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Application of nutrient balance sheets in analysis and design of agricultural systems: examples from the Netherlands and Poland

Paper presented at the Seminar 'Scientific Basis to Mitigate the Nutrient Dispersion into the Environment', held at Falenty - Nadarzyn, 13-14 December 1999

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Abstract

The paper starts with an elaboration of the nitrogen problem in Poland. Only about one fifth of available nitrogen is recovered in agricultural produce. The remainder is apt to emissions. Nutrient balance sheets offer a simple and flexible instrument for the analysis of nutrient flows in agricultural systems, which make them a successful candidate for the analysis of the nitrogen problem and its potential solutions. Several applications of nutrient sheets are discussed. They include national, farm and sub-farm level analysis. In addition, balance sheet applications in graphical analysis, regression analysis, modeling and policy evaluation are discussed. Examples are given of applications in Poland and the Netherlands. It is concluded that nutrient balance sheets calculations can offer a practical and valuable contribution to this development, be it applied in a model or as a sole instrument.

Introduction

A nutrient balance sheet is a calculation sheet where incoming and outgoing nutrient flows of a given agricultural activity are compared. Although not new, its application suddenly boomed towards the end of last century under pressure of unsustainability debates in agriculture (overfertilitzation in intensive production systems in Europe and elsewhere versus underfertilization and soil mining in extensive systems). One of the earliest examples is given by Aarts et al. (1988), who applied the balance sheets in the analysis of farm level nutrient surpluses in Dutch dairy farming. Another example is found in Stoorvogel and Smaling (1990), where nutrient balances are calculated for Sub-Saharan countries in Africa. The first application for Poland was presented in 1994 (Langeveld, 1994a), later followed by several others (e.g. Sapek 1999, Pietrzak, 1999). Balance sheets have several advantages. They are flexible (applicable at any spatial scale, for any temporal unit), require relatively cheap data (statistical information) and have a strong conceptual impact. Disadvantages may be found in the fact that emissions are estimated but not measured. This may lead to over- or underestimations, especially when aggregated data are used covering large numbers of plots/farms/animals over a long period of time. Bio-physical processes that are involved in nutrient emissions (volatilization, (de)nitrification, run-off and leaching) are highly variable, dynamic and non-linear. Senseful analysis of nutrient emissions therefore never can be based solely on balance sheet calculations.

Nutrient balance sheets generally are applied to give insight in the absolute value of nutrient surpluses or deficits, mostly for nitrogen and phosphorus. In this way, they provide an instrument for the analysis of the performance of an agricultural system, be it a farm, field plot, cropping system, animal production system or a regional or national system. While applications are increasing, the use of balance sheets is shifting from merely an analytical instrument to a means of communication in the development process. The *Agrosystems Research* unit of the plant research institute of Wageningen University and Research Centre was one of the firsts to apply nutrient balance sheets. The unit aims at the design and development of accepted agricultural systems, under prevailing economical and ecological conditions. It is working towards this goal by applying a systems approach to nutrient dynamics, where special attention is given to organic farming and multifunctional land use (depicting systems where production function is supplemented by other functions such as landscape preservation, water resource management, nature development, etc.).

This paper will discuss the application of nutrient balance sheets, discussing its use both in agrosystem analysis as in the process of system improvement. It will do so, by presenting results from earlier studies, both for Poland and other countries, referring at different application levels. Results will be focusing mainly on nitrogen. The paper will start, however, by defining the extent of the (alleged) nitrogen problem in Poland.

Nitrogen problem

It is discussed whether there is a nitrogen problem in Poland. For this, we consider the *Nutrient Use Efficiency* (NUE, referred to as the ratio of nutrients in agricultural produce to the total amount of nutrients available) of nitrogen in the Polish agricultural system. Several estimations of this ratio have been given. Most are rather low, varying from 0.12 (Spiess, *this seminar*), to 0.20 (Sapek, *this seminar*), but also higher values (0.50; Langeveld, 1994a) have been given. Still, even if the latter would be correct, then annually some 400 thousand tons of nitrogen are not recovered in agricultural produce every year. It must be feared that this amount is lost to the environment, an equivalent of more than half of total nitrogen fertilizer consumption each year. Table 1 provides a national nitrogen balance sheet. It suggests that there indeed is a nitrogen problem in Poland (and it may be expected that this is also the case in other countries nearby). It certainly is not different in the Netherlands. Of a total nitrogen input of

1.4 million ton per year, almost 600 thousand ton (42 %) is lost. Only 225 thousand tons are recovered in agricultural products that are sold from the farms. This suggests a NUE for Polish agriculture of 0.16, which is in line with estimates presented above.

