Nutrient best management practices need regional material flow management for soil protection

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Abstract
High-intensity animal farming regions are characterised by the production of animal manure nutrients in surplus of what can sustainably be used on the agricultural land. Theoretically, farms in those regions have a high potential for improving their overall productivity and environmental performance by implementing general nutrient and particular animal manure nutrient best management practices (BMPs). In reality, reducing animal manure application to a sensible degree leads to more costs for the export of surplus animal manure to other regions. If a nutrient BMPs framework is to be successful in regions with excess animal manure production, an optimization of animal manure distribution and transportation at lowest costs is a key element as it positively influences the farms' profitability. This case study from Germany provides a model for this purpose. A regional material flow management for animal manures based on this model will enable a substitution of mineral fertilizers with animal manures in regions with little animal farming. At the same time, environmental problems caused by manure over-application in the surplus regions can be reduced. Combining nutrient BMPs with models like this can help farmers in high-intensity animal farming regions and adjacent regions to increase productivity, profitability, system sustainability, and environmental protection.

Key Words
Phosphorus, nitrogen, linear optimization, land use, fertilizer ordinance, nitrates directive

Introduction
High-intensity animal farming regions are characterised by the production of animal manure nutrients in surplus of what can sustainably be used on the agricultural land. These regions often have a history of long-term over-application of manures with associated nutrient accumulation in the soils and nutrient loss to groundwater, surface waters and surrounding ecosystems. To prevent such adverse effects more or less extensive legal regulations regarding mineral fertilizer and animal manure application have been passed since the 1990s in most parts of the developed world. In Europe, national fertilizer ordinances implement the EC Nitrates Directive (1991) and regulate fertilizer use on the farm level. In some countries like The Netherlands, Belgium or Germany this leads to extensive and often costly animal manure exports from high-intensity animal farming regions to adjacent regions with lower animal densities (Wossink *et al.* 1992, Lauwers *et al.* 1998).

Theoretically, farms in high-intensity animal farming regions have a high potential for improving their overall productivity, system sustainability and environmental performance with the implementation of general nutrient and particular animal manure nutrient best management practices (BMPs). Most nutrient BMPs are more specific than general legal regulations as they aim at the right nutrient source at the right rate, right time, and right place. Through consideration of parameters such as the local soils, the crop nutrient demand and the animal manure nutrient composition, nutrient BMPs can facilitate specific applications of animal manures in combination with supplementary mineral fertilizers. At stable crop yields, the result is either a decrease of the total amount of animal manures applied or a partial substitution of mineral fertilizers or both.

In reality, the adaptation of animal manure nutrients BMPs in high-intensity animal farming regions is hampered by their own aims: Reducing the application of animal manure to a sensible and sustainable degree leads to more excess animal manure than legislation "generates" and hence to more export costs. This can decrease monetary farm success considerably. If an (animal manure) nutrient BMPs framework is to be successful in regions with excess animal manure nutrients production, a regional optimization of animal manure distribution and transportation at lowest costs is a key element as it directly and positively influences the farms' profitability.

This case study from Germany highlights the need for a transport optimization scheme for animal manures to complete existing nutrient BMPs in high-intensity animal farming regions. It gives an example of a model which allows optimization of the distribution and transport of the animal manures in and between the administrative districts of north-west Germany at lowest costs. The model aims at avoiding manure over-application in the surplus districts and at the same time making use of the fertilizer value in districts with lower animal densities. Similar modelling approaches have so far considered the farm level instead of whole regions (Wossink *et al.* 1992) or "close" or "far" distances instead of actual distances (de Mol and Beek 1991). In all cases, the animal manure transport systems were modelled under the premise that the animal manure had to be disposed of instead of making use of the fertilizer value.

In this study, the most appropriate nutrient BMPs adapted to the actual land use, soils and surrounding ecosystems of specific smaller scale regions, farms, or fields are disregarded. The transport optimization module is being developed as an additional tool which can be used both on an aggregated regional level (for policy decision makers) as well as on the farm or field levels with site specific geographic information (for advisory services and extension).

Methods

Study area: Lower Saxony, north-west Germany

In Lower Saxony, a federal state in north-west Germany comprising 2.6 million hectares of agricultural land and 45 administrative districts, two major agricultural production zones can be distinguished. The north-western districts are dominated by dairy farming and high-intensity animal agriculture with high farm animal densities. Animal manure export to other districts is necessary but costly – especially for pig and cattle slurries that have high water contents. Long-term over-application of animal manures substantially increased overall and plant available soil phosphorus (P) contents (Leinweber 1996). The level of animal manure application decreased due to the first German Fertilizer Ordinance (DüV 1996). Yet, soil P accumulation slowly continues because legislation focuses on restricting nitrogen (N) application and N balance surpluses and because animal manures are usually applied based on crop N needs. As especially pig and poultry manures have high P contents, the amount of P applied to the soils usually exceeds the amount of P needed for crop growth. In the south-eastern and eastern districts intensive arable farming prevails. The majority of the crop nutrient demand is covered by mineral fertilizers. Long-term under-application of expensive mineral P fertilizers has resulted in large areas with low plant available soil P contents.

