Mineral Concentrates Pilot; synthesis of the results of 2011

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Abstract

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The agronomic and environmental impacts of the production of mineral concentrate and its use as mineral nitrogen (N) fertilizer are examined in a pilot. In this pilot, the mineral concentrate is applied as fertilizer above the application standard for manure, but within the total N application standard (i.e. sum of effective N from manure and mineral fertilizer N) of the Nitrates Directive. The research in 2011 included monitoring of the manure treatment installations, incubation studies to assess immobilization and denitrification of soil-applied mineral concentrate, pot experiments to determine N efficiency of mineral concentrate under controlled conditions, and field experiments to determine N efficiency of mineral concentrate when used for grassland and arable crops. This report summarizes the main results of these studies. The research data will serve for consultation with the European Commission on a possible permanent permission to use mineral concentrate as mineral N fertilizer.

Keywords: manure, mineral fertilizer, manure treatment, mineral concentrate, nitrogen, nitrogen fertilizer replacement value, slurry

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Preface

A pilot study is being carried out in the Netherlands, with the consent of the European Commission, on the agricultural and environmental impacts of the production and use of mineral concentrate as mineral fertilizer. In the pilot, the mineral concentrate is used as mineral fertilizer above the application standard for manure application, but within the nitrogen application standards of the Nitrates Directive. The data from the study will be used for consultation with the European Commission on a possible permanent permission to use mineral concentrate as a mineral nitrogen fertilizer.

The study was conducted by several institutions of Wageningen UR, in close collaboration with representatives of the eight plants which produced mineral concentrate. The eight plants that participate in the pilot are Bmec Salland, KUMAC B.V., Loonbedrijf Jan Reniers (MVS), Van Heugten-Friesen, Maatschap Gebroeders Van Balkom, Houbraken B.V., Kempfarm B.V. and Vermue Poelma.

The research in the pilot was directed by the agricultural industry (Dutch Federation of Agriculture and Horticulture, LTO Netherlands and the Dutch Union of Pig Farmers NVV), the Ministry of Economic Affairs, Agriculture and Innovation (EL&I) and the Ministry of Infrastructure and Environment (IenM). The research was funded by the Dairy Board, the Livestock and Meat Marketing Board, the Ministry of EL&I and the Ministry of IenM. The synthesis in this report is partly based on additional research, funded by the Provinces of Drenthe, Overijssel and Groningen and the Ministry of EL&I.

The different studies in the period 2009 - 2011 are reported separately and a synthesis of the research of 2009 and 2010 has been published in 2011. This report provides a summary and synthesis of the research conducted in 2011

Wageningen, October 2012

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Summary

Treatment of manure can improve the use efficiency of nutrients. One of the possibilities is separation of slurry and using the mineral concentrate that results from reverse osmosis of the liquid fraction as mineral nitrogen (N) - potassium (K) fertilizer. Mineral concentrate is a fertilizer which is manufactured by an industrial process, according to the definition of fertilizer in the Nitrates Directive. It is expected that the characteristics of the concentrate differ from that of animal slurry. However, a mineral concentrate is animal manure, according to the definition of the Nitrates Directive as it is a processed form of animal manure. Therefore, its use is limited by the application standards for manure. The agricultural business (LTO Netherlands and NVV), the Ministry of Economic Affairs, Agriculture and Innovation (EL&I) and the Ministry of Infrastructure and Environment (IenM) investigate, with the consent of the European Commission, the agricultural and environmental effects of the production and use of mineral concentrate to be used as mineral fertilizer (or chemical fertilizer). This approach intends to contribute to a sound disposal of animal slurry and fits in the quest for further closing nutrient cycles. The data from the pilot will be used for consultations with the European Commission on a possible permanent permission to use mineral concentrate as a mineral N fertilizer. This means that mineral concentrate can be applied above the application standard for manure, but within the total N application standard (i.e. the sum of effective N from manure and mineral fertilizer N).

During 2009 and 2010, the eight animal slurry treatment plants for the production of mineral concentrate were monitored, agricultural and environmental impacts of application of mineral concentrate as fertilizer were experimentally determined, and an economic analysis and Life Cycle Assessment (LCA) were carried out. At the end of 2010 the pilot was extended. In 2011 additional research was conducted. Partly it was a continuation of on-going research and partly it was new research aiming to find an explanation for the low N efficiency of mineral concentrate that was sometimes found on grassland in 2009.

This report summarizes the results of the research of 2011. This research included a monitoring of the manure treatment installations, incubation studies to assess immobilization and denitrification of soil-applied mineral concentrates, pot experiments to determine N efficiency of mineral concentrate under controlled conditions, and field experiments to determine N efficiency of mineral concentrate applied to grassland and arable crops.

In 2011, four plants were monitored in detail. The average N content of the concentrates increased from 7.22 g per kg in 2009 to 8.15 g per kg in 2011. The K content also increased, and the phosphorus (P) and organic matter contents decreased in this period. The average fraction of NH_4 in total N increased from 0.90 in 2009 to 0.92 in 2011. It is concluded that the quality of mineral concentrate as a mineral N-K fertilizer has slightly increased over time. The composition of mineral concentrates differed between the different treatment plants. The differences between the plants are due to technical differences between installations, differences in management of the process, and differences in composition of the treated slurry. The results also showed that the slurry treatment plants are able to produce concentrate of a relatively stable composition.

The mineral concentrates contained volatile fatty acids (VFA), but there were large differences in VFA contents between the plants. The contents of VFA in two of the four concentrates were comparable to the contents generally found in slurries, the other two were much lower. Incubation studies were carried out to test if application of mineral concentrates to soil affected immobilization of N and/or denitrification, as the carbon in VFA is readily available for soil micro-organisms. No clear effect of mineral concentrates on immobilization could be detected, but application of mineral concentrates significantly increased the potential denitrification

rate of soils. These results show that immobilization is probably not a major mechanism decreasing the N Fertilizer Replacement Value (NFRV)[1] of mineral concentrates compared to the widely used mineral fertilizer calcium ammonium nitrate (CAN). However, denitrification may occur if mineral concentrates are applied to a nitrate containing soil under relatively wet conditions. Denitrification losses may decrease NFRV of mineral concentrates. The results also showed a higher potential denitrification in grassland soil than in the arable soil. This may be a factor causing the lower NFRV of mineral concentrates applied to grassland than applied to arable land.

The pot experiments showed that the NFRV of mineral concentrate compared to CAN was 78 - 96% and 76 - 97% using Swiss Chard and grass as test crops, respectively. Mineral concentrates were applied with a technique that reduces ammonia emission. The NFRV of mineral concentrates surface-applied to grassland were 36 - 62% and much lower than those of mineral concentrate applied with low ammonia emission (NFRV was 92%). The NFRV of mineral concentrates under controlled conditions were about 10 - 20% higher (absolute figures) than in the field.

In 2011, the NFRV of mineral concentrate applied to grassland with the field trial injector was 80% compared to CAN and higher than the NFRV in the experiments of 2009 and 2010. The NFRV of mineral concentrate was lower than that of liquid ammonium nitrate. The amount of mineral N in the soil profile at the end of the growing season was similar for mineral concentrates and for CAN. This showed that the use of mineral concentrates did not increase risk of nitrate leaching compared to CAN.

In the experiment with silage maize, the average NFRV of mineral concentrate compared to CAN was 84% in 2011. The NFRV of mineral concentrates applied to arable crops in the field experiments of the pilot in 2009 - 2010 ranged from 72% - 84%. In 21 experiments of the additional research programme, the NFRV of mineral concentrate was similar to CAN and in ten experiments it was lower than CAN. Measurements of nitrate concentration in groundwater in the maize experiments and mineral N content in the soil in autumn showed that the risk of nitrate leaching was similar for mineral concentrate as for CAN.

Both the grassland experiments and arable land experiments showed that the use of mineral N concentrate did not increase risk of N leaching losses compared to the use of CAN. This suggests that the lower NFRV of mineral concentrate than of CAN is related to other N loss pathways than N leaching, i.e. gaseous N losses by ammonia emission and/or denitrification. The incubation study showed that mineral concentrate did not increase immobilization of N.

The results of the pot experiments showed NRFV of mineral concentrate of 78 - 96%, which is similar to the theoretical NFRV of mineral concentrate, assuming that part of organic N in concentrate is not available immediately and that some ammonia emission will occur. Clearly, there is scope to increase NFRV in the field by optimizing the use of mineral concentrate by e.g. timing of application, better management of the low ammonia emission application techniques, and further decreasing the organic N content of mineral concentrate. The NFRV in the field experiments in 2011 were 80% for grassland and 84% for silage maize and were higher than those obtained in the trials in 2009 and 2010. The relatively high NFRV of concentrate in 2011 is probably caused by a number of factors, including a higher mineral N fraction of total N in concentrate (this may have increased the NFRV with a few per cent), and weather conditions.

[1] The N fertilizer replacement value indicates how many kg of mineral fertilizer N can be replaced when 100 kg of N are applied in the form of organic fertilizer. In the Netherlands, the N replacement value of a fertilizer is generally determined by comparison with the mineral fertilizer Calcium Ammonium Nitrate (CAN).

1 Introduction

Treatment of manure can improve the use efficiency of nutrients. One of the possibilities is separation of slurry and using the mineral concentrate that results from reverse osmosis of the liquid fraction as mineral N (N) – potassium (K) fertilizer (Figure 1). Mineral concentrate is a fertilizer which is manufactured by an industrial process, according to the definition of fertilizer in the Nitrates Directive. It is expected that the characteristics of the concentrate differ from that of animal slurry. However, a mineral concentrate is animal manure, according to the definition of the Nitrates Directive as it is a processed form of animal manure. Therefore, its use is limited by the application standards for manure. The agricultural business (LTO Netherlands and NVV), the Ministry of Economic Affairs, Agriculture and Innovation (EL & I) and the Ministry of Infrastructure and Environment (IenM) investigate, with the consent of the European Commission, the agricultural and environmental effects of the production and use of mineral concentrate to be used as mineral fertilizer (or chemical fertilizer according to the Nitrates Directive). This approach intends to contribute to a sound disposal of animal slurry and fits in the quest for further closing nutrient cycles. The data from the pilot will be used for consultations with the European Commission on a possible permanent permission to use mineral concentrate as a mineral N fertilizer. This means that mineral concentrate can be applied above the application standard for manure, but within the total N application standard (i.e. the sum of effective N from manure and mineral fertilizer N).

Eight producers take part in the Pilot (Figure 2). Each producer operates a plant that produces mineral concentrate. The users are farmers who apply mineral concentrate as fertilizer on arable land or on grassland. The data from the Pilot are also used for the preparation of technical files of the mineral concentrate.

During 2009 and 2010 the following studies were conducted within the pilot:

- Monitoring of products from the slurry treatment (Hoeksma et al., 2011);
- Agricultural and environmental impacts of application of mineral concentrate and other products from slurry as fertilizer (Ehlert et al., 2009; Ehlert and Hoeksma, 2011; Huijsmans and Hol, 2011; Van Middelkoop and Holshof, 2011; Van Geel et al., 2011a&b; Schröder et al., 2010; 2011; Velthof and Hummelink, 2011; Verloop and Van den Akker, 2011);
- User experiences and an economic analysis of the use of mineral concentrate in the pilot (De Hoop et al., 2011); and a
- Life Cycle Assessment (LCA). Assessing the full environmental consequences of producing and using the mineral concentrate and other products as fertilizer (De Vries et al. (2011).