Table 1. Nitrogen balance sheet for Poland.

Nitrogen flow	Contents (thousands ton N/yr)
Inputs:	
Fertilizer use	890
Fodder	127
Biological fixation	103
Precipitation	263
Total	1393
Sales of agricultural products	225
Surplus	1168
NUE	0.19
Emissions of:	
Ammonia	332
N_2O	021
NO_3	206
Total	549

Source: calculated from Sapek (1999), nitrate emission figure from Sapek (*this seminar*).

The economic value of the loss can be calculated at 200 million US dollar per year (at 0.5$ per kg of N fertilizer), or 10$ per farmer per year. In order to estimate the environmental and political value, one could compare the loss of NO_3-nitrogen with the total discharge into the Baltic Sea (Fejes, *this seminar*): 760 thousand tons. Poland, in other words contributes 27 % of the nitrogen in the Baltic Sea. This gives an indication of the political interest (certainly for other countries around this Sea, but also for the European Union). A comparison to other countries in Europe shows that nitrate losses in Germany (Schulz, *this seminar*) are three times higher, while ammonium losses here are 1.5 times higher. This suggests that Poland is not doing so badly. Comparing to the Swiss total nitrogen input (as presented by Spiess, *this seminar*) however, which is only half of total Polish ammonium-nitrogen losses, shows that it still is considerable. As to the Baltic Sea, Poland is the single biggest contributor of nitrate-nitrogen.

It is concluded that there indeed is a nitrogen problem. It has agronomic, environmental, economic and political features. As to the first aspect, these will be studied here in some more detail. We will use nutrient balance sheets in order to analyze existing agricultural systems in Poland.

National level

Two alternative national balance sheets will be given. The first was calculated by Langeveld (1994a), using data for 1991. The second refers to the period 1996/97, and was given by Sapek (1999). Details are given in Table 2. Results from both studies show a rather strong contrast. While the surplus is less than 30 kg for 1991, it has more than doubled three years later. Also NUE has dropped dramatically. Both are not explained by increased nitrogen inputs, but must be attributed to an immense drop in productivity. Although the same source of information is used, differences in calculation methods may also play a role.

Table 2. National nitrogen balance sheets for Polish agriculture (kg of nitrogen per ha per year).

Source	Nitrogen flow	Nitrogen flow
Input	60	76
Output	31	12
Surplus	28	63
NUE	0.5	0.19

Source: first column: Langeveld (1994a); second column: Sapek (1999).

Farm level

Many applications of the balance sheet refer to the farm level. The use of farm level information has some advantages. Probably the most important advantage is the use of farm to farm data for major farm characteristics (especially fertilizer use, feed purchase, crop sales and yield levels), while national balance sheets often have to refer to average figures. The use of farm level data offers the possibility to assess differences between farms, and therefore is a useful tool to compare farming practices of a given area or district. We will give two examples here which both refer to Poland.

In the first example, Langeveld and Overbosch (1996a) used World Bank data to calculate nitrogen balances for 183 farms in two districts in Poland. Pilskie district, situated in the west of the country has mainly privately owned large farms (average size 13 ha). Fertilizer use is low with 120 kg of macro-nutrients (the sum of nitrogen, phosphorus and potassium) application per ha. Animal density is just over 1 Livestock Unit per ha; feed purchases are high (6 tons per farm per year). Farms in the centrally located Plockie district, are smaller (8.6 ha on average), use more fertilizers (200 kg of macro-nutrients per ha per year), and buy less feed (less than 3 tons per farm) at a comparable animal density. Results of the calculations are presented in Table 2. Average nitrogen surplus exceeds 100 kg of nitrogen per hectare. This is surprisingly high, considering the conditions that Polish private farmers were encountering in the year of the survey (in 1992 prices of fertilizers had just gone up considerably while output prices remained at their old levels). NUE of the whole sample is just under 0.3, but values in Pilskie district are clearly under this level.

