Mineral concentrate from processed manure as fertiliser

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Abstract
A pilot study to determine the agronomic and environmental effects of the production and use of mineral concentrates was carried out in the Netherlands. Mineral concentrates are produced by reverse osmosis of the liquid fraction of separated livestock slurry. On average, 90% of the nitrogen (N) in mineral concentrate is present as ammonium-N, the other 10% as organic N. Pot experiments showed that the Nitrogen Fertiliser Replacement Value (NFRV) of injected mineral concentrate compared to calcium ammonium nitrate (CAN) was on average 91% and higher than that of injected pig slurry (75%). The average NFRV of injected mineral concentrate compared to CAN ranged from 72 to 84% in field experiments on arable land. The NFRV compared to CAN increased from 54% in 2009 to 81% on grassland, in 2014. The reason for the low NFRV in 2009 is not clear. The NFRV compared to liquid ammonium nitrate was higher (79–102%). Laboratory tests showed higher ammonia and nitrous oxide emissions from mineral concentrates than from CAN. Nitrate-leaching from applied mineral concentrates was similar or lower than that from CAN and untreated manure. There is scope to increase NFRV of mineral concentrate by use of low ammonia-emission application techniques, acidification, and reduction of organic N content of the concentrate. Scenario analyses showed that large scale use of mineral concentrate as fertiliser and solid fraction of separated slurry would decrease the need for mineral N and P fertilisers in the Netherlands.

Keywords: fertilizer, manure, mineral concentrate, nitrogen, potassium, processing, reverse osmosis

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Photo cover: Gerard Velthof

Contents

Preface

A pilot study is being carried out in the Netherlands since 2009 on the agricultural and environmental impacts of the production and use of mineral concentrate from processed manure as a fertiliser.

The following manure treatment plants participated in the pilot: Bmec Salland (2009-2011), KUMAC B.V. (2009-2104), Loonbedrijf Jan Reniers (MVS) (2009-2104), Van Heugten-Friesen (2009-2014), Maatschap Gebroeders Van Balkom (2009-2010), Houbraken B.V. (2009-2014), Kempfarm B.V. (2009/2013-2014), Vermue Poelma, (2010-2013), Dankers Bio Energy B.V. (2013-2014), Gebr. Verkooyen B.V. (2013-2014), Varkenshouderij Poels VOF (2013-2014), Hoeven Varkens (2014) and Bleekerheide VOF (2014).

In this pilot, research has been carried out in the period 2009 – 2014 by various WUR institutions (Alterra, WUR Livestock Research, Plant Research International, Applied Plant Research, and LEI) in close collaboration with representatives of the manure treatment plants.

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 (EZ) and the Ministry of Infrastructure and Environment (IenM). This research was funded by the Dutch Ministry of Economic Affairs, the Dairy Board, the Livestock and Meat Marketing Board, and Interreg IVB NWE project Biorefine.

This report provides a summary and synthesis of the research conducted in the period 2009 – 2014. The results of the different studies have been published in research reports and scientific publication (see References).

Parts of this summary report have been presented as a paper to The International Fertiliser Society at a Meeting in Cambridge on 7th December 2012:

G.L. Velthof, P. Hoeksma, J.J. Schröder, J.C. van Middelkoop, W. van Geel, P.A.I. Ehlert, G. Holshof, G. Klop, and J.P. Lesschen (2012) Agronomic potential of mineral concentrate from processed manure as fertiliser. Proceedings No: 716, The International Fertiliser Society, LEEK, Staffordshire, United Kingdom

Wageningen, May 2015

Gerard Velthof, coordinator research Mineral Concentrates Pilot

Summary

Processing of manure is an option to increase the use efficiency of nutrients within it. A concentrated solution of nitrogen (N) and potassium (K) (‘mineral concentrate’) is one of the products that results from manure processing. A pilot study to determine the agronomic and environmental effects of the production and use of mineral concentrates was carried out in the Netherlands. The concentrate was produced by reverse osmosis of the liquid fraction of separated livestock slurry. On average, (161 samples in the period 2009-2014) 90% of the N in mineral concentrate is present as ammonium-N (NH_4^+-N), the other 10% as organic N.

Pot experiments with different soils and crops showed that the Nitrogen Fertiliser Replacement Value (NFRV) of injected mineral concentrate compared to calcium ammonium nitrate (CAN) was on average 91% and higher than that of injected pig slurry in the same experiments (75%). The average NFRV of injected mineral concentrate compared to CAN ranged from 72–84% in field experiments on arable land. The NFRV compared to CAN increased from 54% in 2009 to 81% on grassland, in 2014. The reason for the low NFRV in 2009 is not clear. The NFRV compared to liquid ammonium nitrate was higher than that compared to CAN (79 – 102%).

Mineral concentrate is an ammonium containing fertiliser with a high pH (approximately pH 8). Experiments showed that application of mineral concentrates resulted in ammonia (NH_3) and nitrous oxide (N_2O) emissions. Injection or incorporation of mineral concentrate strongly decreased NH_3 emission. Averaged over three incubation tests, the NH_3 emission from incorporated mineral concentrate was significantly lower than that of incorporated pig slurry. The N_2O emission from mineral concentrate is probably related to the presence of organic carbon in concentrates and/or high NH_3 concentration in the soil. The average N_2O emission in incubation tests of incorporated mineral concentrate was higher than the N_2O emission from surface-applied CAN and pig slurry.

The risk of nitrate leaching from applied mineral concentrates was similar to, or lower than that from CAN and untreated manure, for both grassland and arable land. Obviously, NH_3 emission and denitrification are the dominant N-loss pathways following application of mineral concentrate. There is scope to decrease N-losses and increase NFRV of mineral concentrate by use of low NH_3-emission application techniques, acidification, and further decrease of the organic N-content of the concentrate.

Scenario-analyses on a national scale showed that large scale use of mineral concentrate as fertiliser and the attending solid fraction in the Netherlands would decrease the need for mineral N and P fertilisers by up to 15% and 82%, respectively. The total NH_3 and N_2O emissions and N-leaching in the Netherlands would hardly change. Large scale use of mineral concentrate would increase the N and P use efficiency in agriculture in the Netherlands in the considered scenarios.

Compared to pig slurry, mineral concentrates have a low content of organic matter and P and a relatively high fraction of NH_4-N in total N. However, even though mineral concentrates are obtained through an industrial process, the product is still subject to the legal definition of livestock manure in the Nitrates Directive. The data from the study will be used in consultations with the European Commission on the status of mineral concentrate within the context of the Nitrates Directive. The European Union (EU) Regulation 2003/2003 applies to fertilisers designated as ‘EC fertilizer’, when sold in Europe (European Commission, 2003). This regulation is currently under revision and new products or new groups of products will be added to this legislation in the near future. The status of mineral concentrates in the new regulation is not yet clear.

Samenvatting

Mestverwerking is een optie om de benutting van nutriënten in mest te verhogen. Mineralenconcentraat, een geconcentreerde oplossing van stikstof (N) en kalium (K), is een van de producten die kan worden geproduceerd via mestverwerking. Het mineralenconcentraat wordt geproduceerd door middel van omgekeerde osmose van de vloeibare fractie van gescheiden mest. Er wordt een pilot uitgevoerd in Nederland om de landbouwkundige eigenschappen van mineralenconcentraat en de milieukundige gevolgen van toepassing van dit product te bepalen.

Gemiddeld is 90% van de stikstof in mineralenconcentraat aanwezig als ammonium (161 monsters in de periode 2009-2014); de resterende stikstof is aanwezig als organische stikstof. Van de ingaande dunne varkensmest was 67% van de stikstof aanwezig als ammonium.

Potproeven met verschillende grondsoorten en gewassen laten zien dat de werkingscoëfficiënt van in de bodem geïnjecteerd mineralenconcentraat gemiddeld 91% was ten opzicht van de referentiemeststof kalkammonsalpeter (KAS). De werking van geïnjecteerde varkensmest was in dezelfde proeven lager: 75%. De gemiddelde werkingscoëfficiënt van geïnjecteerd mineralenconcentraat ten opzichte van KAS varieerde in veldproeven op bouwland van 72–84%. De werking op grasland nam toe van 54 in 2009 naar 81% in 2014. Het is niet duidelijk waarom de werking in 2009 zo laag was. De werkingscoëfficiënt was hoger (79–102%) ten opzichte van vloeibaar ammoniumnitraat als referentiemeststof.

Een mineralenconcentraat is een ammoniumhoudende meststof met een hoge pH (ongeveer 8). Experimenten laten zien dat toediening van mineralenconcentraten leidt tot emissies van ammoniak en lachgas. Het injecteren of inwerken van mineralenconcentraat beperkt ammoniakemissie sterk. De ammoniakemissie van ingewerkt mineralenconcentraat was significant lager dan die van ingewerkte varkensmest in drie incubatieproeven. De emissie van lachgas na toediening van mineralenconcentraten wordt waarschijnlijk veroorzaakt door de aanwezigheid van gemakkelijk afbreekbare organische stof en/of door hoge ammoniakconcentraties in de bodem. De gemiddelde lachgasemissie van ingewerkte mineralenconcentraat was in incubatieproeven hoger dan die van KAS en varkensmest.

Het risico op nitraatuitspoeling na toediening van mineralenconcentraten was vergelijkbaar of lager met die van toediening van KAS en onbewerkte mest, voor zowel bouwland als grasland. Deze resultaten duiden erop dat gasvormige emissies (ammoniak en denitrificatie) de belangrijkste posten van stikstofverlies zijn die leiden tot een lagere stikstofwerking dan KAS. Er zijn perspectieven om stikstofverliezen te verminderen en de stikstofwerking te verhogen door het gebruik van emissiearme toedieningssystemen, aanzuren van concentraat en verlaging van het gehalte aan organische stikstof in het concentraat.

Scenarioanalyses op nationale schaal laten zien dat grootschalig gebruik van mineralenconcentraten als kunstmest en dikke fractie van gescheiden mest in Nederland kunnen leiden tot een afname van de behoefte aan stikstof- en fosfaatkunstmest met respectievelijk 15 en 82%. De totale ammoniak- en lachgasemissies en nitraatuitspoeling in Nederland veranderen weinig in de doorgerekende scenario's. Door het op grote schaal toepassen van mineralenconcentraat in Nederland zal de benutting van stikstof en fosfaat in de landbouw toenemen.