The synthesis of the research in 2009 and 2010 was reported by Velthof (2011). The major conclusions were:

- The N fertilizer replacement value (NFRV)[2] of mineral concentrate compared to Calcium Ammonium Nitrate (CAN) was on average 80-90% on arable land and 58% on grassland. The NFRV of mineral concentrate was similar to that of liquid ammonium nitrate.

[2] The N fertilizer replacement value of an organic fertilizer is the percentage of the applied N of this fertilizer, which has the same effect on crop N yield as the same amount of N applied as mineral fertilizer (Schröder et al., 2008). In the Netherlands, the N replacement value of a fertilizer is generally determined by comparison with the mineral fertilizer Calcium Ammonium Nitrate (CAN).

- Besides N, K is important for many arable crops and silage maize. However, the K supply with mineral concentrate limits the applicable amount of mineral concentrate on dairy farms when the K status of the soil is sufficient or higher.
- At slurry supply rates of around 15 euros per ton or higher manure treatment plants can be profitable. The economic viability of the plant is highly dependent on the slurry supply rate and on the prices of end products and of competitive products from manure and fertilizers.
- The use of mineral concentrate did not lead to increased nitrate leaching in grassland and arable land when compared to CAN.
- The high ammonia content and the high pH of mineral concentrate increase risk of ammonia volatilization. However, when low-emission application techniques like deep injection or sod injection are used, the ammonia emission will be limited (<10% of the applied N).
- Incubation tests indicate that the nitrous oxide emissions from mineral concentrate is relatively high when compared to CAN and pig slurry.
- Heavy metals and organic micro-pollutants in mineral concentrate are not a concern for common agricultural use of mineral concentrate.
- Within the LCA system boundaries chosen, the total environmental impact hardly changes when the fattening pig slurry surplus is processed. The emissions of ammonia, particulate matter and greenhouse gases, and the energy consumption will increase if all pig slurry produced is processed and not only the surplus of pig slurry (i.e. the slurry that cannot be used within the region).

At the end of 2010 the pilots were extended and research was continued in 2011. Partly this was a continuation of on-going research and partly new research aiming to find an explanation for the sometimes low N efficiency of mineral concentrate on grassland. In this report, the results of the research of 2011 are summarized and synthesized.

In Chapter 2, the results of the monitoring of the manure treatment installations are summarized. The aim of the monitoring is to analyse the composition of mineral concentrates at the different treatment plants and determine possible changes compared to previous years. The focus of the monitoring is on the contents of N, P, K and organic matter (and trends in time of these contents). Mineral concentrate contain organic matter, but it is not known in what form. The presence of organic matter in mineral concentrate may affect N processes after application to the soil, and by that the N efficiency of mineral concentrate. In 2011, the contents of volatile fatty acids (VFA) in the produced mineral concentrates were measured as VFA contain readily available C.

Mineral concentrates contain available C (including VFA) and when mineral concentrates are applied to the soil, this C may be used for growth by micro-organisms. For this growth also mineral N is needed, and adding C to the soil may result in immobilization of mineral N. Part of the mineral N in the soil or in the mineral concentrate is therefore (temporarily) unavailable to the crop. Immobilization decreases the N efficiency of applied mineral concentrate. Chapter 3 presents the results of an incubation study in which immobilization of N from soil-applied mineral concentrate was determined.

When available C is applied to a nitrate containing soil under wet (anoxic) conditions, denitrifying bacteria may use the C as energy source and the nitrate can be transformed into gaseous nitrous oxide (N_2O) and dinitrogen (N_2). Denitrification caused by C in mineral concentrate may be a possible mechanism that reduces the N efficiency of mineral concentrate in comparison to mineral N fertilizer such as CAN. An incubation experiment was carried out to test the hypothesis that the organic matter in mineral concentrate is available for denitrifying bacteria and that application of mineral concentrate to soil may increase denitrification (Chapter 4).

The field experiments in 2009 and 2010 showed a large variations in NFRV of mineral concentrate in comparison to CAN. The NFRV was higher for arable land than for grassland and there were differences between years, suggesting that the weather conditions affected N efficiency of CAN and mineral concentrate. A pot experiment was carried out in 2011 to determine the N efficiency of different mineral fertilizers, pig slurry, and mineral concentrate in order to get insight in the NFRV of mineral concentrate and other fertilizers compared to CAN under controlled conditions (Chapter 5). The application technique of mineral concentrates may significantly affect gaseous N losses and, by that, NFRV of mineral concentrates. A pot experiment was carried out to quantify NFRV and gaseous N losses after surface-application and injection of mineral concentrates (Chapter 6).

The NFRV of mineral concentrate strongly varied in the field experiments 2009 – 2010. Therefore, field experiments were continued in 2010 and 2011. In 2011, a field experiment was carried out with grassland on sandy soil to determine the NFRV of mineral concentrate in comparison to CAN and to determine the mineral N contents in the soil in autumn, as an indicator for the risk of nitrate leaching (Chapter 7). Moreover, a field experiment was carried with maize on sandy soil to determine NFRV and the nitrate concentration in groundwater using of mineral concentrates, CAN and pig and cattle slurries (Chapter 8).

In Chapter 9 the results are summarized and conclusions presented.

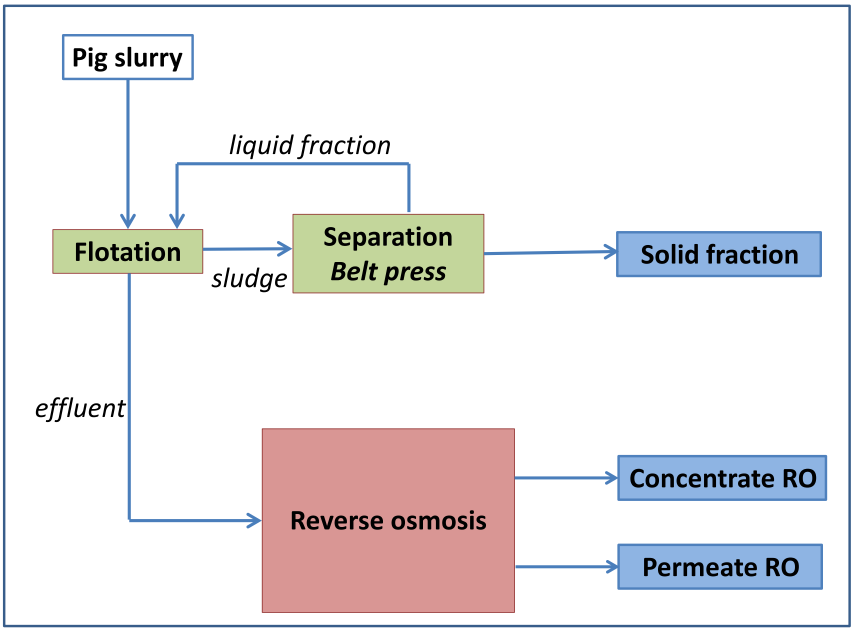

Figure 1
Example of pig slurry treatment using reversed osmosis. The concentrate of reverse osmosis is used as mineral fertilizer. In all eight plants, manure is separated in a solid and a liquid fraction. Plants A and H use a centrifuge for separation, plant B, C, F and G use a belt press system, and D and E an auger press. In systems A and H the liquid fraction is further treated with ultra-filtration and in the other plants with flotation. The permeate from the ultrafiltration and the effluent from the flotation are separated through reverse osmosis into a mineral concentrate (indicated as concentrate RO in the figure) and a permeate (clean liquid fraction; permeate RO in the figure).

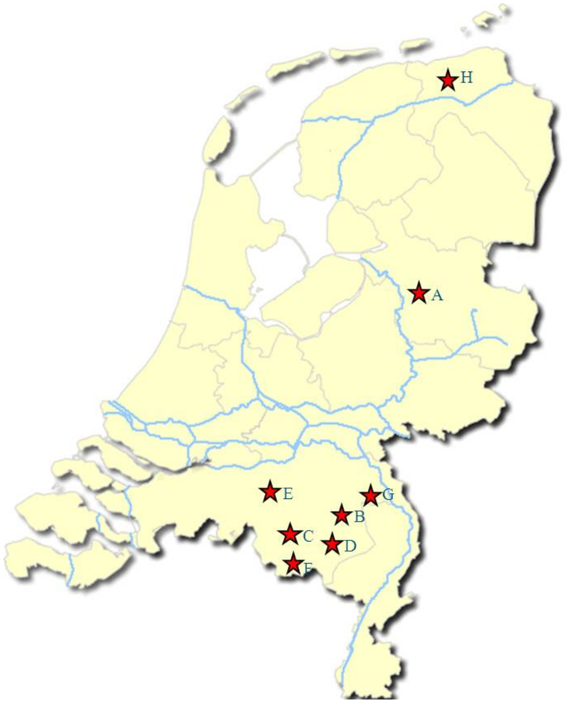

Figure 2
Location of the eight plants taking part in the Mineral Concentrates Pilot.

2 Monitoring of the composition of mineral concentrates

2.1 Introduction and aims

A monitoring program was carried out on the manure treatment plants to determine the composition of the end products and to prepare mass balances of nutrients during 2009 and 2010 (Hoeksma et al., 2011). This monitoring was continued in 2011.

Mineral concentrate contain organic matter, but it is not known in what form. The presence of organic matter in mineral concentrate may affect N processes after application to the soil, and by that the N efficiency of mineral concentrate. Volatile Fatty Acids (VFA) are rapidly degradable carbon compounds in manures and are produced during the digestion in the animal and excreted with faeces (Canh et al. 1998) and during anaerobic storage of animal slurries (Cooper and Cornforth, 1978; Guenzi and Beard, 1981). The carbon in VFA is readily available for micro-organisms in the soil. Addition of VFA may affect both mineralization/immobilization and denitrification processes in the soil (e.g. Kirchmann and Lundvall, 1993; Paul and Beauchamp, 1989). It was not known if mineral concentrates contain VFA. In 2011, the VFA contents of mineral concentrates were analyzed and the effect of application of concentrates to soil on immobilization and denitrification was also determined (See Chapters 3 and 4).

This Chapter shortly describes the Materials and methods and the main results and conclusions of the monitoring. A more detailed description of the methods and results are presented by Hoeksma and de Buisonjé (2012). In addition to the results of Hoeksma and de Buisonjé (2012), results of the analyses of the N and phosphorus (P) contents of mineral concentrate transported in 2009 - 2012 will be presented in this Chapter. All transports of mineral concentrate in the Netherlands are recorded and samples are taken for N and P analysis. The results were provided by the ministry of EL&I.

2.2 Materials and methods

A monitoring was carried on six plants; A, B, C, D, F en H. These installations are described in detail by Hoeksma et al. (2011). Samples of the raw slurry and the end products were taken every three months. Plants A and H had both economic and technical problems (revision of parts of the units), by which it was not possible to obtain representative samples (i.e. samples taken from a stable running treatment unit).