Table 3. Nitrogen balance sheet for private farms in two Polish districts.

	Whole dataset	Pilskie	Plockie
Number of farms	183	81	102
Surplus (kg N/ha)	114	93	132
NUE (kg/kg)	0.29	0.23	0.33

Source: Langeveld and Overbosch (1996a).

Using a comparable approach, Pietrzak (1999) calculated nitrogen balance sheets for two watersheds. The Omulwia-Rozoga-Szkwa (ORS) watershed covers poor soil conditions. Light mineral soils as well as shallow organic soils dominate. Half of the area is covered with arable land, the remainder is in use for grazing. Soils in the Plonia watershed are good to very good, consisting of clay and sand material. Due to these conditions, grain yields are more than twice as high as those in the ORS watershed. While there is much less grassland here, animal density exceeds that in the ORS watershed (0.85 versus 0.63 Livestock Unit per ha). These figures are reflected in the nitrogen balance sheet that was drawn for both areas (Table 3). Differences between the watersheds are more extreme in comparison to those in the previous example. Nitrogen input in the P watershed is more than twice as high as the input in ORS watershed. Although output is more than five times higher, nitrogen surplus still is double that of the ORS watershed. This is reflected in the NUE of the P watershed, which is double that of the ORS area.

Table 4. Nitrogen balance sheet for two watersheds in Poland.

	ORS	P
Number of farms	443	230
Nitrogen input (kg N/ha)	53.4	129.3
Nitrogen output (kg N/ha)	8.5	40.8
Surplus (kg N/ha)	44.8	88.5
NUE (kg/kg)	0.17	0.35

Source: Pietrzak (1999).

Sub-farm level

If sufficient farm data are available, balance sheets can be calculated in a *step by step* approach: following nutrients from the moment they are entering the farm until they leave the farm area either as a crop or animal product, or as a (presumed) emission flow. This allows the calculation of sub-farm level sheets, describing nutrient flows at crop, animal or plot or rotation level. It can also be used to compare nutrient flows for crop and animal production systems respectively, as was discussed by Langeveld and Overbosch (1996b). Using the same dataset discussed above, they calculated sub-farm balance sheets, showing that highest nitrogen surpluses are associated with crop production, rather than livestock production (158 kg of N/ha versus 8 kg respectively). This may be surprising. It is explained by the fact that manure in this setup is defined as an output of the animal production system. The effect of this is reflected by the value of NUE for animal production. Excluding manure output, efficiency drops from 0.9 to 0.2.

Table 5. Nitrogen balance sheet at sub-farm level.

	Animal production	Crop production	Farm level
Nitrogen input (kg N/ha)	83.4	201.2	138.1
Nitrogen output (kg N/ha)	75.5	43.5	14.9
Surplus (kg N/ha)	7.8	157.8	123.2
NUE	0.91	0.34	0.13
NUE (excluding manure)	0.23	-	-

Source: Langeveld and Overbosch (1996b).

Explanation of nutrient surpluses I: graphical analysis

While applications of the nutrient balance approach so far are mostly referring to analysis of the situation (either the current situation or a future option), it may also be used in *explaining* the existence of a given nutrient management practice from farm characteristics. In this way nutrient surpluses are not only calculated, but also tentatively explained, allowing a discussion on what could be changed in order to improve the situation. Two applications are discussed here. First, we discuss a merely graphical methodology of analysis. Next, a statistical regression method is discussed.

