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Research article

A life cycle assessment of liquid pig manure transport in line with EU regulations: A case study from Germany

T. Kuhn*, L. Kokemohr, K. Holm-Müller

Institute for Food and Resource Economics, University of Bonn, D-53115 Bonn, Germany

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ABSTRACT

The transport of excess manure to crop farming systems is a core measure of livestock farmers to comply with environmental regulations like the EU Nitrates Directive. The German implementation of the directive has recently been revised and will lead to a distinct increase of manure transport. We quantify the environmental impact of 1 m^3 of pig manure excreted in scenarios with and without manure transport by life cycle assessment, focusing on farming systems in North-West Germany. Furthermore, we assess how the environmental impact is linked to the regulation which is causing the transport. Compared to a reference scenario without transport, manure transport lowers all assessed impact categories and no trade-off between environmental impacts is found. Major reductions are realized for global warming (39%), freshwater (61%) and marine eutrophication (54%) as well as particulate matter formation (10%). Furthermore, the depletion of fossil fuels and phosphate is lowered. Reductions are mainly caused by an increase of nutrient use efficiency and the savings in chemical fertilizer. However, in a scenario where manure transport is caused by strict regulations regarding phosphate, needed nitrogen leaves the exporting farm likewise and chemical fertilizer use rises at the exporting farm. Caused by the increased fertilizer use, the positive environmental effect of manure transport diminishes, even leading to a rise of fossil fuel depletion by 20% and slight rise of global warming potential by 3%. However, we find that the use of lorries which combine manure and grain transport and, thereby, reduce empty drives, can prevent this trade-off. Our results show the potential of manure transport to reduce the environmental burden caused by the geographical concentration of livestock production. However, the impact of manure transport on global warming and fossil fuel depletion highly depends on the transport distance. Agronomic measures are needed to prevent the increase of chemical N fertilizer use on the exporting farms and policy makers should be aware of possible trade-offs between strict regulations regarding phosphorus and fossil fuel depletion.

1. Introduction

In several European countries, intensive livestock production is highly geographically concentrated. Regions with high stocking density are characterized by high nitrogen (N) and phosphorus (P) inputs and surpluses (Grizzetti et al., 2007) which increase the risk of uncontrolled nutrient loss to the environment. N and P losses pose a threat to air and water quality, biodiversity, and climate (Sutton et al., 2013). In the EU, the Nitrates Directive 91/676/EEC is the key legislation for lower nitrate (NO_3^-) emissions from agriculture and protects drinking water sources and surface waters. The implementation of the Nitrates Directive in member states is often linked to measures to reduce P and ammonia (NH_3) losses, needed to fulfil environmental targets laid down in the Water Framework Directive 2000/60/EC or the Directive on the Reduction of National Emissions of Certain Atmospheric Pollutants 2016/2284.

Mandatory requirements under the above-mentioned directives prescribe maximum amounts of applied nutrients and banning periods for manure application. To comply with these legal requirements, livestock farms can reduce stocking density, rent or buy additional land, or change animal feeding to lower nutrient excretion. Furthermore, manure transport is a major adaption measure of livestock producers to fulfil requirements with regard to nutrient application. The transport leads, following the logic behind the Nitrates Directive, to a reduction of NO_3^- losses on the manure exporting farm. However, manure transport impacts on numerous

* Corresponding author. Nussallee 21, D-53115 Bonn, Germany.
E-mail address: till.kuhn@ilr.uni-bonn.de (T. Kuhn).

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emission sources on the manure exporting and importing farm. In addition, transport itself is linked to emissions and may lead, for instance, to a negative net impact on global warming or the formation of particulate matter (PMF). Life cycle assessment (LCA) quantifies the effect of manure transport on numerous environmental impact categories, includes all potentially affected emission sources and, hence, assesses the environmental effect comprehensively. This allows to detect possible trade-offs or combined benefits of manure transport with other environmental targets, induced by measures to protect ground and surface waters.

In Germany, livestock production is clustered in the Northwest. In this area, high amounts of manure are already transported intra-regionally between farms under the current legal framework; e.g. in Lower Saxony the share lies around 6% of the total manure and biogas digestate production of 59 m t in 2015/16 (LWK Nds, 2017). Transport is triggered by restrictions put in place by the Fertilization Ordinance (FO, BMEL, 2017) which mainly implements the Nitrates Directive in Germany and also comprises measures targeting P and NH_3 emissions. A revised FO entered into force in June 2017 and includes considerably tighter mandatory requirements (Kuhn, 2017). Hence, a further increase of manure transport is likely (LWK Nds, 2017). First estimates for Lower-Saxony predict that around 7% of total livestock manure is affected by stricter maximum nutrient application rates (Osterburg and Techen, 2012) and will potentially be transported. Therefore, the integrated assessment of the environmental impact of manure transport is of recent interest.

