Integrated assessment of manure transport induced by European environmental regulations: a life cycle approach for liquid pig manure in Germany

Kuhn, T. [1], Kokemohr, L. [1]

[1] Institute of Food and Resource Economics, Bonn University, Nußallee 21, 53115 Bonn, Germany, www.ilr.uni-bonn.de, till.kuhn@ilr.uni-bonn.de

Abstract
Concentration of livestock production at the farm and regional level decouples nutrient cycles between animal and plant production. Export of excess manure from livestock to crop farming systems closes cycles without structural change of the production system. In the EU, manure transport is triggered by command and control regulations under EU environmental law. We apply a life cycle approach to assess the environmental impact of raw liquid pig manure transport in northwest Germany. Transport is caused by the proposed revision of the German National Action program implementing the EU Nitrates directive. Results indicate that manure transport decreased NH_3, N_2O, NO_x, NO_3 emissions and P surplus compared to a baseline without transport. Reduction of GHG emissions from replaced mineral fertilizer outweighed transport emissions. When exporting farms do not need to replace exported organic nutrients with mineral fertilizer, there is even a reduction in GHG emissions. Despite emission reductions in total, manure importing farms increased NH_3 and NO_3 losses, caused by higher emissions from manure application and lower efficiency of organic N compared to mineral fertilizers. Results illustrate the potential of manure transport as a short-term solution to reduce environmental burdens caused by livestock concentration. However, additional regulations are needed to prevent negative impacts of regional pollution swapping.

Key Words
liquid manure transport, life cycle assessment, pollution swapping, EU Nitrates directive

Introduction
In several European countries, intensive livestock production is highly spatially concentrated, enabled by feed import and leading to uncoupled nutrient cycles. Regions with high stocking rates are characterized by high nitrogen (N) and phosphate (P) inputs and losses. N and P entering the environment pose a threat to air and water quality, biodiversity and climate. In the EU, the Water Framework directive 2000/60/EC and Nitrates directive 91/676/EEC is the key legislation regulating P and nitrate (NO_3) emissions from agriculture, but impacting also on other forms of reactive N. In Germany, the Nitrates directive is mainly implemented by the German fertilizer directive (FD). Livestock production with high nutrient surpluses need to adapt most to meet existing regulations. Pig and poultry production are more characterized by imbalanced nutrient cycles than cattle production that commonly produces high shares of forage on-farm. In Germany, pig production is focused in the northwest, mainly in Lower Saxony and North Rhine-Westphalia. In this area, high amounts of manure is already transported between farms under current legal framework, e.g. in Lower Saxony around 34 m t in 2014/15 (LWK 2016; including digestates from biogas production, double accounting possible). The FD is currently under revision and will most likely come in force in spring 2017. Recent government drafts (BMEL 2015) and political discussion suggested considerable tightening of regulations. Consequently, a further increase of manure transport is likely and an assessment of its environmental impact is of recent importance.

Several life cycle assessments (LCA) focus on closing nutrient cycles between livestock and plant production, mostly assessing manure transport combined with manure processing techniques (e.g. Lopez-Ridaura et al. 2009; Vries et al. 2012). To our knowledge, transport of raw slurry has not yet been compared to a situation without transport. Results from existing studies indicate that greenhouse gas (GHG) emissions from transport of raw or processed manure only account for a small share of overall GHG emissions and are outweighed by savings from replaced mineral fertilizer (Vries et al. 2012; Lopez-Ridaura et al. 2009). Methane (CH_4) emissions from storage appear to be the major GHG source along the life cycle of manure management (Vries et al. 2012). Ammonia (NH_3) emissions leading to terrestrial acidification and particulate matter formation are mainly from manure storage and manure application (Vries et al. 2012). NO_3 losses follow the application of mineral and organic fertilizer on arable- and grassland.
The objective of this study is to quantify the effect of liquid pig manure transport compared to a situation

without transport. We apply a LCA approach to quantify relevant changes of emissions. In comparison to existing studies, we focus on the impact of the regulations causing manure export and the change in crop production on the exporting and importing farm.

Methods

LCA is used to assess environmental impact along the life cycle of a product or an activity. We relate calculated emissions to 1 ha of land on the exporting farm as well as to 1 m^3 of raw pig slurry transported, containing 6.9 kg N (thereof 4.5 kg total ammoniacal N) and 3.3 kg P. The present study focuses on untreated liquid manure since it is a huge share of transported manure in Germany, e.g. around 40 % in Lower Saxony in 2014/15 (LWK 2016). Furthermore, an increase of anaerobic digestion of manure is unlikely due to changes in the German renewable energy act (EEG). System boundaries are set from manure entering the storage on the exporting farm to the crop production of the importing farm. The following stages are included on both farms: manure storage, manure and mineral fertilizer application, crop production and mineral fertilizer production as well as emissions from transport. Scenarios and the data for the environmental impact accounting represent conditions in northwest Germany.