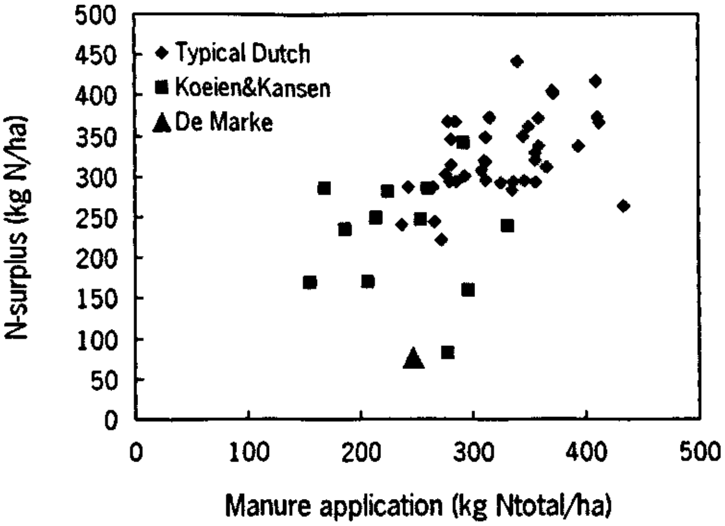

Figure 1. Nitrogen surplus depicted against manure application levels for Dutch dairy farms.

In a recent application in the Netherlands, Reijneveld et al. (2000) calculated nutrient balance sheets for Dutch dairy farms. Three (groups of) farms were included: an experimental farm called 'De Marke' (already introduced by Oenema (*this seminar*), which was developed solely to study emission reductions in dairy farming on sandy soils in practice), a series of pioneer farms - selected for a project on on-farm application of measures so as to reduce nutrient surpluses and emissions - and clusters of common Dutch dairy farms (referred to as 'typical Dutch' farms). Figure 1 shows nitrogen surplus of these farms depicted against manure application levels. While it is commonly thought in the Netherlands that highest nitrogen losses are associated with high animal density and hence manure application rates, this relation seems not so clear here. In stead, the authors found that surpluses seemed more related to fertilizer applications (Figure 2). It appeared, that dairy farmers applied fertilizer levels in exceedence of recommendations, and that highest nitrogen surpluses can be associated with highest exceedences (Figure 3).

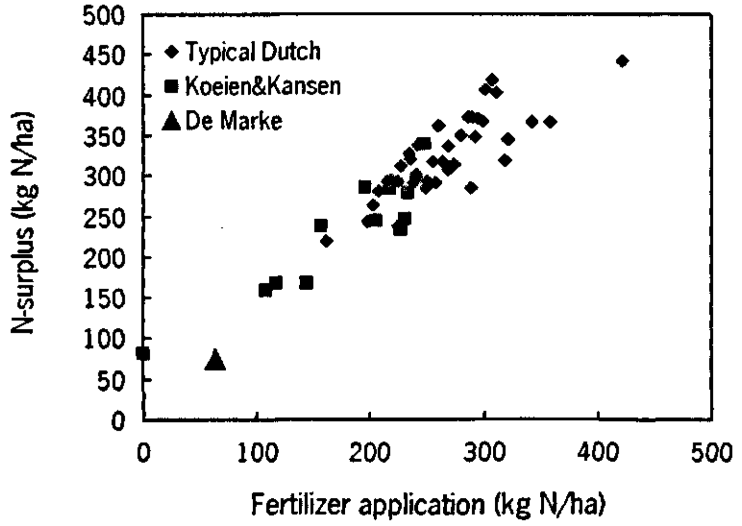

Figure 2. *Nitrogen surplus depicted against fertilizer application levels for Dutch dairy farms.*

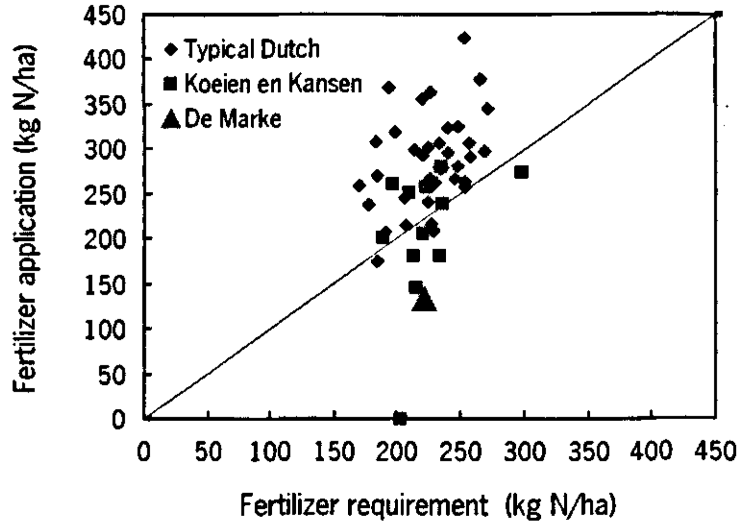

Figure 3. *Nitrogen surplus depicted against the exceedence of fertilizer recommendations.*