The following parameters were measured: dry matter, ash, organic matter, total C, total N, NH_4-N, NO_3-N, P, K, Ca, Mg, Na, Cl, S, SO_4^{2-}, pH, EC, and VFA. The parameters were analysed using the analytical methods required for analysis of animal manure for the Dutch Fertiliser Act. VFA were measured by chromatography. Organic matter was determined as the difference between dry matter and ash. All analyses were carried out by the AFSG environmental laboratory of Wageningen UR.

As part of the manure policy in the Netherlands, transport of manure is recorded uses GPS systems. The transported manure is weighted and samples are taken and analysed for total N and P. This control system is also applied for the transport of mineral concentrate. The results of the N and P analyses of all samples of transported mineral concentrate were provided by the ministry of EL&I. The samples are not analysed for NH_4, so that this data set cannot be used to quantify the NH_4 fraction of total N.

2.3 Results and discussion

2.3.1 Monitoring of the treatments plants

Composition of mineral concentrates in 2011
Table 1 shows the detailed results of the monitoring in 2011. The average total N content of the concentrate in 2011 was 8.15 g N per kg product, from which 7.51 g NH_4-N per kg (92%). The organic matter content was on average 14 g per kg product. The K content was 8.02 g per kg and the P content was 0.16 g per kg.

The EU Regulation 2003/2003 applies to fertilizers products designated as 'EC fertilizer', when sold in Europe. The EU Regulation 2003/2003 contains a list of approved fertilizers, with for each fertilizer the method of preparation and minimum contents of nutrients. A mineral concentrate cannot meet the requirements in the regulation, because i) the contents of N, P and K are lower than the required minimum and ii) a mineral concentrate contains organic nutrients of animal origin (See Velthof, 2011). The EU Regulation 2003/2003 is under revision and probably it is possible to add new products or new groups of products to this regulation in the future. The admission of new products and the constraints on nutrient contents is determined by the European Commission and EU Member States.

Trends in composition of mineral concentrates
Table 2 shows the composition of the mineral concentrates in 2009, 2010, and 2011. The N content increased during the pilot; from 7.22 g per kg in 2009, 7.59 g per kg in 2010, and 8.15 g per kg in 2011. The K content also increased, and the P and organic matter content decreased. The fraction NH_4 in total N was 0.90 in 2009 and 2010, and 0.92 in 2011. These results show that innovations and improved managed of the manure treatments plants (slightly) increased the quality of mineral concentrate as a mineral N-K fertilizer during the years.

Differences in composition of mineral concentrates between treatment plants
The composition of mineral concentrate differed between the treatment plants, which was also shown in the previous years (Table 3). The differences in composition of the mineral concentrates between the plants are due to technical differences between the plants, differences in management of the process, and differences in composition of slurry which is treated. The results of the monitoring in the period 2009 - 20101 shows that the N content of the concentrates of plants C and F are relatively stable (Figure 3). The N content of the concentrates of plants B and D shows an increasing trend, which is mainly due to technical improvements in the treatment slurry installations of these plants.

Table 1
*Average, median, standard deviation (sd.) and coefficient of variation (CV = sd./average * 100) of the contents of dry matter, organic matter, ammonium (NH_4-N), P and K and the C/N-ratio of the mineral concentrate of the four pilot plants in 2011.*

	Average (g/kg)	Median (g/kg)	Sd. (g/kg)	CV. (%)	Number of samples
Dry matter	36.9	33.5	9.18	24.9	16
Organic matter	14.0	13.5	3.97	28.3	16
Total N	8.15	8.21	1.58	19.4	16
NH_4 -N	7.51	7.37	1.66	22.1	16
P	0.16	0.14	0.11	68.7	16
K	8.02	7.73	1.27	15.9	16
pH	7.96	7.95	0.17	2.13	16
EC	59.8	60.3	7.47	12.5	16
C/N	7.85	7.77	0.42	5.41	16

Table 2
Number of samples (n), average (av) and standard deviation (sd) of the contents of organic matter, N, NH_4-N, P en K (in g/kg) in mineral concentrate in 2009, 2010 en 2011.

	2009			2010			2011		
	n	Av.	Sd.	n	Av.	Sd.	n	Av.	Sd.
Organic matter	42	15.2	5.64	29	14.6	4.70	16	14.0	4.15
Total N	42	7.22	1.68	29	7.59	1.42	16	8.15	1.58
NH_4-N	42	6.48	1.43	29	6.82	1.28	16	7.51	1.66
P	42	0.19	0.14	29	0.18	0.13	16	0.16	0.11
K	42	7.60	1.19	29	7.43	0.87	16	8.02	1.27

Table 3
Average contents of organic matter, total N, P, K, and the C/N ratio of the mineral concentrate of the plants B, C, D, and F in 2011 (in g/kg).

Plant	Organic matter	Total N	NH_4-N	P	K	C/N	Number
B	18.9	9.84	9.65	0.02	9.71	7.60	4
C	14.7	8.85	7.81	0.26	8.14	7.50	4
D	9.23	6.19	5.65	0.14	6.96	7.72	4
F	13.0	7.72	6.93	0.26	7.28	8.58	4

Contents of VFA in mineral concentrates
The mineral concentrates contained VFA, but there were large differences between the plants (Table 4). The contents of VFA in concentrate B and C are comparable to the contents found in livestock slurries (e.g. Kirchmann and Lundvall, 1993; Paul and Beauchamp, 1989; Sørensen, 1998; Spoelstra, 1979). It is likely that the differences in VFA contents of the treated slurries are the main cause for the differences in VFA contents

between the mineral concentrates. It is known that both the type of slurry and the storage method and time are factors affecting the VFA contents of slurries. The lower VFA content in the mineral concentrates of plants D and F may be related to a longer storage time of the slurry before it is treated. The presence of VFA in mineral concentrates indicate that the C in mineral concentrates may affect N immobilization and/or denitrification after application to soil. In Chapters 3 and 4 the results are presented of incubation studies in which immobilization and denitrification were determined.

Mass balances
Table 5 show the mass balance calculations of nutrients and organic matter. The input of raw slurry and digestate is set at 100. Notice that the plants also used additives such as acids, salts and flocculants during treatment, by which is the sum of the outputs of dry matter and other parameters is for some plants higher than 100%. This is also the reason for the sometimes negative balances (i.e outputs are higher than the manure input). Positive balances (i.e. manure inputs are higher than outputs) point at losses. For N, this may be due to gaseous N losses by ammonia volatilization and denitrification. For K, it may not be excluded that K precipitation occurs during the treatment (e.g. as potassium struvite), which is not determined.

The N balance calculations show that on average 44% of the treated slurry N is recovered in solid fraction, 53% in the concentrate, and 2% in the permeate (Table 5). The N losses are small; on average one per cent was lost during the treatment process. Both largest part of NH_4-N and K (70 - 78%) is recovered in the concentrate. Most of the organic matter (on average 94%) and P (on average 96%) is recovered in the solid fraction. The differences between input and output are small, suggesting that the losses of nutrients during treatment are small.

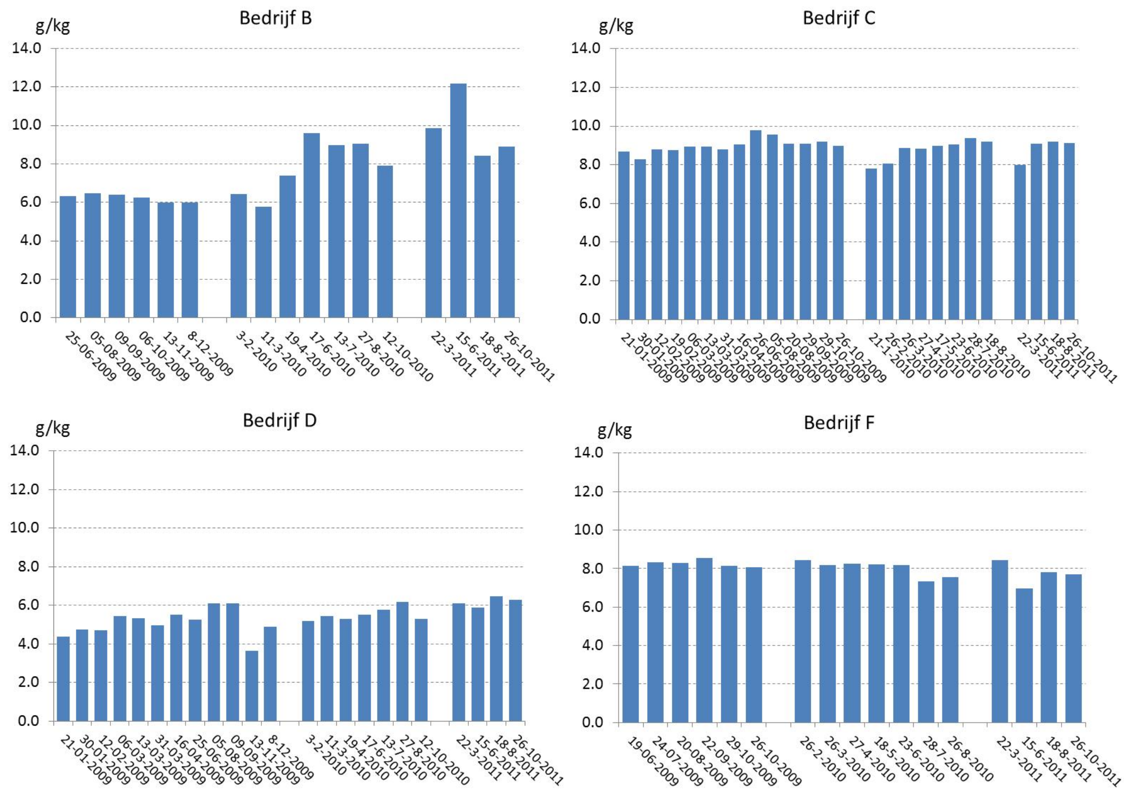

Figure 3
N contents of mineral concentrate (g/kg) of plants B, C, D, and F during the whole monitoring period in 2009 - 2011 ('bedrijf' = treatment plant).

Table 4
Average contents of VFA for of the mineral concentrate of the plants B, C, D, and F in 2011 (in g/kg).

Plant	Number	Acetic acid C2	Propionic acid C3	Iso-Butyric acid i-C4	Butyric acid C4	Iso-Valeric acid i-C5	Valeric acid C5	Total
B	4	3.77	0.94	0.16	0.08	0.32	0.04	5.31
C	4	4.68	1.41	0.24	0.03	0.39	0.04	6.79
D	4	0.20	0.03	0.01	0.01	0.01	0.01	0.26
F	4	0.66	0.11	0.02	0.01	0.03	0.01	0.85

Table 5
Relative mass distribution of dry matter (DM), organic matter (OM), total N, total P and K over the end products of slurry treatment in the four plants in 2011. The balance is calculated as the difference between the input as raw slurry/digestate and the outputs as solid fraction, concentrate RO, and permeate RO.

