Synthesis of the research within the framework of the Mineral Concentrates Pilot

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Abstract

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The agronomic, economic and environmental impacts of the production of mineral concentrate and its use as mineral fertilizer were examined in a pilot in 2009 and 2010. In this pilot, the mineral concentrates were applied as fertilizer above the application standard for manure, but within the nitrogen application standard of the Nitrates Directive. The study consisted of i) monitoring of products from slurry treatment, ii) research on agricultural and environmental impacts of application of mineral concentrate as fertilizer, iii) research on user experience and an economic analysis and iv) Life Cycle Assessment (LCA). This report is a synthesis of the results of the various studies. The research data will serve for consultation with the European Commission on a possible permanent permission to use of mineral concentrates as replacement of mineral fertilizers.

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

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Contents

Preface

Treatment of animal slurry, in addition to feeding and fertilizer exports measures, is seen as an opportunity to improve closing of nutrient cycles and to use nutrients efficiently. One of the possibilities of slurry treatment is separating slurry and using the mineral concentrate, which results from reverse osmosis of the liquid fraction, as mineral fertilizer.

In 2009 and 2010, with the consent of the European Commission, a pilot study was carried out on the agricultural, economic and environmental impacts of the production and use of mineral concentrate as fertilizer. In the pilot, the mineral concentrate was used as mineral fertilizer, above the application standard for slurry application, but within the nitrogen application standards of the Nitrates Directive. The data from the survey will serve for consultation with the European Commission on a possible permanent permission to use mineral concentrate as a mineral N fertilizer.

The study was conducted by various Wageningen UR institutions in close collaboration with representatives of the eight plants which produced mineral concentrates. The eight plants that participate in the pilot are Coöperatie Biogreen Salland, KUMAC B.V., Loonbedrijf Jan Reniers (MVS), Van Heugten-Friesen, Maatschap Gebroeders Van Balkom, Houbraken B.V., Kempfarm 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 are reported separately (see the bibliography of this report). The following investigators are acknowledged for their contribution to the study: Paul Hoeksma, Jerke de Vries, Jantine van Middelkoop, Gertjan Holshof, Karin Groenestein, Fridtjof de Buisonjé and John Horrevorts [Wageningen UR Livestock Research], Willem van Geel, Wim van Dijk, Wim van de Berg and Romke Wustman [PPO], Jitske de Hoop, Co Daatselaar, Gerben Doornewaard and Niels Tomson [LEI], Koos Verloop, Jaap Schröder, Dick Uenk, Wim de Visser and Frank de Ruijter [Plant Research International], Phillip Ehlert, Eduard Hummelink and Falentijn Assinck [Alterra] and Hennie van den Akker [DLV].

This report provides a synthesis of the research conducted in the years 2009 and 2010. At the end of 2010, the pilot was extended with the year 2011. The data from the research in 2011 will also be used for consultations with the European Commission.

Wageningen, 29 August 2011

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Summary

Beside changes in feeding practices and export of slurry, treatment of slurry is considered as a possibility to increase the efficient use of nutrients. One possible way of treatment is that livestock slurry is separated and that the mineral concentrate, which results from reverse osmosis of the liquid fraction, is used as a mineral fertilizer. In 2009 and 2010, with the consent of the European Commission, a pilot investigation was done on the agricultural, economic and environmental impacts of production and use of mineral fertilizers as concentrates. Within the pilot, the mineral concentrates were used as mineral fertilizer, above the application standard for manure, but within the nitrogen application standards of the Nitrates Directive. The data from the survey will serve for consultation with the European Commission on a possible permanent permission to use mineral concentrate as mineral fertilizer. The following studies were conducted:

- Monitoring of products arising from the slurry treatment;
- Agricultural and environmental impacts of application of mineral concentrates and other products from slurry as fertilizer;
- User experiences and an economic analysis of the use of mineral concentrates in the pilot;
- Life Cycle Assessment (LCA). Assessing the full environmental consequences of producing and using the mineral concentrate and other products as fertilizer.