Input parameters for the model

The relevant parameters impacting on animal manure transports and their costs are quantity and quality of the manures produced and the capacity of land use systems to utilize manure as fertilizer.

The 29 animal manure classes considered in the model were determined by using district level data on number of farm animals sorted by species, use, age, and weight (LSKN 2004, TSK 2008). These were combined with the general reference values on N and P excretion of the farm animals and average amount of manure produced by the animals (LWK 2007). A simplifying assumption was made for the type of manure produced: all pig and all cattle manure was considered being slurry, all poultry manure was considered being solid manure.

The N and P demand of a total of 16 land use classes was derived by the combination of agro-statistics (LSKN 2008a) with average yield levels (LSKN 2008b) and fertilizing advice (LWK 2008).

Modelling

To optimize the distribution of manure nutrients at lowest transportation costs a linear optimization model was developed (Biberacher *et al.* 2009). Assumptions for the modelling are that each district can provide nutrients in animal manures and that each district comprises areas of various land uses with a specific nutrient demand. The extent to which the manures are transported depends on local manure production, scenario constraints on manure nutrient application and manure availability after transportation between districts as depending on the constraints. The modelling language is GAMS (General Algebraic Modelling System). The model is linked to an Excel template for data input and result visualization. Its output is the optimal animal manure distribution to the agricultural land and the minimal animal manure transport

between all districts at lowest overall transportation effort. An additional output is the definition of animal manure nutrient deficient or surplus districts as depending on the constraints.
Two scenarios are used for this study. Scenario 1 serves a baseline scenario with compliance to the minimum legal regulations for animal manures. According to the German Fertilizer Ordinance (§5 DüV 2007), a maximum of 170 kg N/ha/a from animal manures may be applied to the farm land. Scenario 2 simulates the adaptation of nutrient BMPs that aim at no further increase of the high plant available soil P levels in the high-intensity animal farming districts. Covering 100% of the crop nutrient demand by organic manure nutrients is not a sensible option from many viewpoints, e.g. regarding plant nutritional and nutrient leaching aspects. In scenario 2, animal manure P and N may be applied up to 80% of the crop demand.

Results and Discussion
Restricting animal manure application to a maximum of 170 kg N/ha/a (scenario 1, Figure 1a) results in far less extensive manure transportation activities between the districts of Lower Saxony than the constraints of scenario 2 that restrict animal manure application to a maximum of 80% of the crop nutrient demand (Figure 1b, 1c). In the model, most western districts with comparatively high animal densities become manure surplus districts and have to export manure in scenario 2. A total of 3 million tons of manure is exported from 19 surplus districts. Nevertheless, most of the manure is used locally in the districts of origin. The liquid slurries are mainly used locally to cover the local crop nutrient demand or, if districts are surplus districts, are exported into districts close by. A detailed view into the manure exports from Cloppenburg (CLP) district shows how the model gives preference to the transportation of water rich slurries to the close vicinity only (Figure 1b, 1c). In contrast to the slurries, poultry dung is transported to the more distant districts because of its low water and high nutrient content.