Mineralenconcentraten hebben ten opzichte van onbehandelde mest een laag gehalte aan organische stof en fosfaat en een hoog aandeel aan ammoniumstikstof in de totale hoeveelheid stikstof. Mineralenconcentraten zijn gemaakt van dierlijke mest en vallen daardoor onder de definitie van dierlijke mest in de EU-Nitraatrichtlijn. De resultaten van het onderzoek worden door de Nederlandse overheid gebruikt voor discussies met de Europese Commissie over erkenning van mineralenconcentraten als kunstmest binnen de Nitraatrichtlijn en de Meststoffenverordening.

1 Introduction

Total nitrogen (N) inputs to European agriculture exceed the N outputs via harvested crop and animal products, resulting in N emissions to the atmosphere, groundwater and surface waters. Total N inputs range from less than 50 kg N per ha per year in regions in Central Europe to more than 300 kg N per ha per year in regions in North West Europe (Velthof et al., 2009; 2014). The surplus of N applied as fertiliser and manure can lead to numerous problems directly related to human health and ecosystem vulnerability, including eutrophication of water, soil acidification, groundwater contamination, and greenhouse gas emissions (e.g. Galloway et al., 2003; Sutton et al., 2011). A series of environmental policies has been implemented in the European Union (EU) to decrease these N emissions (Oenema et al., 2011).

The EU Nitrates Directive (European Commission, 1991) aims to reduce the leaching of nitrate (NO_3) from agriculture to groundwater and surface water. The Nitrates Directive includes measures that EU member states have to take in vulnerable areas to reduce NO_3 leaching. An important measure is that the amount of fertiliser and manure N applied should be balanced with the N need by the crop and the N supply from other sources. The availability of manure N for the crop depends of the amount of ammonia (NH_3) emission and the presence of organic N from which only part is plant-available (Birkmose, 2009; Schröder et al., 2007a). The Nitrates Directive also stipulates that the annual application rate of manure should not exceed 170 kg N per ha. Member states may allow application of more manure when it is shown that this does not lead to an increased risk of NO_3 leaching (derogation). Livestock manure is defined in Article 2 of the Nitrates Directive as waste products excreted by livestock or a mixture of litter and waste products excreted by livestock, even in processed form.

Processing of manure is considered as a possibility to increase nutrient use efficiency of manure (Burton, 2007). One possible way of treatment is separation of livestock slurry in a solid and liquid fraction followed by reverse osmosis of the liquid fraction. This process results in a concentrated N-potassium (K) solution (“mineral concentrate”), in which most of the N is present as ammonium-N.

A pilot is carried out in the Netherlands since 2009 in which mineral concentrates are produced and used as fertiliser on commercial farms (Velthof, 2011; 2012). In this pilot the agronomic and environmental effects of the production and use of mineral concentrates are investigated. This report summarises the main results of the research on mineral concentrates in the period 2009-2014. An overview of the composition of mineral concentrates, the N Fertiliser Replacement Value (NFRV) as determined in pot and field experiments, and the risk of gaseous N emissions and N leaching are presented. Moreover, scenario analyses were carried out using a model to quantify the effects of large scale production and use of mineral concentrates in the Netherlands. The results of the different studies are published in research reports and scientific papers (see References).

2 Production and composition of mineral concentrates

2.1 Production

Figure 1 shows a process scheme of the production of mineral concentrate. The first step in the process is a solid-liquid separation using a decanter centrifuge, a belt press or an auger press, in combination with air flotation. Sometimes the liquid fraction is further polished by ultra filtration (Hoeksma et al., 2011). The effluent from separation enters a reverse osmosis unit, in which water is pushed under high pressure through a semipermeable membrane. Fouling of the membranes by deposition of salts and growth of microorganisms may be a problem using reverse osmosis of the liquid fraction of manure. Therefore, solids and organic matter should be removed as much as possible from the liquid fraction before reverse osmosis (Masse et al., 2007). Reverse osmosis results in a concentrated salt solution, the mineral concentrate. Next to the concentrate two other products are derived from this technique, i.e. a solid fraction and water ('permeate'). The solid fraction and the mineral concentrate can be used as fertilizer. The permeate is sometimes used on the farm for cleaning (e.g. as flushing liquid) or is discharged into the sewer or surface water (Hoeksma et al., 2011).

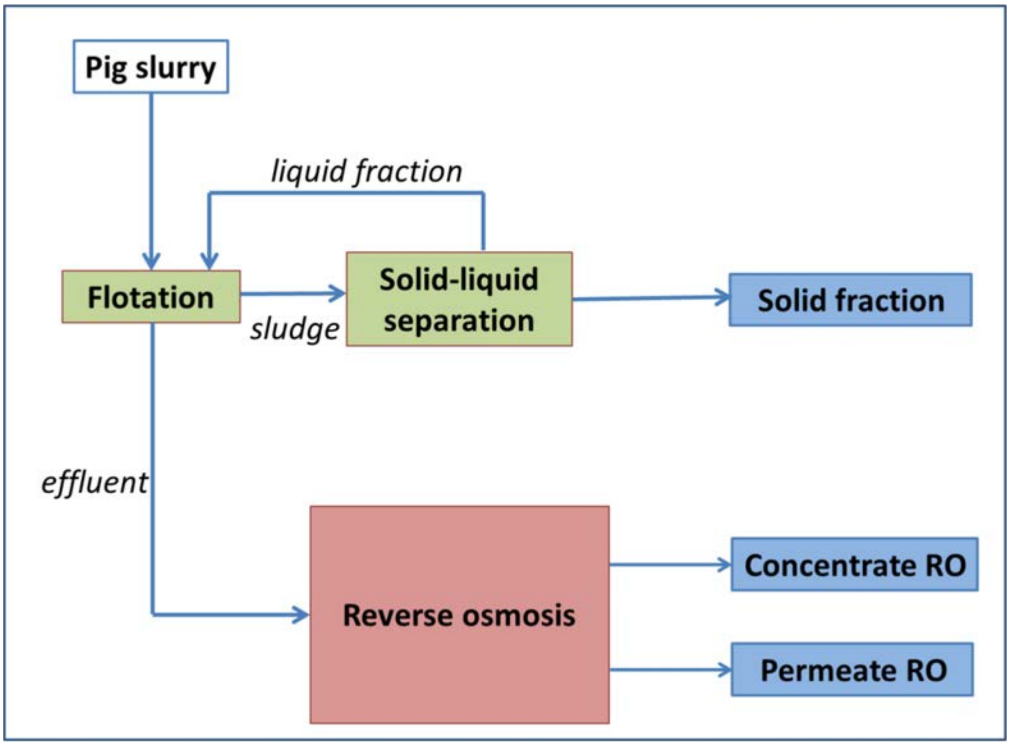

Figure 1 *Example of pig slurry treatment using reverse osmosis. The concentrate of reverse osmosis (RO) is used as mineral fertilizer.*

2.2 Mass balance of treatment installations

Table 1 shows the mass balance calculations of nutrients and organic matter of the manure treatment installations. The input of raw slurry is set at 100. Notice that the installations also used additives such as acids, salts and flocculants during treatment, causing the sum of the outputs of dry matter and other parameters to be higher than 100% for some installations. This also explains why balances are sometimes negative (i.e. outputs are higher than the manure input). Positive balances (i.e. manure input is higher than the summed outputs) point at losses. For N, this may be due to gaseous N losses by NH_3 volatilization and denitrification. For K, it may not be excluded that K precipitation occurs during clogging of pipes (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 1). The N balance suggests that on average one per cent of the slurry N was lost during the treatment process. The largest part of both 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.

Table 1

Average relative mass distribution of dry matter (DM), organic matter (OM), total N, NH_4-N, total P and K over the end products of slurry treatment in four plants in 2011. The balance is calculated as the difference between the input as raw slurry and the outputs as solid fraction, mineral concentrate, and permeate (Hoeksma and de Buisonjé, 2012)[1].

	DM	OM	Total N	NH_4-N	P	K
Raw slurry	100	100	100	100	100	100
Solid fraction	86	94	44	29	96	18
Mineral concentrate	21	12	53	70	4	78
Permeate	0	0	2	0	0	1
Balance (input-output)	-5	-2	6	1	0	3

[1] the installations also used additives such as acids, salts and flocculants during treatment, causing the sum of the outputs of dry matter and other parameters to be higher than 100% for some installations.

2.3 Composition

Table 2 shows the average composition of mineral concentrates produced in the period 2009-2014. The average total N content of the concentrate was 7.12 g N per kg product, from which 6.40 g NH_4-N per kg (90%). The average N content of the untreated slurry was 5.47 g N per kg, from which 67% as NH_4-N. The K content was on average 7.19 g per kg and the P_2O_5 content was on average 0.40 g per kg (0.17 g P per kg). The contents of N, NH_4-N and K are approximately a factor 2 higher in concentrates than in the liquid fraction of separated slurry. The EC of mineral concentrate (average: 56.6 mS/cm) is higher than that of untreated slurry (26.5 mS/cm) and the liquid fraction (29.8 mS/cm). The solid fraction of separated slurry contained on average 12.1 g N per kg product, from which 42% NH_4-N (Table 1). The average P_2O_5 content of the solid fraction was 15.7 g per kg.

Hoeksma and De Buisonjé (2012) showed that treatment installations can produce concentrates with a relatively sTable composition. Variations in composition of mineral concentrates between the installations are due to differences in separation technique, management of the installation, and composition of the treated livestock slurry.

The levels of heavy metals (Cd, Cr, Ni, Pb and As) in mineral concentrates are not a concern for agricultural use of mineral concentrates as fertiliser (Ehlert et al., 2009 and Ehlert and Hoeksma, 2011). The results of analyses of organic contaminants showed that the levels of dioxins, non-ortho PCBs, mono-ortho PCBs, indicator PCBs, PAHs, organochlorine pesticides and mineral oil in mineral concentrates are at or below the detection limit.

Table 2

Average composition (and standard deviation; Std.) of untreated slurry, solid fraction, liquid fraction and mineral concentrate in the period 2009 – 2014 (Hoeksma et al., 2011; Hoeksma and De Buisonjé, 2012; Hoeksma and De Buisonjé, 2015). (Note: P is expressed in both P and P_2O_5, because the norms in the Dutch fertilizer Act are based on P_2O_5).