This report is a synthesis of the results of the various studies. The sub-studies are described in separate reports. All reports are available at www.mestverwerken.wur.nl

Within the pilot, eight producers of mineral concentrates take part, and hundreds of user of the end products. There are seven plants that treat pig slurry and one plant that treats cattle slurry. Two plants have a digester and use co-fermentate materials such as maize. The treatment capacity ranges from 5,000 to 67,500 tons of slurry per year. In all plants, mechanical slurry separation is first applied, which creates a solid and a liquid fraction. The liquid fraction is further cleaned, and finally a mineral concentrate and a permeate are produced by reverse osmosis. In addition, a solid fraction is produced. The solid fraction and the mineral concentrate from reverse osmosis are to be used as fertilizer. The permeate is sometimes used on the farm (e.g. as flushing liquid) or is discharged into the sewer or the surface water.

The nitrogen content of mineral concentrate, averaged per plant, ranges from 4.2 g N per kg to 11.0 g N per kg. The potassium content of mineral concentrates ranges from an average of 5.5 g K per kg to 15.7 g K per kg. The average phosphorus content of mineral concentrates is low (<0.3 g P per kg). The composition of mineral concentrates produced in a plant is relatively constant in time. The differences in mineral composition of concentrates between plants can for a small part be explained by differences in the used slurry.

The separation techniques, strategy and/or the combination of both are the main factors explaining the differences in composition of mineral concentrates. The nitrogen balance of the plants indicates that there may be gaseous nitrogen losses during slurry treatment in the form of ammonia (NH_3), nitrous oxide (N_2O) or N_2 (up to 10% of the incoming nitrogen). Slurry treatment usually shortens the duration of untreated slurry storage, which can lead to less gaseous nitrogen emissions during the storage. During the storage of the solid fraction also gaseous nitrogen emissions occur. No emission measurements were carried out on the plants to quantify the gaseous nitrogen emissions from slurry treatment and from the storage of slurry and slurry products.

The mineral concentrate is a nitrogen-potassium fertilizer. The nitrogen in mineral concentrates is mainly found in the ammonium form (on average 90% of total N in the concentrate). The remaining nitrogen is organically bound. The pH of mineral concentrates is high (about pH 8), thus it is likely that nitrogen partly occurs in the

form of ammonia in mineral concentrates. The efficiency of nitrogen in mineral concentrates used as fertilizer depends on the amount of ammonia emission. Based on the composition it was calculated theoretically that the nitrogen fertilizer replacement value (NFRV)[1] of mineral concentrates compared with calcium ammonium nitrate (CAN, the most widely used nitrogen fertilizer in the Netherlands) will range from 76 to 90% on arable land and from 67 to 81% on grassland. There are no reasons to assume that potassium in mineral concentrates is not fully available to the crop. The phosphorus content in the mineral concentrates is generally low, so that mineral concentrates will have no agricultural value as phosphate fertilizer.

In four field trials on arable land, the NFRV of mineral concentrates applied to potatoes compared to CAN was on average 80% on clay and 92% on sand. The NFRV of mineral concentrates was similar to that of liquid ammonium nitrate in the trial on clay. The NFRV compared to CAN of mineral concentrates was 77% in a trial with maize on sandy soil, and was higher than that for pig slurry (65%) and that for the solid fraction of separated pig slurry (64%). It was found in additional project that the nitrogen efficiency of mineral concentrates was similar to that of CAN in 14 of the 21 experiments (NFRV higher than 95%), in seven trials it was below 70%. In the additional project the nitrogen efficiency could be determined less accurately than in the pilot study, because often only one application rate of mineral concentrate was tested and not a series of rates. In the pilot study, mineral concentrates were tested at several nitrogen application rates.

In four experiments on grassland, the average NFRV of mineral concentrates was 58% compared to CAN. Unlike arable land, on grassland there was no effect of soil type on the NFRV of mineral concentrates. There is no clear explanation for the lower NFRV on grassland when compared to arable land. The mineral concentrates were almost as effective as liquid ammonium nitrate on grassland (average NFRV 96% compared to liquid ammonium nitrate). One additional experiment was conducted on grassland. In this study, the nitrogen efficiency of mineral concentrates was similar to that of CAN.

