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Nitrogen-mass flows and balances of dairy farms in the context of the German fertilizer ordinance

Übersetzung des Artikels:

„Stickstoffmengenflüsse und Bilanzierungen von milchvieh-haltenden Betrieben im Kontext der Düngeverordnung“

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Von Andrea Machmüller und Albert Sundrum

1 Introduction

The disruption of the natural nitrogen (N) cycle is one of the nine processes of the Earth system for which Rockström et al. see planetary boundaries (22), which should not be exceeded in the interest of a safe, environment-based livelihood of mankind. According to estimates by the team of authors, every year around 120 million tons of elementary nitrogen (N_2) are transferred from the atmosphere into reactive N-forms through predominantly agricultural activities. This amount of N exceeds the planetary limit by a factor of four (22, p. 473). In its current special report "Nitrogen: solution strategies for an urgent environmental problem", the German Advisory Council on the Environment (SRU) reveals that in 2012, 94% of ammonia emissions and 77% of nitrous oxide emissions in Germany originated from agriculture. Adding up all atmospheric emissions of reactive N-compounds (ammonia, nitrous oxide and nitrogen oxides), agriculture, with a share of 57%, also constituted the major source of emissions (25, p. 79). In addition, German agriculture, with a share of 79%, is also the main cause of reactive N-inputs into surface waters (25, p. 175) and mainly responsible for the high nitrate concentrations in near-surface groundwater (5, p. 5).

According to the Agricultural Expert Panel at the Federal Environment Agency (KLU), the reduction of the N-surpluses in German agriculture is rather slow to gain momentum (15, p. 3). So far, in Germany, the only political instrument for regulating and reducing farm N-surpluses in agriculture is the "Ordinance on the application of fertilizers, soil additives, cultivation substrates and plant additives according to the principles of good practice in fertilizing", or "Fertilizer ordinance (DüV)" for short. The Fertilizer ordinance is an essential part of the German action programme for the implementation of the "Council directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC)", in short "EC nitrates directive" (3). According to Article 1, the aim of the EC nitrates directive is "to reduce and prevent further pollution of waters caused by nitrates from agricultural sources". As part of the action programme to implement the EC nitrates directive, the German fertilizer ordinance must be reviewed for its effectiveness at least every four years in accordance with the EC nitrates directive (Article 5, paragraph 7 of the EC nitrates directive) and developed further if necessary. In 2012, a federal and federal-state working group evaluated the German fertilizer ordinance (2); on the basis of this evaluation, the German fertilizer ordinance was revised by the Federal Ministry of Food and Agriculture (BMEL). The plans envisaged that the amended German fertilizer ordinance was to enter into force at the end of 2015 (3). The draft ordinance (4, as at 18 December 2014) states under Article 15 (2) that it is planned for the future "to gradually replace the requirements for the nutrient comparison and its assessment laid down in Articles 8 and 9 ... from 1 January 2018 onwards by comparing the quantities of nutrients supplied to and delivered by the farm", i.e. the current area or aggregated field balance (10, p. 5) is to be replaced by the so-called "farm-gate balance".

In the context of these possibly changed framework conditions for the preparation of the legally required nutrient comparison, the present study was intended to investigate the consequences of this for the N-management of livestock farms and for the recording of the nutrient output from farms into the environment. The present study is based on current data on the use of nitrogen (N) collected on 36 dairy farms in Germany. The data sets collected on the farms depicted the external N-turnover of the farms as well as the complete internal N-mass flows. This resulted in a significantly expanded information and data situation for the individual farm compared to the compilation of the farm-gate balance as well as the area or aggregated field balance according to DüV (10). In a farm-gate balance, internal nutrient flows are not taken into account or, in cases of partial balances (area or aggregated field balance), are not recorded in full. However, in order to gain knowledge about the causes of varying N-surpluses and N-efficiencies, it is necessary to document and present all relevant N-mass flows of a farm (18; 21).

With regard to the German fertilizer ordinance as an instrument for regulating and reducing farm N-surpluses in agriculture, the evaluations of the data from the 36 dairy cattle farms were intended to provide assessments and statements as to the extent to which it is true:

(a) that the introduction of the farm-gate balance will ensure equal treatment of all types of agricultural farms;
(b) that efficient fertilizer management is the most important starting point for reducing the farm N-surplus;
(c) that the farm N-surpluses are estimated correctly when applying the German fertilizer ordinance.

2 Materials and methods

In agricultural operating systems, considerable N-quantities are relocated both on and off-farm. Figure 1 illustrates the course of N-mass flows in a dairy farm. In order to make the internal N-mass flows accessible to a corresponding quantification, the internal N-turnover was divided into four distinguishable sub-systems based on the conceptual considerations of KOHN et al. (16): (a) crop/feed storage; (b) livestock; (c) fertilizer storage; and (d) farmland. The N-output of one farm sub-system is at the same time the N-input of the subsequent farm sub-system. In addition, there might be an N-backflow from the sub-system of "crop/feed storage" to the "farmland" sub-system via the seeds and planting material, and if the farm has a biogas plant there will be an additional N-backflow from the "crop/feed storage" sub-system to the "fertilizer storage" sub-system. Additionally, the N-mineralization in the soil (here, according to the determination of fertilizer requirements (10, p. 2), the N_{min} at the beginning of vegetation) is regarded as a further internal N-supply in the sub-system of "farmland". In addition to the internal shifts of N-quantities, considerable N-quantities also pass through the so-called "farm gate", i.e. N-quantities leave the farm or are supplied to the farm from the outside. In Figure 1, the farm gate is marked as a circular line enclosing all internal sub-systems.

The present study was based on comprehensive farm data sets from 36 dairy farms. For each farm, among other things, the nutrient comparison in accordance with the German fertilizer ordinance was available for the fertilization year of 2013, including the raw data used for this purpose. According to the German fertilizer ordinance (10, Article 5 (1)), the nutrient comparison must be carried out annually for the previous fertilization year. The fertilization year always corresponds to a reference period of 12 months. In accordance with the specifications of the responsible federal-state authority, farms can choose from several 12 monthly periods (calendar year, business year as well as fodder year) when preparing the nutrient comparison (20, p. 8).

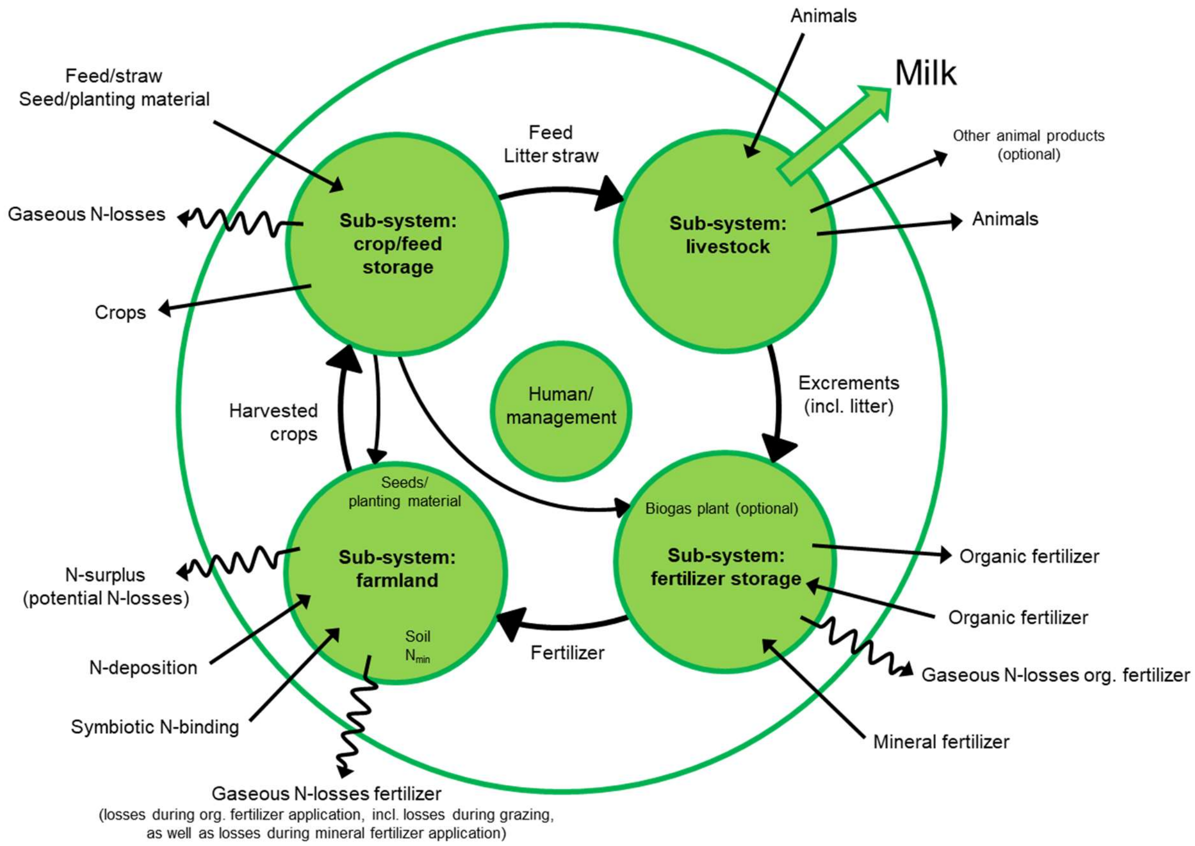

Figure 1: Illustration of the internal and external N-mass flows in a dairy farm. The green circular line enclosing all farm sub-systems marks the farm gate.
Source: Own illustration based on the "Four compartment model of an animal enterprise" of Kohn et al. (1997).

Nineteen of the 36 farms surveyed for the present investigation used data based on the calendar year (1 January 2013 to 31 December 2013) as an annual period for their 2013 nutrient comparison. In contrast, 13 farms chose the business year as a reference period (1 July 2012 to 30 June 2013), while 4 farms compared the data from the fodder year (1 May 2012 to 30 April 2013) for their nutrient comparison. The annual period summarized by the individual farms for their 2013 nutrient comparison was the reference period for all other annual farm data compilations in the present study. The fact that some farms differ by a few months with regard to the annual period summarized for the evaluations is regarded as acceptable for the subsequent studies, since the estimated N-quantities were always added up and balanced over the course of a whole year.

Table 1 shows the key data of the 36 dairy farms. The number of dairy cows on the farms varied from 52 to 2,541 (mean = 555, median = 383). The milk yield of the farms varied between 5,912 and 10,743 kg ECM/cow per year (ECM = energy corrected milk yield; milk with 4% fat and 3.4% protein). The number of livestock units (VE) per farm varied between 78 and 3,855 VE (mean = 822, median = 594), with values varying between 0.2 and 5.5 VE per hectare of agricultural land. With regard to the agricultural land available to the farms, figures ranged from 41 to 4,078 ha (mean value = 958, median = 550) with a variability in the proportion of grassland of 1 up to 85%. The 36 farms were spread over a total of 10 federal states (Table 2).

