

# Simulated nutrient management options for intensive livestock farms with a surplus of manure

Schröder, Jaap\*

\*Agrosystems Research Wageningen University and Research Centre, P.O. Box 16, 6700 AA Wageningen, The Netherlands, tel: ++31 317 480578, [jaap.schroder@wur.nl](mailto:jaap.schroder@wur.nl)

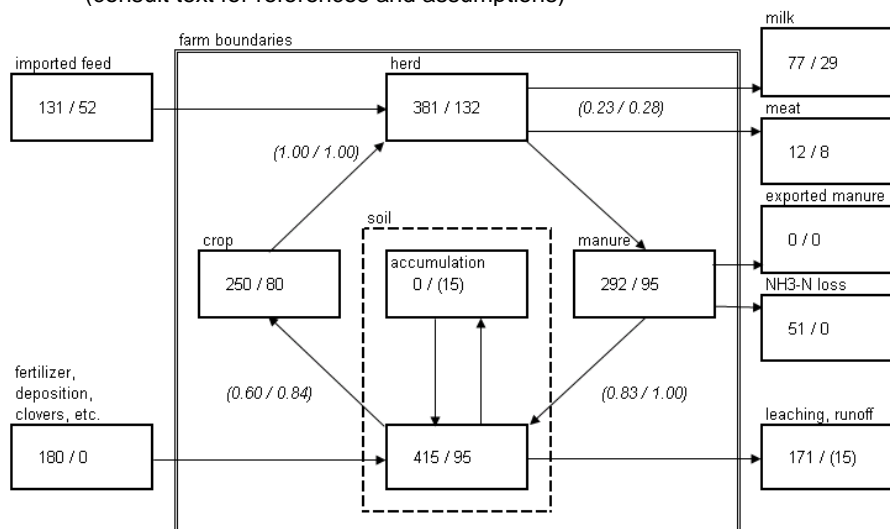
## Abstract

The output levels of intensive livestock farms are sustained with imports of feed. The imminent losses associated with the vast nitrogen (N) and phosphorus (P) fluxes through these farms need to be addressed. A blunt reduction of intensity (i.e. output levels) evidently alleviates the environmental pressure but does not necessarily contribute to a proper utilization of resources, among which N and P. The present paper shows some alternative nutrient management options.

## Introduction

Resources such as rock phosphate and fossil fuels needed for the production of mineral fertilizers are finite. Moreover, the use of mineral and organic fertilizers can have a detrimental effect on our local and global environment. These aspects justify rethinking the current lax use of nitrogen (N) and phosphorus (P) in our societies (Neeteson *et al.*, 2006; Schröder & Bos, 2008). These considerations apply not the least to intensive livestock farms. These farms are not self-sufficient in terms of feed production. Consequently they derive feed from elsewhere and together with this feed nitrogen (N) and phosphorus (P) are imported. The import of P commonly results in the accumulation of P in the soils of livestock farms and the eventual loss of P, as the P uptake of home-grown crops is often much lower than the amount of P available from manures. The utilization of the P in manure is also restricted by the amount of N that can be applied and supplemented within the limits of permissible N losses to the environment. To reduce the environmental pressure, this type of farms should reduce the import of P or export their excess manure. In any case these farms should use the N in manure as efficiently as possible, if alone to reduce the need for mineral fertilizer N supplements. The present paper gives model-based examples of how the inputs and outputs of N and P on livestock farms can be balanced.

**Figure 1.** Simulated annual nutrient fluxes (kg N / P<sub>2</sub>O<sub>5</sub> per ha per year) and, in brackets, conversion coefficients (kg per kg, for N / for P<sub>2</sub>O<sub>5</sub>) in a dairy farm producing approximately 14,000 liters of milk per ha per year (consult text for references and assumptions)



## Inbalances

Figure 1 shows the imaginary N and P fluxes for a dairy farm producing 14,000 liter of milk per ha per year, as simulated with a simple model (Schröder, 2000; Schröder *et al.*, 2003; 2005b). Assuming an achievable annual crop yield level of 250 kg N per ha (with a typical N/P<sub>2</sub>O<sub>5</sub> ratio for forages of approximately 3), this type of farms must inevitably rely on imported concentrates of which the composition is mainly determined by the grain component with a typical N/ P<sub>2</sub>O<sub>5</sub> ratio roundabout 2.5.