The survey of user experiences with mineral concentrate showed that mineral concentrate is most often used on grassland, followed by maize and ware potatoes. On grassland, mineral concentrate was mostly used as a mixture with slurry. Also on maize and potatoes mineral concentrate was often applied as a mixture with slurry. The main reason to apply mineral concentrate mixed with slurry is that it is easier to distribute with existing application techniques. Nitrogen in the mineral concentrates is seen by the users as a valuable fertilizer for any given crop. In addition, the potassium is important for many arable crops and maize. The presence of potassium in the concentrate contributes significantly to the use of mineral concentrate as a replacement for mineral fertilizers in these crops. The supply of potassium with mineral concentrate limits the applicable amount of mineral concentrate on dairy farms when the potassium status of the soil is sufficient or higher.

The variation in nitrogen efficiency in the trials was large and the efficiency was in part of the trials (especially on arable land) similar to that of CAN. Mineral concentrate is a new fertilizer type and there are yet few experimental data and experiences with application of mineral concentrates available. The sometimes high nitrogen efficiency of mineral concentrate indicates that there are perspectives for increasing the nitrogen efficiency, when insight is gained in the factors that cause differences found in nitrogen efficiency. Application techniques may be improved, by which the nitrogen efficiency of mineral concentrates may increase.

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[1] 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 als 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).

The economic analysis shows that seven of the eight plants produce mineral concentrates profitable. Two of these plants are only profitable if the slurry is digested. The slurry treatment plants can be profitable at slurry supply rates of around €15 per tonne or higher. 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 slurry and fertilizers. The average price paid for the mineral concentrate was € 1.25 per tonne in 2009 and € 1.19 per tonne in 2010, but there was a wide variation. The value of the nitrogen and potassium in the concentrate, based on fertilizer prices, is much higher (€ 12 per tonne if both nitrogen and potassium are included, excluding application costs) than the average price paid by the users of the mineral concentrate. The lower nitrogen efficiency of the concentrate when compared to CAN, the higher cost of spreading and the relationship that is still being experienced by the farmers with the prices of slurry, are factors by which most customers are not (yet) prepared to pay a price derived from the price of fertilizers.

The results of the study indicate that on both grassland and arable land the use of mineral concentrate does not lead to increased nitrate leaching when compared to CAN. In the field trial with maize the measured nitrate concentrations in groundwater were lower when using mineral concentrate than when using CAN or pig slurry. The high ammonia content and the high pH make the mineral concentrate a fertilizer with an increased risk of ammonia volatilization after application to soil. However, when low-emission application techniques, like deep injection or sod injection, are used the ammonia emission will be limited (<10% of the applied nitrogen). Incubation experiments indicate that the nitrous oxide emissions from mineral concentrates is relatively high when compared to CAN and pig slurry. Heavy metals and organic micro-pollutants in mineral concentrates are not a concern for responsible agricultural use of mineral concentrates.

Table S1 summarizes the average NFRV, derived from field trials, and an indication of the fate of the ineffective nitrogen from mineral concentrates. The ineffective portion of nitrogen in mineral concentrates will partly be present in the soil as organic nitrogen (about 5%). In addition, part of the nitrogen will be lost through ammonia volatilization, nitrification and denitrification, and some may (temporarily) be immobilized in the soil. Possibly also nitrate leaching can occur, although this was not observed in the experiment. The size of the individual pathways of nitrogen loss is probably limited.