Table 1: Key data of the dairy farms for the evaluation period stating the mean, the standard deviation (SD), the lowest value (Min), the highest value (Max) and the median (n = 36)

		Mean	**±**	**SD**	Min	Max	**Median**
Livestock							
Dairy cows	(number)	555	±	561	52	2,541	383
Milk yield	(kg ECM/dairy cow and year)	9,047	±	955	5,912	10,743	9,192
Livestock units	(number)	822	±	847	78	3,855	594
Livestock units	(number/ha agricultural land)	1.3	±	0.9	0.2	5.5	1.3
Farmland							
Agricultural land	(ha)	958	±	1.061	41	4.078	550
Arable land	(ha)	720	±	806	6	3.300	388
Grassland	(ha)	238	±	329	8	1.708	102
Grassland	(% of the agricultural land)	33	±	21	1	85	27

Source: Own data collection and presentation.

Table 2: Distribution of the dairy farms examined across the German federal states

German federal state	**Number of farms**
Baden-Württemberg	0
Bavaria	3
Berlin	0
Brandenburg	4
Bremen	0
Hamburg	0
Hesse	3
Mecklenburg-Western Pomerania	0
Lower Saxony	2
North Rhine-Westphalia	3
Rhineland-Palatinate	1
Saarland	0
Saxony	8
Saxony-Anhalt	1
Schleswig-Holstein	5
Thuringia	6

Source: Own data collection and presentation.

The industrial partner in the project was the dsp-Agrosoft GmbH software company (Paretz, Parkring 3, 14669 Ketzin), which assisted in the search for suitable dairy farms. Accordingly, all 36 farms used the "Herde" software program by dsp-Agrosoft GmbH for the management of their dairy cow herd during the period under review. Thirteen of the 36 farms also used the feed ration planner "Futter-R" by dsp-Agrosoft GmbH in addition to the "Herde" program. A total of 19 of the 36 farms used a digital field-recording software. Ten farms used "AgroWIN" and six farms "AO5.0", both of which are field-recording software by LAND-DATA Eurosoft GmbH & Co KG (Rennbahnstr. 7, 84347 Pfarrkirchen). Three other farms used "Agrocom net" by Claas KGaA mbH (Münsterstr. 33, 33428 Harsewinkel). Information and data that were not digitally available to the researchers or did not exist in digital form were enquired during a farm visit on site.

The starting point for the present evaluations were the raw data the farms had compiled for the purpose of comparing the nutrients on their farms in accordance with the German fertilizer ordinance (10). The raw data of the nutrient comparisons at farm-level included detailed information: (a) on the average number of livestock: number of animals and housing conditions (slurry, dung or pasture); (b) on fertilizer use: type and quantity of organic fertilizers sold or delivered to other farms and type and quantity of organic or mineral fertilizers purchased or accepted from other farms; and (c) on crop harvests: cultivated plant species, areas and yields. The data from the individual farms were compared with the farm data provided by the additional data sources. With regard to livestock, the data source used was always the average number of animals obtained from the "Herde" data backup for the period under evaluation. The software "AODüngeverordnung" was used for own calculations regarding the farm-level nutrient comparison as well as for the estimation of the farm N-input and N-output quantities according to the German fertilizer ordinance (10). This software is a part of AOAgrar-Office and therefore also a software product of LAND-DATA Eurosoft GmbH & Co. KG. The present evaluations were carried out with the program version 1.14.14.3 and the module status of 14 October 2014. In order to improve the comparability of the farms, the raw data of all farms used in the AODüngeverordnung were evaluated according to the specifications of one federal state only (i.e. Baden-Württemberg). The calculation method for Baden-Württemberg was chosen because this calculation method provides useful, more differentiated information with regard to the N-excretion quantities of the livestock: (a) "gross", i.e. the N-excretion quantities of the livestock without deduction of losses; (b) "storage", after deduction of stable and storage losses; and (c) "field", after deduction of stable, storage and application losses.

In the following, a summary is given of the data origins used for the N-balances carried out for the entire farms and the four sub-systems.

Data origins for evaluations of the entire farm (farm-gate balance):
(a) from the farm accounting for the N-input with regard to the acquisition of feed, straw, seeds and planting material and the N-output with regard to the sale of crops and animal products other than milk (one farm sold sheep wool) using a factor of 6.25 to convert vegetable protein into N-quantities; (b) if available from the digital field records or otherwise estimated using the raw data of the farm-level nutrient comparison in the software "AO Düngeverordnung" for N-input via mineral and organic fertilizers as well as N-input via symbiotic N-binding and for N-output via organic fertilizers; (c) via the website of the German Environment Agency "Map service nitrogen background load data - reference year 2009" (28) to estimate the N-input through N-deposition (selected land-use class was "arable land"); (d) from the herd-management software "Herde" for N-input and N-output via animals using a factor of 3.2 kg N/100 kg live weight for calves up to the age of 4 months and 2.56 kg N/100 kg live weight for all other animals (26, p. 49); and (e) from the monthly dairy factory accounting for N-output through milk using a factor of 6.38 to convert milk protein to milk N-amounts.

Data origins for evaluations of the "crop/feed storage" sub-system:
(a) from the "farmland" sub-system for N-input via the harvested crop; (b) from the farm-gate balance for N-input through feed purchases and N-output through crop sales; (c) estimates using the equation of SCHRÖDER et al. (24, p. 267) for N-output for feeding the dairy cows and using typical values (8) for N-output for feeding all other farm animals; (d) using the software "AODüngeverordnung" for N-output of straw for litter; (e) using typical values (17) for the N-output via seeds and planting material; and (f) from the material records of the farm biogas plant for the N-output caused by supplying the biogas plant if a farm biogas plant existed.

Data origins for evaluations of the "livestock" sub-system:
(a) from the "crop/feed storage" sub-system for N-input via feed and litter straw; (b) from the farm-gate balance for N-input via animals and N-output via animals, milk and other animal products; and (c) estimates using the equation of SCHRÖDER et al. (24, p. 268) for N-output via dairy cows' excrements, and using the "AODüngeverordnung" software for N-output via excrements for all other animals.

Data origins for evaluations of the "fertilizer storage" sub-system:

(a) from the "livestock" sub-system for N-input through the farm's own organic fertilizer (excrements of the farm livestock); (b) from the "crop/feed storage" sub-system for N-input for the supply of the biogas plant if a biogas plant existed on the farm; (c) from the farm-gate balance for N-input via acquisition or intake of mineral and organic fertilizer and N-output through sales of organic fertilizer; (d) estimates using the "AODüngeverordnung" software for gaseous N-losses during storage of organic fertilizer (corresponding to the stable and storage losses according to DüV (10)); and (e) calculation from "sum of N-inputs" minus "N-outputs through sales or deliveries" minus "gaseous N-losses during storage of organic fertilizer" for "N-output fertilizer". At 21 of the 36 farms, all or part of the excrements from the "livestock" sub-system went into a biogas plant. In 13 of the 21 farms, the biogas plant was part of the farm. For the N-balance of these farms, the biogas plant was allocated to the "fertilizer storage" sub-system. For the remaining 8 farms, the biogas plant was located on another farm. In these cases, the N-input into the biogas plant and, where applicable, the N-return in form of organic fertilizer was accounted for via the farm gate (external N-turnover).

Data origins for evaluations of the "farmland" sub-system:

(a) from the "fertilizer storage" sub-system for N-input via fertilizers; (b) from the "crop/feed storage" sub-system for N-input via seeds and planting material; (c) where available, from farm soil sample analyses for N-input as mineralized and plant available N from the soil at the beginning of the vegetation period (N_{min}), otherwise in accordance with DüV (10, p. 3) from data-sets provided by the institutions responsible for advising farms under federal-state law; (d) from the farm-gate balance for N-input via N-deposition and symbiotic N-binding; (e) estimates using the "AODüngeverordnung" software in accordance with DüV (10) for gaseous N-losses during grazing and application of organic fertilizer and, where applicable, the subsequent consideration of any emission-reducing application techniques for liquid manure by applying typical values derived from DÖHLER et al. (9, p. 70); (f) estimates using emission factors for mineral fertilizers (7, p. 94) for gaseous N-losses during the application of mineral fertilizers; and (g), where available, for N-output via harvested crop from digital field records, otherwise estimates using the raw data of the farm-level nutrient comparison and the "AODüngeverordnung" software. For the calculations at field level (Tables 7 and 8), the data basis consisted of the data obtained from the digital field records of the selected farm.

In their entirety, the four sub-systems map the complete N-turnover of a farm and thus allow for a plausibility check of the recorded N-quantities. In order to assess the N-turnover of the farms, the N-inputs and N-outputs for the whole farm and for each of the four sub-systems were put into relation to each other. In the balancing of the N-mass flows, the N-balance (also N-surplus) was calculated as the difference between the N-inputs and the N-outputs. The N-utilization (also N-efficiency) resulted as the quotient between the N-output and N-input. To determine correlations (Pearson), the SPSS software was used (IBM SPSS Statistics 22, Version: 22.0.0.0). All further statistical evaluations and the illustration of the results were done with Excel (Microsoft Excel 2010, Version: 14.0.7153.5000).

3 Results

3.1 Nitrogen mass flows and balances of dairy farms

3.1.1 Overall farm level

Table 3 summarizes the annual N-quantities, N-balances and N-efficiencies of the 36 dairy farms at the level of the entire farm (farm-gate balance). On average, 274 ± 150 kg N/ha were imported through the farm gate and 170 ± 132 kg N/ha (including N-losses from storage and application of the organic and mineral fertilizers used) or 128 ± 131 kg N/ha (excluding N-losses) were exported through the farm gate during the 12-month-period considered. This resulted in an average gross N-balance of 146 ± 65 kg N/ha (without deduction of N-losses) and a net N-balance of 104 ± 52 kg N/ha (with deduction of N-losses). The average N-quantity exported from the farms corresponded to 44 ± 18% (gross N-efficiency) or 52 ± 18% of the imported N-quantity (net N-efficiency).

Table 3: Annual N-quantities, N-balances and N-efficiencies at the level of the entire farm stating the mean, the standard deviation (SD), the lowest value (Min), the highest value (Max) and the median (n = 36)

		Mean	**±**	**SD**	Min	Max	**Median**
Entire farm							
N-input	(kg N/ha)	274	±	150	100	1,020	264
N-output (without N-losses)	(kg N/ha)	128	±	131	39	821	94
N-output (with N-losses)	(kg N/ha)	170	±	132	62	864	136
N-balance (gross)	(kg N/ha)	146	±	65	41	287	145
N-balance (net)	(kg N/ha)	104	±	52	19	222	98
N-efficiency (gross)	(%)	44	±	18	23	81	41
N-efficiency (net)	(%)	52	±	18	29	89	51

Source: Own data collection and presentation.

