A method to handle emissions related to manure production in LCAs with an example from a steer production system

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ABSTRACT

Different methods have been used in LCAs to handle emissions related to livestock manure. Usually, the emissions from use of manure are attributed to the crop production. In this study, an alternative approach is suggested where manure is considered as a co-product from the livestock production. With this approach, the livestock production system 'pays' all environmental costs related to emissions from manure. However, the livestock system also gets credit for the fertilizer value of the manure corresponding to the amount of artificial fertiliser nitrogen that the farmer would otherwise have applied. As an example of using this approach, carbon footprint was calculated from four Danish steer production systems that only differ in housing system/type of manure produced. The steer production systems were: '100% outdoor/grazing', '100% indoor/deep litter', '100% indoor/slurry', or a mix as in the 'real system' from Danish herds.

Keywords: Carbon footprint, LCA methodology, Livestock manure production, Soil carbon changes,

1. Introduction

Different methods have been used in LCAs to handle emissions related to livestock manure, where the emissions from manure have been attributed to either crop production or livestock production. Usually, the emissions from the use of manure are attributed to crop production (van Zeijts et al., 1999). However, Dalgaard and Halberg (2007) suggested that the environmental burden of using manure should be considering as a co-product from the livestock production. This means that the livestock production system 'pays' all environmental costs related to emissions from manure. However, the livestock system also gets credit for the fertilizer value of the manure. This is also reflected in a new guideline from EU on methods for calculating the life cycle environmental performance of products (EU, 2013). The EU guideline suggests that when manure nitrogen is applied to agricultural land and directly substitutes an equivalent amount of the specific fertiliser nitrogen that the farmer would otherwise have applied, the animal husbandry system from which the manure is derived should be credited for the displaced fertiliser production (taking into account differences in transportation, handling, and emissions) (EU, 2013). The substitution rate of 'kg fertilizer N' per 'kg N in manure ex animal' is assumed to follow the Danish legislation (Anonymous, 2010).

The aim of the present study was to illustrate how an alternative approach, where manure is seen as a co-product from the livestock production, can be used to calculate environmental costs related to emissions from manure. This was illustrated by an example, where carbon footprint was calculated from four Danish steer production systems that only differ in housing system/type of manure produced.

2. Methods

To illustrate the suggested approach for including emissions related to manure production, carbon footprint was calculated from four Danish steer production systems that only differ in housing system and type of manure produced. The steer production systems were: 'a real system (1)' as found in private herds '100% outdoor/ grazing (2)', '100% indoor/deep litter (3)', and '100% indoor/slurry (4)'. In the 'real system' (data based on Nielsen, 2003), the steers were grazing for 143 days per year at semi-natural pasture resulting in a daily gain of 550 g. During winter, the youngest steers were housed at deep litter and afterwards in a slurry-based system and the feeding was based on grass clover silage and limited amount of concentrate, resulting in a growth rate of 900 g/d. For the last 45 days the steers were fed more intensively with more concentrate and were gaining 1,100 g/d before slaughtering at 25.4 months of age.

In the system ‘100% outdoor/ grazing’, all manure was deposited at pasture. The system was similar to the ‘real system’, except that it was assumed that the steers were outdoor continuously, though feeding was similar to that in the ‘real system’. In the ‘100% indoor systems’, the steers were housed indoor and produced manure was either ‘deep litter’ or ‘slurry’. Intake of fresh pasture was replaced by the same amount of energy from grass clover silage. Table 1 present the most important input and output from the steer production system. Smaller changes in the steer production exist due to the different housing/manure systems. These are mentioned in the footnotes of Table 1.

According to the new approach, manure is considered a co-product from the livestock system, in this case the steer production system. A process was defined for each of the three types of housing/manure production: ‘slurry’, ‘deep litter’, ‘manure deposit at pasture’. A carbon footprint was calculated for each of the three types of housing/manure with a functional unit (FU) of ‘100 kg manure N ex animal’ according to the method by Mogensen et al. (2014). In other words, the GHG emissions from ‘100 kg manure N ex animal’ from different housing/manure systems was calculated. It was taken into account both the direct emissions from manure, but also that manure cause C and N sequestration, and therefore less leaching, and avoided fertilizer production. Manure N ex animal was calculated as N in animal feed minus N in gain (Nielsen & Kristensen, 2005).