	Untreated slurry			Solid fraction			Liquid fraction			Mineral concentrate		
	Average	Std.	Sample number	Average	Std.	Sample number	Average	Std.	Sample number	Average	Std.	Sample number
Dry matter, g/kg	62.4	23.8	123	280	73.8	136	18.2	8.24	95	33.4	8.11	161
Organic matter, g/kg	42.8	18.5	123	210	56.5	136	8.73	6.13	95	13.3	5.43	162
Total N, g/kg	5.47	1.55	123	12.1	1.78	136	3.72	1.12	95	7.12	1.67	162
NH_4 –N, g/kg	3.66	0.95	123	5.11	1.13	136	3.06	0.87	95	6.40	1.56	162
P, g/kg	1.38	0.51	123	6.87	1.47	136	0.13	0.14	95	0.17	0.14	162
P_2O_5, g/kg	3.16	1.16	123	15.7	3.37	136	0.30	0.32	95	0.40	0.31	162
K, g/kg	3.76	0.85	123	3.69	1.40	136	3.44	0.69	95	7.19	1.42	162
pH	7.68	0.30	123				7.95	0.31	95	7.94	0.28	162
EC, mS/cm	26.5	4.14	119				29.8	7.20	95	56.6	9.23	162
Ntot/P_2O_5	1.99	1.11	123	0.79	0.15	136	24.6	41.9	95	68.8	124	161
NH_4-N/Ntotal	0.68	0.06	123	0.43	0.08	136	0.83	0.08	95	0.90	0.06	161

2.4 Results of samples of transported mineral concentrates

In total 11711 samples have been taken from transported mineral concentrate in the period 2009 – 2014. The average total N contents of mineral concentrate ranged from 6.19 – 7.95 g N per kg (Table 3). There was no clear trend in N content in time. The average N content was 7.26 g N per kg. The P_2O_5 contents decreased from 0.41 g P_2O per kg in 2009 to 0.26 g P_2O per kg in 2014.

The average N and P contents differ somewhat from those of the monitoring presented in Table 1. This is because the number of samples of each farm differ between this monitoring and the transport records (populations are different). The variation in the N contents is caused by a number of factors, including differences between in treatment plants participating in the pilot, contents between the treatment plants (Hoeksma and De Buisonjé, 2012), and uncertainties in sampling of concentrates during the transport and in chemical analyses. The decrease in P contents can be considered as positive, because the P application standards will become stricter in the near future. The presence of P in mineral concentrate may limit the use of mineral concentrate as N fertiliser.

Table 3

*N and P contents of mineral concentrate, sampled from transports of mineral concentrate from the manure treatment plants to users in 2009 - 2014 (Source: Ministry of EZ)**

Year	Number of samples	N content, g/kg		P_2O_5 content, g/kg	
		Average	Stdv.	Average	Stdv.
2009	1209	6.89	1.17	0.41	0.31
2010	1805	7.35	1.59	0.38	0.28
2011	2117	7.95	1.41	0.37	0.27
2012	1791	7.88	1.37	0.30	0.23
2013	2240	7.30	1.15	0.32	0.25
2014	2156	6.19	1.82	0.26	0.27
Total	11318				

* Total number of samples is 11711. Values lower that 1% and higher than 99% percentile are excluded.

2.5 Theoretical value as fertiliser

The mineral concentrate can be used as a liquid N-K fertiliser. The N in mineral concentrates is mainly found in the NH_4 form (on average 90% of total N in the concentrate; Table 2). The remaining N is organically bound. The pH of mineral concentrates is high (about pH 8), thus it is likely that N partly occurs in the form of NH_3 in mineral concentrates.

The efficiency of N in mineral concentrates used as fertiliser depends on the amount of NH_3 emission and the presence of organic N. The NFRV of an organic fertiliser is the percentage of the applied N, which has the same effect on crop N yield as mineral fertiliser. In the Netherlands, the NFRV is generally determined by comparison with broadcast mineral fertiliser Calcium Ammonium Nitrate (CAN), which is the most commonly used mineral N fertiliser in the Netherlands.

Part of the N in mineral concentrates will become available for the crop via N mineralisation. According to fertiliser recommendations in the Netherlands (www.bemestingsadvies.nl; www.kennisakker.nl) it is assumed that the NFRV of organic N in manure amounts to 20-60% during the first 12 months after application. The NH_3 emission from surface-applied slurry amounts 69-74% of the applied NH_4-N and that from slurry incorporated in the soil (including injection) is 2-26% (Huijsmans and Schils, 2009).

Assuming that these figures for slurry also hold for mineral concentrates, it is estimated that the NFRV of surface-applied mineral concentrates is 25-30% and that of incorporated slurry 70-90% compared to CAN. This theoretical approximation of the NFRV has been tested in experiments, of which the results are presented in Section 6.4.3.

If it is assumed that part of the organic N in concentrate becomes available for the crop by N mineralisation (estimated at 45% of organic N; Ehlert and Hoeksma, 2011), then the NFRV compared to CAN of mineral concentrates would theoretically be 96%. However, part of the NH_4-N in mineral concentrate may be lost by NH_3 emission. About 70% of NH_4-N applied as manure will be lost at surface application and about 5-26% for incorporation or injection (Huijsmans and Schils, 2009). In the Netherlands, slurries have to be injected or incorporated according to the Fertiliser Act. Assuming that the NH_3 emission factors for manure also apply to mineral concentrates, the theoretical NFRV of injected mineral concentrate is about 72 – 78% for grassland (sod coulter or sod injection) and 78 – 94% (sod injection or deep injection) for arable land. The theoretical NFRV is less than 40% if mineral concentrate is surface-applied.

The P content in the mineral concentrates is generally low and therefore mineral concentrates will have no agronomic value as P fertilizer. The exact chemical form in which K occurs in mineral concentrate is not known, but based on the chemical analysis it is assumed that potassium occurs as potassium bicarbonate, potassium chloride, potassium sulphate and potassium-containing fatty acids. Therefore, it is likely that the K in mineral concentrates is fully available to the crop.

Mineral concentrates also contain other nutrients. Sulfur (S) and sodium (Na) are of agronomic significance. The levels of Na in mineral concentrates are approximately 20-25% of that of K (Ehlert and Hoeksma, 2011). When using a mineral concentrate as a N fertiliser or K fertiliser a significant amount of Na is applied (20-40 kg Na per ha). Na has a value in animal feeding, and some arable crops (e.g. sugar beet) respond positively to applied Na. Sulphur is a valuable component of mineral concentrate, but the average total S application rate is low (about 4 kg S per 100 kg N as mineral concentrate, of which about 3 kg as sulphate). The availability of this S for the crop is unknown. The levels of calcium, magnesium and trace elements in mineral concentrate are generally too low to be of agronomical significance. The average chloride concentration is 3.1 g Cl per kg (Ehlert and Hoeksma, 2011). Over-application of chloride is not an issue when using mineral concentrate, as long as the chloride supply with other fertilisers is taken into account.

The solid fraction can be used as N-P fertiliser and source of organic matter (Table 2). At least half of the N is present as organic N and this N will only be available for crop uptake after mineralisation.

3 Nitrogen transformations in soil and gaseous N emissions

3.1 Immobilisation

Mineral concentrates contain organic N and carbon (C), including volatile fatty acids (Hoeksma and De Buisonjé, 2012). Application of mineral concentrates to a soil may affect immobilisation-mineralisation of N. The C of mineral concentrates may be used for growth by micro-organisms, resulting in immobilisation of mineral N (Kirchmann and Lundvall, 1993). Immobilisation may decrease the N efficiency of mineral concentrate.

Ehlert *et al.* (2012) carried out an incubation experiment to test the effect of application of mineral concentrate on the mineral N content of soil. The contents of NH_4, NO_3, and total mineral N did not significantly change during an incubation period of 56 days weeks. There was no clear difference in the time course of mineral N content in a soil to which mineral concentrate was applied and a soil to which CAN was applied. This suggests that adding mineral concentrates did not affect immobilisation or mineralisation of N in soil.

3.2 Ammonia emission

The combination of a high NH_4 content and high pH increases risk of NH_3 emissions. The risk of NH_3 emission can be decreased by injection or incorporation into the soil. In a series of incubation studies, the NH_3 emissions from untreated pig slurry, mineral concentrate, mineral fertilisers and the solid fraction from separated slurry have been quantified (Velthof and Hummelink, 2011). In these experiments also N_2O emission was measured (section 3.3). The products were both surface applied and injected. Laboratory studies give an impression of the differences in gaseous emissions from fertilisers, but provide no quantitative estimate of emissions that occur under field conditions.

Surface application of mineral concentrate, pig slurry, and urea resulted in high NH_3 emission, as shown in Figure 2 for one of the experiments. Incorporation into the soil strongly reduced NH_3 emission. Averaged over the three incubation tests of Velthof and Hummelink (2011), the NH_3 emission from incorporated mineral concentrate was significantly ($P<0.05$) lower than that of incorporated pig slurry. This is probably due to the lower dry matter contents of mineral concentrates (Table 2), by which mineral concentrate rapidly filtrates in the soil. The NH_3 emission from mineral concentrate incorporated in the soil was low and similar to that of surface applied CAN. With a proper application technique NH_3 emission from mineral concentrate can be reduced strongly. Field experiments of Huijsmans and Hol (2011) in 2010 showed that the NH_3 emission after sod injection of concentrate to cereals was 3% of the applied NH_4-N in the mineral concentrate and 12% when applied via a trailing hose dosing machine. The NH_3 emission from mineral concentrate applied with sod injection to grassland averaged 8% of the applied NH_4-N.

The NH_3 emission from a surface-applied solid fraction of separated slurry was on average lower than from surface-applied pig slurry and mineral concentrate (Figure 2). Emission of NH_3 from a surface applied solid fraction was higher than from incorporated pig slurry. Incorporation of solid fraction reduced NH_3 emission.