Table 4 shows how the annual quantities of total N-input and N-output were distributed among the underlying partial quantities. At 45.8 ± 14.5%, the acquisition of mineral fertilizers accounted for the largest share of N-input among the farms, on average. In second place came the feed purchases, which amounted to 33.7 ± 14.4%. In third place, at 7.8 ± 5.6%, came the N-input via the N-binding of the legumes cultivated on the farmland. The atmospheric N-input came in fourth place with an average share of 6.1 ± 2.4%, followed by the N-input via the acquisition or acceptance of organic fertilizer with 5.7 ± 10.0%. The N-inputs for the purchases of seeds and planting material, straw or animals accounted for less than 1% of the annual quantities, respectively. At 29.5 ± 13.5%, the gaseous N-losses during storage and application of the organic and mineral fertilizers used on the farms accounted for the largest share of the total N-output, closely followed by the N-quantities which left the farms via the crops sold (28.1 ± 22.0%). The N-quantities which left the farms via the milk sold accounted for 25.1 ± 9.1% of the total N-output on average. With a share of 12.6 ± 18.0%, N-quantities of organic fertilizers sold or disposed of followed in fourth place. The average quantity of N leaving the farms through the sale of animals was less than 5% (4.6 ± 2.2%). Only one of the 36 farms surveyed sold another animal product than milk and meat, i.e. sheep's wool.

Table 4: Composition of the annual N-quantities at the level of the entire farm stating the mean, the standard deviation (SD), the lowest value (Min), the highest value (Max) and the median (n = 36)

		Mean	**±**	**SD**	Min	Max	**Median**
Entire farm							
N-input							
Purchase of mineral fertilizer	(%)	45.8	±	14.5	0.9	69.5	45.3
Purchase of feed	(%)	33.7	±	14.4	7.5	87.3	31.1
Symbiotic N-binding	(%)	7.8	±	5.6	0.5	21.7	6.0
N-deposition	(%)	6.1	±	2.4	1.4	15.0	5.8
Purchase of organic fertilizer	(%)	5.7	±	10.0	0.0	47.3	0.0
Purchase of seeds and planting material	(%)	0.4	±	0.3	0.0	1.2	0.3
Purchase of straw	(%)	0.3	±	0.9	0.0	4.4	0.0
Purchase of animals	(%)	0.2	±	0.4	0.0	2.1	0.0
N-output							
N-losses storage and fertilizer application	(%)	29.5	±	13.5	5.0	53.0	31.4
Crops sales	(%)	28.1	±	22.0	0.0	77.4	26.7
Milk sales	(%)	25.1	±	9.1	6.4	41.2	25.9
Sales of organic fertilizer	(%)	12.6	±	18.0	0.0	59.6	3.6
Animal sales	(%)	4.6	±	2.2	1.3	12.9	4.6
Sales of other animal products	(%)	0.0	±	0.0	0.0	0.1	0.0

Source: Own data collection and presentation.

3.1.2 Sub-system level

Table 5 shows the annual N-quantities, N-balances and N-efficiencies relating to the four sub-systems of the farms. On average, the annual N-input for the "crop/feed storage" sub-system was 284 ± 155 kg N/ha and the N-output 253 ± 146 kg N/ha. This results in an average N-balance for this sub-system of 31 ± 40 kg N/ha and an average N-efficiency of 90 ± 13%. In the "livestock" sub-system, the annual N-input was 208 ± 165 kg N/ha on average and the N-output 202 ± 161 kg N/ha, resulting in an average N-balance of 7 ± 6 kg N/ha. The N-efficiency relating to animal products sold was 24 ± 2% (relating to all animal products sold) and 20 ± 2% (relating to milk sold only). For the "fertilizer storage" sub-system, an average annual N-input of 287 ± 122 kg N/ha was calculated. Taking into account the gaseous N-losses due to storage of the organic fertilizers, an equally high N-output was assumed. Thus, the average gross N-balance for the "fertilizer storage" sub-system of the farms was 17 ± 9 kg N/ha (corresponding to the N-losses from this sub-system) and the net N-balance was 0 ± 0 kg N/ha (taking into account the N-losses as N-output). In terms of N-efficiency, this sub-system had a gross N-efficiency of 87 ± 4% (based on the quantity of organic fertilizers stored) or 94 ± 3% (based on all fertilizers stored) and a calculated net N-efficiency of 100 ± 0%. For the "farmland" sub-system, an average N-input of 301 ± 82 kg N/ha and an N-output of 175 ± 49 kg N/ha or 200 ± 61 kg N/ha, where the gaseous N-losses during application of the fertilizers were included, were calculated for the farms. This resulted in an average gross N-balance of 126 ± 42 kg N/ha for the "farmland" sub-system (without deduction of N-losses) and a net N-balance of 101 ± 36 kg N/ha (with deduction of N-losses), as well as a gross N-efficiency of 58 ± 6% and a net N-efficiency of 63 ± 8%. For the "farmland" sub-system, a second balancing in accordance with the current German fertilizer ordinance (10) was carried out. In the current German fertilizer ordinance, only the quantities entered via fertilizers and symbiotic N-binding are considered as N-inputs. For the 36 dairy farms, the calculation method according to DüV (10) resulted in an average N-input of 251 ± 81 kg N/ha. Where this N-input was compared with the N-output via crops and N-losses (fertilizer application), an average N-balance of 51 ± 36 kg N/ha and an N-efficiency of 79 ± 11 % resulted.

Table 5: Annual N-quantities, N-balances and N-efficiencies at the level of the sub-systems stating the mean, the standard deviation (SD), the lowest value (Min), the highest value (Max) and the median (n = 36)

		Mean	**±**	**SD**	Min	Max	**Median**
Sub-system: crop/feed storage							
N-input	(kg N/ha)	284	±	155	118	1058	273
N-output	(kg N/ha)	253	±	146	108	986	233
N-balance (gross)	(kg N/ha)	31	±	40	-40	176	29
N-efficiency	(%)	90	±	13	56	127	89
Sub-system: livestock							
N-input	(kg N/ha)	208	±	165	45	1007	187
N-output	(kg N/ha)	202	±	161	43	988	182
N-balance (gross)	(kg N/ha)	7	±	6	0	23	5
N-efficiency (all animal products)	(%)	24	±	2	17	31	24
N-efficiency (milk only)	(%)	20	±	2	14	27	20
Sub-system: fertilizer storage							
N-input	(kg N/ha)	287	±	122	100	742	284
N-output (without N-losses)	(kg N/ha)	270	±	117	92	714	272
N-output (with N-losses)	(kg N/ha)	287	±	122	100	742	284
N-balance (gross)	(kg N/ha)	17	±	9	0	35	17
N-balance (net)	(kg N/ha)	0	±	0	0	0	0
N-efficiency (gross)	(%)	94	±	3	89	100	94
N-efficiency (gross, org. fertilizer only)	(%)	87	±	4	82	100	86
N-efficiency (net)	(%)	100	±	0	100	100	100
Sub-system: farmland							
N-input	(kg N/ha)	301	±	82	164	516	295
N-output (without N-losses)	(kg N/ha)	175	±	49	90	283	172
N-output (with N-losses)	(kg N/ha)	200	±	61	102	321	184
N-balance (gross)	(kg N/ha)	126	±	42	57	273	117
N-balance (net)	(kg N/ha)	101	±	36	32	224	90
N-efficiency (gross)	(%)	58	±	6	47	73	58
N-efficiency (net)	(%)	63	±	8	50	83	63
N-input (DüV)	(kg N/ha)	251	±	81	108	468	241
N-output (DüV)	(kg N/ha)	200	±	61	102	321	184
N-balance (DüV)	(kg N/ha)	51	±	36	-13	176	45
N-efficiency (DüV)	(%)	79	±	11	58	109	79

Source: Own data collection and presentation.

Table 6 shows the composition of the annual N-input and N-output in the four sub-systems. In the "crop/feed storage" sub-system, the N-input via the farm's own crop averaged at more than two thirds (67.1 ± 13.9%). The N-input from feed purchases was just under one third (32.3 ± 13.6%). Further marginal N-inputs resulted from the purchases of seeds and planting material (0.4 ± 0.3%) as well as straw (0.3 ± 0.8%).

Table 6: Composition of the annual N-quantities at the level of the sub-systems stating the mean, the standard deviation (SD), the lowest value (Min), the highest value (Max) and the median (n = 36)

		Mean	**±**	**SD**	Min	Max	**Median**
Sub-system: crop/feed storage							
N-input							
Harvested crops	(%)	67.1	±	13.9	12.9	89.7	70.3
Purchase of feed	(%)	32.3	±	13.6	9.4	84.2	29.0
Purchase of seeds and planting material	(%)	0.4	±	0.3	0.0	1.0	0.3
Purchase of straw	(%)	0.3	±	0.8	0.0	3.6	0.0
N-output							
Feed for livestock	(%)	76.2	±	19.7	28.0	99.7	78.3
Crops sales	(%)	19.7	±	17.8	0.0	70.5	16.7
Feed for biogas plant	(%)	2.8	±	5.8	0.0	29.9	0.0
Litter straw	(%)	0.8	±	0.7	0.2	3.0	0.6
Seeds and planting material	(%)	0.5	±	0.3	0.0	1.3	0.4
Sub-system: livestock							
N-input							
Feed for livestock	(%)	98.5	±	1.2	95.5	99.7	98.9
Litter straw	(%)	1.1	±	0.9	0.2	3.7	0.8
Purchase of animals	(%)	0.3	±	0.7	0.0	3.2	0.0
N-output							
Animal excrements	(%)	75.3	±	2.5	68.0	82.1	75.6
Milk sales	(%)	20.9	±	2.5	14.9	27.5	20.9
Animal sales	(%)	3.8	±	0.8	2.3	6.5	3.8
Sales of other animal products	(%)	0.0	±	0.0	0.0	0.0	0.0
Sub-system: fertilizer storage							
N-input							
Animal excrements	(%)	49.4	±	15.3	12.8	92.1	51.0
Purchase of mineral fertilizer	(%)	42.6	±	13.8	0.9	68.6	42.6
Purchase of organic fertilizer	(%)	5.7	±	10.4	0.0	50.9	0.0
Feed for biogas plant	(%)	2.3	±	4.3	0.0	19.8	0.0
N-output							
Mineral fertilizer for the farmland	(%)	42.6	±	13.8	0.9	68.6	42.6
Organic fertilizer for the farmland	(%)	41.8	±	11.6	12.2	59.9	43.4
Sales of organic fertilizer	(%)	9.5	±	16.7	0.0	69.5	2.2
N-losses organic fertilizer storage	(%)	6.1	±	2.7	0.0	10.5	6.4
Sub-system: farmland							
N-input							
Organic fertilizer for the farmland	(%)	38.2	±	11.0	16.6	66.4	37.5
Mineral fertilizer for the farmland	(%)	37.8	±	10.6	1.2	57.1	37.8
N_{min} in the soil	(%)	12.3	±	4.1	5.8	24.5	12.2
Symbiotic N-binding	(%)	6.4	±	4.4	1.0	19.9	4.7
N-deposition	(%)	5.1	±	1.4	3.3	9.2	4.9
Seeds and planting material	(%)	0.3	±	0.2	0.0	0.8	0.3
N-output							
Harvested crops	(%)	87.9	±	3.6	80.6	95.2	88.5
N-losses organic fertilizer application	(%)	9.7	±	4.2	3.0	18.2	9.2
N-losses mineral fertilizer application	(%)	2.4	±	2.1	0.0	8.4	1.6

Source: Own data collection and presentation.