Consequently, more P is added to the soil via manure than taken up by crops. Several measures can be taken to avoid the resultant accumulation of P in soils. Numerical effects of five of these measures are listed in Table 1. One obvious measure is to adjust the livestock density (i.e. feed requirements and milk production level) to the home grown amount of forage. P accumulation is stopped then, but, *ceteris paribus*, this measure implies an increased demand for mineral fertilizers, mainly N. Probably it is more profitable to maintain the milk production and spend money on the adjustment of the concentrate composition. P accumulation can be drastically reduced by switching to concentrates with a N/ P<sub>2</sub>O<sub>5</sub> ratio of 3.6 instead of 2.5. Alternatively, the use of low-protein rations (either by importing low-protein concentrates or by avoiding harvests of forage in too young a stage) can improve the feed-N conversion (Kebreab *et al.*, 2001). Another option to balance P inputs with P outputs would be to remove P from the system by the export of manure. In the present example approximately 15% of the manure needs to be exported to arrive at a P surplus of 0 kg per ha. Again, this would lead to an increased demand for mineral fertilizer N, as some N is inevitably exported together with the manure P. All measures but the first one result in less manure P whilst maintaining milk and meat outputs. All measures but the first two ones would also reduce the loss of N, including ammonia, per unit milk produced.

**Table 1.** Simulated fluxes (kg N / kg P<sub>2</sub>O<sub>5</sub> per ha per year) and conversion coefficients (kg per kg) of dairy farms according to different strategies aiming at P surpluses close to 0 (all being alternatives to the systems reflected in Figure 1) to improve the utilization of inputs (consult text for references and assumptions)

	Strategy:				
	Livestock density reduction	Higher N/P <sub>2</sub> O <sub>5</sub> ratio in concentrates	Low protein diets + higher N/P <sub>2</sub> O <sub>5</sub> ratio in concentrates	Manure export	Manure export + better N utilization*
<i>Fluxes:</i>					
Imported feed	0 / 0	131 / 36	160 / 44	131 / 52	131 / 52
Fertilizers, etc	245 / 24	180 / 0	78 / 0	216 / 0	162 / 0
Milk and meat	58 / 24	89 / 37	89 / 37	89 / 37	89 / 37
Exported manure	0 / 0	0 / 0	0 / 0	45 / 15	46 / 15
Ammonia-N loss	35 / 0	51 / 0	38 / 0	47 / 0	45 / 0
Leaching and runoff	151 / 0	171 / 0	142 / 7	166 / 0	113 / 0
<i>Coefficients:</i>					
From herd to milk and meat	0.23 / 0.30	0.23 / 0.32	0.25 / 0.36	0.23 / 0.28	0.23 / 0.28
From manure to soil	0.82 / 1.00	0.82 / 1.00	0.85 / 1.00	0.82 / 1.00	0.82 / 1.00
From soil to crop	0.62 / 1.00	0.60 / 1.00	0.62 / 0.90	0.60 / 1.00	0.69 / 1.00
From crop to herd	1.00 / 1.00	1.00 / 1.00	1.00 / 1.00	1.00 / 1.00	1.00 / 1.00