A life cycle assessment (LCA) was carried out aiming to compare the environmental impact of a system based on production and use of mineral concentrates with the current system using slurry and fertilizer. Within the defined system boundaries, the use of mineral concentrate leads to replacement of fertilizer in the vicinity of the slurry treatment plant. It is calculated that the transport of slurry to arable areas located further away decreases, and the use of fertilizer in those areas will therefore increase as a result of equal crop demand. The total environmental impact hardly changes when only the fattening pig slurry surplus is treated without digestion. The emissions of ammonia and particulate matter and nitrate leaching hardly change due to production and use of mineral concentrates from fattening pig slurry (up to 3%). With mono-digestion of slurry, or the solid fraction with the concentrate from ultrafiltration of separated slurry, the emission of greenhouse gases and consumption of fossil energy decrease. Utilization of waste heat further decreases greenhouse gas emissions and fossil energy use. The emission of ammonia increased with 13 to 20% when compared to the reference, if all pig slurry was treated and not just the surplus of pig slurry (i.e. the slurry that can not be deposited within the region). Furthermore, the emission of particulate matter and greenhouse gases, and fossil energy consumption increased as a result of treatment of all slurry.

A mineral concentrate is produced using high-tech slurry treatment techniques, using reverse osmosis as the last step, and can be seen as a mineral fertilizer which is manufactured by an industrial process. A mineral concentrate would then be defined as a 'fertilizer' according to the Nitrates Directive. However, a mineral concentrate is produced from slurry products and is therefore defined as 'manure' according to the Nitrates Directive. 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 can not meet the requirements in the regulation, because i) the contents of nitrogen, phosphorus and potassium are lower than the required minimum and ii) a mineral concentrate contains organic nutrients of animal origin. It is possible to add new products or new groups of products to the EU Regulation 2003/2003. The admission of new products is determined by the European Commission and EU Member States. Mineral concentrates and other products made from slurry may therefore be included in the Regulation 2003/2003, if adequately supported by the European Commission and EU Member States. Our results show that the slurry treatment plants are capable to produce mineral concentrates with a constant composition.

Table S1
Summary of Nitrogen Fertilizer Replacement Values (NFRV)[1] and the fate of ineffective nitrogen from mineral concentrates[1].

		Arable land	**Grassland**
NFRW	**Compared to CAN**	84%	58%
	Effect of soil type	yes potato sand: 92% potatoes clay: 80%	no
	Compared to liquid ammonium nitrate	117%	96%
Fate of ineffective nitrogen from mineral concentrates	**Non-mineralized organic N**	On average 5% of applied N	
	Ammonia emission	< 10% of applied N Chance sod injection grassland > deep injection Chance calcareous clay soil > sandy soil	
	Gaseous loss by nitrification and denitrification	< 10% of applied N Chance on grassland > arable land	
	Leaching	< 5% of applied N Chance on sandy soil > clay soil Chance on arable land > grassland	
	Immobilisation in soil	< 10% of applied N Chance on grassland > arable land	

[1] The NFRV values in this table are based on field experiments in which mineral concentrates were tested at different nitrogen application rates: four trials with basal dressing on potatoes on sandy and clay soil by Van Geel et al. (2011a), one trial with maize on sandy soil by Schroder et al. (2011), and four trials with grassland on sandy and clay soil by Van Middelkoop and Holshof (2011). The fate of the inactive nitrogen is partly based on results from the experiments and partly on estimates.

It is concluded that the NFRV of mineral concentrates compared to CAN is on average 80-90% on arable land (for basal dressing via injection) and 58% on grassland. The variation in NFRV is large: in some trials the efficiency of mineral concentrates is similar to that of CAN, but it is lower in other trials. The nitrogen efficiency of mineral concentrate is similar to that of liquid ammonium nitrate in grassland and in arable land on clay. Mineral concentrates thus have a similar nitrogen efficiency as liquid nitrogen fertilizers. Besides nitrogen, potassium is important for many arable crops and maize. Potassium supply with mineral concentrate limits the applicable amount of mineral concentrate on dairy farms when the potassium status of the soil is sufficient or higher.

In 2011, further studies will be carried out on the nitrogen efficiency of mineral concentrate in field and pot trials. Furthermore, a survey will be conducted on the environmental effects of large-scale application of mineral concentrate in the Netherlands. Insights from this research may be used to optimize the use of mineral concentrate and to increase the nitrogen efficiency.