The main part of the N-output from the "crop/feed storage" sub-system (76.2 ± 19.7%) was accounted for by feed transferred to the subsequent "livestock" sub-system. On average, another 20% of the N-quantities (19.7 ± 17.8%) stored in the "crop/feed storage" sub-system were sold or left the farm via the farm gate. The N-outputs in the form of litter straw or seeds and planting material were relatively low at 0.8 ± 0.7% and 0.5 ± 0.3%, respectively. For the "livestock" sub-system, the feed supply from the feed storage accounted for almost the entire N-input with 98.5 ± 1.2%. Only small N-quantities were supplied to the "livestock" sub-system via the litter straw (1.1 ± 0.9%) or the acquisition of animals (0.3 ± 0.7%). About three-quarters of the annual N-quantities leaving the "livestock" sub-system were part of the intra-farm N-turnover and contained in the excrements of the animals kept on the farms (75.3 ± 2.5%). The remainder of the N-output from the "livestock" sub-system was products for sale, mainly the milk produced (20.9 ± 2.5%), but also animals sold (3.8 ± 0.8%) and, for one farm, the wool of the sheep it kept, accounting for 0.05% of the N-output from the "livestock" sub-system. For the "fertilizer storage" sub-system, there were two N-inputs of similar size, on average, on the one hand the supply of animal excrements from the "livestock" sub-system (49.4 ± 15.3%) and on the other hand the acquisition of mineral fertilizer (42.6 ± 13.8%). However, some of the farms examined also recorded an N-input via the acquisition of organic fertilizer (the average share of farms was 5.7 ± 10.4%). Some farms had their own biogas plant, which they also fed with feed from the feed storage (average N-input 2.3 ± 4.3%). With regard to the N-output from the "fertilizer storage" sub-system, there were also two similarly sized shares of N-outputs, via mineral fertilizers (42.6 ± 13.8 %) and organic fertilizer (41.8 ± 11.6 %), which were intended for internal use on the farmland. Some of the farms surveyed also sold their own organic fertilizers or delivered them to other farms. Across all farms, this resulted in an average N-output of 9.5 ± 16.7% of the annual N-quantity stored in the "fertilizer storage" sub-system. The gaseous N-losses that occurred during the storage of organic fertilizers on farms accounted for 6.1 ± 2.7% of the annual N-output from the "fertilizer storage" sub-system. Regarding the annual N-input into the "farmland" sub-system, six N-inputs were taken into account in the present study. On average, the N-input via fertilizers (organic fertilizer: 38.2 ± 11.0% and mineral fertilizer: 37.8 ± 10.6%) accounted for the largest share of the N-input with more than three quarters. However, relevant N-quantities were also added to the crops cultivated on the farmland via the soil (N_{min} at the beginning of the vegetation period), the air (N-deposition) and the cultivated legumes (symbiotic N-binding). Thus, the average value for N_{min} in soil was 12.3 ± 4.1%, for symbiotic N-binding 6.4 ± 4.4% and for N-deposition 5.1 ± 1.4%. The N-input via seeds and planting material was less relevant with a share of 0.3 ± 0.2%. Three components were quantified for the N-output from this "farmland" sub-system, the N-output via the crops and the gaseous N-losses during application of the organic as well as the mineral fertilizers. On average, the N-output from the harvested crop was 87.9 ± 3.6%. During the application of the fertilizers on the farmland, gaseous N-losses into the surrounding environment averaged at 9.7 ± 4.2% (organic fertilizers) and 2.4 ± 2.1 % (mineral fertilizers).

4 Discussion

4.1 Nitrogen-mass flows and balances of dairy farms show a high variability

Regarding structural features such as the size of the dairy cow herds, the agricultural land available, milk yield level, livestock density, proportion of grassland and proportion of harvested crops sold, the 36 dairy farms represent the wide range of production structures of dairy farms in Germany.

The average gross N-balance of all 36 farms in the farm-gate balance (overall farm level) was 146 kg N/ha with the net N-balance amounting to 104 kg N/ha. These values correspond to the results of other studies. SCHERINGER (23, p. 28) calculated an average gross N-balance of 146 kg N/ha for 39 dairy farms. The "Grassland project van Bruchem" (LHV, 19, p. 36) revealed an average gross N-balance of 141 kg N/ha for 16 dairy farms. KELM et al. (14, p. 30) published an average net N-balance of 117 kg N/ha for 8 dairy farms. However, the total gross N-efficiency of 52% determined in the present study was much higher than the values of SCHERINGER (23, p. 28), LHV (19, p. 36) and KELM et al. (14, p. 30), who gave average values of 25, 30 and 34%, respectively. The net N-balance of agricultural land (area balance) also revealed different values: 101 kg N/ha (present study) and 134 kg N/ha (14, p. 25). The results published by SCHERINGER (23, p. 13) were based on data from the years 1995 to 1998 and the data analysed by LHV (19, p. 36) and KELM et al. (14, p. 30) on data from the years 2003 to 2005. That means the farm data they used were between 8 and 18 years older than the farm data collected in the present study. It is also considered relevant that SCHERINGER (23, p. 11), LHV (19) and KELM et al. (14) collected their data in only one region or federal state (Lower Saxony or Schleswig-Holstein) with comparatively homogeneous farm structures.

Due to the large variety in the number of animals kept per farm and the area available for crop production, there were also large differences in the N-mass flows and balances of the farms in the present study. For better comparability, the N-inputs and N-outputs for both the entire farm and the four farm sub-systems were put into relation to the individually available agricultural land. At the overall farm level, the N-input of the farms varied between 100 and 1,020 kg N/ha with the N-output (excluding N-losses) varying between 39 and 821 kg N/ha. The resulting large differences in the farm N-balance (41 to 287 kg N/ha, gross N-balance) and the N-efficiency (23 to 81%, gross N-efficiency) show that the farms had different approaches to managing nitrogen as a resource. This also became clearly evident from the balancing values in the "farmland" sub-system. Here, the gross N-balance varied between 57 and 273 kg N/ha and the gross N-efficiency between 47 and 73%. The enormous ranges make it very clear that the N-emissions into the environment and the potential for making better use of nitrogen as a resource vary a lot between the farms. Calculations based on the present data set revealed that in relation to the N-balance of the entire farm, the worst 25% of farms had a gross N-balance of 230 kg N/ha on average and the best 25% of farms had a gross N-balance of 67 kg N/ha on average. Regarding the "farmland" sub-system, the gross N-balance for the best 25% of farms was 83 kg N/ha on average and 182 kg N/ha for the worst 25% of farms. As a result, even the apparently best farms overburden their agricultural land with considerable N-quantities.

4.2 A farm-gate balance discriminates dairy farms

According to the draft of the new German fertilizer ordinance (4, p. 22), the current requirements for the nutrient comparison at farm-level are to be gradually replaced by a farm-gate balance from 2018. A possible introduction of the farm-gate balance was controversially discussed in the federal and federal-state working group (BLAG) on the evaluation of the German fertilizer ordinance (2). The DüV regulates the fertilization of agricultural land, while a farm-gate balance must also record "material flows not directly related to agricultural land" (2, p. 40). This particularly applies to livestock farms, including the 36 dairy farms on which this study is based. In addition, BLAG (2, p. 40) also considered the recording of feed purchases and the sales of all plant and animal products to be very time-consuming. This would lead to additional problems for a robust balancing method applicable to all agricultural farms.

If sub-balances are generated for the farm, describing the entire farm operation, the balance of the entire farm will result from the sum of the farm's sub-balances (1, p. 14). In the present study, four sub-balances were carried out in accordance with the four specified intra-farm sub-systems. The comparison of the net N-balances at the level of the entire farm (farm-gate balance) and the net N-balances at the level of the "farmland" sub-system (area balance) therefore revealed a further important aspect in the present study with regard to a possible introduction of a farm-gate balance. Figure 2a shows that there was a positive correlation ($r = 0.624$; significance level $p < 0.001$) between the net N-balance of the entire farm and the net N-balance of the "farmland" sub-system. However, the point cloud of the 36 farms around the trend line shows a relatively large dispersion. For Farm no. 6, the net N-balance of the entire farm was 222 kg N/ha, while the net N-balance of the "farmland" sub-system was only 68 kg N/ha. On the other hand, for Farm no. 7, the net N-balance at overall farm level was much lower than the net N-balance calculated for the "farmland" sub-system (19 kg N/ha versus 57 kg N/ha). Farms no. 6 and no. 7 differed mainly in the N-balance of the sub-system of "crop/feed storage". Farm no. 6 had the largest N-balance of 176 kg N/ha in the "crop/feed storage" sub-system during the period under review and Farm no. 7 the lowest N-balance at -40 kg N/ha. In contrast to Farm no. 6, Farm no. 7 withdrew more N from the "crop/feed storage" sub-system than it had supplied to it during the same period. In the "crop/feed storage" sub-system it is possible to achieve negative N-balances. Due to the use of conservation methods (in particular drying and ensiling), on forage-producing farms such as the present dairy farms, the fodder harvested during the 12-month-period under review is often not completely fed to the farm livestock in the same 12-month-period. These farms usually have feed stocks from previous harvest years.