Explanation of nutrient surpluses II: regression analysis

Explanation of the nutrient surplus can also be done in a more formal way, by application of a regression model. We will give two examples here, both referring to Poland. Using their data on Pilskie and Plockie districts, Langeveld and Overbosch (1996a) designed a model for the explanation of nitrogen and phosphorus surpluses in the area. The model was used to check which factors are associated with the highest surpluses. Factors which appeared significantly in this respect are fertilizer use, animal density and crop choice, while farm size, farmers' age and farm location in either of the two regions showed not to be relevant. From Table 5 we can see that high nitrogen surpluses are expected on farms with high fertilizer applications, high animal density, large areas of grassland and small areas of sugar beets. From the model it further appears that 90 % of fertilizer applications are recovered in the nitrogen surplus. In other words, only 10 % of nitrogeneous fertilizers leave the farm in farm products, the remainder must be considered lost. The fact that high sugar beet area is associated with low surpluses is further suggesting that reduction of surpluses (and emissions) may be simply attained by adjusting cropping patterns, or selection of crop variety.

A comparable model was developed by Pietrzak (1999), be it that in this study also incoming nitrogen flows (fertilizer purchases, feed imports, legume fixation, etc.) are used as explanatory factors. While this is appealing, it is not correct in a statistical sense. Results, as presented in Table 6, show that animal density appears to be associated with low nitrogen surpluses, which is surprising. Further, grassland area is again associated with high surpluses, while highly educated farmers show lower surpluses that those who are less well trained (both is in line with expectations).

Table 6. Nitrogen surplus explained from farm characteristics.

Variable to be explained	Model definition
Nitrogen surplus (kg/ha) =	24.4 + 0.9*fertilizer application - 9.7*animal density + 7.9* (animal density)**2 + 8.8*grassland area - 3.9*sugar beet area + 0.06*(sugar beet area)**2
Nitrogen surplus (kg/ha) =	22.7 - 8.8*animal density - 1.6*famer's education + 0.068*share of grassland + 0.88*(amount of nitrogen in fertilizers) + 2.2* (amount of nitrogen in sowing material) + 1.3*(amount of nitrogen in animal feed) + 1.0*(amount of nitrogen fixed by legumes)

Source: first row Langeveld and Overbosch (1996a); second row Pietrzak (1999).

Model applications

While examples discussed so far only refer to the use of nutrient balance sheets as a stand-alone instrument in the analysis of an agricultural system (be it the national agricultural system, a farm, watershed or a sub-farm system), balance sheets can also be implemented in agricultural models. We will give two examples. The NUTMON approach is a relatively simple method, which aims at the design of appropriate nutrient management practices. The approach has been developed for and applied in Kenya (Jager et al., 1998), and combines calculation of nutrient sheet balances with interactive participatory design of alternative nutrient management practices. The fact that sheet calculations include map information, especially on soils, and that socio-economic data are used in the analysis makes this approach different from most other balance sheet applications.

The second example of a model applying nutrient balance calculations is the Nutrient Flow Model, that was developed for Dutch farm analysis. This model, described by Dijk et al. (1996), calculates nitrogen and phosphorus surpluses at farm, crop or animal level using a large, nationwide farm level dataset. While this dataset is limited in the type of data that is available, some flows are calculated using agronomic relations that were derived using more detailed data sets. The model is extended to economic farm level calculations which offer the opportunity to evaluate economic effects of alternative management practices. It is applied in farm level analysis, policy evaluation and interactive farm design. Currently, the model used in an ex-ante evaluation of the most recent policy measures on reduction of agricultural nutrient emissions in the Netherlands, where it is linked to a strategic farm model (for insight in long term farm adaptions) and a model for nutrient leaching and run-off (for a detailed calculation of nutrient losses to ground and surface water).