1 Introduction

Beside changes in feeding practices and export of slurry, treatment of slurry is considered as a possibility to use nutrients efficiently. One of the possibilities is separation of slurry and using the mineral concentrate, which results from reverse osmosis of the liquid fraction, as mineral 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. But simultaneously concentrate is animal manure, according to the definition of the Nitrates Directive, even after treatment. And so its use remains 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) investigated during 2009 and 2010, with the consent of the European Commission, the agricultural, economic and environmental effects of the production and use of mineral concentrate to be used as mineral fertilizer. This is part of the aim of the sound disposal of animal slurry, and it fits in the quest for further closing nutrient cycles. The data from the survey will serve 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 slurry, but within the nitrogen application standard.

Eight producers take part in the pilot (Figure 1) and hundreds of users. Each producer operates a plant that produced 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. The technical file is used for testing if the mineral concentrate meets the European regulations for mineral fertilizers (EU, 2003) and the Dutch Protocol 'Beoordeling stoffen Meststoffenwet' (Van Dijk et al., 2009).

During 2009 and 2010 the following studies were conducted within the pilot:
- Monitoring of products arising from the slurry treatment;
- Agricultural and environmental impacts of application of mineral concentrates and other products from slurry as fertilizer;
- User experiences and an economic analysis of the use of mineral concentrates in the pilot;
- Life Cycle Assessment (LCA). Assessing the full environmental consequences of producing and using the mineral concentrate and other products as fertilizer.

At the end of 2010 the pilots were extended with up to one year to the end of 2011. In 2011, additional research is conducted on environmental impacts (see Chapter 7).

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 investigations and related matters in the pilot were directed by the Ministry of EL&I, the Ministry of IenM, LTO Netherlands and NVV.

This report is a synthesis of the results of various studies. These studies are described in separate reports (see box for list of reports; all reports (which are in Dutch) are available at www.mestverwerken.wur.nl). 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.

Ehlert, P.A.I., P. Hoeksma en G.L. Velthof, 2009. Anorganische en organische microverontreinigingen in mineralenconcentraten. Resultaten van de eerste verkenningen. Rapport 256. Animal Sciences Group, Wageningen, 17 p.
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Vries, de J.W., P. Hoeksma en C.M. Groenestein, 2011. LevensCyclusAnalyse (LCA) Pilots Mineralenconcentraten. Wageningen UR Livestock Research, rapport 480, 77 p.

In Chapter 2 a description is given of the slurry treatment plants participating in the pilot. The results of the monitoring of nutrient flows in the plants, and end products from the slurry treatment, are given in Chapter 3.

In Chapter 4 the results of the study on the agronomic effectiveness of mineral concentrate are described. An assessment is made of the agronomic prospects based on the composition, the results of field trials on the nitrogen efficiency are reported, and a summary is given of the survey on user experiences. Chapter 4 also addresses the agronomic perspectives of the solid fraction resulting from slurry separation.

Chapter 5 describes the economic aspects, including the prices of mineral concentrate as fertilizer and an economic analysis of slurry treatment plants.

Chapter 6 examines the environmental aspects of mineral concentrate used as fertilizer with a focus on levels of heavy metals and organic micro-pollutants and the risk of nitrate leaching and emissions of ammonia and nitrous oxide. This chapter contains the results of a Life Cycle Assessment (LCA). In this LCA, the environmental effects of a system in which mineral concentrate is produced and applied are compared with the effects of a conventional system in which slurry is not treated.

Chapter 7 provides a brief overview of the research done in 2011. A synthesis and discussion of all results are given in Chapter 8.

Figure 1
Location of the eight plants taking part in the Mineral Concentrates Pilot.

2 Description of the slurry treatment plants

This Chapter gives a brief description of the eight slurry treatment plants participating in the pilot. The treatment is based on reverse osmosis (RO). For a detailed description of the plants see Hoeksma et al. (2011).