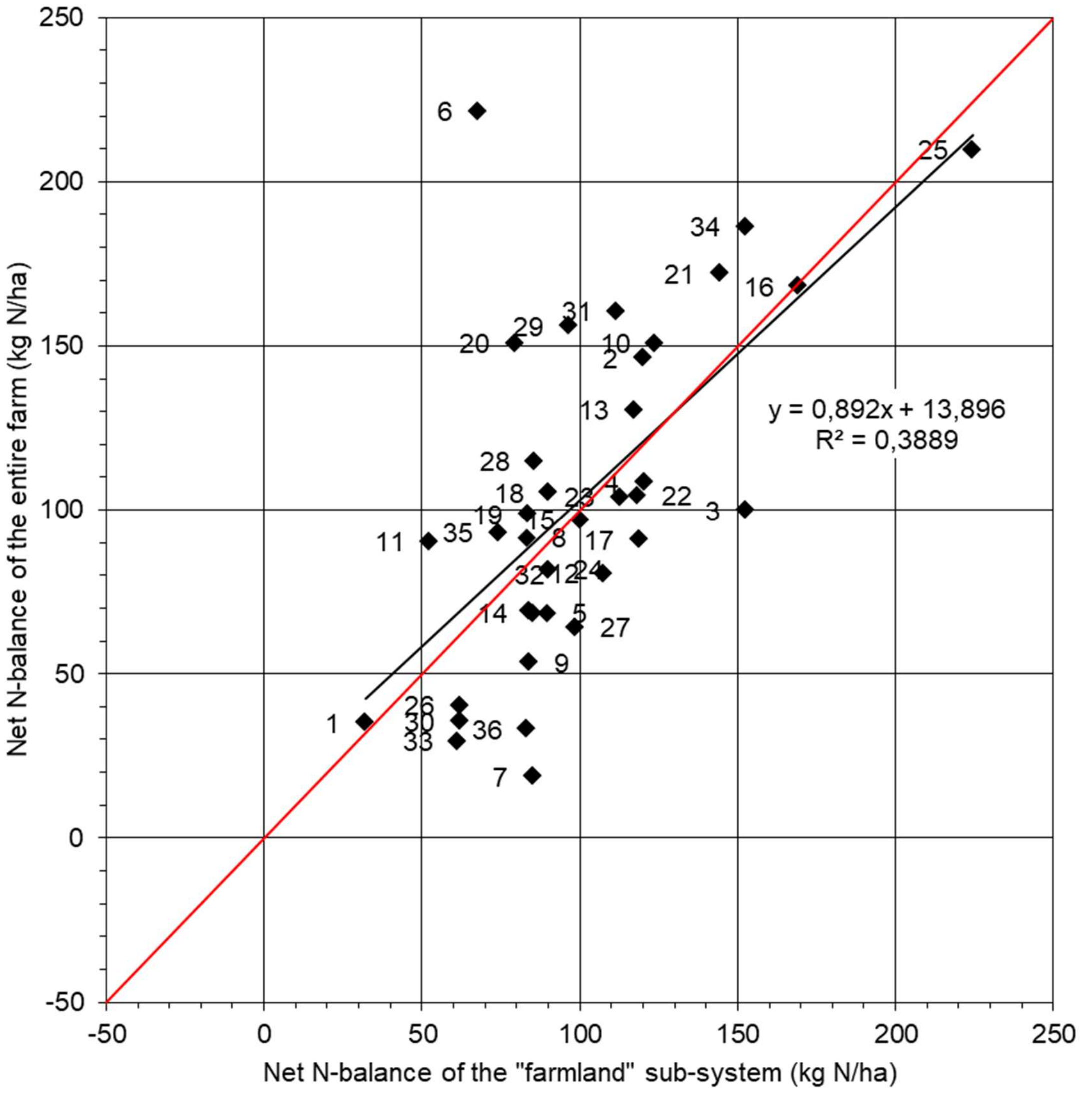

Figure 2a: Net N-balance of the entire farm in relation to the net N-balance of the "farmland" sub-system (n = 36). The red line indicates the 1:1 diagonal.
Source: Own calculations and illustration.

The possible differences in the input and output quantities in the "crop/feed storage" sub-system and the resulting positive or negative N-balances were taken into account in Figure 2b. For Figure 2b, the net N-balance of the entire farm was corrected by the N-balance of the "crop/feed storage" sub-system and then once more compared with the net N-balance of the "farmland" sub-system. This correction of the N-balance at the overall farm level improved the correlation between the N-balances to a value of r = 0.971 (significance level $p < 0.001$). Accordingly, the point cloud of the farms narrowed around the trend line. For all farms, the net N-balance of the entire farm was now smaller than the net N-balance of the "farmland" sub-system. In contrast to the balancing in the "farmland" sub-system, N-inputs via N_{min} were not considered at the overall farm level.

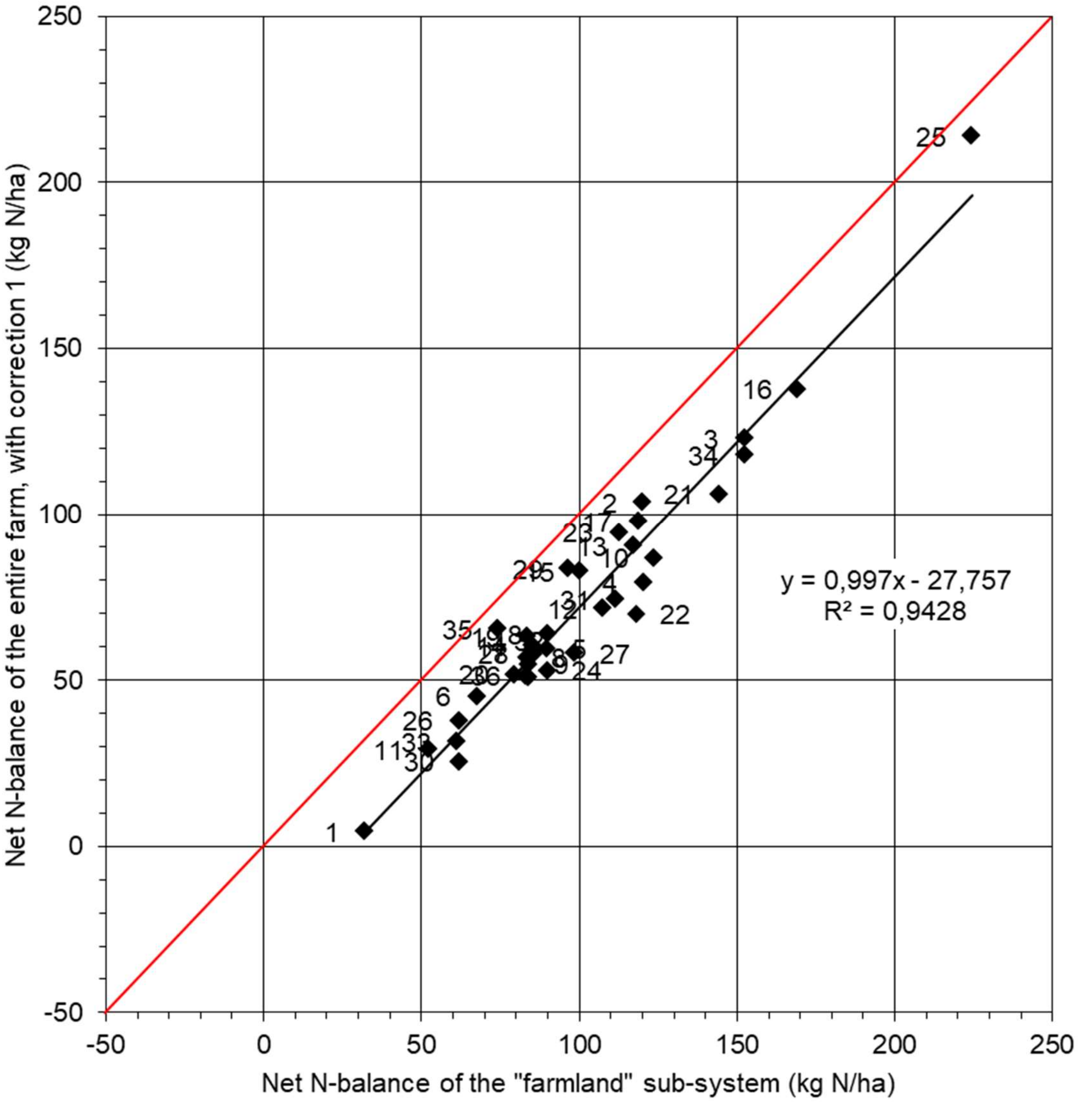

Figure 2b: Net N-balance of the entire farm (corrected for the N-balance of the "crop/feed storage" sub-system (correction 1)) in relation to the net N-balance of the "farmland" sub-system (n = 36). The red line indicates the 1:1 diagonal.
Source: Own calculations and illustration.

For Figure 2c, the net N-balance for the "farmland" sub-system was therefore calculated for all farms without the N-input of N_{min}. The correlation between the two net N-balances, entire farm and "farmland" sub-system, increased again to reach a value of r = 0.989 (significance level p < 0.001). For all farms, the net N-balance of the entire farm was now higher than the net N-balance for the "farmland" sub-system.

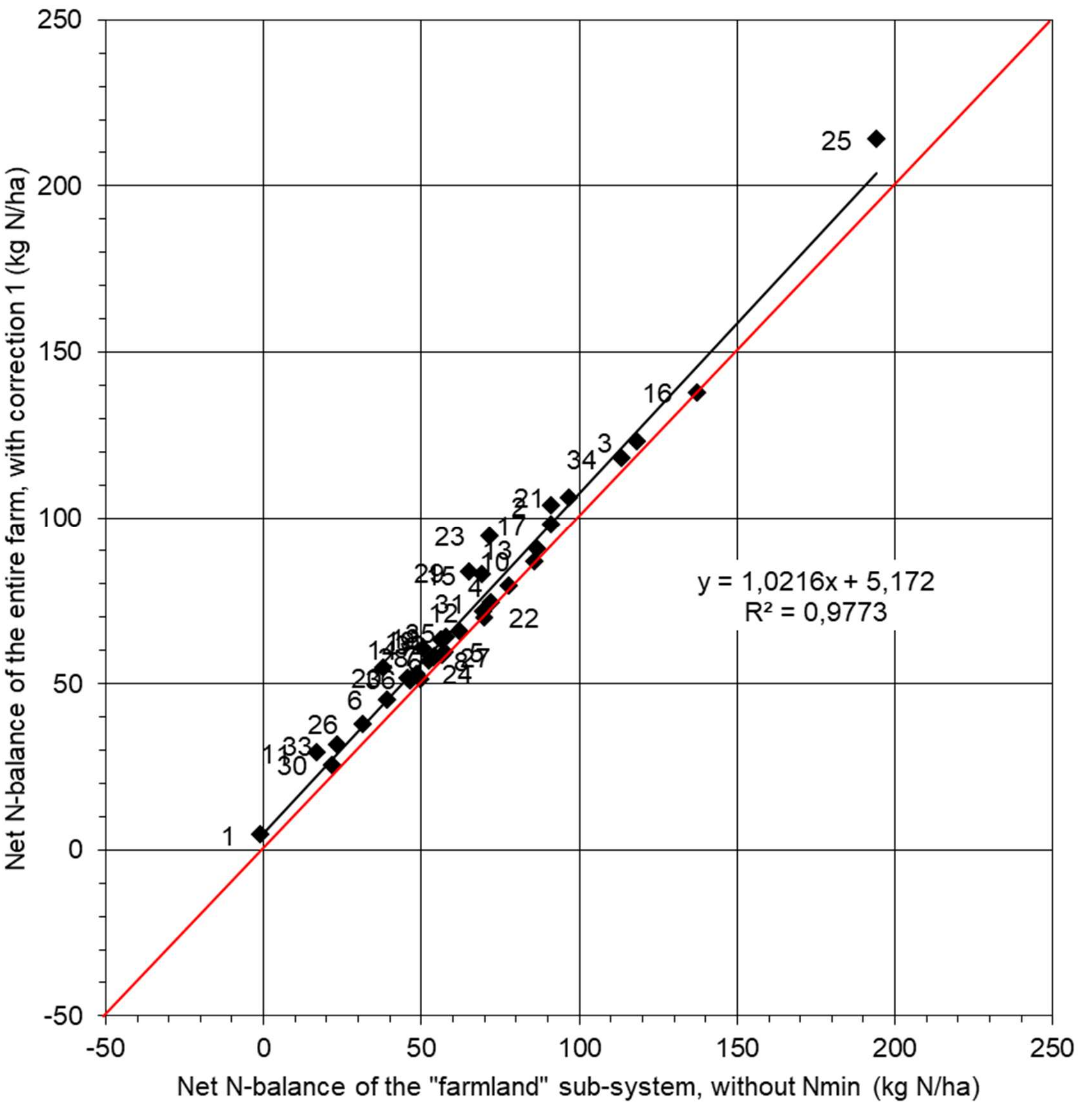

Figure 2c: Net N-balance of the entire farm (corrected for the N-balance of the "crop/feed storage" sub-system (correction 1)) in relation to the net N-balance of the "farmland" sub-system, without N_{min} (n = 36). The red line indicates the 1:1 diagonal.
Source: Own calculations and illustration.