The results of these three housing/manure production process were used in calculating carbon footprint of the four steer production systems, where FU was 1 kg carcass at farm gate. With the new approach, the steer production systems were treated as’ landless systems’ i.e. GHG contribution from feed production and livestock production was calculated independent of each other. Crops were assumed imported to the farm and grown with use of artificial fertilizer. However, this contribution was offset to a certain degree by including the fertilizer value of the co-product manure. For each of the feedstuff used (see Table 1), a carbon footprint was calculated according to the method by Mogensen et al. (2014).

GHG emissions from soil carbon changes were calculated as suggested by Petersen et al. (2013). The approach by Petersen et al. (2013) is based on a single year’s addition of C (from crop residues, etc.) and the associated effect on atmospheric CO_2. Petersen et al. (2013) estimated that 10% of the C added to the soil will be sequestered in a 100-year perspective. The input of carbon to soil C was based on the input of above- and below-ground crop residues. In the present study, contribution to soil C changes was divided into the contribution from C input from crop residues and the contribution coming from C input from different types of manure.

Table 1. Input and output in the steer production system.

Per produced steer	
Input of a dairy calf (30 days), kg live weight	55
Input of feed, kg DM	
- Grass clover silage	1,690
- Straw	220
- Barley	360
- Rapeseed cake	80
- Grazing 1)	1,440
- Milk powder	20
Total feed, kg DM	3,820
Straw for bedding, kg 2)	1,160
Output of a steer, kg live weight	574
- Kg carcass	293

1) Grazing was used in steer system 1 and 2. In system 3 and 4 grass grazed was replaced by same amount of energy from grass clover silage

2) Amount of straw used in steer system 1, in system 2 and 3 with slatted floor and slurry produced no straw was used at all, and in system 4 2,482 kg straw per produced steer was used

Indirect land use change (iLUC) was calculated according to Audsley et al. (2009) where all use of land for crop production is assumed to increase the pressure on land use and thus causing land use change somewhere in the world. The indirect land use change causes a release of 8.5 Gt CO_2-eq per year, to which agriculture contributes 58%. This gives a contribution of 1.43 t CO_2-eq per ha when divided by the total agricultural area of 3,475 Mha (Audsley et al., 2009). In the present study, iLUC was included by multiplying land use (m^2/kg DM feed) by the iLUC factor of 143 g CO_2-eq /m^2.

3. Results and discussion

Table 2 shows the overall effect on GHG emissions of three different ways of housing/manure production; as ‘slurry’, ‘deep litter’, or as ‘manure deposit at pasture’. This overall effect of manure takes into account both the emissions from manure and the benefit from the avoided fertilized production. Contribution to GHG emission from direct and indirect emissions of N_2O and NH_3 from manure from housing, storage and application varied from 1,171 kg CO_2-eq per ‘100 kg N ex animal in a slurry-based system’ to 1,569 kg CO_2-eq per ’100 kg N ex animal in a deep litter-based system’.

Table 2. Greenhouse gas (GHG) emission from three different housing/manure systems, FU = 100 kg N ex-animal (Mod. after Mogensen et al., 2014)

Manure system [1]	**Deposit at pasture**	**Slurry**	**Deep litter**
Housing System	Outdoor	Indoor	Indoor
Emissions from manure:			
N_2O-N direct, kg [2]			
-housing	0	0.2	1.0
-storage	0	0.5	0.5
-application	2.0	1.0	1.0
NH_3-N, kg [3]			
-housing	0	8.0	15.0
-storage	0	2.2	25.0
-application	7.0	12.0	6.0
N_2O-N indirect, kg [2]			
-from NH_3-N	0.07	0.22	0.46
-from leaching [4]	0.68	0.58	0.39
Total GHG from emissions, kg CO_2-eq	**1,288**	**1,171**	**1,569**
C sequestration from manure			
N input to soil after losses, kg N [5]	90	75	58
Related C input to soil, kg C [6]	939	783	1,581
Soil C remaining in soil, kg soil C [7]	94	78	158
Total GHG from C sequestration, kg CO_2-eq [8]	**-344**	**-287**	**-579**
N from manure stored in soil and reduced leaching [9]			
N stored in soil, kg N	9.4	7.8	15.8
Saved indirect N_2O emissions, kg N_2O-N	0.07	0.06	0.12
Total GHG from avoided leaching, kg CO_2-eq	**-21**	**-17**	**-55**
Total GHG emissions from manure, kg CO_2-eq	**923**	**867**	**935**
Avoided fertilizer production:			
Fertilizer value of manure			
N, kg [10]	70	70	45
P, kg [10]	14	14	20
K, kg [10]	91	91	137
GHG from avoided fertilizer prod., kg CO_2-eq			
- N [11]	-298	-298	-191
- P [12]	-67	-67	-93
- K [13]	-54	-54	-82
GHG from avoided fertilizer prod., kg CO_2-eq	**-418**	**-418**	**-366**
Avoided emission from fertilizer			
N_2O-N_{direct}, kg from spreading [2]	0.7	0.7	0.45
NH_3-N, kg from spreading [3]	1.54	1.54	0.99
N_2O-$N_{indirect}$, kg from NH3 and leaching	0.53	0.53	0.34
GHG from avoided fertilizer emission, kg CO_2-eq	**-574**	**-574**	**-370**
Total GHG from avoided fertilizer	**-992**	**-992**	**-736**
Total GHG from 100 kg N in manure (ex animal) , kg CO_2-eq [14]	**-69**	**-125**	**199**

