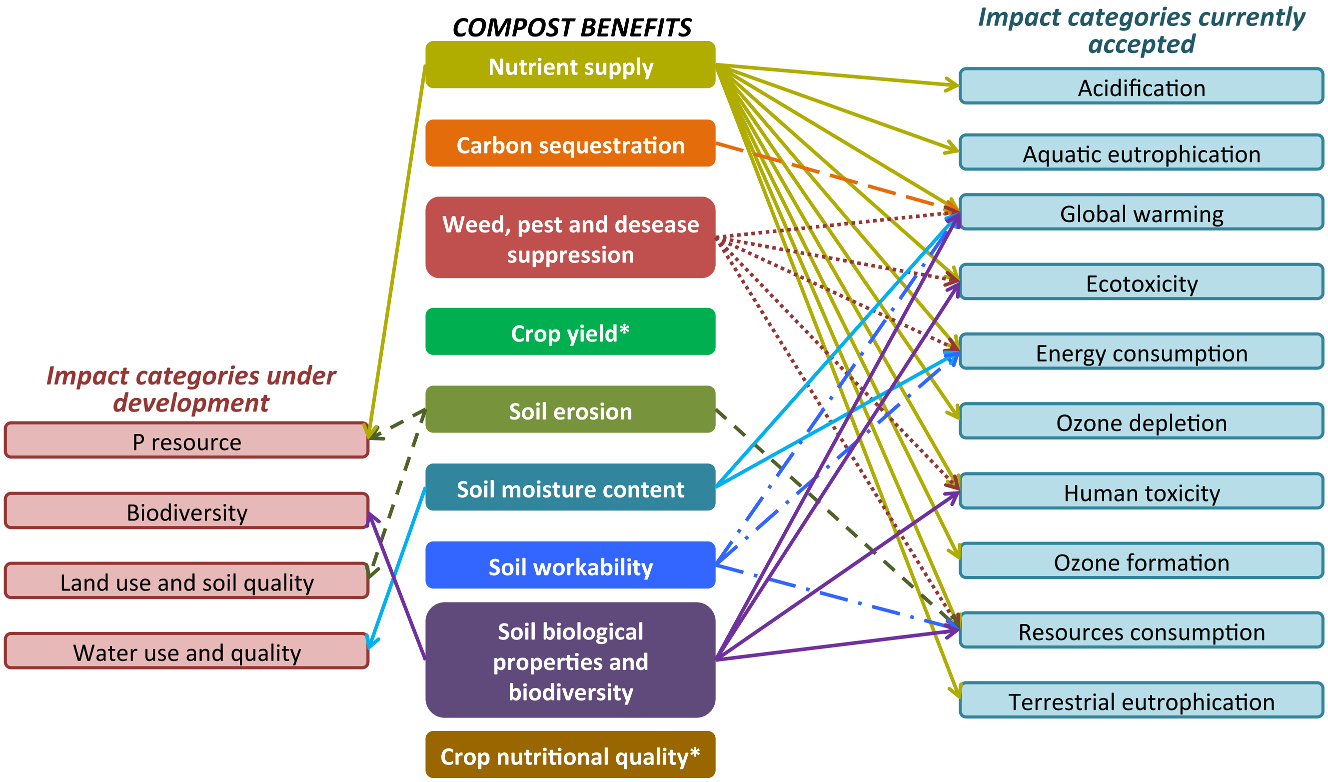

Figure 1. Midpoint LCA impact categories involved in the evaluation of the potential benefits of biowaste compost use-on-land.

* Could be considered as improvement of the function of agricultural processes and included in the functional unit definition.