Plant		DM	OM	Total N	NH_4-N	P	K
	Raw slurry/digestate	100	100	100	100	100	100
B	Solid fraction	87	89	48	33	100	21
	Concentrate RO	21	11	51	73	0	75
	Permeate RO	0	0	0	0	0	0
	Balance (input-output)	-8	0	1	-6	0	4
C	Solid fraction	87	95	46	31	94	21
	Concentrate RO	21	12	50	66	4	72
	Permeate RO	0	0	2	0	0	2
	Balance (input-output)	-8	-7	2	3	2	5
D	Solid fraction	87	101	43	26	96	14
	Concentrate RO	23	14	58	73	4	88
	Permeate RO	0	0	3	0	0	2
	Balance (input-output)	-8	-15	-4	1	0	-4
F	Solid fraction	81	90	40	26	93	15
	Concentrate RO	19	12	53	67	7	75
	Permeate RO	0	0	1	0	0	1
	Balance (input-output)	0	-2	6	7	0	9
Average	Solid fraction	86	94	44	29	96	18
	Concentrate RO	21	12	53	70	4	78
	Permeate RO	0	0	2	0	0	1
	Balance (input-output)	-5	-2	6	1	0	3

2.3.2 Results of samples of transported mineral concentrates

In total 6579 samples have been taken from transported mineral concentrate in the period 2009 - 2012. The number of samples increased in the period 2009 - 2011, suggesting that the use of mineral concentrates has increased in this period.

The total N contents of mineral concentrate increased from 6.92 g N per kg in 2009 to 8.05 g N per kg in 2012. The P contents decreased from 0.19 to 0.13 g P per kg product. These results confirm the results of the monitoring (Table 2) and show that quality of mineral concentrate as N fertilizer (slightly) improved. The average N and P contents differ somewhat from those of the monitoring described in Paragraph 2.3.1. This is because the number of samples of each farm differ between this monitoring and the transport records (populations are different). The decrease in P contents can be considered as positive, because the P application standards will become more strict in the near future. The presence of P in mineral concentrate may limit the use of mineral concentrate as N fertilizer.

The variation in the N contents is caused by a number of factors, including the differences in contents between the treatment plants (see for example Table 3), variations in time (see for example Figure 3), and uncertainties in sampling of concentrates during the transport and in chemical analyses. The differences in composition between the treatment plants are probably the main cause of the variation in composition. The monitoring showed that each plant is able to produce a product with a relative constant composition (Figure 3), taking into consideration that some of the treatment plants (e.g. plant B) have modified their management and techniques during the pilot to increase nutrient contents of concentrates and to optimize the installations. This has led to variations in composition.

Table 6
N and P contents of mineral concentrate, sampled from transports of mineral concentrate from the manure treatment plants to users in 2009 - 2012 (Source: Ministry of EL&I).

Year	Number of samples	N content, g N per kg product		P content, g P per kg product	
		average	standard deviation	average	standard deviation
2009	1215	6.92	1.42	0.19	0.16
2010	1874	7.32	1.84	0.17	0.15
2011	2199	7.88	1.61	0.17	0.16
2012	1291	8.05	1.82	0.13	0.12
Total	6579				

2.4 Conclusions

- The average total N content of the concentrate in 2011 in the monitoring study was 8.15 g N per kg product, from which 92% NH_4-N. The K content was 8.02 g per kg and the P content was 0.16 g per kg.
- The average N content of the concentrate increased from 7.22 g per kg in 2009 to 8.15 g per kg in 2011. The K content also increased, and the P and organic matter content decreased in this period. The average fraction NH_4 in total N was 0.90 in 2009 and 2010, and 0.92 in 2011. It is concluded that the quality of mineral concentrate as a mineral N-K fertilizer (slightly) increased in the course of years.
- The composition of mineral concentrate differed between the treatment plants, which was also shown in the previous years. The differences between the plants are due to technical differences between installations, differences in management of the process, and differences in composition of treated slurry.
- In total 6579 samples have been taken from transported mineral concentrates in the period 2009 – 2012. The total N contents of the transported mineral concentrate increased from 6.92 g N per kg in 2009 to 8.05 g N per kg in 2012. The P contents decreased from 0.19 to 0.13 g P per kg product. The (slight) differences between the average nutrient contents of the monitoring of treatment plants and those of the transport samples are due to differences in the distribution of the treatment plants over both surveys. The

composition of the concentrates differ between the treatment plants and affects the average of all samples.

- The mineral concentrate contained VFA, but there are large differences between the plants. The contents of VFA in two of the four concentrate were comparable to the contents generally found in slurries.
- The N balance calculations show that on average 44% of the treated slurry N is recovered in the solid fraction, 53% in the concentrate, and 2% in the permeate. Most of the NH_4-N and K (70 - 78%) is recovered in the concentrate. The N losses are small; on average one per cent was lost during the treatment process.

3 Incubation study on immobilization

3.1 Introduction and aims

Immobilization of N is one of the possible mechanisms that may decrease the N efficiency of mineral concentrate in comparison to mineral N fertilizers. Mineral concentrates contain available C (including VFA) and when mineral concentrates are applied to the soil, this C may be used for growth by micro-organisms. For this growth also mineral N is needed, and adding C to the soil may result in immobilization of mineral N. Part of the mineral N in the soil or in the mineral concentrate is therefore (temporarily) unavailable to the crop. Immobilization results in a decrease in efficiency of N of mineral concentrate.

Ehlert et al. (2012) carried out an incubation experiment to test the hypothesis that the presence of (biodegradable) organic matter in mineral concentrate - temporarily - increases the immobilization of N in the soil. This Chapter shortly describes the Materials and methods and the main results and conclusions of the study. A more detailed description of the methods and results are presented by Ehlert et al. (2012).

3.2 Materials and methods

An incubation study was carried out with CAN and mineral concentrate, incubated in soil without a crop at 15°C. The treatments were:

- Two soil types: sand and clay
- Two land use types: grassland and arable land
- Four N treatments: control, CAN and two mineral concentrates at 19 mg N/100 g soil.

The experiment was carried out in three replicates. The soil (200 g per bag) was incubated in audiothene bags, i.e. bags that are permeable for oxygen. After 0, 3, 7, 28 en 56 days all treatments were analysed for ammonium and nitrate N contents.

3.3 Results and discussion

The contents of ammonium, nitrate, and total mineral N did not clearly change during the experiment (see Figure 4 for total mineral N contents). Differences between mineral N in the treatments with CAN and those with mineral concentrates were small. There was no or hardly any difference in the time course of mineral N in soil to which mineral concentrate was applied and soil to which CAN was applied, indicating that the C in mineral concentrate did not result in a clear N immobilization. Kirchmann and Lundvall (1993) found in a laboratory study that fatty acids present in slurries decomposed within 1-2 days after application, which was accompanied by N immobilization. They concluded that fatty acids act as an easily decomposable C source for microorganisms and cause immobilization of N. The immobilization of N only took place during about the first week of slurry application to soil. Thereafter, N was released by mineralisation. The VFA acids contents in the slurries used by Kirchmann and Lundvall (1993) were about 10 - 30 g per kg, which is higher than the VFA acids contents in the mineral concentrate (Table 4). The higher C contents of the slurries used by Kirchmann and Lundvall (1993) than those in mineral concentrate may be an explanation for the difference in N immobilization in both experiments.

3.4 Conclusions

The incubation study with soils from arable land and grassland on sand an clay shows that application of mineral concentrate did not or hardly result in immobilization of mineral N. Obviously, the C in mineral concentrate (from which part as VFA) did not induce immobilization of mineral N after soil application. These results suggests that the lower N efficiency of mineral concentrate in comparison to CAN is not caused by N immobilization.

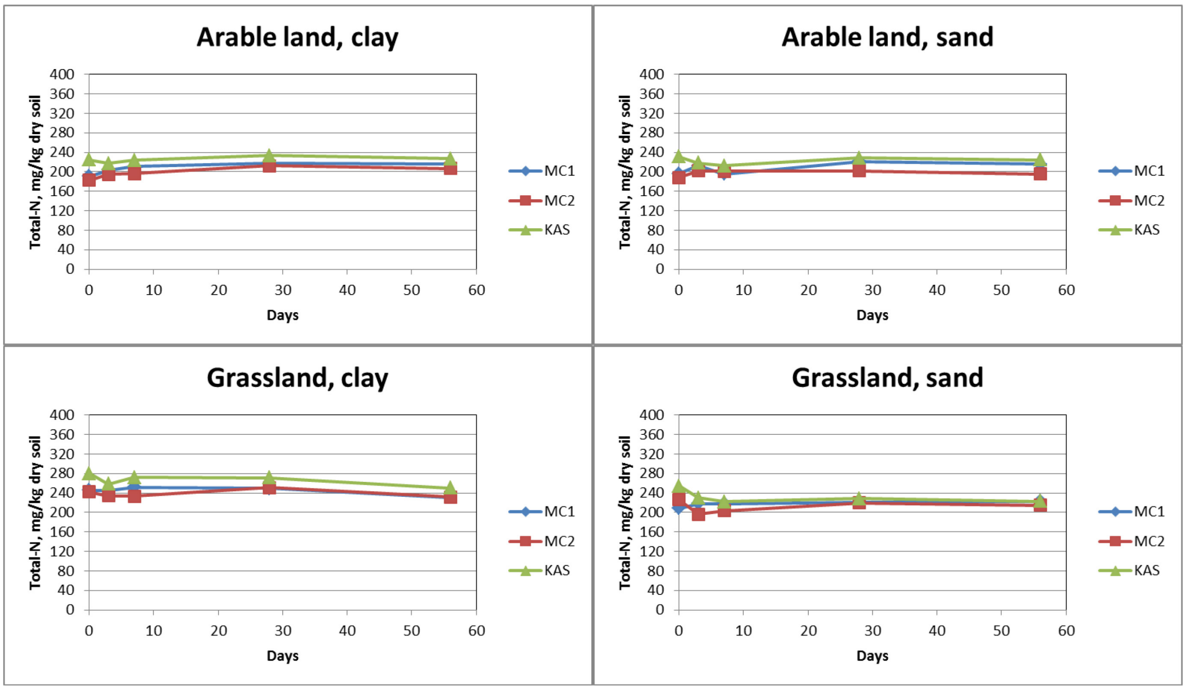

Figure 4
Net mineral N contents in clay soil (left) and sand soil (right) of arable land (upper figures) and grassland (lower figures) during incubation of CAN and two mineral concentrates (MC1 and MC2) at a N application rate of 240 kg N/ha, at 15°C during 56 days.

4 Incubation study on denitrification

4.1 Introduction and aims

Mineral concentrates contain available C (including VFA). When available C is applied to a nitrate containing soil under wet (anoxic) conditions, denitrifying bacteria may use the C as energy source and the nitrate can be transformed into gaseous N_2O and N_2. Denitrification caused by C in mineral concentrate may be a possible mechanism that reduces the N efficiency of mineral concentrate in comparison to mineral N fertilizer such as CAN.

Ehlert et al. (2012) carried out an incubation experiment to test the hypothesis that the organic matter in mineral concentrate is available for denitrifying bacteria and that application of mineral concentrate to soil may increase denitrification. This Chapter shortly describes the Materials and methods and the main results and conclusions of the study. A more detailed description of the methods and results a presented by Ehlert et al. (2012).

4.2 Materials and methods

An incubation study was carried out in which the potential denitrification rate was determined of soil amended with different products. Potential denitrification is measured under anaerobic conditions, at a fixed reference temperature and in the presence of excess of nitrate. Differences in potential denitrification between soils or fertilizers are due to differences in available C, as the other factors controlling denitrification are optimal.