1) CF from import of straw is not included in this calculation
2) Calculated according to IPCC, 2006
3) Calculated according to Mikkelsen et al., 2006
4) Leaching (NO_3-N) calculated as input minus other emission
5) Input to soil is the ‘100 kg N ex animal’ minus all losses.

6) In the deep litter system there is an extra N input from N content in straw. C:N in manure deposited at pasture and in slurry 8:1 (Wesnæs et al., 2009) and C:N in deep litter of 21:1 (Osda et al., 2001) both multiplied by a factor of 1.3 (Petersen, B pers comm., 2013)
7) According to the model by Petersen et al. (2013)
8) From C to CO_2 by factor multiplication 44/12
9) Per 10 kg C stored in soil, 1 kg N is stored in soil (Sundberg et al., 1999)
10) Anonymous, 2010
11) CF of N in fertilizer: 4,25 kg CO_2/kg N (Elsgaard, 2010)
12) CF of P in fertilizer: 4,63 kg CO_2/kg P (Ecoinvent, 2010)
13) CF of K in fertilizer: 0,596 kg CO_2/kg K (Ecoinvent, 2010)
14) Taking into account both the emissions from use of manure and the saved fertilized production

Table 3. Greenhouse gas (GHG) emission of animal feed, CO_2 g/kg DM feed (modified after Mogensen et al., 2014)

	Barley	**Barley Straw**	**Rape seed cake**	**Grass clover silage**	**Grass clover grazed**
Contribution to CF					
- Growing	484	49	390	404	453
- Processing	11	1	28	0	0
- Transport	18	18	75	0	0
Total CF	**512**	**68**	**494**	**404**	**453**
C sequestration [1)]	86	8	-44	-61	-226
LUC	328	33	182	173	202
CF including soil C and LUC	**926**	**109**	**632**	**516**	**429**

1) For grazed crops contribution from C input from manure deposited is included in soil C changed.

Carbon footprint per kg carcass weight is shown in Table 4 for the four Danish steer production systems that only differ in housing/manure system. GHG from manure was calculated based on the values (Table 2) per '100 kg N ex animal' corrected to actual amount of N ex animal in each steer production system and taking into account the distribution between the different housing/manure systems. Before including contribution from soil C and iLUC, CF per kg carcass was estimated to 16.6 kg CO_2/kg carcass in the 'real steer system', where the steers are grazing during summer and housed indoor during winter, i.e. manure system include a mixture of manure deposited at pasture, as slurry and as deep litter. Similar level of CF per kg carcass was estimated for the '100% outdoor system'. Here the steers are outdoor all year, but fed the same way, i.e. same contribution to CF from feed production. Lower emissions from manure from stable and storage in system 2, and lower CH_4 from manure deposited at pasture compared with as slurry was counterbalanced by less credit from substitution of fertilizer. CF per kg carcass was higher in steer system 3 with manure handled as deep litter compared with system 1 and 2. This was mainly due to higher contribution from enteric fermentation as the digestibility of grass clover silage is lower than that of fresh grass clover, which increases methane emission. Beside that there was a higher GHG contribution from production of straw for bedding. Before taking into account contribution from soil C and iLUC, steer system 4 has the lowest CF per kg carcass of all systems, even though GHG from enteric fermentation was at the same high level as in system 3, but total GHG from manure handling was lowest in the slurry-based system.

