Life cycle environmental impacts of source-separated and slurry-based cow manure systems

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Abstract
Different manure management systems result in different manure types. When faeces, urine and barn waters are mixed together, slurry is formed. When faeces (+bedding) and urine are collected separately and without barn waters, solid manure and urine are produced. Different manures are collected, stored and utilised in different ways thus resulting in different environmental impacts. In this study, the life cycle environmental impacts of source-separated and slurry-based manure management systems were compared for dairy cows. Also the costs and energy content as biogas were estimated. In nearly all impact categories considered, slurry had less harmful impacts on the environment and its cost was only two thirds of source separation. Moreover, the energy content of slurry can easily be utilised as biogas. The most emissions from slurry were produced in field processes after application, while with source separation the storage of faeces was the environmentally weakest point.

Introduction
Depending on the animal housing system, faeces and urine from cattle may be kept separate (i.e. source separation) or mixed together to form slurry. In a slurry system, all washing waters and spillage from drinking are directed into the mix of urine and faeces and the amount of bedding used is minimal. In a source-separation system, urine is collected separately, washing waters are mostly kept separate and the bedding material ending up in faeces is higher.

In general, 40% of nitrogen (N) and 95% of phosphorus (P) from cows is excreted into faeces, while the rest end up in urine. Thus, urine contains mostly soluble N and little P and faeces is P-rich with mostly organic N. While slurry contains all nutrients in one mix, source separation is assumed to enable more efficient nutrient management due to the ability to utilise either N-rich urine or P-rich faeces in fertilising according to need. On the other hand, source separation results in having to build two different storages: one for urine and the other for faeces. It is also often seen more laborious as compared to the slurry system. Both housing systems may result in emissions to air, water and soil and different measures, such as quick collection and covered storages should be taken to minimise them.

In this abstract, the environmental impacts of two manure management systems for dairy cows, namely source separation (SS) and slurry (S), are compared using life cycle assessment (LCA). Special attention is given to eutrophication, climate impacts and the economy of the systems. Additionally, manure energy production potential as biogas is considered.

Material and Methods
Life cycle assessment
The environmental impact assessment was based on LCA [1,2,3,4], used to evaluate the environmental implications of manufactured products or services and environmental performance of management systems (e.g. regional waste management alternatives; [5]) during their entire life cycle. Consequential LCA [6,7,2] is used to recognise the most important direct and indirect implications as a result of changes in the system studied, and to take all those consequences into account when assessing the changes in environmental and other impacts. In this study, consequential LCA was applied.

System boundaries of the two manure management chains were similar, i.e. they included all relevant life cycle phases needed for manure handling, starting from manure excretion and ending to manure application on field. The emissions after application were also considered. For all life cycle phases, inventory data was collected on energy use (GJ), emissions to waters (kg of N and P) and emissions to the atmosphere (kg of NH_3, N_2O, CH_4, CO_2, oxides of N and S). The functional unit of the study was one ton of manure ex animal, i.e. one ton of excreted manure (faeces+urine). Gaseous emissions were based on commonly used emission factors and calculation guidelines, e.g. of IPCC. Characterised impact assessment results, based on the EDIP 2003 method [8], are presented for the impact categories of climate change, terrestrial eutrophication, acidification and aquatic N and P eutrophication.

The effect of manure use on nutrient transport from fields was calculated for Loimijoki river basin (FI) by modelling the transport in a base case and according to different scenarios. N transport was modelled with a dynamic catchment scale model INCA-N [9,10]. P transport modelling was based on P balance and soil soluble P concentration of the fields [11]. Effect of volatilisation was removed from total N. The base scenario included the fertilisation requirements of the Finnish agri-environmental programme and the Nitrate Directive. Manure was assumed to be applied on spring cereals and grasses assuming maximum allowed amount in autumn and the rest in spring. Of total P, soluble N and organic N in manure, 85%, 100% and 10% were respectively assumed to be available for plants. Additional mineral fertiliser was assumed, if manure was not sufficient to achieve the allowed fertilisation. In the study area, the average fertilisation level of P was 10.6 kg/ha.

Economical assessment

The economy of a barn with 120 dairy cows was estimated for both S and SS systems. The amount of slurry produced was assumed to be 2880 m^3/a (24 m^3/cow/a), while with SS, 1140 m^3/a of faeces and 960 m^3/a of urine were produced (faeces 9.5 m^3/cow/a, urine 8 m^3/cow/a). The cost for the required storages was 17 €/m^3 for slurry and urine and 23 €/m^3 for faeces. All storages (life-span 20 a) were assumed to be covered (slurry: floating cover 20 €/m^2, urine: fixed cover 50 €/m^2, faeces: fixed cover and walls 60 €/m^2). Contracted application on field cost 2.1 €/m^3 for slurry and urine and 2.3 €/m^3 for faeces. The farms in both manure systems were assumed to consume 35 000 kWh/a of electricity and the price of electricity was 8.58 cnt/kWh (average for years 2001-2011; Finnish Energy Market Authority). S and SS were estimated to consume 275 and 284 kWh/cow/a, respectively (including transport of manure from barn to storage, slurry mixing, pumping/loading manure to application machinery, 3 km transport from storage to fields, application on fields).