The potential denitrification rate was determined by incubation of a water-saturated soil under anaerobic condition (by flushing the headspace of incubation bottles with N_2) at 20°C. The soil was enriched with 10 mM KNO_3. The experiments consisted of the following treatments:

- Two soils from different land use types: arable land and grassland (derived from the sites were in 2010 field experiments have been carried out with mineral concentrate).
- A control (no product added).
- Five products: glucose (source of C), CAN and three mineral concentrates. The N application rate of CAN and mineral concentrates are based on a rate of 120 kg N per ha.
- Three replicates.

Denitrification was measured using the acetylene inhibition technique, i.e. acetylene inhibits the reduction of N_2O to N_2 by which N_2O is the end product of denitrification. The N_2O concentration in the headspace of the bottle was measured just before application of the products (including mineral concentrate) and after two days incubation, using a photo-acoustic gas monitor.

4.3 Results and discussion

Table 6 presents the results of the composition of the products and the potential denitrification rates. Differences between the treatments in potential denitrification rates are mainly due to differences in the content of available C (i.e. C available for denitrifying bacteria), but other factors that affect microbial activity may not be excluded (e.g. effects on soil pH and EC).

Addition of glucose increased the potential denitrification rate compared to the control, which was expected because glucose contains rapidly available C. The higher potential denitrification rate in grassland soil than in soil from arable land after glucose addition suggests that grassland contains a different (more active) population of denitrifying bacteria. The effect of CAN on potential denitrification was small, suggesting the CAN contains a small amount of C or CAN influences potential denitrification by other factors (e.g. the lime in CAN may increase pH).

All mineral concentrates strongly increased potential denitrification, showing that the C in mineral concentrate is available for denitrifying bacteria. Paul and Beauchamp (1989) showed that VFA are effective energy sources for denitrifiers. All three concentrates contain organic C and VFA, but there was no clear relation between total C and denitrification potential of the three concentrates and between VFA and potential denitrification (Table 7). This suggest that not all C in mineral concentrate is available for micro-organisms and that there are also other available C compounds than VFA present in the concentrate. The higher potential denitrification rates after application of mineral concentrate than after glucose are due to higher C application rates with mineral concentrate. Application of mineral concentrates to grassland soil increased potential denitrification more strongly than application to arable soil, which may be related to a more active population of denitrifying bacteria in the grassland soil .

The increase in potential denitrification after application of mineral concentrate indicates that the C in concentrate may enhance denitrification of nitrate which is already present in the soil. This mechanism decreases N efficiency of mineral concentrate and may enhance N_2O emission. The risk of N losses by denitrification after application of mineral concentrate to soil is also dependent on the nitrate content of the soil and of the soil moisture status. Highest losses will be found during wet conditions in a nitrate containing soil. The higher potential denitrification of grassland soil than of arable soil suggests that risk of N losses by denitrification is higher for grasslands than for arable land. This may be a factor causing the lower NFRV of mineral concentrates applied to grassland than applied to arable land. Other studies also showed lower potential denitrification rates in arable land than in maize land (Munch and Velthof, 2007).

Table 7
Potential denitrification rates of untreated arable and grassland soils, and those in soils amended with glucose, CAN, and three mineral concentrates (MC1, MC2, and MC3). The composition of CAN and the three mineral concentrates is also presented.

Treatment	OM g/kg DM	Total g C/kg DM	C*Total g N/kg	NAmmonium g N/kg	Organic g N/kg	NVFA** g/kg	Denitrification potential, ppm N_2O per hour	
							Arable land	Grassland
Control	*	*	*	*	*	*	0.1	0.9
Glucose	*	*	*	*	*	*	5.6	12.9
CAN	*	*	268	138	*	*	1.3	2.6
MC 1	541	51	9.3	9.2	0.08	2.45	9.3	22.0
MC 2	570	127	5.4	5.0	0.43	0.01	39.9	74.5
MC 3	599	99	10.6	10.1	0.50	8.77	53.0	83.5

* Kurmies

**VFA: volatile fatty acids; for composition see Ehlert et al. (2012).

4.4 Conclusions

Application of mineral concentrate to soil from grassland and arable land increased the potential denitrification rates in an incubation study. These results show that the C in mineral concentrate is available for denitrifying bacteria. Application of mineral concentrate to a nitrate containing soil may increase denitrification, especially under wet conditions. If denitrification losses from mineral concentrates occur in the field, the N efficiency of concentrate decreases. The results also showed a higher potential denitrification in the grassland soil than in the arable soil. This may be a factor causing the lower NFRV of mineral concentrates applied to grassland than applied to arable land.

5 Pot experiment on nitrogen efficiency

5.1 Introduction and aims

The field experiments in 2009 and 2010 showed a large variations in N Fertilizer Replacement Values (NFRV) of mineral concentrate in comparison to CAN (Velthof, 2011). The NFRV was higher for arable land than for grassland and there were differences between years, suggesting that the weather conditions affected N efficiency of CAN and mineral concentrate.

A pot experiment was carried was carried out to determine the N efficiency of different mineral fertilizers, pig slurry, and mineral concentrate in order to get insight in the NFRV of mineral concentrate and other fertilizers compared to CAN under controlled conditions (Ehlert et al., 2012). The pot experiment was carried out with Lolium perenne L. (perennial ryegrass) grass and an arable crop, Beta vulgaris L. var. vulgaris, 'groene snijbiet' (Swiss chard), as test crops to determine the Apparent N Recovery (ANR) and the NFRV after application of mineral concentrates, fertilizers, and slurries. All fertilizers were applied in liquid form, but the reference fertilizer CAN was broadcast or placed in a row as granules.

This Chapter shortly describes the Materials and methods and the main results and conclusions of the study. A more detailed description of the methods and results a presented by Ehlert et al. (2012).

5.2 Materials and methods

A greenhouse pot experiment was carried with Rye-grass and Swiss chard as test crops. Both crops can easily be grown in a pot experiment. Moreover, both crops can be cut, so that the release of N from fertilizers can be determined over a longer period than other arable crops.

The experiments were carried out on both sand and clay soils using a modified Mitscherlich pot technique. Mitscherlich pots (height 22 cm, Ø 20 cm, volume 5.2 l). The experiments consisted of a randomized block design in three replicates, two soils (clay and sand), and eight N objects:

- Control
- CAN
- Ammonium sulphate
- Ammonium nitrate
- Ammonium chloride
- Urea
- Two mineral concentrates
- Pig slurry

CAN was applied as granules, both broadcast application and row application in a slot. Broadcast CAN was the reference for the calculation of NFRV. All other fertilizers were applied as liquid by row application in a slot.

Mineral concentrate 1 contained 9.3 g N per kg from which 99 % NH_4-N, mineral concentrate 2 contained 5.4 g N per kg from which 92 % NH_4-N, and pig slurry contained 5.47 g N per kg from which 74 % NH_4-N. The experiment was carried out at two application rates (based on 60 and 120 kg N per ha) and three replicates. Other nutrients (P, K, Mg, Na, and trace elements) were applied so that N was the only factor controlling the difference in yields between the pots. The fresh and dry matter yields and the N contents of the crops were determined. The grass was harvested in four cuts; the stubbles were also harvested at the last cut. The N yield was calculated from the dry matter yield of the harvested part and the N content. The Swiss chard was harvested in two cuts.

The ANR of the fertilizers was calculated as the difference of the N yield of the fertilized crop and the control (unfertilized crop) and expressed as a fraction of the total N input. The NFRV was calculated as the ratio between the ANR of the tested fertilizer and the ANR of the reference fertilizer broadcast CAN.

5.3 Results and discussion

The ANR of broadcast CAN was on average 76% for grass and 84% for Swiss chard (Table 8). Part of the applied N of CAN is taken up by the roots (which were not harvested) and some losses by denitrification and/or ammonia emission may have occurred. Therefore, the ANR of CAN is less than 100%. The ANR was on grassland similar for sand and clay and slightly higher for the low application rate than the high application rate. The ANR in the experiment of Swiss chard was higher on sand than on clay, which suggest that growing conditions were better in the sand soil.

Table 8
ANR of broadcast CAN in the pot experiments with two crops and two soils, %.

Soil	N rate	Grass	Swiss chard
Clay	Low	78	74
	High	75	83
	Average	*77*	*79*
Sand	Low	77	88
	High	75	91
	Average	*76*	*89*
Average		76	84

The experiment with Swiss chard shows that the NFRV of liquid ammonium nitrate, ammonium sulphate, and ammonium chloride were on average similar to broadcast CAN (Table 9). The NFRV of ammonium fertilizers were thus similar to those of CAN. The NFRV of urea applied to Swiss Chard was on average lower than CAN (96%), which is probably due to ammonia emission. In the pot experiment, urea was applied as liquid and band-placed in slot, which will have reduced ammonia emission. Surface-spreading of urea granules may result in high ammonia losses (up to more than 25%; Harrison and Webb, 2001). The NFRV of mineral concentrate was on average 80% on clay soil and 93% on sand soil. The differences between clay and sand may be related to higher ammonia emission from clay soil, because the pH of the clay is higher than of the sand. The NFRV in the pot experiment was about 10% higher (absolute figure) than in the field experiment (Chapter 8). In the field experiments, NFRV was also lower on clay than on sand. The fact that NFRV was lower than 100% compared to CAN is likely due to a combination of N losses by ammonia emission and denitrification and the presence of some organic N in the mineral concentrate. Part of the organic N is probably not available for the crop. The NFRV of pig slurry was consistently lower than that of mineral concentrate (NFRV of pig slurry was 67% on clay and 76% on sand; Table 9).

Table 9
N Fertilizer Replacement Value of injected liquid fertilizers, mineral concentrate and pig slurry in comparison to broadcast CAN, in a pot experiment with Swiss chard and grass at two N application rates. On grassland, CAN was also band-placed in a slot (similar application technique as the liquid fertilizers).

Crop	Fertilizer	Clay			Sand		
		60 kg N/ha	120 kg N/ha	average	60 kg N/ha	120 kg N/ha	average
Swiss chard	CAN	100	100	100	100	100	100
	Liquid ammonium nitrate AMNMS	115	100	108	99	102	101
	Liquid ammonium sulphate	112	104	108	97	102	100
	Liquid ammonium chloride	92	103	98	102	103	103
	Liquid urea	90	102	96	95	97	96
	Mineral concentrate 1	78	77	78	93	98	96
	Mineral concentrate 2	82	81	82	92	86	89
	Pig slurry	64	70	67	77	74	76
Grass	CAN; broadcast	100	100	100	100	100	100
	CAN; band placed in slit	94	105	100	94	106	100
	Liquid ammonium nitrate AMNMS	92	101	97	98	103	101
	Liquid ammonium sulphate	101	106	104	109	112	111
	Liquid ammonium chloride	92	103	98	93	105	99
	Liquid urea	94	99	97	98	101	100
	Mineral concentrate 1	91	94	93	98	95	97
	Mineral concentrate 2	79	81	80	81	70	76
	Pig slurry B	75	71	73	72	69	71

On grassland, the NFRV of the other mineral N fertilizers were similar to CAN. The NFRV of urea was similar as CAN on sand soil and slightly lower on clay soil. There was a difference in NFRV between the two mineral concentrates. The mineral concentrate with the lowest organic N content (concentrate 1) had an average NFRV of 93% on clay and 97% on sand. The difference between sand and clay is probably caused by N losses by ammonia and/or denitrification. The NFRV of the concentrate with a higher organic N content (concentrate 2) was 80% on clay and 76% on sand. These results show that a mineral concentrate with a low content of organic N has a NFRV which is similar to CAN, when it is applied with a technique reducing ammonia emission. The NFRV of pig slurry applied to grassland was consistently the lowest 71 - 73%.