Compost application might raise the capacity of soil to retain rainfall and irrigation water (green water, i.e. rainwater stored in the soil as soil moisture) allowing the reduction of irrigation water consumption (blue water, i.e. water from surface and groundwater resources). This may result in two distinguished consequences: on one hand, blue water is saved; on the other hand, because more green water is available, crop yield could increase in those areas where irrigation water is scarce. However, there is not a direct relation between the retention capacity and the amount of water saved, as it depends on the water demands of the plants, management practices, and previous moisture content of soils. The theoretical saving of irrigation water could be calculated for a particular case study if all these data are available (ROU 2007). Environmental burdens from irrigation water supply are linked to water extraction, transport, and distribution in the field (electricity, pumps, pipes, etc.), and are found in several inventories, also at a regional level. Potential impacts from these processes are typically those related to energy supply and consumption, thus Global Warming, Acidification, and Eutrophication categories (Figure 1). There is indeed a growing consensus on the fact that water use and consumption should be included in LCA assessing, apart from volumetric amounts, its environmental effects on the three Areas of Protection (Human Health, Natural Environment and Resources) (Núñez et al. 2013).

Improved soil workability can potentially decrease energy requirements for agricultural operations (Favoino and Hogg 2008; ROU 2007). Soil ploughing typically involves large consumption of energy and fuel. In an 8-year long study, McLaughlin et al. (2002) reported that, under a 100 t ha^{-1} application of stockpiled and rotted manure on a corn field, the plough draft was reduced 27–38%, resulting in 13–18% reduction of fuel consumption, due to the improvement in soil quality related to the increase in SOM. No other studies were found linking compost application and fuel consumption for agricultural operations, meaning that more comprehensive data are needed to be able to relate, for example, fuel consumption with soil bulk density. From an LCI point of view, reduced fuel consumptions can be credited to the system as avoided use of diesel. Avoided diesel consumption mainly affects Global Warming impact category, while avoided emissions of nitrogen oxide could also have an influence on Acidification and Eutrophication (Figure 1).

Changes in soil biodiversity after compost addition might influence either positively or negatively the services “delivered” by the ecosystem (i.e. nutrient cycling regulation of soil water and pest incidence), with consequences in terms of impacts associated to the substitution or compensation of those ecosystem services. In LCA terms, alterations in the system service in connection to biodiversity changes could be modelled within the traditional categories if those changes could be quantified in the inventory (Figure 1). If, for example, increased biodiversity can be directly related to increased nutrient cycling and lower need for fertilization, then the benefits from increased biodiversity could be modelled in terms of reduced production of fertilizers. However, data linking compost use, biodiversity and ecosystem services are non-existing, apart from a first attempt of establishing a preliminary relation by Nemecek et al. (2011). In addition, general figures cannot be established in all cases, as the effects of land management practices are highly variable depending on regional and scale dependent factors (Bengtsson et al. 2005). An alternative approach is to consider biodiversity and ecosystem services as independent endpoint categories when assessing the environmental impacts of land management alternatives (Zhang et al. 2010). Some recent initiatives have established baseline diversity indices for different soil organisms and under different soil uses that can be used as a reference to evaluate the impacts of compost on soil biodiversity (Cluzeau et al. 2012).

Different nutrient contents in food products resulting from compost application can have a repercussion on the LCA modelling depending on how the functional unit is defined. When the functional unit includes qualitative aspects (e.g. nutritional and/or economic value), increased nutritional level of a food product may have as a consequence that lower amounts of that specific food product are needed. In general terms, including qualitative aspects in the functional unit, would have an effect on the agricultural production (Martínez-Blanco et al. 2011), which could be modelled similarly to changes in crop yield.

4. Discussion

Regarding the environmental assessment – including quantification and characterization – of the benefits of compost application to soils, four different scenarios were identified: (i) The positive effects of compost application are proved, effects are quantifiable, and there are tools for their consideration with LCA. This includes nutrient supply and carbon sequestration, which are (and should be) included in LCA studies. (ii) The benefits are proved, but their magnitude is too variable as a consequence of the synergetic effect of many factors. Thus, inventory data cannot be unambiguously quantified. Impact categories and characterization factors exist for most of the benefits. (iii) The benefits are proved and quantifiable. However, corresponding characterization factors and/or impact categories are non-existing. (iv) Benefits are not fully proved and thus their inclusion in the modelling is not yet feasible.