3.3 Denitrification and nitrous oxide emission

Mineral concentrates contain organic C, including volatile fatty acids (Hoeksma and de Buisonjé, 2012). When available C is applied to a NO_3 containing soil under wet conditions, denitrifying bacteria may use the C as energy source and the NO_3 can be transformed into gaseous N_2O and N_2. Paul and

Beauchamp (1989) showed that volatile fatty acids are effective energy sources for denitrifiers. An incubation study was carried out to determine the potential denitrification rate of an untreated soil and a soil amended with glucose, CAN, and three mineral concentrates (Ehlert et al., 2012). Potential denitrification was measured under anoxic conditions, at a temperature of 20 ^{o}C and in the presence of excess of NO_3. All mineral concentrates increased potential denitrification, showing that the C in mineral concentrate is available for denitrifying bacteria.

The presence of C in mineral concentrate and its effect on denitrification may also affect N_2O emission. Moreover, application of mineral concentrate may result in a high NH_3 concentration in the soil. This may result in NH_3 toxification of nitrifier bacteria which in turn may increase N_2O emission. These effects are likely to be similar as those found in urine patches (Oenema et al., 1997).

In incubation tests of Velthof and Hummelink (2011), N_2O emission was determined after application of mineral concentrate and other manures and fertilizers. The incorporation of mineral concentrate and pig slurry resulted in higher N_2O emissions than surface application (Figure 2). Velthof and Mosquera (2011a) also showed in field experiments that injection of pig slurry increases N_2O emission when compared to surface application. The average N_2O emission of incorporated mineral concentrate was higher than the N_2O emission from a similar N rate of surface-applied CAN (Velthof and Hummelink, 2011). The N_2O emission from mineral concentrate was approximately 1.5-fold higher than from untreated pig slurry, averaged over all tests and application techniques (Velthof and Hummelink, 2011). Many factors play a role in N_2O emission from soils (Granli and Bøckman, 1994). No clear explanation can be given for the relatively high N_2O emission after application of mineral concentrate. Differences in N_2O emission will be related to the form and content of N, pH, presence of organic matter and other factors that influence the microbial processes of nitrification and denitrification.

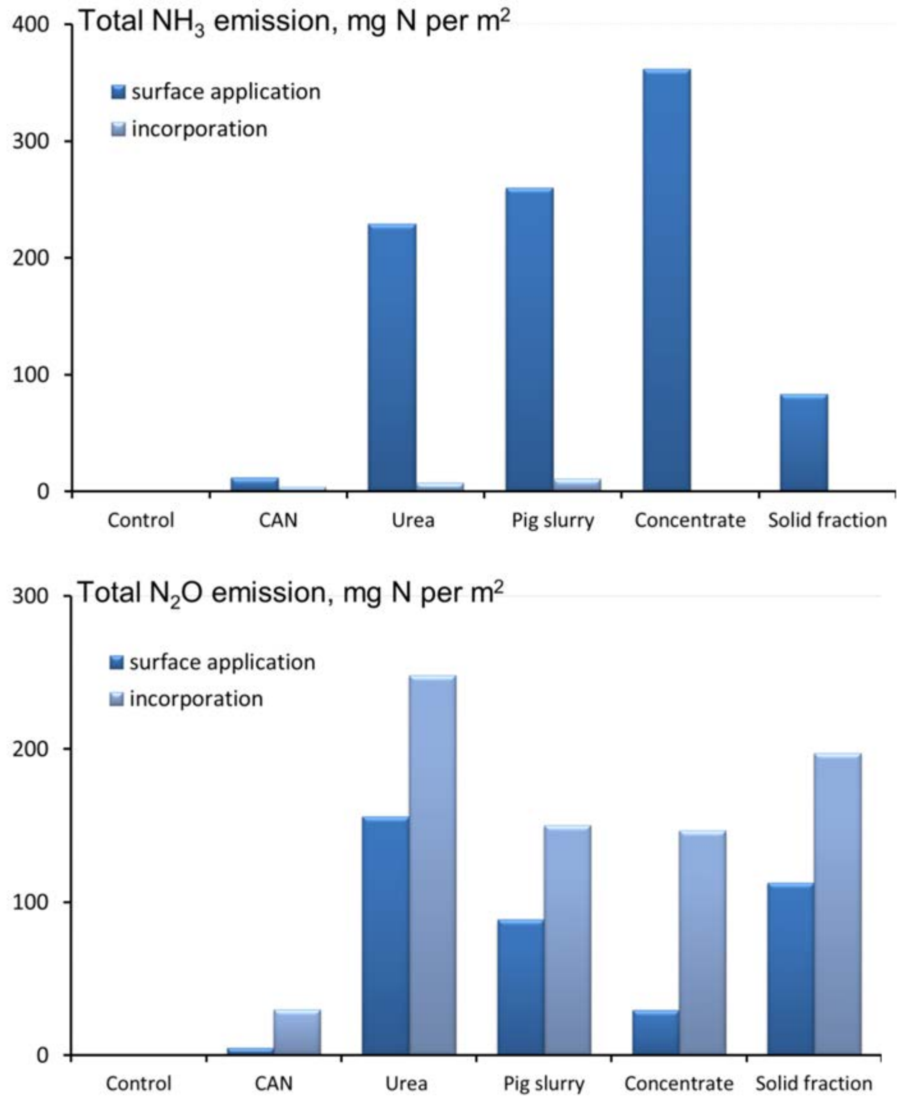

Figure 2 *Average NH_3 (upper figure) and N_2O (lower figure) emission in a laboratory study with arable soil. Calcium ammonium nitrate (CAN), urea, pig slurry, mineral concentrate, and solid fraction were surface-applied and incorporated at the same total N application rate. Fluxes of NH_3 and N_2O were determined during incubation of 1 month, using a photo-acoustic gas monitor (Velthof and Hummelink, 2011).*

4 Nitrogen efficiency of mineral concentrates under controlled conditions

Pot experiments have been carried out by Ehlert *et al.* (2012), Klop *et al.* (2012), and Rietra and Velthof (2014). The NFRV of injected mineral concentrate compared to CAN was on average 91% and higher than that of pig slurry in the same experiments (75%; Table 4).

A pot experiment was carried was carried out by Ehlert *et al.* (2012) to determine the NFRV of several mineral fertilisers, pig slurry, and mineral concentrate under controlled conditions. The pot experiment was carried out with Lolium perenne L. (perennial ryegrass) grass and Beta vulgaris L. var. vulgaris, 'groene snijbiet' (Swiss chard) as test crops. The NFRV of liquid ammonium nitrate, ammonium sulphate, and ammonium chloride were on average 100%. The NFRV of urea was somewhat lower (except grass on sand), which is probably due to NH_3 emission (Sommer et al., 2004). The NFRV of mineral concentrate was on average 86-87% (Table 4). The NFRV of pig slurry was 72% for both Swiss chard and grassland.

Klop *et al.* (2012) carried out a pot experiment with grass. The NFRV of surface-applied mineral concentrate was 37 – 62% and much lower than injected mineral concentrate (96%). The lower yields of surface-applied mineral concentrate were party due to scorching of grass after surface application of mineral concentrate and pig slurry. Scorching did not occur after injection of concentrate or pig slurry and after 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, NH_3 and/or volatile fatty acids 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 NH_3 emission. The NFRV of pig slurry was only 41% after surface-application and increased to 79% when injected. Measurements in this experiment confirmed that NH_3 emission was much lower from injected concentrate than from surface-applied concentrate. Emission of N_2O from mineral concentrate was higher than from CAN, but lower than from pig slurry.

In a pot experiment of Rietra and Velthof (2014), effects of soil moisture content and acidification of mineral concentrate on NFRV was tested. The highest N uptake was shown using CAN and liquid NH_4NO_3 at the highest soil moisture content. The NFRV of incorporated and acidified concentrates (83 – 106%) were significantly higher than surface-applied concentrate (64-79%). The NFRV of incorporated concentrates (93%) was lower and of acidified concentrate (106%) higher than of liquid NH_4NO_3 (101%) and CAN (100%), at the highest moisture content. Averaged over the three tested moisture contents there was no statistically significant difference between incorporated and acidified concentrates, liquid NH_4NO_3 and CAN. The NFRV of an incorporated mixture of pig slurry and concentrate was 74–82% and between that of incorporated pig slurry (58-76%) and that of incorporated mineral concentrate (83-106%). The highest N_2O emission in this experiment was found for pig slurry and the mixture of pig slurry and concentrate. The N_2O emission of acidified mineral concentrate was lower than of incorporated mineral concentrate. Acidification decreased NH_3 emission.

Table 4

NFRV of injected mineral concentrate compared to CAN (in%) in pot experiments.

Experiment	**Crop**	**Injected mineral concentrate** **%**	**Injected pig slurry** **%**
Ehlert *et al.* (2012)	Grass	86	74
Ehlert *et al.* (2012)	Swiss chard	87	71
Klop *et al.* (2012)	Grass	96	79
Rietra and Velthof (2014)	Grass	93	76
Average		91	75

5 Nitrogen efficiency and nitrate leaching in field experiments

5.1 Arable land

Field experiments on arable land were carried out in 2009-2011 (Schröder et al., 2012a&b; Van Geel et al., 2012a & 2012b). In these experiments, the NFRV of mineral concentrate was determined. Mineral concentrate was injected to a depth of 5-10 cm in the soil. The average NFRV ranged from 72 – 84% in these experiments (Table 5). These values are in the range or somewhat lower than the theoretically estimated NFRV values (Section 2.5).

In an experiment with potato on clay, Van Geel *et al.* (2012a) used a liquid ammonium nitrate fertiliser as reference fertiliser. This fertiliser was injected with the same equipment as the mineral concentrate. The NFRV of mineral concentrate was 117% compared to liquid ammonium nitrate. The NFRV compared to CAN was 76% in the same experiment. This shows that the NFRV of mineral concentrate was similar to that of a liquid mineral fertiliser in this experiment.

Van Geel *et al.* (2012b) also determined the NFRV in field experiments with a less detailed set-up than those of Van Geel *et al.* (2012a) and Schröder *et al.* (2012b). The results of these experiments showed a wide range in NFRV (0 -130%). In 20 experiments the NFRV of mineral concentrate was similar to CAN, in 10 experiments it was lower than CAN and 1 experiment it was higher.

Table 5

NFRV of injected mineral concentrate compared to CAN (in%) in field experiments with potatoes and maize (Schröder et al., 2012a&b; Van Geel et al., 2012a & 2012b).