5.4 Conclusions

The pot experiment showed that the N Fertilizer Replacement Value of mineral concentrate compared to CAN was 78 - 96% for the arable crop Swiss Chard and 76 - 97% for grassland. The NFRV of pig slurry was consistently about 10 - 20% (absolute value) lower than that of NFRV. The NFRV under controlled conditions were about 10 - 20% (absolute values) higher than in the field. This indicates that there is scope to increase NFRV in the field by optimizing the use of mineral concentrate by e.g. timing of application, use of low ammonia emission equipment, and decreasing organic N content of mineral concentrate.

6 Pot experiment on nitrogen efficiency and gaseous nitrogen losses

6.1 Introduction and aims

The field experiments in 2009 and 2010 showed a large variations in N Fertilizer Replacement Values (NFRV) of mineral concentrate in comparison to CAN (Velthof, 2011). The NFRV was higher for arable land than for grassland and there were differences between years, suggesting that the weather conditions affected N efficiency of CAN and mineral concentrate.

A pot experiment was carried by Klop et al. (2012) to determine the N efficiency of different mineral fertilizers, pig slurry, and mineral concentrate at different application techniques in order to get insight the NFRV of mineral concentrate and other fertilizers compared to CAN, under controlled conditions. In the pot experiment measurements of ammonia and nitrous oxide emissions were included in order to get insight in the effects of mineral concentrate on gaseous emissions. This Chapter briefly describes the Materials and methods and the main results and conclusions of the study. A more detailed description of the methods and results is presented by Klop et al. (2012).

6.2 Materials and methods

A greenhouse experiment with perennial ryegrass (Lolium perenne L.) growing on a sandy soil was set up as a randomized block design with two factors: application technique (surface application or injection) and N source (control, mineral concentrate 3, mineral concentrate 4, calcium ammonium nitrate (CAN), liquid ammonium nitrate, ammonium chloride and pig slurry as treatment factors. This resulted in fourteen treatments, with four replicates per treatment.

A greenhouse pot experiment was carried with grass and a sandy soil, using polyvinylchloride (PVC) pots with a height of 22 cm and a diameter of 20 cm. Due to an application error, two treatments (injection of mineral concentrate 4 and injection of ammonium chloride) had to be excluded from the experiment. Mineral concentrate 3 contained 10.6 g N per kg from which 97 % NH_4-N, mineral concentrate 2 contained 5.6 g N per kg from which 91 % NH_4-N, and pig slurry contained 8.1 g N per kg from which 58 % NH_4-N.

The experiment was carried out at one application rates and four replicates. The fresh and dry matter yields and the N contents of the crops were determined. The grass was harvested in two cuts; the roots were also harvested at the last cut. The N yield was calculated from the N content of the dry matter of the harvested part.

The NFRV was calculated as the ratio between the ANR of the tested fertilizer and the ANR of broadcast CAN (the reference fertilizer).

Fluxes of ammonia and nitrous oxide were measured using a flux chamber technique and a photo-acoustic gas monitor.

6.3 Results and discussion

The ANR of CAN was 61% at surface-application and 64% at injection (Table 10). The difference is likely due to lower ammonia emission after injection (Table 11), because CAN is a lime containing fertilizer from which some ammonia may be released after application (but losses are low: Velthof et al., 1990). The NFRV of surface-applied mineral concentrate was 36 - 62% and much lower than injected mineral concentrate (92%). The lower yields at surface-application were party due to scorching of grass after surface application of mineral concentrate and pig slurry. Scorching was not shown at injection of concentrate and pig slurry and at surface-application of CAN. Deposition of urine during grazing has also shown to induce scorching of grass (Richards and Wolton, 1975; Lantinga et al., 1987). Probably, salt and/or ammonia concentrations near the grass roots were too high after surface-application of mineral concentrate and pig slurry, but not after injection. Part of the difference between surface-application and injection will be due to difference in ammonia emission.

This experiment shows that application with a low ammonia emission application technique increases the NFRV of mineral concentrate. The ammonia measurements confirmed that ammonia losses were much lower from injected concentrate than from surface-applied concentrate (Table 11). The NFRV of pig slurry was only 25% after surface-application and increased to 48% when injected (Table 10). Injection strongly decreased ammonia emission from pig slurry (Table 11), which is consistent with results from many previous studies (e.g. Sommer and Hutchings, 2001).

The NFRV of liquid ammonium nitrate was higher than of CAN, both when surface-applied and injected. The exact reason is not clear, but it may be due to lower ammonia losses from liquid ammonium nitrate (Table 11). Nitrous oxide emission from mineral concentrate was higher than that from CAN, but lower than that from pig slurry (Table 11). Injection increased nitrous oxide emission from pig slurry, but not from mineral concentrate. Significantly higher N_2O emissions from injected pig slurry when compared to surface applied pig slurry have also been reported from field studies (Velthof and Mosquera, 2011).

Table 10
Apparent N recovery (%) and N fertilizer replacement value for different fertilizers in the pot experiment with grass.

Treatment	Apparent N recovery, %		N fertilizer replacement value, % compared to CAN	
	Surface-applied	Injected	Surface-applied	Injected
CAN	61	64	100	100
Mineral concentrate 3	38	59	62	92
Mineral concentrate 4	22	*	36	-*
Ammonium Nitrate	70	75	115	117
Pig slurry	25	48	41	75

*not available because experimental error

Table 11
Ammonia emissions during the first seven days and nitrous oxide emissions during the first 25 days after application of different fertilizers to grassland in the pot experiment.*

Treatment	Ammonia emission, mg N/m^2		Nitrous oxide emission, mg N/m^2	
	Surface-applied	Injected	Surface-applied	Injected
CAN	8	-22	-2	-1
Mineral concentrate 3	294	-15	5	5
Mineral concentrate 4	271		8	
Ammonium Nitrate	-4	-16	1	-1
Pig slurry	615	-7	6	13

*negative fluxes are likely due to uncertainties in the measurements

6.4 Conclusions

A pot experiment with grass showed that injection of mineral concentrate decreased ammonia emission and increased NFRV compared with surface-applied mineral concentrate. The NFRV of surface-applied mineral concentrate were 36 - 62% and those of injected mineral concentrate 92%. The results of this pot experiment confirmed the results of the pot experiment presented in Chapter 5 that NFRV of a mineral concentrate with a low content of organic N has a NFRV which is similar to CAN, when it is applied with a technique reducing ammonia emissions.

7 Field experiments on grassland

7.1 Introduction and aims

The N efficiency of mineral concentrate applied to grassland varied strongly in the field experiments in 2009 and 2010 and were lower than expected values (Ehlert and Hoeksma, 2011). Therefore, an additional field experiment on grassland was carried out in 2011.

Middelkoop and Holshof (2011) carried out a field trial for determining the N efficiency of mineral concentrate on grassland (follow-up of the field trial of Van Middelkoop and Holshof; 2011). This Chapter shortly describes the Materials and methods and the main results and conclusions of the study. A more detailed description of the methods and results are presented by Van Middelkoop and Holshof (2011).

7.2 Materials and methods

A field experiment on grassland on sand soil was carried out in 2011. Mineral concentrate was applied at three rates (100, 200 and 300 kg N per ha) and an unfertilized control was included. Besides the fertilized objects, four objects without N fertilization were included. The mineral concentrate was applied using an application machine developed for field trials and a sod injector used in practice. This field trial machine cuts with coulters through the sod and places the liquid fertilizer in the slot. For grassland the coulter was set on 5 cm below surface, comparable with a well-adjusted disc injector.

It was not possible to apply low rates of mineral concentrate using the sod injector (3 m^3 per ha). Therefore, the concentrate had to be diluted with an equal amount of water (1:1). The dilution of concentrate may affect the N efficiency, as it may decrease risk of ammonia emission because the concentrate will penetrate deeper into the soil. At the end of the growing season, the 0-30, 30-60 and 60-90 cm soil layers were analysed for mineral N as an indicator for the risk of nitrate leaching. The dry matter and N yields of the cuts are added up to calculated yields for the whole year.

7.3 Results and discussion

In 2011, the NFRV of mineral concentrate applied with the field trial injector was 80% compared to CAN and was higher than that in 2009 and 2010 (Table 12). The NFRV of diluted concentrate applied with the sod injector was higher (91%). The higher NFRV of diluted concentrate applied with the sod injector than undiluted concentrate applied with a trial injector may be due to reduction of ammonia emission because of dilution with water. The NFRV of mineral concentrate was lower than that of liquid ammonium nitrate; in 2009-2010 similar NFRV were found for mineral concentrate and liquid ammonium nitrate. The reason for this difference is not clear, but in general weather conditions have large effects on N efficiency of fertilizers because weather conditions strongly affect crop growth and N processes and losses in the soils.

The amount of mineral N at the end of the season is an indicator of the nitrate leaching, because in the winter in the Netherlands the surplus of rainfall leaches the nitrate to deeper soil layers and the groundwater (Ten Berge, 2002). The amount of mineral N in the soil profile at the end of the growing season was similar for mineral concentrate and CAN (Table 13). A statistical analysis of the results of all years showed no significant difference in soil mineral N contents between CAN, liquid ammonium nitrate and mineral concentrate. This shows, that the use of mineral concentrate did not increase the risk of nitrate leaching compared to CAN. Obviously, the lower N efficiency of mineral concentrate is related to N losses by ammonia emission and denitrification and to N leaching losses.

Table 12
N Fertilizer Replacement Value (NFRV) of concentrate in comparison to CAN and liquid ammonium nitrate on basis of N uptake, expressed in %. Results of 2009, 2010, and 2011 for sand and clay soil.

Year	Fertilizer	Sand		Clay	
		CAN	Liquid AN	CAN	Liquid AN
2009	CAN	100	159	100	159
	Liquid AN	63	100	63	100
	Mineral concentrate A	54	86	54	86
	Mineral concentrate C	47	74	47	74
	Mineral concentrate D	54	86	54	86
2010	CAN	100	144	100	144
	Liquid AN	69	100	69	100
	Mineral concentrate A	71	102	71	102
	Mineral concentrate B	78	113	78	113
	Mineral concentrate E	67	97	67	97
2011	CAN	100	98	-	-
	Liquid AN	102	100	-	-
	Mineral concentrate B; field trial injector	80	79	-	-
	Diluted mineral concentrate B; sod injector	91	89	-	-

7.4 Conclusions

In 2011, the NFRV of mineral concentrate applied with the field trial injector was 80% compared to CAN and higher than that in 2009 and 2010. The NFRV of mineral concentrate was lower than that of liquid ammonium nitrate; in 2009-2010 similar NFRV were found for mineral concentrate and liquid ammonium nitrate. The amount of mineral N in the soil profile at the end of the growing season was similar for mineral concentrate and CAN. This shows that the use of mineral concentrate did not increase risk of nitrate leaching compared to CAN. The results suggest that the lower N efficiency of mineral concentrate is related to N losses by ammonia emission and denitrification and to N leaching losses.