\*zero grazing, perfect timing and placement of slurry

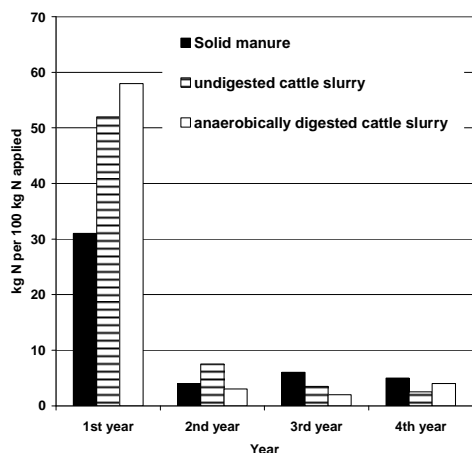
The permitted manure rates stipulated in the current Dutch Nitrates Directive Action Programme, 90 kg P<sub>2</sub>O<sub>5</sub> and 250 kg N per ha for most dairy farms and 80 kg P<sub>2</sub>O<sub>5</sub> and 170 kg manure-N per ha for other farms (Schröder & Neeteson, 2008), have strongly reduced the room for manure application and have indeed increased the necessity to take additional measures on livestock farms, including the export of manure. Wherever nearby arable spreading lands are scarce, however, the export of manure incurs costs for transport or even for the acceptance of manure as such. In any case livestock farmers will face the need to purchase more mineral fertilizer N, as indicated above. They are hence stimulated to increase the amount of available N per unit of applied manure P and improve the utilization of this available N from both manure and mineral fertilizers.

### Better utilization of N

The amount of available N per unit manure P can be increased by limiting the gaseous N losses from housings and manure storage. Separation of manure can also increase the amount of N per unit manure P. The resultant solid fraction, rich in P, is less bulky and can be exported at lower costs to arable farms. The higher N (largely ammonia-N) to P ratio of the remaining liquid fraction matches better with the requirements of forage crops. Mineral fertilizer N could thus partly or largely be replaced by the liquid fraction, depending on the quality of the separation process (Sørensen & Thomsen, 2005; Birkmose *et al.*, 2006; Schröder *et al.*, 2007c).

The greater the availability of N in manure, the more sensitive manures become for appropriate timings and methods of application. From this perspective spring injected manures are better utilized by crops than, for instance, manures that are surface applied in late summer. Note that autumn grazing too is therefore not conducive to a good utilization of N by crops, at least not in temperate regions where crop growth, including the growth of catch crops, is hampered by low temperatures (Schröder, 2005).

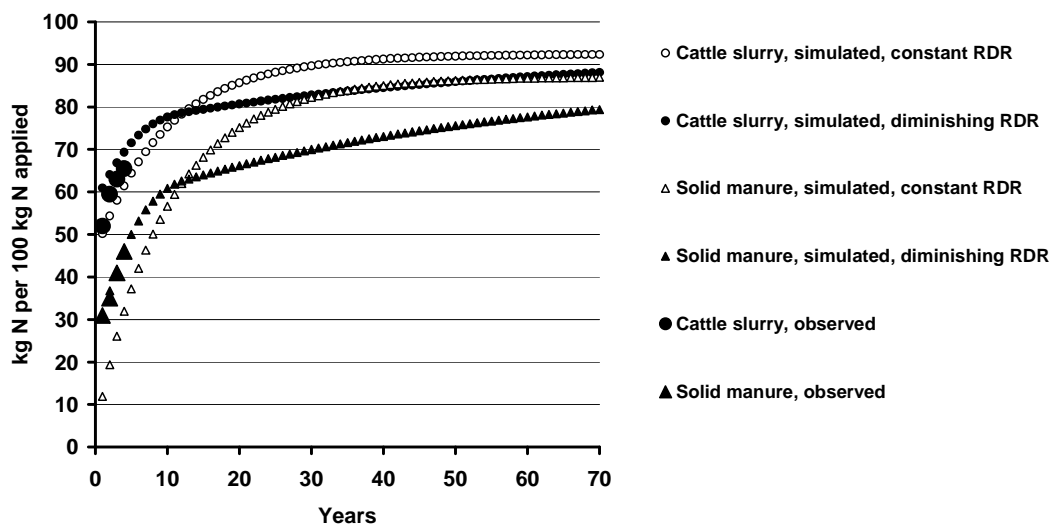
**Figure 2.** Nitrogen fertilizer replacement value (kg N per 100 kg N applied) in the four years following application, as affected by the type of manure (Schröder *et al.*, 2007b)



According to short term trials, anaerobic digestion (AD) of manure appears to contribute to a slightly better availability of N per unit manure P. However, long term trials have also shown that AD contributes little to cumulative availability of N over longer periods (Figure 2). Moreover, farmers are often inclined to stimulate the methane production of digesters by either importing substrates from food industries or sacrificing home grown crops. Schröder & Uenk (2006) have demonstrated that this deteriorates the N utilization at the whole farm level.