2.1 Reverse osmosis

Osmosis is the filtration process in which clean water flows through a semipermeable membrane. Dissolved salts and bacteria cannot pass the membrane. If pressure is exerted on the liquid with high salt concentration, water will flow in the opposite direction through the membrane (i.e. from the liquid with high salt concentration to the liquid with low salt concentration). This process is called reverse osmosis. Reverse osmosis is used in the manure treatment plants to separate the liquid manure fraction into water that can be discharged and a concentrated salt solution, the so-called mineral concentrate. Dissolved salts remain in the mineral concentrate.

Fouling of the membranes by deposition of salts and growth of microorganisms is a problem when using reverse osmosis of the liquid fraction of slurry. Therefore, before the reverse osmosis solids and organic matter should be removed as much as possible from the liquid fraction. After a first rough mechanical separation of the slurry with a mortar press, belt press or a decanter/centrifuge, additional cleaning techniques are applied on the liquid fraction. This includes techniques such as ultrafiltration (UF), dissolved air flotation[1], low pressure membrane filtration and using cloth or paper filters. For increasing the effectiveness of these techniques chemical additives are often used, i.e. coagulants and flocculants. The purpose of the use of flocculants is to separate suspended and floating materials from the liquid fraction.

2.2 Treatment plants in the pilot

A description of the plants is given in Table 1. Seven plants treat pig slurry and one plant treats cattle slurry (system H). Plants A and H have a digester in which materials such as maize are co-digested. In these plants digestate is treated with mineral concentrate as end products. Plants D, E, G and H treat slurry of the own farm, while plants A, B, C and F treat slurry from 20 to 50 pig farms. The treatment capacity ranges from 5000 tons (plant E) to 67,500 tons (plant A) of slurry per year.

Figure 2 shows the process schemes of the plants. In all plants, mechanical separation of the slurry is applied first, which creates 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, D and E an auger press, in some cases after flotation. 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

[1] Flotation is the process in which small bubbles are blown from below through the liquid manure that drag organic material into a floating layer that can be scraped from the surface of the liquid

ultrafiltration and the effluent from the flotation are separated through reverse osmosis into a mineral concentrate and a permeate (liquid fraction).

Different products are formed during treatment of the slurry into mineral concentrate:
• digestate from anaerobic digestion, in the case of plants A and H;
• solid fraction after mechanical slurry separation;
• concentrate from ultrafiltration (this is usually brought back into the installation);
• concentrate from reverse osmosis, and
• permeate from reverse osmosis.

The solid fraction and the mineral concentrate from reverse osmosis are used as fertilizer. The mineral concentrate can be applied in the pilot as mineral fertilizer. The permeate of reverse osmosis is sometimes used on the farm (e.g. as flushing liquid) or is discharged into the sewer or surface water.

Chapter 3 discusses the composition of the products formed in the various plants.