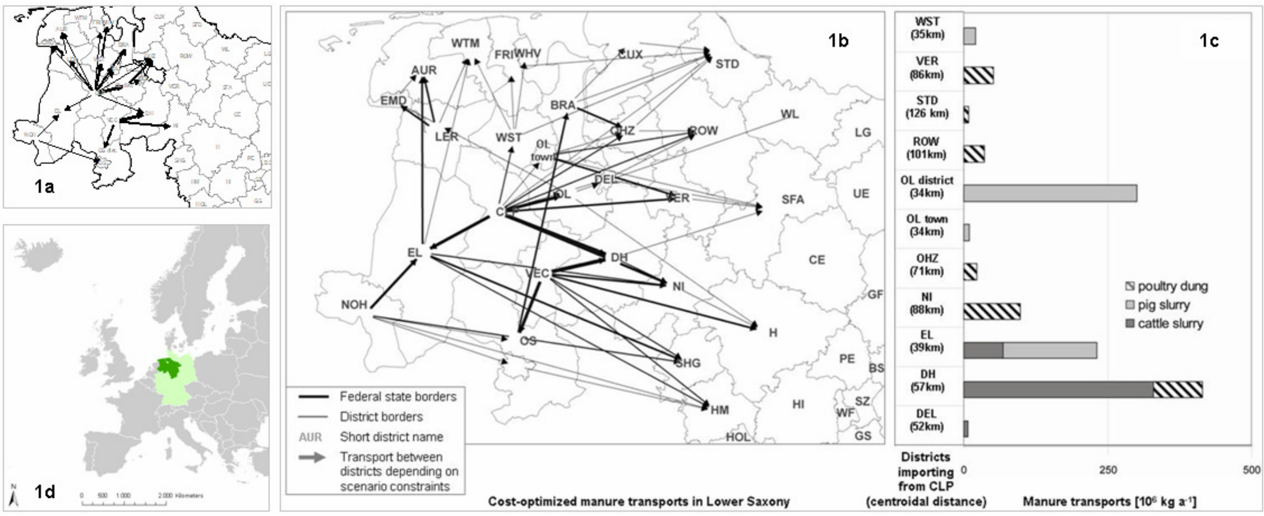

Figure 1. Modelling results: Manure transport and distribution in scenario 1 (Figure 1a) under compliance with §5 DüV (2007) (max. 170 kg N/ha/a) and in scenario 2 (Figure 1b and 1c) if animal manure P and N may cover a maximum of 80% of the crop demand. Figure 1a and 1b depict the least possible transport effort of manures between the districts in Lower Saxony at model constraints. Bold/slim arrows indicate large/small manure flows. Figure 1c gives an example of how the model distributes the different types of manure from a surplus district (Cloppenburg, CLP) to the receiving districts in scenario 2. The cumulative terms of poultry dung, pig slurry and cattle slurry contain the 29 manure classes of the model. Figure 1d shows the location of Lower Saxony in Germany and Europe.

Even at transport optimization as simulated by the model, costs associated with the export of excess animal manure are high. In reality, these costs were even higher due to the lack of the universal knowledge of supply and demand that the model has. These figures show that an actual adaptation of nutrient BMPs that indirectly increase animal manure surpluses in the high-intensity animal farming regions can only be expected if the farmers will be able to give away excess animal manure for little money or for free or if they can even make profits. Hence, a basic model setup as presented in this study can considerably contribute to reaching the overall aims of nutrient BMPs: to help farmers in high-intensity animal farming regions and the adjacent regions to increase productivity, profitability, system sustainability, and environmental protection. However, modifications in the model setup are required before that. The current setup of the model is regional, based on aggregated data, and aims at policy makers. Advisers for farmers or animal manure transport agencies need different setups which include site-specific geographic information. The model can be easily adjusted for such purposes.

Conclusion

A framework for nutrient BMPs in high-intensity animal farming regions must comprise a solution for transport optimization of animal manures to become accepted. A regional material flow management for animal manures based on models like this will enable a reasonable substitution of often expensive, limited and energy-intensive mineral fertilizers with animal manures in regions with little animal farming. At the same time, environmental problems caused by manure over-application can be reduced in high-intensity animal farming regions.

References

Biberacher M, Warnecke S, Brauckmann H-J, Broll G (2009) A linear optimisation model for animal farm manure transports in regions with high intensity animal farming. In '18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics and Computers in Simulation, July 2009' (Eds RS Anderssen, RD Braddock and LTH Newham) pp. 470-476. ISBN: 978-0-9758400-7-8. http://www.mssanz.org.au/modsim09/B1/biberacher_B1.pdf

DüV, Düngeverordnung (1996) Verordnung über die Grundsätze der guten fachlichen Praxis beim Düngen. Düngeverordnung in der Fassung der Bekanntmachung vom 26. Januar 1996 (BGBl. I 1996 S. 118).

DüV, Düngeverordnung (2007) Verordnung über die Anwendung von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis. Ausfertigungsdatum 10. Januar 2006 (BGBl. I S. 33). Düngeverordnung in der Fassung der Bekanntmachung vom 27. Februar 2007 (BGBl. I S. 221).

EC Nitrates Directive (1991) Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources, Official Journal L 375, 31/12/1991 pp. 0001 – 0008.

GAMS, General algebraic modeling system, GAMS Development Corporation, http://www.gams.com/, 04.03.2009.

Lauwers L, Van Huylenbroeck G, Martens L (1998) A Systems Approach to Analyse the Effects of Flemish Manure Policy on Structural Changes and Cost Abatement in Pig Farming, *Agricultural Systems*, Vol. **56**, No. 2, 167-183.

Leinweber P (1996) Phosphorus fractions in soils from an area with high density of livestock population. *Z. Pflanzenernaehr. Bodenkd.* **159**, 251-256.

LSKN, Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen (2004) Agrarstrukturerhebung 2003. Viehhaltung.

LSKN, Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen (2008a) Agrarstrukturerhebung 2007. Bodennutzung.

LSKN, Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen (2008b) Erntestatistik der Jahre 2003 bis 2008.

LWK, Landwirtschaftskammer Niedersachsen (2007) Nährstoffausscheidungen landwirtschaftlicher Nutztiere je Stallplatz und Jahr. Ausfertigungsdatum 25.04.2007.

LWK, Landwirtschaftkammer Niedersachsen (2008) Richtwerte für die Düngung in Niedersachsen. Stand März 2008. http://www.lwk-niedersachsen.de/download.cfm?file=341,duengeempfehlung2008~pdf, 17.12.2008.

Mol M de, Beek P (1991) An OR contribution to the solution of the environmental problems in the Netherlands caused by manure. *European Journal of Operational Research*, **52**, 16-27.

TSK, Niedersächsische Tierseuchenkasse (2008) Unpublished data on number of animals in the districts of Lower Saxony on 02.01.2008.

Wossink GAA, de Koeijer TJ, Renkema JA (1992) Environmental-Economic Policy Assessment: A Farm Economic Approach. *Agricultural Systems,* **39**, 421-438.