Recent field trials have yet indicated that the long term N fertilizer replacement values (NFRVs) of slurries in particular, deserve an upgrade from the present 20-50 percent to 80 percent, provided that sufficient attention is given to an appropriate timing and method of application (Schröder *et al.* 2005a; 2007b). The common short term trials tend to underestimate the NFRV of solid manures even stronger although it may take many decades before the NFRV of solid manures approximates the NFRV of slurries (Figure 3, Schröder *et al.*, 2007b).

**Figure 3.** Observed and simulated nitrogen fertilizer replacement value (kg N per 100 kg N applied), as affected by the number of consecutive applications, the type of manure and the adopted relative decomposition rate (RDR) (Schröder *et al.*, 2007b)



## Environmentally sound manure rates

Numerous factors including weather, soil type, manure composition, management skills, crop type, harvest regime, and environmental targets, determine which combinations of manure and mineral fertilizer are justifiable from an environmental point of view. We developed another model to handle this complexity (Schröder *et al.*, 2007a). Simulations indicate that environmentally sound manure rates on dairy farms (i.e. rates associated with a P surplus of 0 kg per ha and a N concentration in the upper groundwater or nearby surface water < 11.3 mg N per litre) range from as much as 300 kg cattle slurry N (110 kg P<sub>2</sub>O<sub>5</sub>) per ha, to as little as 190 kg cattle slurry N (70 kg P<sub>2</sub>O<sub>5</sub>) per ha, including the N and P in dung and urine excreted during grazing. Highest rates are, for instance, applicable to clay soils with only 'zero grazing' grasslands, whereas the lowest rates apply to dairy farms on dry sandy soils where silage maize is grown next to grazed grassland. In any case judicious supplements of either mineral fertilizer N or biologically fixed N are needed to exploit the manure P, thus avoiding P accumulation, whilst limiting risks of excessive N leaching. The simulated mineral fertilizer rates corresponding to the above manure rates and conditions, are 270 and 100 kg N per ha, respectively (Schröder *et al.*, 2008). The simulated scenarios indicate that rates of 170 kg manure-N per ha as stipulated by the EU Nitrates Directive (Anonymous, 1991) are unnecessarily stringent for dairy farms using cattle slurry. If pig slurry or solid manures would be used instead of cattle slurry, however, rates of 170 kg manure-N per ha are generally associated with amounts of P that exceed the off-take in harvested crops (Schröder, 2005).

## Discussion and conclusions

In intensive livestock systems feed requirements are partly met with imported feed stuffs. Under such conditions substantial losses are imminent due to an imbalance of imports (inputs) of N and P into the farm and exports (marketable outputs) of N and P from it. As potential local losses can thus be described by the following equations:

Losses = input – output (kg/(ha.yr)) and output / input = efficiency (- / -)

↔

Losses = input x (1 – efficiency)

↔

Losses = output x ((1/efficiency) – 1),

these losses can be limited by reducing the inputs whilst improving the efficiency, or by accepting a reduction of marketable outputs. The equations also show that efficient systems are not necessarily clean if their inputs are high, just as low input systems are not clean if their efficiency is low. The definition of environmentally sound livestock systems hence boils down to finding the right balance between intensities and efficiencies, as both factors may be interdependent.

Our model explorations also indicate that there is little justification for uniform rules that would apply to all environments. We conclude that there is strong need to differentiate permitted manure application rates, unless policy makers do not mind that regulations are too slack in one situation and unnecessarily stringent in another situation.

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