Two out of the nine potential benefits initially proposed, are proved and the quantification and assessment are possible, while different research efforts are required for the rest of the effects for a full assessment both regarding improved modelling and characterization. Modeling and quantification issues are related to the fact that LCA models are typically linear steady-state models of physical flows (Guinée et al. 2002) whereas fluxes of nutrients and pollutants after compost application to soil are not linear in most of the cases. This also applies, for instance, to repeated applications of compost: LCA studies typically look at the effects of a single application over 100 years, while the cumulative effects on several applications may not be linear with the amount of compost added. Also, LCA models assume that impacts depend on the compost characteristics while they rarely include environmental parameters as determining factors, which highlights the necessity of coupling LCA and agronomic models to gain a more precise picture. Another methodological issue is derived from the fact that many of the benefits discussed in this paper might be interrelated and therefore their contribution to a specific impact category might be overlapping. This should be clearly identified in order to avoid the overestimation of the benefits.

Finally, for LCA of the agricultural sector, the functional unit is typically defined per area used or product yield. As different functional units can lead to different results for the same product system (Martínez-Blanco et al. 2011), there may be a need for a qualitatively more precise definition when dealing with compost application, especially in those cases where the product quality is affected. Better definitions could, for example, include the economic value or the nutritional content of a product (Schau and Fet, 2008). A more accurate definition dealing with nutritional differences may include a combination of quality (nutritional quality) and quantity (yield). This was for example done in Charles et al. (1998) and Audsley et al. (2003), where the functional unit was defined as "1 equivalent ton grain with 12–13% protein". This involved the use of marginal productions to adjust the overall output of the system under assessment. Finally, the choice of the time horizon of the LCA should be harmonized. The studies reviewed showed in fact that such choice is in many cases very important, as both the foreground and background effects of compost application vary largely depending on the time frame.

In addition to improved quantification and modelling of compost application, the development of new impact categories or modifications of the current ones in the future will allow for a more comprehensive assessment of compost benefits. These should deal with depletion of P resources, biodiversity, loss of arable soil, and consumption of water. Depletion of P as a resource is currently modelled similarly to other natural resources. A revision of the characterization factors is thus needed for the assessment of non-replaceable non-renewable resources such as P. In this respect, the ReCiPe model adds value to resources; it is based on the geological distribution of mineral and fossil resources, and assesses how the use of these resources causes marginal changes in the efforts to extract future ones (Goedkoop et al., 2009).

Although there is no consensus yet on which indicators use in the assessment of land use impacts, there is a common agreement that land use is one of the main drivers of biodiversity loss, and that must be assessed taking into account different taxonomic groups and a spatially explicit approach (De Baan 2013).

Soil loss involves the loss of cultivable land but also the loss of soil organic carbon (SOC), plant nutrients, as well as the associated plant, animal and microbial biodiversity (Cowell and Clift 2000). Loss of soil can thus be included in some of the abovementioned impact categories. However, for a more comprehensive assessment the loss of soil mass could be considered as the loss of a resource and included in the inventory as 'resource depletion' (Núñez et al. 2013). In alternative, soil erosion can be included within the impact category Land Use, whose characterization factors are based on soil quality indicators such as SOM, structure, heavy metals, biodiversity, aesthetic value, etc. (Brentrup 2004; Mattsson et al. 2000).

Depletion of water resources is gradually gaining importance, particularly in certain geographical regions. There is currently only a preliminary scientific consensus about the parameters to consider and the methodology to follow (Núñez et al. 2013). Methodological issues concerning impact assessment methods include the types of water use accounted for, the inclusion of local water scarcity conditions, and the differentiation between watercourses and quality aspects (Berger and Finkbeiner 2010).

5. Conclusion

Most potential environmental benefits of compost are so far not included in LCA studies because of scarcity of data, high variability in the observed effects, or lack of appropriate impact assessment methods. For two of the nine benefits – nutrient supply and carbon sequestration – the literature review showed that both quantification and impact assessment of the effects could be performed, meaning that these two benefits should be regularly included in LCA studies. For four of the nine benefits – increase in crop yield, soil workability, crop nutritional quality, and enhancement of soil biological properties and biodiversity –, quantitative figures could not be provided, either because of complete lack of data or because the effects are both very variable and too depending on specific local conditions. For "soil erosion" and "soil water content" effects could be quantitatively addressed, but available impact assessment methodologies were considered unsuitable to comprehensively evaluate the implication of compost application with regards to these two benefits. Finally, based on the available literature, "suppressive effects of compost on weed, pests, and diseases" could not be generally proved. Efforts at different levels are needed in order to comprehensively evaluate the benefits of compost use, such as the collection of more empirical data to accurately determine the magnitude of some of the effects. Long-term studies are particularly scarce. Further, the comprehensive assessment of compost benefits would also need further improvement of the modeling for the quantification of the benefits, as well as a better understanding of how the local environmental conditions would influence the effects of compost, through the use of agronomic models. Additional impact categories dealing with phosphorus resources, biodiversity, soil losses, and water depletion, may be required.