Scenarios

We compare a baseline scenario without transport to a scenario with manure transport. We differ between two reasons of manure export induced by the revised FD. Already under the current FD, there is a limitation of the N and P surpluses of the farm land nutrient balance. The proposed revision of the FD reduces the allowed P surplus from 20 to 0 kg P/ha/a on highly P enriched soils. This is a likely cause for manure transport since soils in livestock dominated regions are P oversupplied on the large scale (scenario Ex_P). Furthermore, the revised FD will strengthen enforcement of rules. In the second scenario, we assume that more manure than allowed is applied in the baseline. Thus, N and P surplus limitations and the total organic N application threshold of 170 kg/ha/a are exceeded. The revised FD forces farms to respect the thresholds and increase N efficiency (scenario ExF).

The revised FD will make fertilizer planning compulsory following a defined methodology. This planning will ensure an N efficiency, calculated as share of fertilizer in harvested product, of around 0.8 for mineral N and around 0.6 for organic N. In the transport scenario, we assume that farmers stick to the fertilizer planning, representing a lower efficiency bound. Furthermore, the same assumption holds for the baseline scenario of Ex_P to isolate the impact of manure transport induced by a stricter P threshold.

In the baseline on the exporting farm, we assume that in Ex_P 170 kg N/ha/a are applied and in Ex_F 200 kg N/ha/a. Empirical findings provide indications that in livestock dominated regions, farmers fully use, and partly violate, this threshold given by the current FD and directly by Nitrates directive (LWK 2016). Manure is on average stored for 6 months in open tanks and applied by drag hose on winter wheat. In the baseline scenario on the importing farm, we assume winter wheat cultivation on an arable farm without organic fertilizer use. In the transport scenario, manure is stored in average for 3 months on the exporting and importing farm, respectively. Importing farms receive 150 kg organic N/ha (about 21 m^3 liquid manure). Manure is transported 100 km by lorry, representing the distance between livestock and plant production dominated regions in northwest Germany.

Environmental impact calculation

Emissions of NH_3, nitrous oxide (N_2O), nitrogen oxides (NO_x), NO_3, CH_4, carbon dioxide (CO_2) and the P surplus are calculated, essential sources are named below. CH_4 emissions from storage are modelled based on Sommer et al. (2004), NH_3 emissions from storage based on Rigolot et al. (2010). Both models allow differentiation depending on storage time and temperature. N_2O and NO_x emissions from storage are estimated following Rösemann et al. (2015). We did not take NO_3 leaching from storage into account because it is prevented by environmental regulations in Germany. Different emissions occur during and after application of mineral fertilizer and manure to agricultural soils. Following Rösemann et al. (2015), NH_3 emissions from manure application were quantified as a share of total ammoniacal N depending on technology, time of incorporation and crop. For mineral fertilizer, we assume a fix loss share based on EMEP (2013). For simplification, we assumed that emission factors for N_2O, NO_x and N_2 are equal for organic and mineral N, what is in line with specifications from IPCC (2006), EMEP (2013) and Rösemann et al. (2015). NO_3 leaching is calculated using regressions from field trials for winter wheat following oilseed rape from Sieling & Kage (2006), differentiating between mineral and organic N. Relevant P losses occur at the crop production stage. We calculate a P surplus as the difference between P input and plant removal. It serves as an indicator for potential P losses. Indirect N_2O emissions from NO_3 leaching as well as NO_x and

NH_3 deposition are included on all stages of the life cycle following IPCC (2006). The inventory for mineral N and P fertilizer production and lorry transport are taken from the life cycle database ProBas. Manure storage and fertilizer spreader production are excluded since they have a negligible impact.

Results and discussion

In the baseline, emissions of NH_3, N_2O, NO_3, CH_4 and P surplus per ha are higher on the exporting than on the importing farm (Table 1, absolute values for importing and exporting farm), caused by the storage and application of manure. NO_x and CO_2 emissions are higher on the importing farm due to higher use of mineral fertilizer. Based on the definition of the baseline scenario, manure application per ha is higher in Ex_P than in Ex_F, causing differences in NH_3, N_2O, NO_3, CH_4 emissions and P surplus.