Policy evaluation

It has already been mentioned that farm balance sheets can be used in policy evaluation. An example for the Netherlands is presented by Dijk et al. (1996), who applied the Nutrient Flow Model for the evaluation of manure injection practices. Langeveld and Overbosch (1996b) used balance sheet data for an ex-ante evaluation of alternative measures to reduce ammonia emissions. First, ammonia emission figures were calculated. As most emissions originate from application of manure and fertilizers, three quarters appears to be associated with crop rather than livestock production. See also Table 7[1].

Table 7. *Ammonia volatilization at (sub-)farm level (kg NH_3 $farm^{-1}$).*

	Animal production	Crop production	Farm level
Stable/storage	100.7	-	-
Grazing	-	12.3	-
Manure application	-	228.4	-
Fertilizer application	-	133.9	-
Total	100.7	374.5	475.2

Source: Langeveld and Overbosch (1996b).

Next, alternative emission abatement measures were described in terms of investment requirements, operation costs and reduction efficiency. Measures included were stable adjustment, manure storage coverage, and manure injection. While investments were high for the first two, they were considerably lower for the latter (see Table 8). Comparing economic to emission figures shows that manure injection by far is the most economic measure, and that an economic policy towards reduction of ammonia emissions should concentrate on injection rather than on stable or storage adjustment. The cost for reduction of ammonia emission ranges between 1 and 1000 German Marks per kg of not emitted ammonia. Comparing these figures to those presented by Fejes (*this seminar*), shows that abatement costs for measures suggested by this author (costs of 2500 - 3500 Euro per ton of nitrate-nitrogen, which is equal to 5 -7 German Marks per kg of nitrogen per year), are very cost efficient, be it less efficient than manure injection.

Table 8. *Average emission reduction (kg NH_3 $farm^{-1}$), Required investment (Thousands of German Marks per farm), Annual Costs (Thousands of German Marks per farm) and Cost Efficiency (Thousands of German Marks per kg of NH_3) of volatilization reduction measures.*

Measure	Average reduction	Investments required	Annual Costs[a]	Cost Efficiency[b]
Stable adjustment	46.6	27.4	5.5	300 (924)
Storage covering	10.0	57.4	6.9	999 (2623)
Manure application	195.9	0	0.07	1 (3)
Total farm	252.5	84.8	12.5	119 (355)

a Calculated as initial investment divided by the total number of years effectively working, plus annual costs;

b Standard deviations are given between brackets. Source: Langeveld and Overbosch (1996b).

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[1] Calculation of fertilizer emissions were based on figures from literature. For Poland, with its acid soils, they may be expected to be somewhat lower. Still, they will remain considerable.

Discussion and Conclusion

After the extent of the nitrogen problem in Poland was elaborated, it was discussed how nutrient balance sheets can be used as an instrument in the analysis and the design of agricultural systems such as farms. They can be applied at any spatial or temporal unit, require relatively cheap data and have a strong conceptual impact. The major disadvantage of balance sheets is the fact that their application generally does not well reflect the variable and dynamic character of bio-physical processes involved in nutrient emissions. Applications which take this limitation into account can however be very informative and useful. In this paper, applications are discussed at the national level, as well as farm and subfarm level. In addition, balance sheet applications in graphical analysis, regression analysis, modeling and policy evaluation is discussed.

Analysis and design of agricultural systems is becoming more and more a process for quick and direct interaction, where direct calculations are used for immediate insight. Development of computer hard- and software further facilitate increased calculation and data storage capacity allowing cheaper and quicker calculations. In addition, analysis and design become more and more farm- and location-specific, requiring more and more tailor-made solutions for each farm or group of farms. In line with this, agrosystem development increasingly is becoming a bottom-up, interactive and participatory field of work, where several groups (farmers, researchers, and increasingly policy makers) from different levels cooperate in a process aiming at a successful system that combines goals of the subsequent participants: productivity, profitability, and sustainability. From the examples discussed above, it may be clear that nutrient balance calculations can offer a practical and valuable contribution to this development, be it applied in a model (as in NUTMON) or as a sole instrument.

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