6. References

Audsley E, Alber S, Clift R, Cowell S, Crettaz P, Gaillard G, Hausheer J, Jolliet O, Kleijn R, Mortensen B, Pearce D, Roger E, Teulon H, Weidema BP, Zeijts H (2003) Harmonisation of Environmental Life Cycle Assessment for Agriculture. Final Report Concerted Action AIR 3-CT94-2028:101

Bengtsson J, Ahnström J, Weibull ANNC (2005) The effects of organic agriculture on biodiversity and abundance: a meanalysis. J Appl Ecol 42:261-269

Berger M, Finkbeiner M (2010) Water Footprinting: How to Address Water Use in Life Cycle Assessment?. Sustainability 2:919-944

Birkved M, Hauschild MZ (2006) PestLCI-A model for estimating field emissions of pesticides in agricultural LCA. Ecol Model 198:433-451

Boldrin A, Andersen JK, Moller J, Christensen TH, Favoino E (2009) Composting and compost utilization: accounting of greenhouse gases and global warming contributions. Waste Manage Res 27:800-812

Buratti C, Fantozzi F (2010) Life cycle assessment of biomass production: Development of a methodology to improve the environmental indicators and testing with fiber sorghum energy crop. Biomass Bioenergy 34:1513-1522

Charles R, Jolliet O, Gaillard G (1998) Taking into account quality in the definition of functional unit and influence on the environmental optimisation of fertiliser level. In: Ceuterick D (ed) International Conference on Life Cycle Assessment in Agriculture, Agro-Industry and Forestry, Proceedings, 3–4 December 1998. VITO, Brussels, pp 11-16

Cluzeau D, Guernion M, Chaussod R, Martin-Laurent F, Villenave C, Cortet J, Ruiz-Camacho N, et al. (2012). Integration of biodiversity in soil quality monitoring: Baselines for microbial and soil fauna parameters for different land-use types. Eur J Soil Biol 49:63-72

Colón J, Cadena E, Pognani M, Barrena R, Sánchez A, Font X, Artola A (2012) Determination of the energy and environmental burdens associated with the biological treatment of source-separated Municipal Solid Wastes. Energy Environ Sci 5(2): 5731-5741

Cowell SJ, Clift R (2000) A methodology for assessing soil quantity and quality in life cycle assessment. J Clean Prod 8:321-331

De Bertoldi M (2010) Production and Utilization of Suppressive Compost: Environmental, Food and Health Benefits. In: Insam H, Franke-Whittle I, Goberna M (eds) Microbes at Work: From Wastes to Resources Springer, Heidelberg, Germany, pp 153-170

Diacono M, Montemurro F (2010) Long-term effects of organic amendments on soil fertility. A review. Agronomy Sustainable Development 30:401-422

European Commission (2006) Impact Assessment of the Thematic Strategy on Soil SEC (2006) 620

Favoino E, Hogg D (2008) The potential role of compost in reducing greenhouse gases. Waste Manage Res 26:61-69.

Goedkoop M, Heijungs R, Huijbregts M, Schryver AD, Struijs J, van Zelm R. 2009. ReCiPe 2008. A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. PRé Consultants BV, Amersfoort, the Netherlands.