Crop	Soil	Year	NFRV, %
Potato	Clay	2009	75
Potato	Sand	2009	84
Potato	Clay	2010	76
Potato	Sand	2010	81
Maize	Sand	2010	72
Maize	Sand	2011	84

Mineral N in the soil in autumn is an indicator for the risk of NO_3 leaching in winter in the Netherlands (Ten Berge et al., 2002). Measurements of mineral N contents in the soil after harvest in autumn showed overall no differences between CAN and mineral concentrates (Schröder et al., 2012a&b; Van Geel et al., 2012a). This suggests that risk of NO_3 leaching was similar for CAN and mineral concentrates. Measurements of NO_3 concentration in the groundwater of the field experiments with maize in 2010 and 2011 showed that the NO_3 concentration from the plots, to which mineral concentrate was applied was slightly lower than that of CAN and cattle and pig slurry (Figure 3). A winter crop strongly reduced leaching of NO_3. In these maize experiments, the NFRV of mineral concentrate compared to CAN was 72 – 84%. The lower NFRV did, however, not increase N leaching losses from concentrates compared to CAN. Immobilisation of mineral N did probably occur neither (Section 3.1). A reduced availability of N from mineral concentrate due to an incomplete mineralisation is also not likely, given the only small content (5-10%) of organic N. All these results indicate that the lower NFRV of mineral concentrates compared to CAN is most likely related to N losses by denitrification and NH_3 emission.

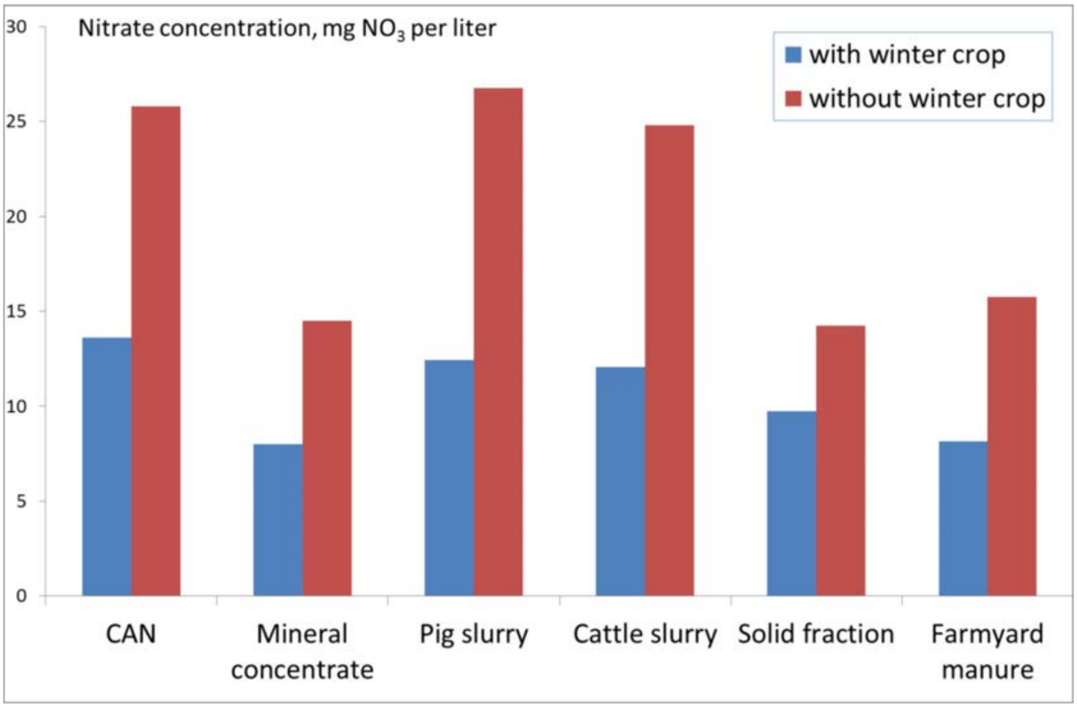

Figure 3 *Average nitrate concentration (mg* NO_3*-N per litre) in the upper groundwater in a field experiment with maize in 2010 and 2011. Several fertilizer and manures were tested, and the experiment was carried out with and without a winter crop (Schröder et al., 2012a).*

5.2 Grassland

The NFRV of mineral concentrate was determined in field experiments on grassland in 2009 – 2012 (Holshof and Middelkoop, 2014). Mineral concentrate was injected to a depth of 5 cm in the soil and was applied at different rates. In the experiments both broadcast CAN and injected liquid ammonium nitrate were used as reference fertiliser.

The NFRV compared to CAN increased from 54% in 2009 to 81% in 2014 (Table 6). The reason for the low NFRV in 2009 is not clear. The NFRV compared to liquid ammonium nitrate was higher than that compared to CAN (79 – 102%).

Averaged over all experiments in 2009-2012, the mineral N content (0-90 cm soil layer) at the end of the growing season in soils to which mineral concentrates had been applied was (somewhat) lower than that in soils to which CAN and liquid ammonium nitrate had been applied (Holshof and Middelkoop, 2012; Figure 4). These results suggest, that the use of mineral concentrate did not increase the risk of NO_3 leaching compared to CAN on grassland. The lower mineral N contents in soil after application of mineral concentrate than after application of cattle slurry point at a lower risk of nitrate leaching for mineral concentrates than cattle slurry. Measurements of nitrate concentration in the upper groundwater in the grassland experiment in 2012 showed no clear differences in nitrate concentration between mineral concentrate and CAN (Holshof and Middelkoop, 2012).

In an experiment of Schils *et al.* (2014), nitrate concentration in upper groundwater was measured in 10 maize and 20 grassland fields on farms. In one part of the field mineral fertiliser and cattle slurry were applied and in another part of the field, mineral fertilizer was replaced with mineral concentrate. The variation in nitrate concentration was large and concentrations were higher in maize land than in grassland (Table 7). There was no statistically significant difference in nitrate concentration between the fertilizer and mineral concentrate plots on both grassland and maize land. Replacement of mineral fertiliser with mineral concentrate did not increase nitrate leaching. These results confirm the results of the field experiments on arable land and grassland.

Table 6

NFRV of injected mineral concentrate compared to CAN and liquid ammonium nitrate (in%) in grassland experiments (Holshof and Middelkoop, 2014).

Year	Soil	Reference fertilizer	
		CAN	Liquid ammonium nitrate
2009	Sand/clay	54	86
2010	Sand/clay	71	102
2011	Sand	80	79
2012	Sand	81	83

Table 7

Average nitrate concentrations (mg/l) in grassland and maize land on sandy soils for plots to which mineral fertilizer (CAN) and slurry were applied and plots to which mineral concentrate and slurry were applied (Schils et al., 2014).

Crop	Mineral fertilzer and slurry	Mineral concentrate and slurry	Average
Grassland	48^{a}	45^{a}	**46^{a}**
Maize land	142^{b}	169^{b}	**155^{b}**
Average	**95^{a}**	**107^{a}**	**101**

a,b: difference in letters show statistical significant difference (5%) using REML analysis

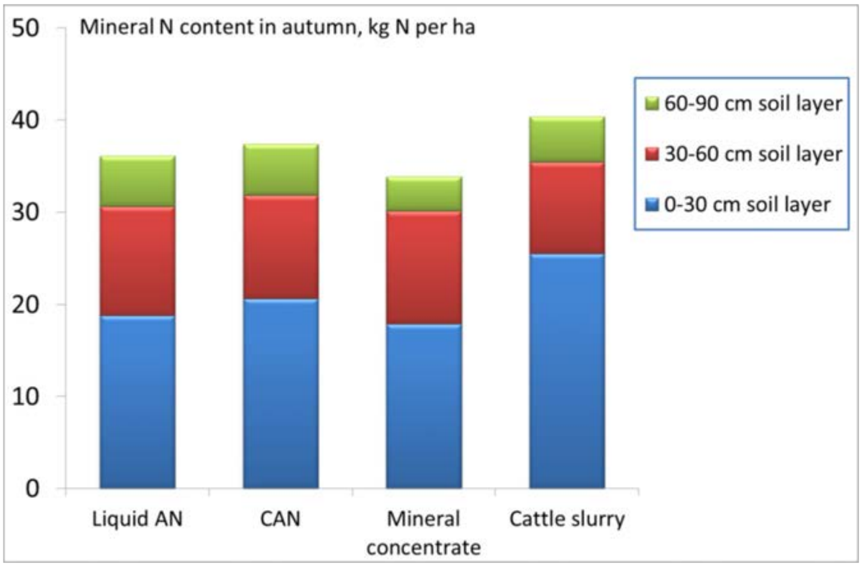

Figure 4 *Average mineral N contents (0-90 cm soil layer) at end of the season, in all grassland experiments in period 2009 (Holshof and Middelkoop, 2014).*

6 Effects of large scale use of mineral concentrates in the Netherlands

Scenario analyses of effects of large scale use of mineral concentrates in the Netherlands were carried out in 2012 using the MITERRA model. The reference was a scenario with the legal application standards for N, P and manure that were in 2012 foreseen for 2015 (Lesschen et al., 2011).

MITERRA calculates N and P balances, emissions of NH_3, N_2O, N_2, NOx and CH_4 to the atmosphere, and leaching of N to groundwater and surface waters (Velthof et al., 2009). The MITERRA model was parameterised with emission factors and data sets of the Netherlands, including crop and livestock statistics, N and P excretion figures for livestock, yields, and N and P contents of crops. Leaching was calculated using NO_3 leaching fractions (Fraters et al., 2007; Schröder et al., 2007b), and NH_3 and N_2O emission using emission factors used in the Netherlands for the reporting for the NEC and UNFCCC (Velthof and Mosquera, 2011b; Velthof et al., 2012).

The calculations were carried out on a provincial level (NUTS II) and slurry and mineral concentrates were distributed based on the application standards per crop, areas of crops, manure production, and the distance between provinces. In the scenarios, mineral concentrates were considered as mineral N fertilizers and were not accounted for in the application standards of manure. Based on the experiments described in Chapter 6, it was assumed that the non-effective N of mineral concentrate was lost by NH_3 emission and denitrification. It was assumed that NH_3 emission factor was 6% of the NH_4-N applied and the N_2O emission factor was 0.5% of total N.