Manure energy potential

Manure energy production potential was estimated as biogas for 120 dairy cows with the same assumptions for manure amounts as with the economical assessment. Dairy cow slurry and solid manure (faeces) were assumed to hold an average biological methane potential of 15 and 40 m^3CH_4/ton of fresh material, respectively. Urine was neglected due to containing little organic matter. The energy content of one m^3 of methane was assumed to be 10 kWh.

Results

Life cycle assessment

The life cycle environmental impacts calculated for the two dairy cattle manure management systems are presented as relative figures, i.e. S has a value of "1" and the value of SS is scaled to this (Table 1). SS had a significantly higher impact value in the impact category of "Climate change" than S. The reason was high CH_4 and N_2O emissions from solid manure (faeces) during housing and storing.

Avoided use of mineral fertilisers always resulted in a negative impact due to avoided environmental consequences during their manufacturing, application and field processes. The higher the avoided use of mineral fertilisers was, the higher the negative environmental impact value (credits). S was found to have higher credit values in all other impact categories than in "Aquatic P eutrophication". This was due to higher NH_3 emissions in SS resulting in decreased fertilising value of the manure and thus increased need for mineral N-fertilisers. In "Aquatic P eutrophication", the high emission credits were due to avoided use of mineral fertilisers and subsequent avoidance of emissions in mineral P production. Simultaneously no differences between the two systems were shown as the P content of manure ex animal and P runoff from the fields were similar in both.

SS had somewhat higher impact values in the impact categories of "Terrestrial eutrophication" and "Acidification" as compared to S. This was due to the high NH_3 emissions from storing the solid manure (faeces), not compensated for even with the subsequent lower emissions after application. High NH_3 emissions from storage were caused by spontaneous composting resulting in favourable conditions for N evaporation [12]. NH_3 emissions after solid manure application were relatively low compared to slurry due to the relatively low concentration of NH_4-N in solid manure. On the other hand, low NH_4-N content in solid manure potentially resulted in relatively low N runoff from the field after application as seen from the results of "Aquatic N eutrophication". However, the impact of organic N on N leaching is poorly understood and thus the result may be misleading.

Compared to S, SS had a higher potential for efficient utilisation of manure nutrients due to the possibility to use the N-rich urine and the P-rich faeces on different fields. In both systems and especially in SS, N and P leaching from the fields can be reduced by optimising the timing and dosing of manure application. However, no quantitative estimates about this were made in the present study.

Table 1. Characterised environmental impact values of two manure management systems (slurry S and source separation SS) presented as relative values (S=1). Values are comparable between the two manure management systems within impact categories but not between them.

	Climate		Acidification		Terr-eutr.		Aq-eutr. N		Aq-eutr. P	
	S	SS	S	SS	S	SS	S	SS	S	SS
Animal house	0.33	1.36	0.44	0.46	0.42	0.44	0.16	0.17	0.00	0.00
Outdoor storage	0.69	3.75	0.15	0.89	0.14	0.85	0.06	0.33	0.00	0.00
Transport & Application	0.06	0.07	0.01	0.01	0.00	0.01	0.00	0.00	0.02	0.02
Field processes	0.50	0.66	0.51	0.17	0.49	0.16	0.97	0.58	0.24	0.24
Avoidance of mineral fertilisers	-0.58	-0.40	-0.11	-0.08	-0.05	-0.03	-0.19	-0.12	-1.26	-1.26
Total	1.00	5.44	1.00	1.45	1.00	1.43	1.00	0.97	-1.00	-1.00

Economical assessment

When considering energy consumption, storage and contracting of field application in the two manure management systems, the costs for S were significantly smaller. Per cow, the cost was calculated to be 96 €/a when using S, while the cost for SS became 289 €/a. In a dairy farm of 120 animals considered, the resulting annual total costs are thus 11 571 € and 34 635 €, respectively.

Energy potential as biogas

The energy potential of manure from 120 dairy cows was estimated as biogas. Theoretically, 43 200 m^3 of methane could be annually produced with S and 45 030 m^3 with SS. As energy, these translate to 432 MWh/a and 450 MWh/a, respectively. If the combined heat power (CHP) engine assumed had an electrical efficiency of 38% and a thermal efficiency of 55%, the respective energy potentials translate to annual production of 164 MWh and 171 MWh as electricity and 238 MWh and 248 MWh as heat.