Finally, for Figure 2d, the entire farm net N-balance of all farms was adjusted not only for the N-balance of the "crop/feed storage" sub-system but also for the N-balance of the "livestock" sub-system. This eliminated the differences between the net N-balance at the overall farm level and the net N-balance at the level of the "farmland" sub-system (r = 1.000; significance level $p < 0.001$). An adjustment for the N-balance of the "fertilizer storage" sub-system was not necessary, since, in accordance with the farm nutrient comparison (10), the net N-balance of the "fertilizer storage" sub-system was assumed to be even over a period of 12 months, i.e. here, the annual consumption values were used.

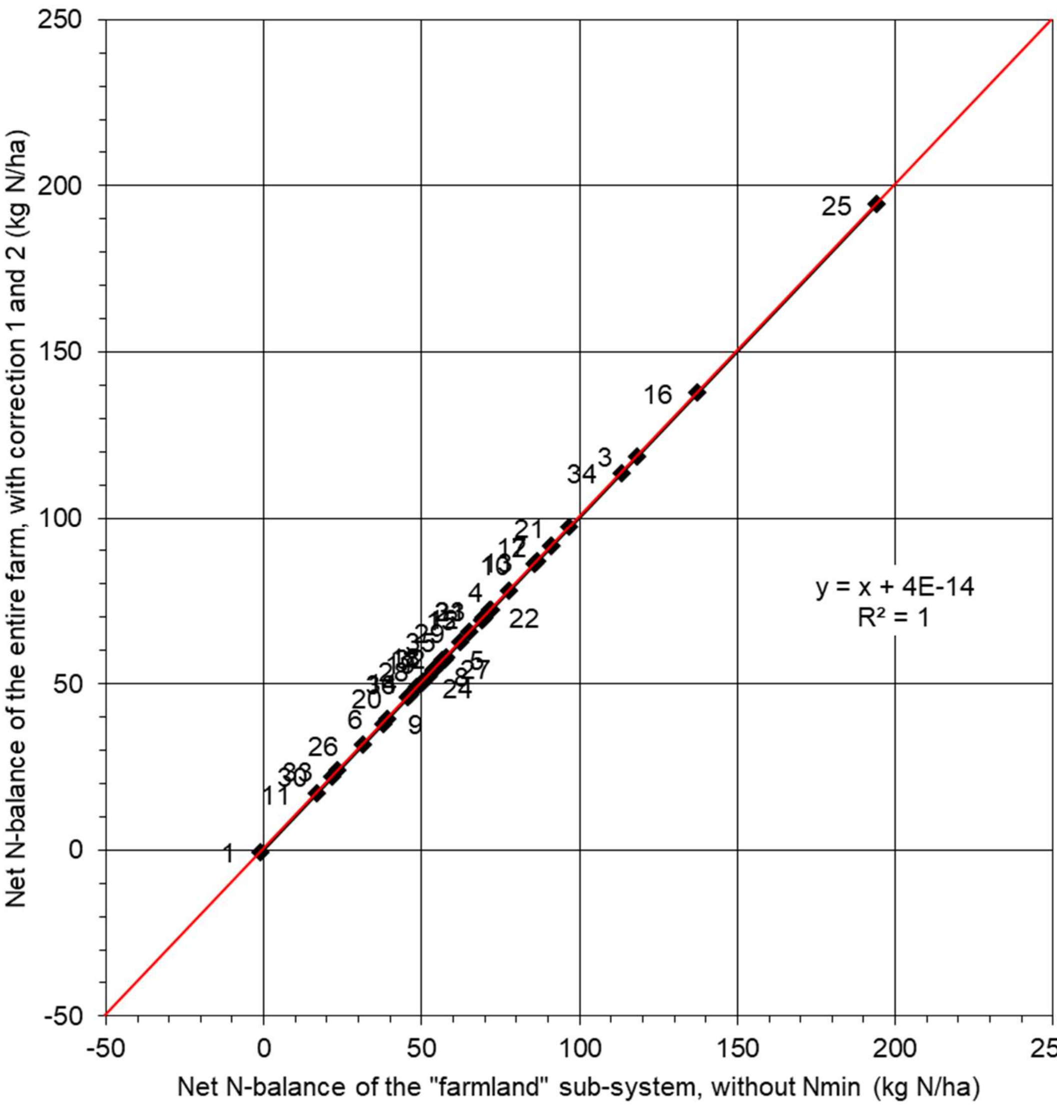

Figure 2d: Net N-balance of the entire farm (corrected for the N-balance of the "crop/feed storage" sub-system (correction 1) and corrected for the N-balance of the "livestock" sub-system (correction 2)) in relation to the net N-balance of the "farmland" sub-system, without N_{min} (n = 36). The red line indicates the 1:1 diagonal.
Source: Own calculations and illustration.

Across the 36 farms, an average N-balance of 31 kg N/ha was determined for the sub-system of "crop/feed storage" and 7 kg N/ha for the "livestock" sub-system. In total, an average of 38 kg N/ha of the overall farm N-surplus was located in the sub-systems of "crop/feed storage" and "livestock" and thus not on the agricultural land of the farms ("farmland" sub-system). Similar balance surpluses were also estimated by BACH and FREDE (1) in a "stable balance" for the German agriculture. For the years 1991 to 2000, the average stable balance was between 29 and 43 kg N/ha (1, p. 29). For the overall farm balance (farm-gate balance), which is composed of the two components, stable and area balance, the average overall farm N-surplus for the German agriculture was 113 kg N/ha, with 77 kg N/ha of the N-surplus being allocated to the agricultural land of the farms and 36 kg N/ha to the stable (1, p. 29).

Nitrogen that is still present in the various storage sites of the farm at the time of accounting (i.e. in the sub-systems "crop/feed storage", "livestock" or "fertilizer storage") cannot yet be regarded as "relevant to fertilization". In a nutrient accounting, therefore, these N-quantities should not be allocated to a fertilizer-relevant farm N-surplus. In his publication "Use of farm and field-related nutrient balances in agricultural consultancy against the background of the German fertilizer application ordinance", FRITSCH (11, p. 109) made two important statements: "The farm-gate balance differs from the field-stable balance in that the feed and manure produced and used on the farm are not taken into account" and "Without animal husbandry (fodder production and manure), the farm-gate and field-stable balance are identical anyway". The field-stable balance corresponds to the field or area balance (29).

With the existing data of the 36 dairy farms, "farms without animal husbandry" were simulated. That is to say that, at the overall farm level, the N-quantities relating to animal husbandry were taken out of the N-mass flows whereas the N-quantities relating to plant production were adjusted accordingly. In detail, this meant: (a) no animals, feed or litter are purchased; (b) no animals, animal products (milk, wool) or manure are sold; (c) the fertilization regime on the farmland remains the same (same use of organic and mineral fertilizers); (d) the crop produced on the farmland is sold in its entirety; and (e) the N_{min} value of the soils at the beginning of the growing season is also considered to be an N-input into the farm. This simulation of "farms without animal husbandry" would no longer result in a difference between the N-balance of the entire farm (farm-gate balance) and the N-balance for the "farmland" sub-system (area balance) for the 36 farms examined in this study. Across all 36 farms, both N-balances would then be 66 ± 36 kg N/ha on average.

How much N is purchased in the form of animal feed and how much N is stored in the sub-system of "crop/feed storage" depends on the number of livestock on the farm. With the present data set of the 36 dairy farms, a correlation of $r = 0.896$ (significance level $p < 0.001$) was found between livestock numbers (VE) and purchased feed (kg N) and a correlation of $r = 0.443$ (significance level $p < 0.01$) between livestock numbers (VE) and N-balance of the "crop/feed storage" sub-system (kg N).

From this it can be concluded that farms with large livestock numbers or large reserves of farm fodder in particular do not perform as well when the farm-gate balance is applied to assess a resourceful use of nitrogen on farms. This is also reflected in the differences between the two correlations between livestock numbers (VE/ha) and the net N-balance of the entire farm (kg N/ha) and between livestock numbers (VE/ha) and the net N-balance of the "farmland" sub-system (kg N/ha). The correlation coefficient with the net N-balance of the entire farm was $r = 0.421$ (significance level $p < 0.05$), but there was no significant correlation with the net N-balance of the "farmland" sub-system ($r = 0.232$; $p = 0.17$).

According to VDLUFA (29), the balancing method at the level of the farm gate considers changes in the stocks of purchased feed and market products sold. However, this method completely ignores N-quantities that can only be assigned to feed produced and used on the farm (11, p. 109). In most cases, farms do not trade their own feed such as maize and grass silage. Therefore, these feeds are not usually included in the feed passing through the farm gate and are therefore not taken into account when balancing at this level. Of the 36 dairy farms, only 31% sold their own maize silage and 19% their own grass silage, although 35 of the 36 farms produced their own maize silage and all 36 farms produced grass silage. The failure to take into account the exclusively internal use of N-stocks of the farm's own feed could also explain some of the discrepancies between the net-balances calculated using the farm-gate and field-stable method for cattle farms described by Gutser (12, p. 134).

4.3 The fertilizer management determines the amount of the farm N-surplus

A comparison of farm-level nutrient balances carried out in accordance with DüV (10) showed that forage-producing farms (including dairy farms, in particular) are as good or bad at using fertilizer as commercial farms (cash crop farms) and that the proportion of farms with a net N-balance of more than 60 kg N/ha was just under 15% (forage-producing farms) or 25% (cash crop farms) (2, p. 187). In the present study, the net N-balances calculated according to DüV (10) were found to be above 60 kg N/ha in 10 of the 36 dairy farms (equivalent to 28% of the farms).

In the present study, the fertilization of agricultural land is assigned to the "farmland" sub-system of the farms. Figure 3 compares the net N-balance of the "farmland" sub-system with the net N-efficiency. It was shown that with increasing N-efficiency, the N-balance and thus the N-surplus on the agricultural land decreased ($r = -0.613$; significance level $p < 0.001$). For the farms examined, N-efficiency values between 50 and 83% were determined. This is consistent with the range that JARVIS et al. (13, p. 215) identified for what is technically possible on the one hand and what is currently encountered in practice on the other: 53 to 76% N-efficiency. Figure 3 also shows that despite the same N-efficiency, the N-balance between farms can vary considerably. Thus, for Farm no. 25, an N-efficiency of 52% and an N-balance of 224 kg N/ha were calculated. Whereas for Farm no. 12, an N-efficiency equal to that of Farm no. 25 was coupled with an N-balance of 108 kg N/ha. This shows that in addition to improving the farm N-efficiency, the farm N-balance, which indicates the absolute amount of excess nitrogen on the farm, must continue to be taken into account.