Several LCA studies examine the management of excess manure in livestock production systems (McAuliffe et al., 2016), including the use of manure processing techniques. Manure importing farms are able to reduce chemical fertilizer use which is associated with emission reduction (Prapaspongsa et al., 2010; Brockmann et al., 2014). On the other hand, transport itself is related to carbon dioxide (CO_2) and nitrogen oxides (NO_x) emissions (Lopez-Ridaura et al., 2009; De Vries et al., 2013). Different manure processing techniques are able to reduce the ratio between nutrients and volume and, hence, decrease transport emissions per unit of nutrient. However, the processing is partly linked to direct emissions and to additional costs (Willeghems et al., 2016; De Vries et al., 2012). Furthermore, the environmental impact of manure transport and processing depends on the regulatory regimes on nutrient application (Hoeve et al. 2016). We contribute a case study on manure transport in Germany to existing research and explicitly include the impact of the regulation which causes manure transport.

Depending on the regulations triggering manure export, one of two scenarios applies: First, livestock farms are often characterized by inefficient nutrient management, leading to high N and phosphate (P_2O_5) surpluses (Osterburg et al., 2004; Osterburg and Techen, 2012). In this case, exported manure does not have to be replaced with chemical fertilizer to sustain nutrient need of crops. The nutrient use efficiency, understood as the relation between nutrient input and output, increases as the total amount of applied nutrient is lowered, but crop output stays constant. Second, the exporting farms may have to substitute exported nutrients with chemical fertilizer to sustain nutrient demand by crops. This generally can be caused by direct thresholds for manure N application as prescribed in Annex III of the Nitrates Directive. Furthermore, restrictions for one nutrient can limit the application of another nutrient as they are combined in manure. The N:P_2O_5 ratio in manure is generally lower than 2:1 whereas plant needs reflect on average a ratio over 2.5:1 (Schröder, 2005). This ratio is even worsened by a comparatively low nutrient use efficiency of manure N compared to manure P_2O_5. It implies an over application of P_2O_5 when a high share of plant N needs are met with manure (De Vries et al., 2015). Hence, strict thresholds with regard to P_2O_5 limit the use of manure N at the same time. This is the case for the Fertilization Ordinance 2017 (FO 17) which comprises very strict measures with regard to the application of P_2O_5 and can cause an increase of the chemical N need on the importing farm. The described scenarios most likely influence the environmental impact of manure transport and, therefore, need to be taken into account in its assessment.

The objective of our study is to quantify the environmental effect of liquid pig manure transport by lorry from a livestock to an arable farm, compared to a situation without transport using LCA. Furthermore, we explicitly assess the impact of different manure application thresholds in environmental legislation which can cause manure transport. We develop our scenarios for triggers of manure transport based on the current revision of the FO in Germany and, thereby, provide an analysis of a recent policy change.

2. Material and methods

2.1. LCA approach and functional unit

LCA is a methodology to quantify the emissions and resource consumption of a product along its whole life cycle, standardized by international norms (ISO, 2006a; 2006b). In this study, the environmental consequences of changing from a management without to a management with manure transport are assessed. To do so, we take all relevant emission sources and resource needs along the life cycle of manure into account and relate them to the functional unit of 1 m^3 of pig manure excreted.

2.2. System characterization and scenarios

System boundaries are starting from manure entering the subfloor storage on the exporting farm to the crop production stage, and include changes in the chemical fertilizer use. Assumptions regarding manure composition and storage are equal in all scenarios. Manure is excreted by pigs with a nutrient content of 8 kg N m^{-3} and 2.93 kg P_2O_5 m^{-3} (Table 1), representing excretion rates based on N and P reduced feeding strategies (BMEL, 2017), which are commonly applied in Germany. Manure is stored in-house under fully slatted floor for 4 months and in a slurry tank with a natural crust cover for 5 more months. We assume that the manure storage is emptied completely in May and then filled up evenly. There is no scrubber system in place to reduce NH_3 and particulate matter emissions from housing. Four scenarios are defined:

- Reference (Ref): Manure is stored and applied at the exporting farm by trailing hose. Manure nutrients do not replace chemical N or P fertilizer.
- Reference and replace N (RefN): Manure is stored and applied at the exporting farm by trailing hose. Manure N replaces chemical N fertilizer.
- Transport (Trans): Manure is stored on the exporting farm, transported by lorry to the importing farm and applied by

Table 1
Mass balance flow at the storage and application stage for all scenarios.

	Ntot	NTAN	Norg	P_2O_5
After excretion	8.00	5.60	2.40	2.93
After stable and storage	5.98	3.63	2.35	2.93

Ntot – total nitrogen; NTAN - total ammoniacal nitrogen; Norg – organic nitrogen; P_2O_5 - phosphate.