The results show that the production and large scale use of mineral concentrate and solid fraction in the Netherlands decrease the need for both mineral N fertilizer (up to 15%) and P fertiliser (up to 82%; Figure 5). Part of the manure produced cannot be used on agricultural land in the Netherlands within the application standards. This manure surplus has to be exported or treated and used outside agriculture (the manure that cannot be used in the Netherlands is indicated by “export” in Figure 5). The production and large scale use of mineral concentrate in the Netherlands decreases the need for export of manure up. The decrease in need for mineral fertiliser and the need for less export is due to a more efficient distribution of N and P in case manure is separated in a mineral concentrate and solid fraction. It was concluded that the large scale use of mineral concentrate and solid fraction in the Netherlands increases the N and P use efficiency, because both the input of N and P fertilisers and the export of manure decrease.

Total NH_3 and N_2O emissions in the Netherlands hardly change in the scenarios with large scale use of mineral concentrates (Table 8). However, on a regional scale, the NH_3 emission increases in regions where mineral concentrate is produced, i.e. the region with high livestock density, and deceases in the regions with low livestock density. Total NO_3 leaching decreases slightly by increasing use of mineral concentrates.

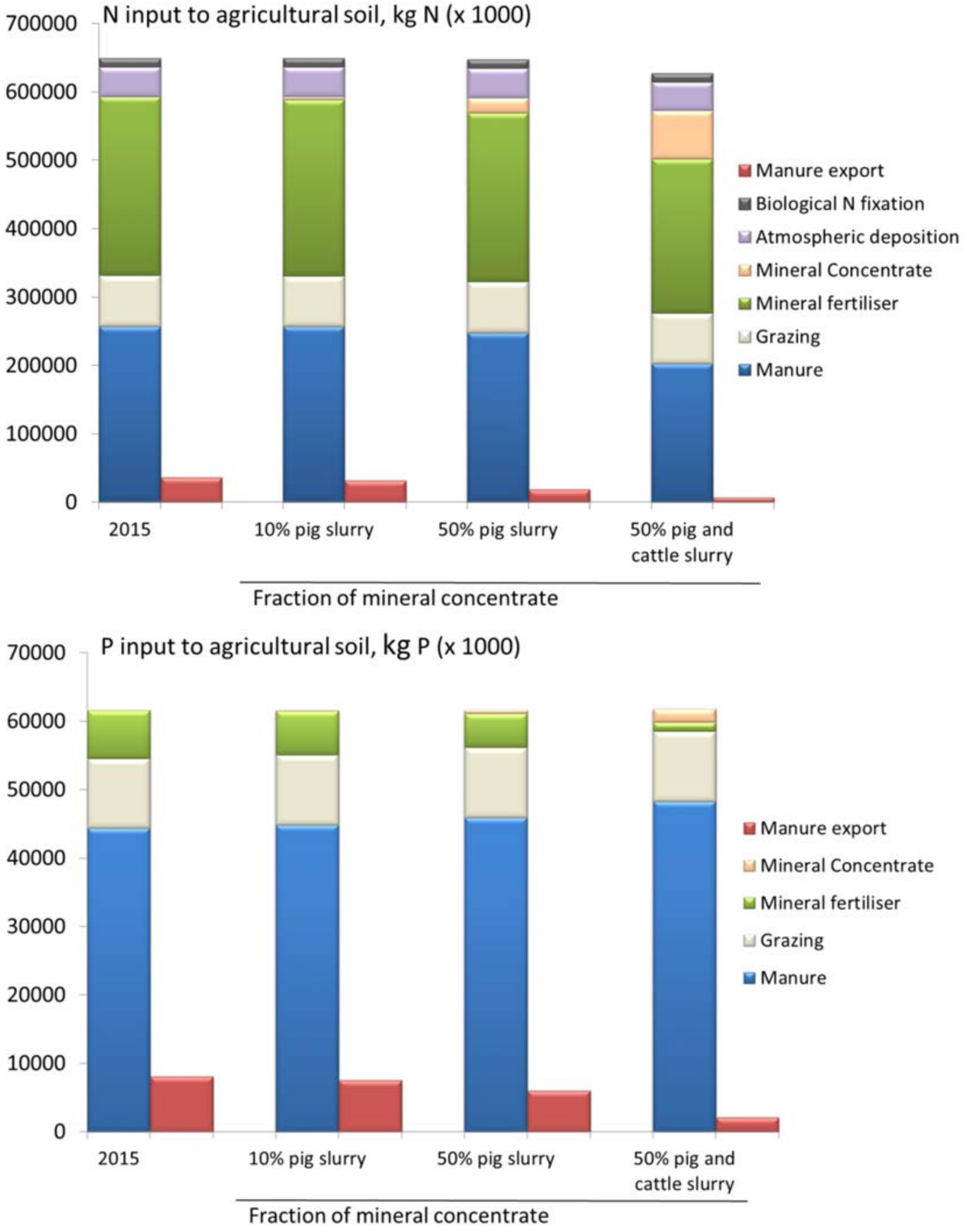

Figure 5 *Total inputs of N (upper figure) and P (lower figure) to agricultural land in the Netherlands in scenarios with different levels of mineral concentrates. The total amount of manure that cannot be applied in the Netherlands within the application standards (i.e. the manure surplus) is indicated as manure export (Lesschen et al., 2011). The reference was a scenario with the legal application standards for N, P and manure that were in 2012 foreseen for 2015.*

Table 8

Calculated emissions of NH_3 and N_2O and N leaching in scenarios with different levels of mineral concentrates (expressed in% of produced pig and cattle slurry). The reference 2015 was a scenario with the legal application standards for N, P and manure that were in 2012 foreseen for 2015 (Lesschen et al., 2011).

Source of N loss	Scenario	Housing and storage	Manure treatment	Grazing	Manure application	Fertiliser	Mineral concentrate	Other	Total
NH_3 emission, kg N (x 10^6)	2015	46.8		1.4	34.5	9.9			92.6
	10% pig slurry	46.8	0.4	1.4	34.2	9.7	0.6		93.1
	50% pig slurry	46.8	2.2	1.4	32.0	9.3	2.9		94.6
	50% pig and cattle slurry	46.8	7.1	1.4	22.7	8.5	7.1		93.5
N_2O emission, kg N (x 10^6)	2015	2.1		2.2	1.9	3.2		3.8	13.2
	10% pig slurry	2.1	0.0	2.2	1.9	3.1	0.0	3.8	13.2
	50% pig slurry	2.1	0.2	2.2	1.9	3.0	0.1	3.8	13.3
	50% pig and cattle slurry	2.1	0.7	2.2	1.5	2.7	0.4	3.7	13.4
N leaching, kg (x 10^6)	2015								52.5
	10% pig slurry								52.6
	50% pig slurry								52.2
	50% pig and cattle slurry								48.4

7 Discussion

7.1 Agronomic aspects

7.1.1 Mineral concentrates

The production of mineral concentrate and solid fractions using high-tech separation techniques can improve the use of N, P, and K. Mineral concentrate is a liquid N-K fertiliser, with low levels of P. The solid fraction contains P and organic matter and can be deposited on arable land, or can be processed after which the P can be recovered.

The pot experiments showed that the NFRV of mineral concentrate compared to CAN was on average 91%. 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 NH_3 emission will occur. The NFRV of pig slurry was consistently lower (on average 75%) than that of mineral concentrates in these experiments.

The NFRV values of mineral concentrate in the field experiments were lower than in the pot experiment, but variation was large (72 – 84% for arable land and 54 – 81% for grassland in the detailed field experiments and 0 – 130% in the simpler experiments on arable land). The NFRV compared to CAN on grassland increased from 54% in 2009 to 81% in 2014. The reason for the low NFRV in 2009 is not clear. The NFRV compared to liquid ammonium nitrate was higher than that compared to CAN (79 – 102%). The distribution of N in the soil differs between broadcast applied CAN and of injected liquid fertilizers, and this could be a factor that played a role in the differences in N use efficiency between CAN and the liquid fertilisers.

The results of the experiments indicate that there is scope to increase NFRV in the field by optimising the use of mineral concentrate by use of low NH_3 emission application techniques, and decreasing organic N content of mineral concentrate. Acidification of mineral concentrates to decrease risk of NH_3 losses may also be an option (Rietra and Velthof, 2014). Acidification may also decrease N_2O emission, as high NH_3 in soils may inhibit nitrification and increase N_2O emission (Rietra and Velthof, 2014). It is also likely that timing of the application of mineral concentrates may be a factor influencing NFRV, as weather conditions affect the distribution of N in the soil and the risk of N losses by NH_3 emission and denitrification.

The supply of K with mineral concentrate leads to reduced need for K fertiliser (De Hoop et al., 2011). This is particularly advantageous for crops with a high K demands such as potatoes and maize. The K demand of grassland is also high, but this is partly covered by the cattle manure that is produced on the farm. Additional supply of K in mineral concentrate to a dairy farm with a good K status of the soil (and therefore small need for K) can cause an excess of K on the farm. The amounts of K in the feed, fertiliser, and manure should hence be taken into consideration when importing mineral concentrates to a dairy farm.

A significant amount of Na is applied when mineral concentrate is used as N or K fertiliser. Na is important for animal feeding, and the yields of some arable crops (e.g. sugar beet) may increase when Na is applied. Sulfur is a valuable component of mineral concentrate, but the average total S application rate is low.

7.1.2 Solid fraction

The solid fraction can be used in agriculture as a source of P and organic matter. The application of iron flocculants in manure may reduce the short-time P efficiency of the solid fraction (Schröder et al., 2010). The solid fraction also contains N, from which 45% as NH_4-N (Table 2). This N should be considered in the fertilisation plan when farmers use solid fraction. Sörensen and Rubaek (2012) showed that the application of solid fraction is not without risks for N leaching when applied before the start of the growing season. The NFRV of the solid fraction compared to CAN was 32 to 55% in field experiments with potatoes (Van Geel et al., 2012a) and 64% in an experiment with maize (Schröder et al., 2012a). The risk of NH_3 emission from the solid fraction is lower than that of untreated slurry, but is not negligible (Velthof and Hummelink, 2011). Direct incorporation of the solid fraction reduces NH_3 emission and may increase the NFRV.

Composting and drying the solid fraction may alter the composition of the solid fraction, and thereby the agronomic performance and environmental impacts. Besides sales in the arable areas in the Netherlands, the solid fraction is exported from the Netherlands (De Hoop et al., 2011).