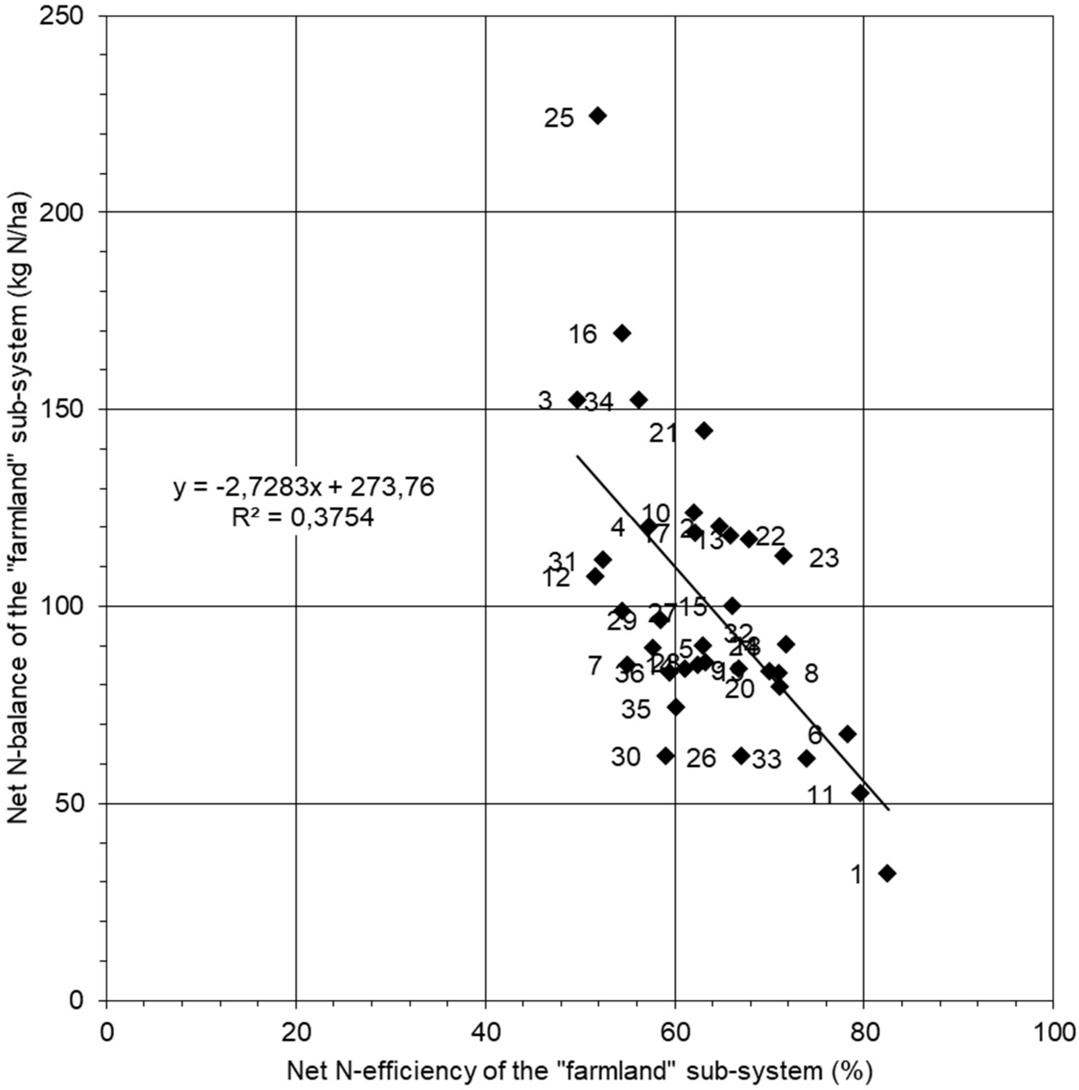

Figure 3: Net N-balance of the "farmland" sub-system in relation to the net N-efficiency of the "farmland" sub-system (n = 36).
Source: Own calculations and illustration.

The reasons why the two farms, no. 12 and no. 25, differed so much in the N-balance while showing the same N-efficiency can be explained by Figure 4. Here, the net N-input in the "farmland" sub-system was compared with the crop yield of the farms (net N-output of the "farmland" sub-system). Farms no. 12 and no. 25 differed both in the crop yield (115 versus 243 kg N/ha) and the net N-input (222 versus 467 kg N/ha) during the year under review.

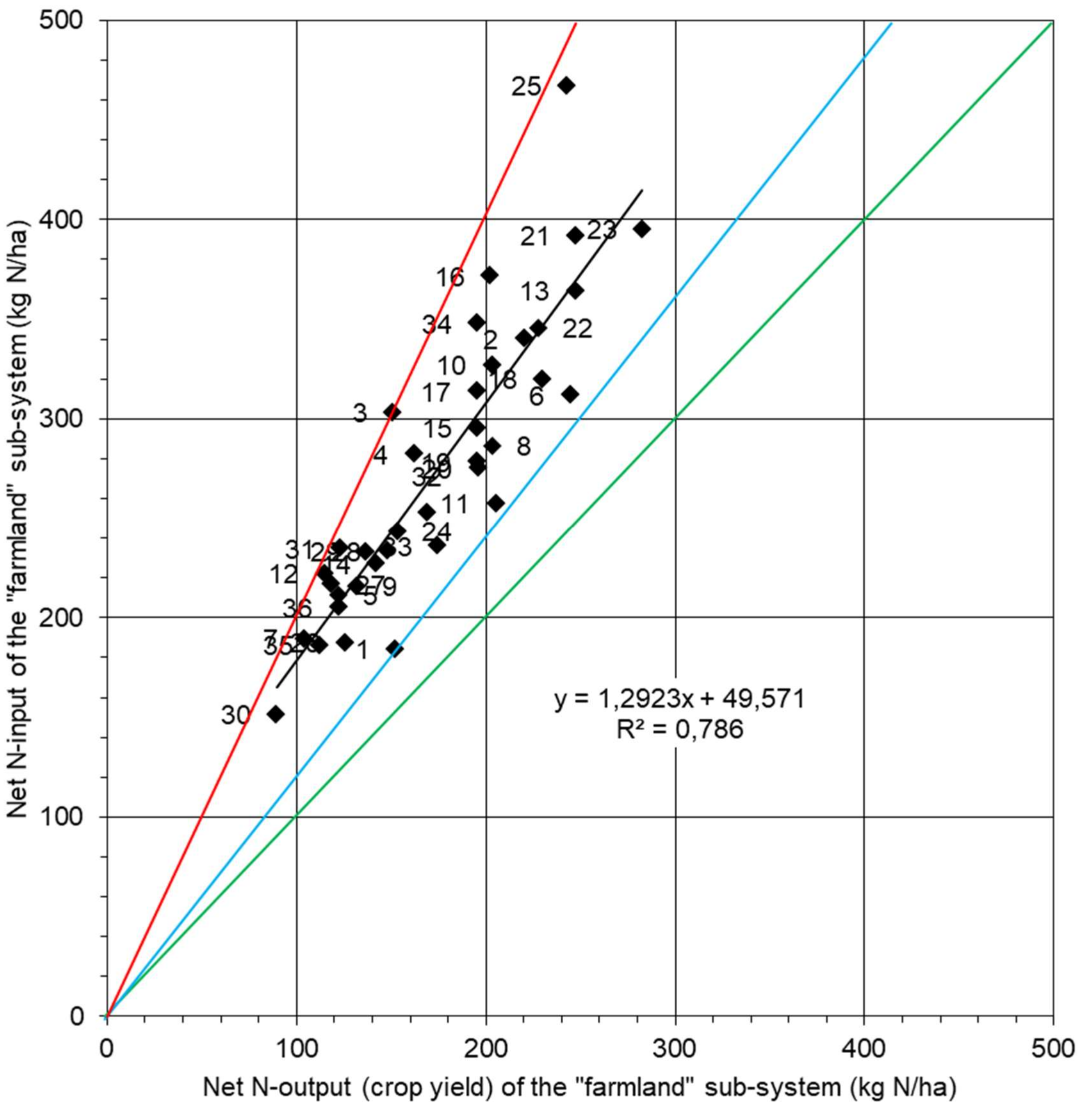

Figure 4: Net N-input of the "farmland" sub-system in relation to the net N-output (crop yields) of the "farmland" sub-system (n = 36). The green line indicates the diagonal (N-efficiency = 100%), the blue line crosses the farm with the highest N-conversion rate (N-efficiency = 83%) and the red line crosses the farm with the lowest N-conversion rate (N-efficiency = 50%).
Source: Own calculations and illustration.

Figure 4 shows that with increasing crop yields, the net N-input to the agricultural land increased as well (r = 0.910; significance level $p < 0.001$). At higher crop yields, however, the black trend line of the data moves further and further away from the ideal line (green line = 100% N-efficiency). Consequently, the transfer rate from the net N-input into the crop (= N-efficiency) deteriorates with increasing crop yields. This is also evident from the fact that the slope of the trend line is greater than 1.

On the other hand, even at approximately the same crop yield level, the farms showed different N-efficiencies (range between blue (= best operational N-efficiency, Farm no. 1 with 83%) and red (= worst operational N-efficiency, Farm no. 3 with 50%). Due to the fertilization management they chose, the farms were not equally “successful” in transferring the N-input into the crops growing on their agricultural land, i.e. they differed in the necessary synchronization of the N-input with the plant requirements (6). Thus, in addition to the level of the crop yield, it is, above all, the fertilizer management of the farms that determines the farm N-surplus. One example of unsuccessful fertilizer management offering huge possibilities for optimization is Farm no. 25. Farm no. 25 had a livestock population of 3.0 VE/ha and was therefore under a certain pressure to utilize its own manure accordingly. However, with regard to an over-fertilization of their agricultural land, the transfer of excess manure to other farms should be the better option for such farms.

4.4 The current calculation method underestimates farm N-surpluses

The farm N-surpluses resulting from fertilization occur at the field level. Nitrogen that is not bound in the soil or crops is at risk of: (a) being washed out into the groundwater in the form of nitrate; or (b) escaping into the air in the form of nitrous oxide. According to the German Advisory Council on the Environment (25), the total amounts of N that escape or are lost from agricultural land in Germany amount to 557,000 t N per year (N-input into surface waters: 457,000 t N (25, p. 175), N-input into the air via nitrous oxide 90,000 t N (25, p. 79)). Together with the likewise very extensive losses of ammonia (N-input into the air: 427,000 t N; 25, p. 79) resulting from the storage and application of fertilizers in agriculture, this constitutes a dramatic loss of N-resources for German agriculture and a considerable burden on the surrounding environment.

It is concluded from the results of the present study that the current calculation method used to determine the farm N-surplus (10) underestimates the N-surplus of the individual farm. On the one hand, this results from the fact that not all annual, area-related N-inputs are taken into account, and on the other hand from the fact that, at field level, negative N-balances are not correctly considered in the aggregated field balance. Negative N-balances at field level should be interpreted to mean that: (a) there was no "excess" nitrogen on these fields in the fertilization year; and (b) thus the "N-surplus" to be derived from these negative N-balances was zero. By definition of the term "surplus", a farm N-balance relevant for the calculation of the farm N-surplus is always above zero.