However, if GHG contribution from changes in soil carbon due to input to soil C from crop residues ('soil C from feed') and C from manure ('soil C from manure'), steer system 1 'the real steer system' has the lowest CF/kg carcass weight. Steer systems 4 and 2 have almost similar CF and system 3; the 'deep litter system' has the highest CF per kg meat even though manure as deep litter has a huge positive effect due to soil C sequestration. Including contribution from LUC did not change the ranking of the four steer production systems.

Table 4. Carbon footprint (CF) in four steer production systems that only differ in the way of housing/type of manure, CO_2 kg/kg carcass

Steer system	**1** **The real system**	**2** **100% outdoor**	**3** **100% indoor Deep litter**	**4** **100% indoor Slurry**
N in feed, kg N [4]	117	117	107	107
N in gain, kg N	14	14	14	14
N ex animal, kg N	103	103	93	93
Manure system, % of N ex animal				
- deposited at pasture	**39**	**100**	**0**	**0**
- slurry	**15**	**0**	**0**	**100**
- deep litter	**45**	**0**	**100**	**0**
GHG from feed production, kg CO_2/kg carcass				
- growing, processing, transport	6.1	6.1	6.3	6.3
- soil C	-1.4	-1.4	-0.6	-0.6
Total GHG from feed, kg CO_2	4.7	4.7	5.7	5.7
GHG from manure, kg CO_2				
- Emissions	3.4	2.8	4.1	2.4
- Saved fertilizer production [2]	-1.0	-0.7	-0.6	-1.1
- Effect on soil C	-1.3	-0.8	-2.5	-1.0
Total GHG from manure	1.1	1.3	1.0	0.3
GHG from CH4 enteric, kg CO_2/kg carcass	7.2	7.2	7.7	7.7
GHG from input of calf	0.6	0.6	0.6	0.6
Others, straw, minerals [3]	0.3	0.1	0.6	0.1
CF, kg CO_2/kg Carcass	**16.6**	**16.6**	**18.6**	**15.9**
CF incl. soil C from feed, kg CO_2 [1]	15.2	15.2	18.0	15.3
CF incl. soil C from feed and manure kg CO_2	13.9	14.4	15.5	14.3
CF incl. soil C and LUC	**16.4**	**16.9**	**18.0**	**16.8**

1) For grazed crops contribution from C input from manure deposited is included in soil C change of the crop 'grazed grass'.
2) In system 2 only 50% of manure deposited at pasture is assumed utilized for grass production, for the other 50% no fertilizer value was assumed, however this manure contribute to soil C input (included in 'GHG from manure'
3) No straw was used in system 2,
4) In system 3 and 4 intake of pasture is replaced by same energy form intake of grass clover silage, which lower N intake

5. Conclusion

The present paper has illustrated an approach, where the environmental burden of manure could be handled by considering it as a co-product from the livestock production. That means that the livestock production system 'pays' all environmental costs related to emissions from manure, and on the other hand that the livestock system also gets credit for the fertilizer value of the produced manure. Thereby, the calculated carbon footprint of feed crops is independent by use of manure or not.

The total GHG emissions from three types of manure when taking into account both the emissions from manure handling, the positive effect of soil C sequestration and reduced N leaching due to use of manure and the benefit from the avoided fertilized production, was investigated. Production and use of manure as either slurry or deposited at pasture generated a positive effect for the environment compared with use of fertilizer, whereas the opposite was seen for producing and use of manure in a deep litter system. It was found that the total GHG emission from using manure in term of 'slurry' will cause a reduction in GHG emission of 125 kg CO_2-eq per 100 kg N ex animal. Similar, the overall effect was a saved GHG emission of 69 kg CO_2-eq/100 kg N ex animal if manure was deposited at pasture. Whereas there was an overall GHG release of 199 kg CO_2-eq per 100 kg N ex animal as deep litter. There estimates are under the assumption that the manure was used in a way that it will be utilized to substitute use of fertilizer. Due to that, carbon footprint of identical steer production system that only differ in the type of housing/manure system, came out with a lower CF in a steer production systems, where the type of manure was 'slurry' or 'deposited at pasture' compared with CF of a steer production system on deep litter.

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