Guinée JB, Gorrée M, Heijungs R, Huppes G, Kleijn R, Koning A, Oers L, Wegener Sleeswijk A, Suh S, Udo de Haes HA, Bruijn H, Duin R, Huijbregts MAJ (2002) Handbook on life cycle assessment. Operational guide to the ISO standards. I: LCA in perspective. IIa: Guide. IIb: Operational annex. III: Scientific background. Kluwer Academic Publishers, Dordrecht

Hansen TL, Bhander GS, Christensen TH, Bruun S, Jensen LS (2006) Life cycle modeling of environmental impacts of application of processed organic municipal solid waste on agricultural land (EASEWASTE). Waste Manage Res 24:153-166

Hargreaves J, Adl M, Warman P (2008) A review of the use of composted municipal solid waste in agriculture. Agric Ecosyst Environ 123:1-14

ICF Consulting (2005) Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions: 2005 Update Final Report

Köllner T (2002) Land use in product life cycles and its consequences for ecosystem quality. Int J Life Cycle Assess 7:130-130

Martínez-Blanco J, Antón A, Rieradevall J, Castellari M, Muñoz P (2011) Comparing nutritional value and yield as functional units in the environmental assessment of horticultural production with organic or mineral fertilization. Int J Life Cycle Assess 16:12-26

Martínez-Blanco J, Colón J, Gabarrell X, Font X, Sánchez A, Artola A, Rieradevall J (2010) The use of life cycle assessment for the comparison of biowaste composting at home and full scale. Waste Manage 30:983-994

Martínez-Blanco J, Lazcano C, Boldrin A, Muñoz P, Rieradevall J, Möller J, Antón A, Christensen TH (2013) Assessing the environmental benefits of compost use-on-land through an LCA perspective: a review. Sustainable Agriculture Reviews 12

Mattsson B, Cederberg C, Blix L (2000) Agricultural land use in life cycle assessment (LCA): case studies of three vegetable oil crops. J Clean Prod 8:283-292

McLaughlin N, Gregorich E, Dwyer L, Ma B (2002) Effect of organic and inorganic soil nitrogen amendments on mouldboard plow draft. Soil Tillage Res 64:211-219

Milà i Canals L, Dubreuil A, Gaillard G, Müller-Wenk R (2007) Key Elements in a Framework for Land Use Impact Assessment Within LCA. Int J Life Cycle Assess 12:5-15

Nemecek T, Dubois D, Huguenin-Elie O, Gaillard G (2011) Life cycle assessment of Swiss farming systems: I. Integrated and organic farming. Agric Syst 104:217-232

Núñez M, Antón A, Muñoz P, Rieradevall J (2013) Inclusion of soil erosion impacts in life cycle assessment on a global scale: application to energy crops grown in Spain. Int J Life Cycle Assess 18(4): 755-767

Núñez M, Pfister S, Antón A, Muñoz P, Hellweg S, Koehler A, Rieradevall J (2013) Assessing the environmental impacts of water consumption by energy crops grown in Spain. J Industrial Ecology 1: 90-102

ROU (2007) Life Cycle Inventory and Life Cycle Assessment for Windrow Composting Systems. NSW Department of Environment and Conservation. The University of New South Wales, Sydney, Australia

Schau EM, Fet AM (2008) LCA studies of food products as background for environmental product declarations. Int J Life Cycle Assess 13:255-264

Sikora LJ, Szmidt R (2004) Chapter 14: Nitrogen Sources, Mineralization Rates, and Nitrogen Nutrition Benefits to Plants from Composts. In: Stoffella PJ, Kahn BA (eds) Compost utilization in horticultural cropping systems CRC Press Lewis Publ, New York, pp 287-305

Suer P, Andersson-Sköld Y (2011) Biofuel or excavation?-Life cycle assessment (LCA) of soil remediation options. Biomass Bioenergy 35:969-981

Thamsiriroj T, Murphy J (2010) Difficulties associated with monodigestion of grass as exemplified by commissioning a pilot-scale digester. Energy Fuels 24:4459-4469

Weidema BP, Lindeijer E (2001) Physical impacts of land use in product life cycle assessment. Final report of the EURENVIRON-LCAGAPS sub-project on land use. Department of Manufacturing Engineering and Management, Technical University of Denmark, Lyngby

Zhang Y, Baral A, Bakshi BR (2010) Accounting for ecosystem services in life cycle assessment, Part II: Toward an ecologically based LCA. Environ Sci Technol 44:2624-263

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