Table 13
Mineral N contents (kg N per ha) in 0-30, 30-60, and 60-90 cm soil layers at an application rate of 300 kg N per ha on sand (2009) and clay (2010).

Year and soil	Fertilizer	Soil layer			
		0-30	30-60	60-90	0-90
2009 sand	CAN	35	26	19	79
	Liquid AN	42	44	22	108
	Mineral concentrate A	29	14	0	43
	Mineral concentrate C	37	40	20	97
	Mineral concentrate D	34	30	0	64
2010 sand	CAN	81	75	9	164
	Liquid AN	71	49	21	140
	Mineral concentrate A	87	47	23	156
	Mineral concentrate B	61	87	21	169
	Mineral concentrate E	95	86	10	191
2010 clay	CAN	78	44	20	142
	Liquid AN	110	43	13	166
	Mineral concentrate A	86	53	10	149
	Mineral concentrate B	107	26	6	139
	Mineral concentrate E	77	23	10	110
2011 sand	CAN	50	34	18	101
	Liquid AN	46	38	12	95
	Mineral concentrate B	51	39	20	111

8 Field experiments on arable land

8.1 Introduction and aims

The field experiment of 2010 in which the N efficiency of mineral concentrate applied to silage maize was determined was continued in 2011. In this experiment, the nitrate leaching to groundwater was also measured. In this Chapter only the main results of this trial are presented. A detailed description of the set-up and results of this trial is presented in Schröder et al. (2012a and b).

Van Geel et al. (2012) present an overview of a number of trials on arable land carried out at several locations. In these trials, NFRV were determined. The set-up of these trials are less detailed that those of Schröder et al. (2012a and b), so that the NFRV can be less accurately determined.

8.2 Materials and methods

In a field experiment with silage maize on sandy soil, the N efficiency of different organic N fertilizers was determined. In this experiment, the NFRV compared to CAN was determined for mineral concentrate, pig slurry, cattle slurry, and the solid fraction of separated pig slurry. A treatment with and without winter crop (rye) was included for all treatments. All fertilizers were tested at different N levels. Liquid fertilizers were applied with an injector for arable land (approximately 5-10 cm depth and tine distance of 26 cm) combined with a disc harrow. Solid manure was applied with a spreader for solid manure. The experiment was set up as a split plot trial in four replicated blocks.

The fresh, dry matter, and N yield of the maize was determined. The upper groundwater of the maize site was sampled in March 2012 at a depth of around 20 cm below the groundwater table. Five water samples were taken per plot on each location. For each sample a new temporary well was used. The groundwater samples were analyzed for nitrate.

8.3 Results and discussion

The average NFRV of mineral concentrate compared to CAN was 84% in 2011, and was higher than the NFRV obtained in 2010 (72%). The NFRV of both pig and cattle slurry was similar to CAN and higher than mineral concentrate in 2011. The high NFRV of the slurries may be related to the dry conditions in the period of N application. It may be suggested that the N of CAN is less available during dry conditions than the N of slurry, because of a low dissolution process of the CAN granules. However, if this factor played a role, it may also be expected that the NFRV of mineral concentrate was higher than that of CAN. It is not clear which factor determined the differences in NFRV between fertilizers and manures in this experiment.

Table 15 shows the nitrate concentrations in the upper groundwater. In both years, the nitrate concentration in the upper groundwater was lower with mineral concentrate than with CAN. The largest (statistical significant) effect was shown for the highest application rate without a winter crop. The results show that the use of mineral concentrate did not increase risk of nitrate leaching compared to CAN (and sometimes decreased leaching). The NFRV of mineral concentrate compared to CAN was lower than 100%, which suggests that the N loss of mineral concentrate was higher than that of CAN. The fact that N leaching losses are lower after application of mineral concentrate than after application of CAN, suggests that gaseous N losses by ammonia emission and/or denitrification are the main loss pathways of N from mineral concentrate. The nitrate concentration in the groundwater after application of pig and cattle slurry was for most application rates higher than that of mineral concentrate, in both years. The results also clearly demonstrate that a winter crop reduced the leaching of nitrate.

Table 14

N fertilizer replacement value (NFRV, %) in comparison to CAN, as related to the N source and N rate (based on cover cropped treatments only).

Year	Product	N-rate* (kg N per ha):			Average
		50	100	150	
2010	Mineral concentrate	62	71	82	72
	Pig slurry	42	62	74	59
	Cattle slurry	42	72	60	58
	Solid fraction	60	56	63	60
2011	Mineral concentrate	65	109	79	84
	Pig slurry	88	129	96	104
	Cattle slurry	81	128	93	101
	Solid fraction	45	68	47	53

*envisaged rates of supposedly available N

Table 15

Nitrate concentration (mg NO_3-N per liter) of the upper groundwater at different effective N application rates in 2010 and 2011, with and without a winter crop.*

Year	Product	Winter cover and N-rate* (kg N per ha):						LSD (P<0.05)
		Rye				Fallow		
		0	50	100	150	0	150	
2010	CAN	8.1	7.3	11.5	22.6	13.2	35.2	4.2
	Mineral concentrate	6.5	6.1	6.2	13.6	14.9	17.6	
	Pig slurry	9.6	7.1	16.1	17.1	14.6	26.9	
	Cattle slurry	6.2	9.7	12.1	15.7	16.1	26.9	
	Solid fraction	8.0	6.3	9.4	13.3	17.1	14.6	
	Farmyard manure	4.3	11.2	7.5	12.6	10.7	19.8	
2011	CAN	4.1	4.0	4.4	4.6	14.8	16.4	3.7
	Mineral concentrate	5.4	3.0	2.1	2.4	13.8	11.4	
	Pig slurry	6.1	3.6	11.2	7.8	15.7	26.6	
	Cattle slurry	4.0	7.3	5.3	8.4	18.0	22.7	
	Solid fraction	3.6	2.5	4.3	6.2	15.2	13.9	
	Farmyard manure	1.0	5.7	1.7	3.7	8.2	11.7	

*envisaged rates of supposedly available N

Table 16 summarizes the results of NFRV in the experiments on arable land in the Pilot mineral concentrates in 2009 - 2011. The average NFRV per year ranges from 72 - 84 per cent, which falls in the range of theoretical estimated NFRV (Ehlert and Hoeksma, 2011).

Table 17 summarizes the results of all additional experiments. This table shows a wide range in NFRV (0 - 130%). In 21 experiments the NFRV of mineral concentrate was similar to CAN and in ten experiments it was lower than CAN. NFRV of mineral concentrate was assessed as similar to CAN if it did not differ significant from 100.

Table 16
N fertilizer replacement value (NFRV, kg N per 100 kg total N applied), as related to the N rate and N source (Schröder et al., 2012a).

Crop-soil	Year	Mineral concentrate	N-rate (kg N per ha)*			
			50	100	150	Average
Potato-clay	2009	Average of three concentrates	80	66	81	75
Potato-sand	2009	Average of three concentrates	-	89	79	84
Potato-clay	2010	Average of three concentrates	73	78	78	76
Potato-sand	2010	Average of three concentrates	75	80	88	81
Maize-sand	2010	Mineral concentrate D	62	71	82	72
Maize-sand	2011	Mineral concentrate D	65	109	79	84

*supposedly plant-available N

8.4 Conclusions

- In the experiment with silage maize, the average NFRV of mineral concentrate compared to CAN was 84% in 2011. The NFRV of cattle and pig slurries were similar to CAN, which may be related to the dry conditions after N application in 2011.
- The NFRV of mineral concentrate determined in the field experiments of the pilot ranges from 72 - 84 per cent, which falls in the range of theoretical NFRV of mineral concentrates (assuming that part of the organic N is not available and that some gaseous emissions may occur).
- In 21 experiments of the additional research programme, the NFRV of mineral concentrate was similar to CAN and in ten experiments it was lower than CAN.
- The nitrate concentration in the upper groundwater was in both 2010 and 2011 lower with mineral concentrate than with CAN. The nitrate concentration after application of pig and cattle slurries were higher than after application of mineral concentrate.
- The fact that N leaching losses are lower after application of mineral concentrate than after application of CAN, suggests that the lower NFRV of mineral concentrate than of CAN is related to gaseous N losses by ammonia emission and/or denitrification.

Table *17*
The NFRV of mineral concentrate in the various *experimen*ts on arable land *(Van Geel et al., 2011a and 2012).*

Experiment	**Moment of application**	**Method of application**	**NFRV, %**	**Rating**
Starch potatoes	basal dressing	deep injection	126	similar to CAN
recl. peat, 2010	add. fertilization	tubes	130	similar to CAN
Starch potatoes	basal dressing	deep injection	36	lower than CAN
sand 2011	add. fertilization	tubes	56	lower than CAN
Ware potatoes SE	basal dressing	deep injection	123	similar to CAN
sand, 2010	add. fertilization	tubes	82	similar to CAN
Ware potatoes SW	basal dressing	surface	95	similar to CAN
clay, 2010	ditto plus slurry	surface	48	lower than CAN
	add. fertilization	tubes	52	lower than CAN
Ware potatoes SW	basal dressing	Sod injection	91	similar to CAN
clay, 2011	band application	silt couter	133	similar to CAN
	add. fertilization	tubes	< 0	lower than CAN
Winter wheat heavy	2nd appl.	slit coulter	69	lower than CAN
marine clay, 2009	2nd appl.	tubes	119	similar to CAN
	2nd appl. + 3rd appl. CAN	slit coulter	95	similar to CAN
Winter wheat heavy	2nd appl.	slit coulter	102	similar to CAN
marine clay, 2010	2nd appl.	tubes	46	lower than CAN
	2nd appl. + 3rd appl. CAN	slit coulter	95	similar to CAN
Summer barley	basal dressing	deep injection	128	similar to CAN
recl. peat, 2009	basal dressing	surface	102	similar to CAN
Summer barley	basal dressing	deep injection	40	lower than CAN
sandy soil, 2010	basal dressing	surface	9	lower than CAN
Maize SE sand,	before sowing	deep injection	129	seems better than CAN
2010	during sowing	coulter	94	similar to CAN
	after emergence	coulter	95	similar to CAN
	after emergence + start fert. CAN at sowing	coulter	70	lower than CAN
Maize SE sand,	before sowing	deep injection	96	similar to CAN
2011	during sowing	coulter	87	similar to CAN
	after emergence	coulter	91	similar to CAN
	after emergence + start fert. CAN at sowing	coulter	107	similar to CAN
Leek sand, 2011	Basal + 2x additional	coulter	82	similar to CAN

9 General discussion and conclusions

The aim of the monitoring of the products was to analyse the composition of mineral concentrates and changes compared to previous years, with focus on content of N, P, K and organic matter. The average N content of the concentrate increased from 7.22 g per kg in 2009 to 8.15 g per kg in 2011 (Chapter 2). The K content also increased, and the P and organic matter content decreased in this period. The average fraction NH_4 in total N increased from 0.90 in 2009 to 0.92 in 2011. This increase in the fraction of NH_4 in total N may have increased the NFRV of mineral concentrate with a few per cent. It is concluded that quality of mineral concentrate as a mineral N-K fertilizer slightly increased during the years. The composition of mineral concentrate differed between the treatment plants, which was also shown in the previous years. The differences between the plants are due to technical differences between installations, differences in management of the process, and differences in composition of raw slurry. The results also showed that the slurry treatment plants are able to produce concentrate of a relatively stable composition (Figure 3).