In order to illustrate the possible underestimation of the farm N-surplus, field-related data of one farm were evaluated. The selected farm was one of the few farms to keep continuous digital field records. In addition, the farm data given in the digital field records were consistent with the nutrient comparison submitted by the farm in accordance with DüV (10). In the 12-month-period evaluated, the selected farm managed a total of 1,242.7 hectares of agricultural land, divided into 258 fields 195 of which were grassland and 63 arable land. The average size of the fields was 4.8 ± 5.1 ha, with a range of 0.1 to 28.8 ha per field. A calculation according to DüV (10) resulted in net N-balances for the farm fields between -151 and +154 kg N/ha, with a negative net N-balance for 185 (176 of them grassland and 9 arable land) of the 258 fields. When further N-inputs were taken into account in the field balance (N_{min} at the beginning of the vegetation period, annual N-deposition as well as seeds and planting material), the farm field net N-balances were between -96 and +209 kg N/ha. Under these circumstances, only 50 (43 of them grassland and 7 arable land) of the 258 fields had negative net N-balances.

Using four different calculation methods in the aggregated field balance, Table 7 shows the results of the net N-surplus of the selected farm. The four calculation methods differed in terms of which N-inputs were taken into account and whether negative N-balances were equated with a zero N-surplus or not. It should be noted that these are the net N-surpluses and therefore the gaseous N-losses occurring during the storage and application of the fertilizers have already been deducted. For the selected farm, these gaseous N-losses amounted to a total of 25,347 kg N.

Table 7 shows that, applying the N-inputs according to DüV (10) and the official procedure for preparing the nutrient comparison using an aggregated field balance (27, p. 3), a total net N-surplus of 10,187 kg N can be calculated for the selected farm. When the negative net N-balances at field level were equated with a zero N-surplus, the calculated net N-surplus of the farm was more than three times higher at 31,611 kg N. There are also other field-related N-inputs on the agricultural land in addition to the N-inputs taken into account in the DüV (10): N_{min} at the beginning of the growing season and annual N-deposition as well as input through seeds and planting material. When these additional N-inputs were taken into account, a net N-surplus of 79,419 kg N or 82,821 kg N was calculated, depending on how the negative net N-balances were viewed at field level. As a consequence, one farm can have very different net N-surplus values, depending on the calculation method used. Despite the considerable discrepancy relative to the value of 10,187 kg N calculated according to DüV (10) it is assumed that a net N-surplus of 82,821 kg N comes closest to the actual farm value, since the annual N-input was estimated rather realistically (including further relevant N-inputs) and the negative net N-balances at field level were not used as a deduction for the positive net N-balances. Thus, it was shown for the selected farm that the current calculation method according to DüV (10) would detect only 12% of the actual net N-surplus of the farm. This is due to the fact that the current calculation method: (a) does not take into account all annual, area-related N-inputs; and (b) by a summation of the N-input and N-output at a higher level, a possible unequal distribution of the N-input over the fields or crops is levelled out.

Table 7: Net N-surplus of an exemplary farm using four different calculation methods for the aggregated field balance*

N-inputs taken into account	Negative N-balances	**Farm net N-surplus** kg N	%
Organic fertilizer, mineral fertlizer and symbiotic N-binding	N-surplus < 0	10,187	12
(according to DüV)	N-surplus = 0	31,611	38
Organic fertilizer, mineral fertlizer and symbiotic N-binding as well as N_{min},	N-surplus < 0	79,419	96
N-deposition and seeds/planting material	N-surplus = 0	82,821	100

Source: Own data collection and presentation.

**Explanatory notes: The calculation methods differed in terms of which N-inputs were taken into account and whether negative net N-balances were equated with a zero N-surplus or not.*

The data of the exemplary farm show that the allocation of N-inputs to the agricultural land, crops or single fields is not always exactly based on the demand of the crops. For the exemplary farm, Table 8 gives an overview of how the farm net N-surplus from Table 7 was spread across the different crops grown during the 12-month-evaluation period. The net N-surpluses for the different crops on the farm, calculated by means of aggregated field balances, differed considerably. For the selected farm, it was found that in relation to the area under cultivation: (a) the crops grown on the arable land had higher net N-surpluses than the grassland; (b) winter crops had a higher net N-surplus than summer crops; and (c) winter oilseed rape was the crop with the highest net N-surplus.

Table 8: Allocation of the farm net N-surplus to the crops grown on the exemplary farm*

	Crop-related net N-surplus			
	Considering the N-inputs according DüV		Considering further N-inputs	
Crop	**kg N**	**kg N/ha**	**kg N**	**kg N/ha**
Winter oilseed rape	8,354	74	14,582	129
Winter barley	4,362	59	8,622	117
Silage maize	3,722	44	8,394	100
Spring barley	3,465	40	8,271	96
Spring oats	1,590	33	4,398	91
Triticale	2,763	33	7,520	90
Grass-clover	1,166	16	4,132	57
Grassland	6,189	9	26,901	39
Total	**31,611**		**82,820**	

Source: Own data collection and presentation

**Explanatory notes: For the calculation of the crop-related net N-surplus, two calculation methods were used in the aggregated field balance. On the one hand, only N-inputs according to the current DüV were considered, and on the other hand, further N-inputs (N_{min}, N-deposition and seeds/planting material) were taken into account. For both calculation methods, a possible negative net N-balance was equated with a zero N-surplus.*

5 Conclusions

The experience gained in connection with the data evaluation of the 36 dairy farms supports the statement already made by the VDLUFA (29, p. 5) and the WBA (30, p. 332) that only a farm-gate balance will produce reproducible and justifiable results with regard to a farm-level nutrient balance. However, the results of the current study suggest that when introducing the farm-gate balance, especially for forage-producing farms such as dairy farms, it must be taken into account in the annual nutrient balance that substantial N-quantities may be located in the stocks of the farm's own forage production. These N-quantities would be disregarded if the external N-turnover was recorded according to the farm-gate balance only, resulting in the N-balance of such farms being adversely affected in comparison with other farms such as cash crop farms.

In addition, the results of the present study show that even if the internal N-stocks are considered in the calculation of the farm-gate balance, the farm N-surplus could still be considerably underestimated. This is due to the effect that, at the level of the farm gate, the actual distribution of fertilizer-relevant N-inputs on the agricultural land remains unrecognized. Therefore, a farm-gate balance should be reasonably combined with information from the field balance. The VDLUFA (29, p. 9) has already recommended a combination of farm-gate and field balance, arguing that this was the only way "to meet the increasing requirements on the ability to control ..., to locate deficiencies within the farm ... and to optimise fertilization in a targeted manner". A first step in this direction can be seen in the fact that the determination of the nutrient requirements, which, according to DüV (10, p. 2), must be carried out for each field or crop-management unit, will be subject to the obligation to make written records and to keep these records for possible controls in the future (4, as of 18 December 2014) (Art. 10 (1)). This is the only way to create a greater awareness of the required "balance between the expected nutrient requirements and the nutrient supply" (10, Art. 3 (1)) in agricultural practice, which should be the aim for all areas of a farm.

Having established such a written documentation of the field- and crop-related determination of the nutrient requirements in agricultural practice, the next logical step could be to apply the DüV threshold value with regard to the tolerable N-surplus at the level of the fields or crops as well. The fact that the real farm N-surplus can only be determined at this level is being made sufficiently clear by the present research results. A correct quantification of the farm N-surplus would become particularly relevant if the claim of the German Advisory Council of Environment (25, p. 349) to introduce a tax on N-surpluses was realized.

Summary

The present study is based on extensive farm records regarding the annual N-turnover of 36 dairy farms. The following statements can be derived from the N-mass flows and balances calculated:

- Dairy farm N-mass flows and balances show a high variability.
- A farm-gate balance is to the detriment of a large proportion of dairy farms respectively forage-growing farms.
- Where fertilization of arable land is concerned, dairy farms respectively forage-growing farms operate just as well or as badly as cash crop farms.
- Apart from improving the farm N-efficiency, the level of the farm N-surplus needs to be continuously monitored.
- The level of the farm N-surplus is predominantly determined by the farm’s harvest yields and fertilization management.
- Given the current calculation methods, many of the farm N-surpluses and their inherent risks for the environment tend to be considerably underestimated.

Zusammenfassung

Stickstoffmengenflüsse und Bilanzierungen von milchvieh-haltenden Betrieben im Kontext der Düngeverordnung

Die Grundlage der vorliegenden Untersuchung waren umfangreiche Betriebsdatensätze zum N-Umsatz eines Jahres auf 36 milchviehhaltenden Betrieben. Aus den daraus ermittelten, betrieblichen N-Mengenflüssen und Bilanzierungen können nachfolgende Aussagen abgeleitet werden:

- Die N-Mengenflüsse und N-Bilanzen milchviehhaltender Betriebe zeigen eine hohe Variabilität.
- Eine Hoftorbilanz benachteiligt einen Großteil der milchviehhaltenden Betriebe beziehungsweise Futterbaubetriebe.
- In Bezug auf die Düngung der landwirtschaftlichen Nutzflächen wirtschaften milchviehhaltende Betriebe beziehungsweise Futterbaubetriebe genauso gut oder schlecht wie reine Marktfruchtbetriebe.
- Neben einer Verbesserung der betrieblichen N-Effizienz muss die Höhe des betrieblichen N-Überschusses weiterhin im Blickfeld bleiben.
- Über die Höhe des betrieblichen N-Überschusses entscheiden vor allem das Niveau der betrieblichen Ernteguterträge sowie das betriebliche Düngungsmanagement.
- Mit dem derzeitigen Berechnungsverfahren werden die betrieblichen N-Überschüsse und damit das Gefahrenpotenzial für die Umwelt für viele Betriebe wahrscheinlich erheblich unterschätzt.

Résumé

Les flux de quantité d’azote et la comptabilisation d’exploitation de cnsacrant à l’élevage de bétail laitier dans le contexte de l’ordonnance relative aux engrais

La présente étude est basée sur des vastes séries de données sur la transformation annuelle d’azote dans 36 entreprises laitières. L’analyse des flux opérationnels d’azote et des bilans mène aux conclusions suivantes:

- Les flux et les bilans d’azote des entreprises laitiéres sont hautement variable.
- Un bilan à partir de l‘exploitation (farmgate balance) s’avère être au détriment d’une grande partie des exploitations laitières ou fourragères.
- En ce qui est de la fertilisation des superficies agricoles, les exploitations laitières ou fourragères gèrent aussi bien ou mal que les exploitations d’aliments destinés à la vente.

- Outre une amélioration de l'efficacité d'azote, un regard attentif sera à jetér sur l'ampleur de l'ecxédent d'azote dégagé par l'exploitation.
- L'ampleur de l'excédent d'azote de chaque exploitation est déterminée surtout par le niveau de rendements des récoltes ainsi que le gestion des fertilisants.
- Pour beaucoup d'enterprises et avec la méthode de calcul actuelle, les excédents d'azote des exploitations et alors les dangers potentiels pour l'environnement risquent d'être considérablement sous-estimés.

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