7.1.3 Technological developments in manure processing

The treatment process runs optimally and with the current techniques no substantial increase in the nutrient contents of the mineral concentrate can be achieved (Hoeksma et al., 2011). New techniques are needed if further quality improvements are aimed for, either connected to the system of reverse osmosis or not. Examples include the use of another type of membrane in order to increase the N and K contents in the mineral concentrate. Higher contents can also be achieved by evaporating the concentrate, for example by using heat from air from housing. Another example is stripping of the N from the manure (Alitalo et al., 2012).

The technical, economic, agricultural and environmental feasibility of new treatment techniques demands further investigation. Further increase of the nutrient concentration in mineral concentrates will reduce the costs for transportation of concentrates, because less water has to be transported. It also provides opportunities for mineral concentrate to be transported to arable areas that are relatively far away. However, the advantages of lower transport costs must be balanced with the disadvantage of a potentially lower fertiliser value of too strongly concentrated mineral concentrates.

7.1.4 Economic viability

An economic analysis of production of mineral concentrates by De Hoop *et al.* (2011) showed that the treatment plants were profitable. However, two of the eight plants were only profiTable if the manure was digested. The economic viability of the plant strongly depends on fertiliser prices, the slurry supply rate and the disposal prices of end products from manure, including the mineral concentrate. Also the prices of competing products from manure and of fertilizers are important in the sales of mineral concentrate and for the profitability of the plants. The prices for N, P, and K fertilisers have fluctuated greatly in recent years due to changing energy prices and potential shortages of raw materials. The value of the N and K in the concentrate, based on fertiliser prices, is much higher than the average price paid by the users of the mineral concentrate (De Hoop et al., 2011). The lower NFRV efficiency of the concentrate when compared to CAN, the higher cost of application, and the tendency of farmers to compare the price of mineral concentrates with locally available almost free excess untreated slurry, suggests that most customers are not (yet) prepared to pay a price derived from conventional mineral fertilisers. The willingness to pay higher prices for mineral concentrate will increase if the mineral concentrate is recognized as mineral fertiliser and the agronomic value is similar to fertiliser. This can lead to higher profitability of the manure treatment plants.

7.2 Environmental aspects

7.2.1 Nitrogen leaching

The risk of NO_3 leaching from applied mineral concentrates was similar or lower than that from CAN, for both grassland and arable land. The N leaching losses from cattle and pig slurries were higher than that from mineral concentrate, which is probably due to release of mineral N by mineralisation outside the growing period of the crop. The organic N contents of mineral concentrates are much lower than those of untreated pig and cattle slurries. The N leaching of the solid fraction and farmyard manure was similar to that of mineral concentrates, despite the much higher organic N contents. This suggests that only part of the organic N is rapidly mineralised (Chadwick et al., 2000). These findings suggest that the lower N efficiency of mineral concentrate compared to CAN is not associated with an increase of N leaching in comparison to CAN. Obviously, NH_3 emission and denitrification were the dominant N loss pathways after application of mineral concentrate.

7.2.2 Ammonia emission

Mineral concentrate is a NH_4-containing fertiliser with a high pH and therefore there is a risk of NH_3 emission (Velthof and Hummelink, 2011; Huijsmans and Hol, 2011). Injection or incorporation of mineral concentrate reduces NH_3 emission. Weather conditions have a major effect, as NH_3 emission is highest in dry, sunny and windy weather (Søgaard et al., 2002). Part of the lower N efficiency of mineral concentrate compared to CAN can be explained by NH_3 emission. The risk of NH_3 emission from applied mineral concentrate is probably higher when applied to soils containing lime than to neutral or acid soils, as is the case for any other NH_4-based mineral fertilisers (Sommer et al., 2004). Additional NH_3 abatement techniques may be applied to decrease NH_3 emission and to increase N efficiency, including dilution with water and acidification. Rietra and Velthof (2014) showed in a pot experiment that acidification of mineral concentrates minimised NH_3 emission. The NFRV of acidified mineral concentrate was equal to that of CAN. The scenario analyses of the effects of large scale production and use of mineral concentrates in the Netherlands showed that the total NH_3 emissions hardly change with large scale production of mineral concentrates, but emissions in regions with high livestock density may further increase. The focus of additional NH_3 abatement should hence be on these regions.

7.2.3 Nitrous oxide emission

Velthof and Hummelink (2011) concluded that N_2O emission after application of mineral concentrate was relatively high. Both nitrification and denitrification may play a role in this. High NH_3 concentrations in soil may inhibit nitrification, while N_2O is formed (Chalk and Smith, 1983). Mineral concentrate may contain volatile fatty acids and other available C forms which may lead to denitrification of soil NO_3 after application. The amount of N lost via N_2O emission is, however, low (usually less than 2% of the applied N as fertiliser or manure; Velthof and Mosquera, 2011). Similar amounts of N will be lost in the form of NO_x. Emissions of N_2 can be high under wet conditions. The total gaseous N losses by nitrification and denitrification are higher than N_2O emission and may significantly affect the N efficiency of mineral concentrates. The scenario analyses of the effects of large scale use of mineral concentrates in the Netherlands showed that the total N_2O emissions hardly change. The use of nitrification inhibitors, acidification and removal of organic C from mineral concentrates may be measures to decrease N_2O emissions from mineral concentrates.

7.2.4 Heavy metals and organic micropollutants

The contents of heavy metals (Cd, Cr, Ni, Pb and As) and organic contaminants (dioxins, non-ortho PCBs, mono-ortho PCBs, indicator PCBs, PAHs, organochlorine pesticides and mineral oil) in mineral concentrates were low and often below the detection limit and also meet the norms in the Dutch fertiliser act. Use of mineral concentrate as fertiliser does not lead to an unaccepTable loading of the soil with heavy metals and organic micropollutants,

7.2.5 Environmental impact of production and use of mineral concentrates

Losses of N may occur during the production of mineral concentrate and when used as fertiliser. Nitrogen balances of manure treatment systems indicate that N losses were low during manure treatment (Table 1). It is not clear in what form N is lost during manure treatment, but most likely it will be in the form of NH_3 and a small part will be lost through denitrification.

In a study of De Vries *et al.* (2011; 2012) the change in the environmental impact of production and use of the end products from several treatment installations of mineral fertiliser and substrate for anaerobic digestion was considered in a theoretical region with both livestock and arable farming systems. Without anaerobic digestion, no change in the environmental performance was observed for treatment of the surplus of pig slurry. Digestion of slurry and related energy production reduced greenhouse gas emissions and fossil energy use. A sensitivity analysis showed higher NH_3 emissions but no changes in NO_3 leaching when more pig slurry was processed than only the surplus (De Vries et al., 2011; 2012).

Scenario analyses on the national scale, showed that large scale use of mineral concentrate and solid fraction in the Netherlands decreased the need for N and P fertilisers up to 15% and 82%, respectively (Lesschen et al., 2011). Moreover, the manure surplus in Netherlands decreases. It was assumed in the scenario that the N of mineral concentrates is not to be accounted in the permitted manure N application standard. The total NH_3 and N_2O emissions and N leaching in the Netherlands hardly changed in these scenarios. Large scale use of mineral concentrate increases the N and P use efficiency in agriculture in the Netherlands.

7.3 Legal aspects

The pilot mineral concentrates was designed to examine whether mineral concentrates can be used as fertilizer. Compared to pig slurry, mineral concentrates have a low content of organic matter and P and a relatively high fraction of NH_4-N in total N (Table 2). However, even though mineral concentrates are obtained through an industrial process, the product is still subject to the legal definition of livestock manure in the Nitrates Directive. The data from the study will be used in consultations with the European Commission on the status of mineral concentrate within the context of the Nitrates Directive.

The EU Regulation 2003/2003 applies to fertilisers designated as "EC fertiliser", when sold in Europe (European Commission, 2003). The EU Regulation 2003/2003 contains a list of approved fertilisers, whilst defining the method of preparation and the required minimum contents of nutrients for each fertilizer. The EU Regulation 2003/2003 is under revision and new products or new groups of products will be added to this regulation in the near future. The status of mineral concentrates in the new regulation is not yet clear.

References

Alitalo A., A. Kyrö A, and A. Aura (2012) Ammonia stripping of biologically treated liquid manure. *Journal of Environmental Quality* 41, 273-80.

Birkmose, T.S. (2009) Nitrogen recovery from organic manures: improved slurry application techniques and treatment; the Danish scenario. *Proceedings International Fertilizer Society* 656,, York, United Kingdom, 24 pp.

Burton, C.H. (2007). The potential contribution of separation technologies to the management of livestock manure. *Livestock Science* 112 (2007) 208-216

Chadwick, D. R., F. John, B.F. Pain, B.J. Chambers, and J. Williams (2000). Plant uptake of nitrogen from the organic nitrogen fraction of animals manures: a laboratory experiment. *Journal of Agricultural Science (Cambridge)* 134, 159–168.

Chalk, T.J. and C.J. Smith (1983) Chemodenitrification. In: Gaseous loss of nitrogen from plant-soil systems. *Developments in plant and soils sciences* 9, 65-89.

De Hoop, J.G., C.H.G. Daatselaar, G.J. Doornewaard and N.C. Tomson (2011). Mineral concentrates of manure; Economic analysis and user experiences in the pilot mineral concentrates in 2009 and 2010. *Report 2011 - 030, LEI*, The Hague, 68 p. (In Dutch).

De Vries, J.W., P. Hoeksma, and C.M. Groenestein (2011) Life Cycle Assessment Mineral Concentrates Pilot. Wageningen UR *Livestock Research Report* 480, Lelystad, the Netherlands. (In Dutch).

De Vries, J.W., C.M. Groenestein, and I.J.M. De Boer (2012) Environmental consequences of processing manure to produce mineral fertilizer and bio-energy. *Journal of Environmental Management* 102, 173-183.

Ehlert, P.A.I., P. Hoeksma & G.L. Velthof (2009) Inorganic and organic pollutants in mineral concentrates. Results of first screening. *Report 256. Animal Sciences Group,* Wageningen, 17 p. (In Dutch).

Ehlert, P.A.I. and P. Hoeksma (2011) Agronomic and environmental perspectives of mineral concentrates. Study in the framework of the pilot mineral concentrates. *Report 2185, Alterra*, Wageningen, 78 p. (In Dutch).