In Ex_P, the exporting farm exports 5.40 m^3 (36.08 kg N, 17.98 kg P) of manure per ha, corresponding to 0.25 ha on the importing farm. In Ex_F, 5.78 m^3 (38.63 kg N, 19.24 kg P) manure per ha are exported, corresponding to 0.27 ha on the receiving farm. Emission changes caused by manure transport, including changes on the exporting and importing farm as well as transport emissions, are shown in Table 1. In both scenarios, overall NH_3, N_2O, NO_x, NO_3 and P surplus are reduced.

Table 1. Environmental impact of manure transport in scenario Ex_P (export caused by stricter P threshold) and Ex_F (export caused by enforcement of rules). Reported values for the exporting and importing farm are values per ha in the baseline and percent change from the baseline under the listed scenario. Total emission change refers to change under the listed scenario, related to ha on the exporting farm and m^3 of manure exported.

	NH_3	NO_x	NO_3	N_2O	CH_4	CO_2	GWP	P surplus
Scenario Ex_P								
Exporting farm (kg/ha)	27.1	3.7	65.9	6.0	8.3	292.3	2,292.8	18.0
Change due to manure export	-4.8%	-0.1%	-5.9%	+5.8%	+2.2%	+26.6%	+8.2%	-100%
Importing farm (kg/ha)	5.9	6.6	43.8	5.5	1.3	712.4	2,397.6	0
Change due to manure import	+17.2%	-45.1%	+28.6%	-29.6%	-33.1%	-53.0%	-36.6%	0%
Total emission change	-1.1	-0.8	-0.7	-0.1	+0.1	+22.8	+4.1	-18.0
(kg/ha on exporting farm)*	-3.9%	-14.3%	-0.9%	-2.1%	+1.0%	+4.8%	+0.2%	-100%
Total emission change	-0.2	-0.1	-0.1	-0.0	+0.0	+4.2	+0.76	-3.3
(kg/m^3)	-0.7%	-2.6%	-0.2%	-0.4%	+0.2%	+0.9%	+0.0%	-18.5%
Scenario Ex_F								
Exporting farm (kg/ha)	30.6	3.8	70.2	5.9	9.5	211.4	2,202.1	36.7
Change due to manure export	-6.8%	-8.6%	-11.8 %	-6.1%	-0.4 %	0 %	-4.9%	-52.5%
Importing farm (kg/ha)	5.9	6.6	43.8	5.5	1.3	712.4	2,397.6	0
Change due to manure import	+17.2%	-45.1%	+28.6%	-29.6%	-33.1%	-53.0%	-36.6%	0%
Total emission change	-1.8	-1.1	-4.9	-0.8	-0.1	-58.9	-299.8	-19.3
(kg/ha on exporting farm)*	-5.6%	-20.3%	-6.0%	-16.8%	-0.7%	-14.6%	-10.5%	-52.5%
Total emission change	-0.3	-0.2	-0.9	-0.1	-0.0	-10.2	-51.75	-3.3
(kg/m^3)	-1.0%	-3.5%	-1.0%	-2.9%	-0.1%	-2.5%	-1.8%	-9.1%

*1 ha on the exporting farm corresponds to 0.25 ha on receiving farm in ExP and 0.27 ha in Ex_F

For CO_2 and overall GHG emissions, there are considerable differences between the scenarios. In Ex_F, CO_2 emissions are reduced by 14.6% per ha and 2.5% per m^3 manure exported. CO_2 emissions from transport are more than counterbalanced by the reduction of mineral fertilizer on the receiving farm, in line with findings from other studies (e.g. Lopez-Ridaura et al. 2009). In Ex_P, CO_2 emission increased by 4.8% per ha and 0.9% per m^3 manure exported. The exporting farm needed to transfer manure because of the tighter P threshold. Since N and P are combined in manure, needed N leaves the exporting farm and has to be replaced by mineral N fertilizer. This is not counterbalanced by saved fertilizer on the manure importing farm. The result indicates the importance of taking the regulation into account that triggers manure export. The specified effect also causes differences in overall GHG emissions between both scenarios. In Ex_P, GHG emissions stay almost constant with a 0.2% increase per ha, whereas in Ex_F there is a decrease of 10.5%. In contrast to Vries et al. (2012), we identified N_2O from crop production, not CH_4 from storage, as the main GHG source along the life cycle of manure transport. The variation is mainly caused by different methodological approaches, e.g. with regard to the chosen system boundaries.

In both scenarios, manure transport decreases total NH_3 and NO_3 emissions. However, NO_3 and NH_3 emissions increase on the receiving farm by 12.5 kg (28.6%) and 1.0 kg (17.2%) per ha, respectively. NH_3 emissions rise because of emission from storing manure on the receiving farm and, especially, emissions from application. The increase of NO_3 losses on the importing farm is caused by lower efficiency of organic compared to mineral N.