Even though the energy potentials of slurry and solid manure (faeces) differ only slightly, their different characteristics (esp. dry matter (DM) content) result in different technical requirements for the biogas plant. While slurry (DM 6-10%) digestion is a mature, well-known and easily-available technology, solutions for digestion of solid manure (DM >20%) are scarce, inefficient and under-developed. In order to harness the energy content of source-separated faeces is most likely either impossible or inefficient until more effective and reliable technologies are available or solid manure should be co-digested with e.g. slurry.

Conclusion and perspectives

The LCA of the two alternative manure management systems for dairy cows, i.e. slurry (S) and source separation (SS) showed that S had less environmental impacts in nearly all parts of the manure management chain. Its climatic, acidifying and terrestrially eutrophying impacts were smaller than those of SS. S also resulted in more avoidance of mineral fertilisers. With aquatic P eutrophication, the two systems did not differ. The total result for also aquatic N eutrophication was nearly the same, but the emissions happened in different stages of the management chains (S: field processes after application, SS: storage). Still, compared to S, SS has a higher potential for efficient utilisation of manure nutrients due to the possibility to use the N-rich urine and the P-rich faeces on different fields. From the economical perspective, S cost 67% less than SS. The manure energy content of both S and SS as biogas was nearly the same, but reliable technical solutions are only available for digestion of slurry. The lack of digestion technology for solid manure also translates to emissions from the two manure types. While the whole slurry chain can be built to minimise emissions (incl. quick collection and feed into digester, post-digestion, covered storages, injection into soil), similarly efficient solutions are not available for solid manure. Available plant designs usually result in only partially degraded solid manure and have no post-digestion to collect the methane produced after the digester.

In conclusion, slurry-based manure management may be environmentally, economically and energetically more beneficial for dairy farms than source separation of manure. However, with optimisation of the SS chain, including e.g. prevention of spontaneous composting during storage, its environmental impacts can be decreased.

References

[1] EC, 2010. ILCD Handbook: General guide for Life Cycle Assessment - Detailed guidance. 1st ed. European Commission, Joint Research Centre, Institute for Environment and Sustainability

[2] Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh S. 2009. Recent developments in Life Cycle Assessment. Journal of Environmental Management 91, 1–21

[3] ISO (International Organization for Standardization), 2006a. ISO 14040. Environmental management. Life cycle assessment. Principles and framework. International Organization for Standardization, Brussels

[4] ISO (International Organization for Standardization), 2006b. ISO 14044. Environmental management. Life cycle assessment. Requirements and guidelines. International Organization for Standardization, Brussels

[5] Grönroos J, Myllymaa T, Kuisma M, Havukainen J, Luostarinen S, Kahiluoto H, 2013. Environmental sustainability of alternative regional management systems of organic wastes and by-products. Manuscript

[6] Ekvall T, Weidema BP, 2004. System boundaries and input data in consequential life cycle inventory analysis. The International Journal of Life Cycle Assessment 9(3), 161-171

[7] Kløverpris J, Wenzel H, Nielsen PH, 2007. Life cycle cnventory modelling of land use induced by crop consumption. Part 1: Conceptual analysis and methodological proposal. The International Journal of Life Cycle Assessment 13(1), 13–21

[8] Hauschild M, Potting J, 2005. Spatial differentiation in life cycle impact assessment – The EDIP 2003 methodology. Environmental news no. 80, Danish Ministry of the Environment, Environmental Protection Agency, Copenhagen, Denmark

[9] Wade A, Durand P, Beaujoan V, Wessels W, Raat K, Whitehead PG, Butterfield D, Rankinen K, Lepistö A, 2002. Towards a generic nitrogen model of European ecosystems: New model structure and equations. Hydrology and Earth System Sciences 6, 559-582

[10] Whitehead PG, Wilson EJ, Butterfield D, 1998. A semi-distribution Integrated Nitrogen model for multiple source assessment in Catchments (INCA): Part I – Model structure and process equations. The Science of the Total Environment 210/211, 547-558

[11] Ekholm P, Turtola E, Grönroos J, Seuri P, Ylivainio K, 2005. Phosphorus loss from different farming systems estimated from soil surface phosphorus balance. Agriculture, Ecosystems and Environment 110, 266-278

[12] Amon B, Amon Th, Boxberger J, 1998. Untersuchungen der Ammoniakemissionen in der Landwirtschaft Österreichs zur Ermittlung der Reduktionspotentiale und Reduktionsmöglichkeiten. Final report. Forschungsprojekt Nr. L 883/94 im Auftrag des Bundesministeriums für Land- und Forstwirtschaft. Universität für Bodenkultur, Institut für Land-, Umwelt- und Energietechnik, Wien. 311 p