Ehlert P.A.I., J.A. Nelemans and G.L. Velthof (2012) Nitrogen efficiency and losses by denitrification and nitrogen immobilisation obtained under controlled conditions. Wageningen, Alterra, *Alterra-rapport* 2314. (In Dutch).

European Commission (1991) Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. Official Journal L 375 , 31/12/1991.

European Commission (2003) Regulation No 2003/2003 of the European parliament and of the council of 13 October 2003 relating to fertilizers. Official Journal of the European Union L 304/1, 21/11/2003.

Fraters, B., L.J.M. Boumans, T.C. van Leeuwen, and J.W. Reijs (2007). Leaching of the nitrogen surplus to ground and surface water on farms. *RIVM Report 680716002/2007,* RIVM, Bilthoven. (In Dutch).

Galloway, J.N., J.D. Aber, J.W. Erisman, S.P. Seitzinger, R.W. Howarth, E.B. Cowling, and B.J. Cosby (2003) The N Cascade. *BioScience* 53: 341-356.

Granli, T. and O.C. Bøckman (1994) Nitrous oxide from agriculture. *Norwegian Journal of Agricultural Sciences Supplement* 12, 7-128.

Hoeksma, P., F.E. de Buisonjé, P.A.I. Ehlert and J.H. Horrevorts (2011) Mineral Concentrates from animal slurry. Monitoring of the pilot plants. *Report WUR Livestock Research* 481 (In Dutch), Wageningen.

Hoeksma P. and F.E. de Buisonjé (2012) Mineral Concentrates from animal slurry. Monitoring of the pilot production plants in 2011. *Report WUR Livestock Research* 626 (In Dutch).

Hoeksma, P. and F.E de Buisonjé (2015) Production of mineral concentrates from animal manure using reverse osmosis; Monitoring of pilot plants in 2012 - 2014. Lelystad, Wageningen UR (University & Research centre) Livestock Research, Livestock Research Report 858.

Holshof G. and J.C. van Middelkoop (2014) Stikstofwerking van mineralenconcentraten op grasland. Veldproeven 2012 en overall analyse. *Report WUR Livestock Research* 769, Wageningen (In Dutch).

Huijsmans, J.F.M. and J.M.G. Hol (2011) Ammonia emission after application of mineral concentrate to arable land and grassland. *Report Plant Research International* 398, Wageningen, 26 p. (In Dutch).

Huijsmans, J.F.M. and R.L.M. Schils (2009) Ammonia and nitrous oxide emissions following field-application of manure: state of art measurements in the Netherlands. *Proceedings International Fertilizer Society* 655, International Fertilliser Society, York.

Kirchmann H. and A. Lundvall (1993) Relationship between N immobilization and volatile fatty acids in soil after application of pig and cattle slurry. *Biology and Fertility of Soils* 15:161–164.

Klop G., G.L. Velthof and J.W. van Groenigen (2012) Application technique affects the potential of mineral concentrates from livestock manure to replace inorganic nitrogen fertilizer. *Soil Use and Management* doi: 10.1111/j.1475-2743.2012.00434.x

Lantinga, E. A., J.A. Keuning, J. Groenwold, and P.J.A.G. Deenen (1987) Distribution of excreted nitrogen by grazing cattle and its effect on sward quality herbage production and utilization. In: *Animal manure on grassland and fodder crops: fertilizer or waste?* (ed H. G. Van der Meer et al.), Martinus Nijhoff publishers, Dordrecht, pp. 103-117.

Lesschen, J.P., I. Staritsky and G.L. Velthof (2011) Assessment of effects of large scale use of mineral concentrates in the Netherlands; Effects on nutrient flows and emissions. Wageningen, *Alterra, Report* 2247. (In Dutch).

Masse, L., D.I. Massé and Y. Pellerin (2007) The use of membranes for the treatment of manure: a critical literature review. *Biosystems Engineering* 98 (2007) 371-380.

Munch J.C. and G.L. Velthof (2007) Chapter 22. *Denitrification and agriculture*. p. 331- 343. In: Bothe, H., Ferguson, S., Newton, V. (eds.) *Biology of the nitrogen cycle*, Elsevier.

Oenema, O., G.L. Velthof, S. Yamulki and S.C. Jarvis (1997) Nitrous oxide emissions from grazed grassland. *Soil Use and Management* 13:288-295.

Paul J.W. and Beauchamp E.G. (1989) Effect of carbon constituents in manure on denitrification in soil. *Canadian Journal of Soil Science* 69: 49–61.

Oenema, O., Bleeker, A., Braathen, N. A. *et al.* (2011) *Nitrogen in current European policies*. In: Sutton, M.A., C.M. Howard, J.W. Erisman, G. Billen, A. Bleeker, P. Grennfelt, H. van Grinsven and B. Grizzetti (Eds). The European Nitrogen Assessment. Cambridge, UK, Cambridge University Press, Chapter 4, pp. 62-81.

Richards, I. R. and K.M. Wolton (1975) A note on urine scorch caused by grazing animals. *Grass and Forage Science,* 30, 187-188.

Rietra, R.P.J.J. and G.L. Velthof (2014) Stikstofwerking van mineralenconcentraat onder gecontroleerde omstandigheden; Effecten van aanzuren, vocht en toedieningstechniek. Alterra report 2518, Wageningen.

Schils, R., R. Geerts, J. Oenema, K. Verloop, F. Assinck en G.L. Velthof (2014) Effect van bemesting met mineralenconcentraat op het nitraatgehalte van grondwater. Verkennend onderzoek in het kader van de Pilot Mineralenconcentraten. Alterra report 2570, Wageningen.

Schröder, J.J., D. Uenk and G.J. Hilhorst (2007a) Long-term nitrogen fertilizer replacement value of cattle manures applied to cut grassland. *Plant and Soil* 299, 83-99.

Schröder, J.J., H.F.M. Aarts, J.C. van Middelkoop, R.L.M. Schils, G.L. Velthof, B. Fraters, and W.J. Willems (2007b) Permissible manure and fertilizer use in dairy farming systems on sandy soils in The Netherlands to comply with the Nitrates Directive target. *European Journal of Agronomy* 27, 102–114.

Schröder, J.J. D. Uenk and W. de Visser (2010) The availability of phosphorus from the solid fraction of separated livestock slurry. *Plant Research International Nota* 661, Wageningen, 9 p. (In Dutch).

Schröder J.J., W. de Visser, F.B.T. Assinck and G.L. Velthof (2012a) Effects of short-term nitrogen supply from livestock manures and cover cropping on silage maize production and nitrate leaching. Submitted to *Soil Use and Management.*

Schröder J.J., W. de Visser, F. Assinck, G.L. Velthof, W. van Geel and W. van Dijk (2012b) Nitrogen fertilizer replacement value of the liquid fraction of separated livestock slurries applied to potatoes and silage maize. *Communications in Soil Science and Plant Analysis (Accepted)*.

Søgaard, H.T., S.G. Sommer, N.J. Hutchings, J.F.M. Huijsmans, D.W. Bussink and F. Nicholson (2002) Ammonia volatilization from field-applied animal manure-the ALFAM model. *Atmospheric Environment* 36: 3309-3319.

Sommer, S.G., J.K. Schjoerring and O.T. Denmead (2004) Ammonia emission from mineral fertilizers and fertilized crops. *Advances in Agronomy* 82, 557 – 622.

Sørensen, P. and G.H. Rubaek (2012) Leaching of nitrate and phosphorus after autumn and spring application of separated solid animal manures. Soil Use Management 28, 1-11.

Sutton, M.A., Howard, C., Erisman, J.W., Billen, G., Bleeker, A., Grennfelt, P., van Grinsven, H. and Grizzetti B. (2011) The European Nitrogen Assessment: Sources, Effects and Policy Perspectives (Eds.) Cambridge University Press. 612 pp.

Ten Berge H ed. (2002) A review of potential indicators for nitrate loss from cropping and farming systems in the Netherlands. *Plant Research International Report* 31, Wageningen.

Van Geel W., W. van den Berg and W. van Dijk (2012a) Nitrogen efficiency of mineral concentrates applied to potatoes. Report of field research in 2009 en 2010. *Praktijkonderzoek Plant & Omgeving, Wageningen. PPO*, report no. 475, 68 p. (In Dutch).

Van Geel W, W. van den Berg, W. van Dijk and R. Wustman (2012b) Additional research mineral concentrates 2009-2011 on arable land and grassland. Summary of the results of the field experiments and determination of the nitrogen use efficiency. *PPO, Wageningen, Report* nr. 476. (In Dutch).

Velthof, G.L., D. Oudendag, H.P. Witzke, W.A.H. Asman, Z. Klimont and O. Oenema (2009) Integrated assessment of nitrogen emissions from agriculture in EU-27 using MITERRA-EUROPE. *Journal of Environmental Quality* 38, 402-417.

Velthof, G.L. (2011) Synthesis of the research within the framework of the Mineral Concentrates Pilot. *Alterra report* 2224. Wageningen.

Velthof, G.L. (2012) Mineral Concentrates Pilot; synthesis of the results of 2011. *Alterra report* 2363. Wageningen

Velthof, GL and J. Mosquera (2011a) The impact of slurry application technique on nitrous oxide emission from agricultural soils. *Agriculture, Ecosystems & Environment*, 140, 298-308.

Velthof G.L. and J. Mosquera (2011b). Calculation of nitrous oxide emission from agriculture in the Netherlands. Update of emission factors and leaching fraction. *Alterra report* 2151, Wageningen.

Velthof G.L. and E. Hummelink (2011) Ammonia and nitrous oxide emission after application of mineral concentrates. Results of laboratory studies as part of the pilot mineralen concentrates. *Alterra, report* 2180, Wageningen (In Dutch).

Velthof, G.L., C. van Bruggen, C.M. Groenestein, B.J. de Haan, M.W. Hoogeveen and J.F.M. Huijsmans (2012) A model for inventory of ammonia emissions from agriculture in the Netherlands. *Atmospheric Environment* 46, 248 - 255.

Velthof, G.L., Lesschen, J.P., Webb, J., Pietrzak, S., Miatkowski, Z., Pinto, M., Kros, J. and Oenema, O. (2014) The impact of the Nitrates Directive on nitrogen emissions from agriculture in the EU-27 during 2000-2008. *Science of the Total Environment* 15, 468-469

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