The results indicate that manure transport can reduce environmental impacts caused by regional or on farm livestock concentration. Transporting manure contributes to closing nutrient cycles and reduces the amount of reactive N introduced to the production system by reducing reliance on mineral fertilizer. However, our results indicate that NH_3 and NO_3 emissions increase on the importing farm. Deposition of NH_3 emissions is a main driver for loss of terrestrial biodiversity, NO_3 poses a threat to groundwater and surface water quality. This 'regional pollution swapping' is of special concern when the importing area is in or next to sensitive ecosystems or to areas with low groundwater recharge. In Germany, existing nature conservation and water law does not sufficiently prevent manure transport to such areas. Furthermore, certain concerns of manure transport like phytosanitary issues or noise from traffic were not included in the study.

The outcome of a LCA depends on assumptions with regard to the inventory data. Two limitations of the study need to be considered. There is little knowledge on actual fertilizer practices of single farms since statistics on mineral fertilizer are only accounted on a regional level. We made a restrictive assumption by presuming that all farmers follow fertilizer planning required by the revised FD. More efficient or inefficient management, the latter enabled by a continuing lack of enforcement, will influence the impact of manure transport. Empirical research is needed on actual fertilizer use of farmers, especially when facing the upcoming FD. NO_3 leaching was quantified using regressions from field trials for one crop, taking different effect of mineral and organic N as well as the total N level into account. This approach is an improvement compared to the use of fixed factors suggested by IPCC (2006). Nevertheless, more results from plant trials augmented by the use of crop models, and different crops should be included for a more valid outcome.

Conclusion

Manure transport can reduce N emissions, CO_2 emissions and P surplus caused by uncoupled nutrient cycles between plant and livestock production. Our results indicated that how regulation was implemented influenced the environmental outcome of manure transport and illustrated the dangers of regional pollution swapping. Despite the found benefits of manure transport, the regional distribution of livestock manure is not sufficient to substantially increase the environmental viability of recent hog production systems.

References

BMEL (2015): Verordnung zur Neuordnung der guten fachlichen Praxis beim Düngen. http://www.bmel.de/SharedDocs/Downloads/Service/Rechtsgrundlagen/Entwuerfe/EntwurfDuengeverordnung.pdf. Accessed 26 Apr 2016.

EMEP (2013): EMEP/EEA air pollutant emission inventory guidebook - 2013. http://www.eea.europa.eu/publications/emep-eea-guidebook-2013. Accessed 26 Apr 2016.

IPCC (2006): Guidelines for national greenhouse gas inventory. Volume 4: Agriculture, Forestry and Other Land Use. Geneva.

Lopez-Ridaura S, Werf H, Paillat JM, Le Bris B (2009): Environmental evaluation of transfer and treatment of excess pig slurry by life cycle assessment. Journal of Environmental Management 90 (2), 1296-1304.

LWK (2016): Nährstoffbericht in Bezug auf Wirtschaftsdünger für Niedersachsen 2014/2015. www.lwk-niedersachsen.de/download.cfm/file/1787,370ad30c-9ae7-cff8-0ae7d6877de6ab56~pdf.html. Accessed 26 Apr 2016.

Rigolot C., Espagnol S, Robin P, Hassouna M, Béline F, Paillat JM, Dourmad, JY (2010): Modelling of manure production by pigs and NH3, N2O and CH4 emissions. Part II: effect of animal housing, manure storage and treatment practices. Animal 4 (08), 1413-1424.

Rösemann C, Haenel HD, Dämmgen U, Freibauer A, Wulf S, Eurich-Menden B, Döhler H, Schreiner C, Bauer B, Osterburg B (2015): Calculations of gaseous and particulate emissions from German agriculture 1990 – 2013: Report on methods and data (RMD) Submission 2015. Thünen Rep 27, Braunschweig.

Sieling K and Kage H (2006): N balance as an indicator of N leaching in an oilseed rape – winter wheat – winter barley rotation. Agriculture, Ecosystems & Environment 115 (1-4), 261-269.

Sommer SG, Petersen SO, Moller H B (2004): Algorithms for calculating methane and nitrous oxide emissions from manure management. Nutrient Cycling in Agroecosystems 69, 143-154.

Vries JW, Groenestein CM, Boer IJM (2012): Environmental consequences of processing manure to produce mineral fertilizer and bio-energy. Journal of Environmental Management 102, 173-183.