The EU Regulation 2003/2003 applies to fertilizers products designated as 'EC fertilizer', when sold in Europe. The EU Regulation 2003/2003 contains a list of approved fertilizers, with for each fertilizer the method of preparation and minimum contents of nutrients. A mineral concentrate cannot meet the requirements in the regulation, because i) the contents of N, P and K are lower than the required minimum and ii) a mineral concentrate contains organic nutrients of animal origin (See Velthof, 2011). The EU Regulation 2003/2003 is under revision and probably it is possible to add new products or new groups of products to this regulation in the future. The admission of new products and the constraints on nutrient contents is determined by the European Commission and EU Member States.

Mineral concentrate contain organic matter, but it is not known in what form. The presence of organic matter in mineral concentrate may affect N processes after application to the soil, and by that the N efficiency of mineral concentrate. In 2011, the contents of VFA in the produced mineral concentrates were measured, because VFA contain readily available C. The mineral concentrate contained VFA, but there were large differences in VFA between the plants (Table 4). The contents of VFA in two of the four concentrates were comparable to the contents generally found in animal slurries. It is likely that the differences in VFA contents of the treated slurries are the main cause for the differences in VFA contents between the mineral concentrates. It is known that both the type of slurry and the storage method and time are factors affecting the VFA contents of slurries. The lower VFA content in the mineral concentrates of two plants may be related to a longer storage time of the slurry before it is treated. The presence of VFA in mineral concentrates indicate that the C in mineral concentrates may affect N immobilization and/or denitrification after application to soil. Immobilization of N and denitrification may be a possible mechanism that reduce the N efficiency of mineral concentrate in comparison to mineral N fertilizer such as CAN.

Incubation studies were carried out to test if application of mineral concentrate to soil affects immobilization and/or denitrification (Chapters 3 and 4). Immobilization could not or hardly be detected (Chapter 3), but application of mineral concentrate increased the potential denitrification rate of soils (Chapter 4). The absence of an effect on immobilization suggests that the amount of available C in mineral concentrates is too small to significantly affect the mineral N content in the soil. Immobilization is probably not a mechanism decreasing the N Fertilizer Replacement Value (NFRV) of mineral concentrate in comparison to CAN. By contrast, the C in mineral concentrates increased denitrification under optimal conditions (i.e. anaerobic conditions, excess of nitrate, and temperature of 20°C). Denitrification may thus occur if mineral concentrate is applied to a nitrate containing soil under relatively wet conditions. Losses of N by denitrification may decrease NFRV of mineral concentrate. The results also showed a higher potential denitrification in the grassland soil than in the arable soil. This may be a factor causing the lower NFRV of mineral concentrates applied to grassland than applied to arable land.

The field experiments in 2009 and 2010 showed a large variation in NFRV of mineral concentrate in comparison to CAN. The NFRV was higher for arable land than for grassland and there were differences between years, suggesting that the weather conditions affected the N efficiency of CAN and mineral concentrate. A pot experiment was carried out in 2011 to determine the N efficiency of different mineral fertilizers, pig slurry, and mineral concentrate in order to get insight in the NFRV of mineral concentrate and other fertilizers compared to CAN under controlled conditions. The pot experiments showed that the NFRV of mineral concentrate compared to CAN was 78 - 96% for the arable crop Swiss Chard and 76 - 97% for grassland (Chapter 5 and 6). Mineral concentrate was applied with a technique that reduces ammonia emission. A second pot experiment showed that the NFRV of mineral concentrate surface-applied to grassland was 36 - 62% and much lower than NFRV of mineral concentrate applied with low ammonia emission to grassland (NFRV was 92%). Thus, bot pot experiments showed that the NFRV under controlled conditions was about 10 - 20% higher (absolute figures) than in the field. The NFRV obtained in the pot experiments were similar to the theoretical NFRV of mineral concentrate, assuming that part of organic N is not available for plants and that some ammonia emission will occur (Ehlert and Hoeksma, 2011). Clearly, there is scope to increase NFRV in the field by optimizing the use of mineral concentrate by e.g. timing of application, use of better low ammonia emission equipment, and decreasing organic N content of mineral concentrate.

The NFRV of mineral concentrate strongly varied in the field experiments 2009 - 2010. Therefore, field experiments were continued in 2010 and 2011. The NFRV of mineral concentrate applied to grassland with the field trial injector was 80% compared to CAN and higher than that in 2009 and 2010. The NFRV of mineral concentrate was lower than that of liquid ammonium nitrate; in 2009 - 2010 similar NFRV values were found for mineral concentrate and liquid ammonium nitrate. The amount of mineral N in the soil profile at the end of the growing season was similar for mineral concentrate and CAN. This shows that the use of mineral concentrate did not increase the risk of nitrate leaching compared to CAN. In the experiment with silage maize, the average NFRV of mineral concentrate compared to CAN was 84% in 2011. The NFRV of mineral concentrate determined in the field experiments of 2009 - 2001 of the pilot ranged from 72 - 84%, which falls in the range of theoretical estimated NFRV. In 21 experiments of the additional research program, the NFRV of mineral concentrate was similar to CAN and in ten experiments it was lower than CAN. Measurements of nitrate concentration in groundwater in the maize experiments and of mineral N contents in the soil in autumn in grasslands and arable lands showed that the risk of nitrate leaching was similar (and sometimes lower) for mineral concentrate than for CAN.

Both the experiments on grassland and the experiments on arable land showed that the use of mineral N concentrate did not increase risk of N leaching losses compared to the use of CAN. This suggests that the lower NFRV of mineral concentrate than of CAN is related to other N loss pathways than N leaching, i.e. gaseous N losses by ammonia emission and/or denitrification. The incubation study (Chapter 3) showed that mineral concentrate did not increase immobilization of N.

The NFRV values in the field experiments in 2011 were 80% for grassland and 84% for silage maize land and were higher than those obtained in the trials in 2009 and 2010. The relatively high NFRV of concentrate in 2011 is probably caused by a number of factors, i.e. a higher mineral N fraction of total N in concentrate (Chapter 4), and weather conditions. The higher mineral N fraction in mineral concentrate may have increased the NFRV with a few percent. Innovations in manure treatment techniques and methods of application of mineral concentrate may further increase NFRV of mineral concentrate.

Application of mineral concentrate results in ammonia and nitrous oxide emissions (Chapter 6; Velthof, 2011). However, the effects of the production and use of mineral concentrate as replacement of CAN on the ammonia and nitrous oxide emission should be evaluated on a national scale, taking all the emissions of N fertilizers and manures into account. A modeling study of Lesschen et al. (2011) with different manure treatment scenarios showed that large scale use of mineral concentrate in the Netherlands instead of CAN and untreated slurry did not significantly change emissions of ammonia and nitrous oxide to the atmosphere and leaching to groundwater.

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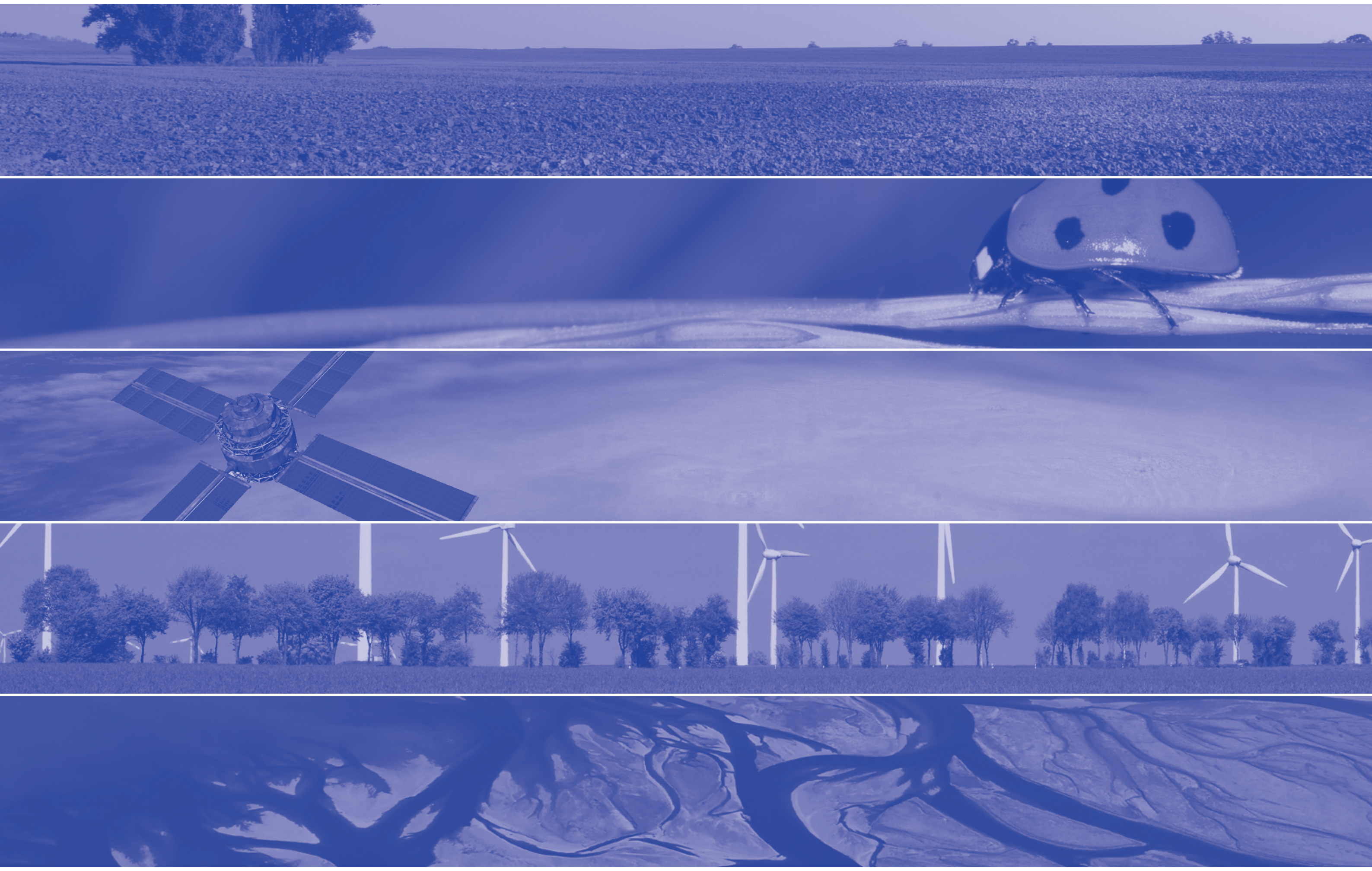

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