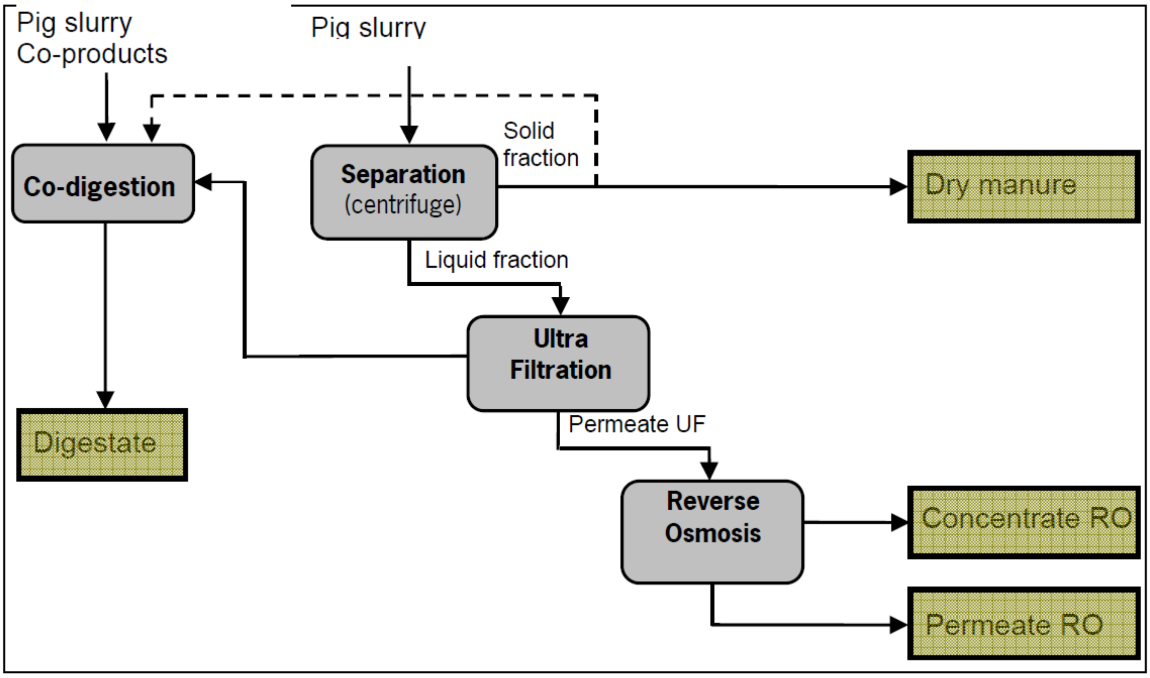

Figure 2a
Treatment scheme of plant A (after September 2009). RO: reversed osmosis.

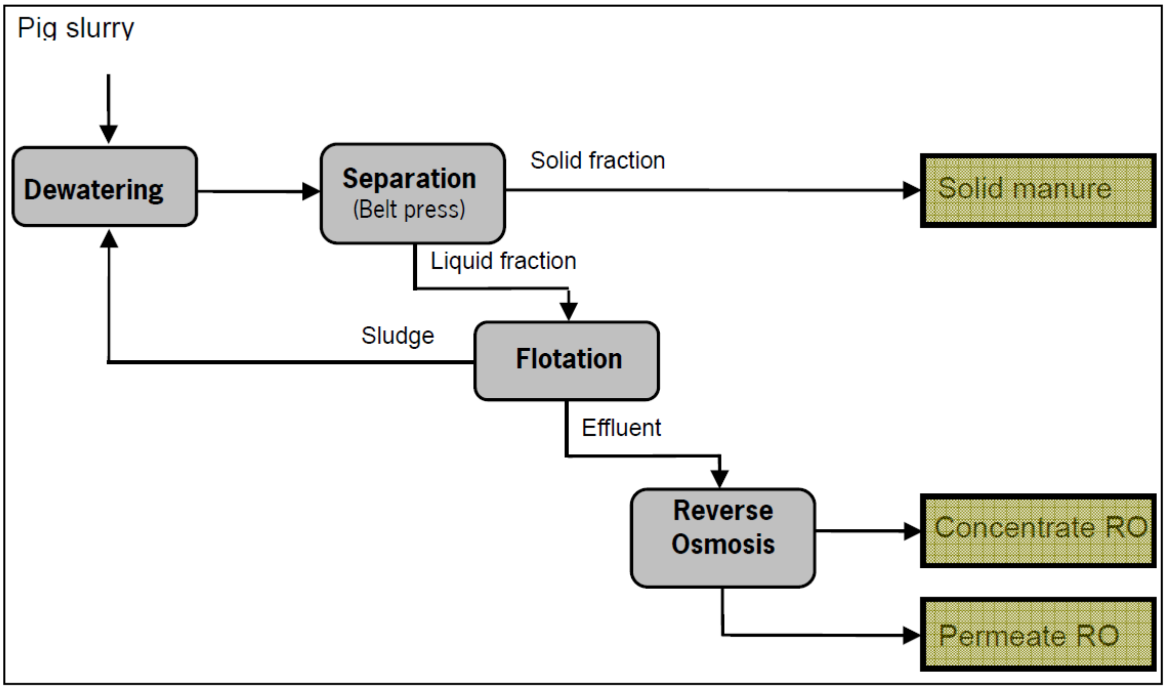

Figure 2b
Treatment scheme of plant B.

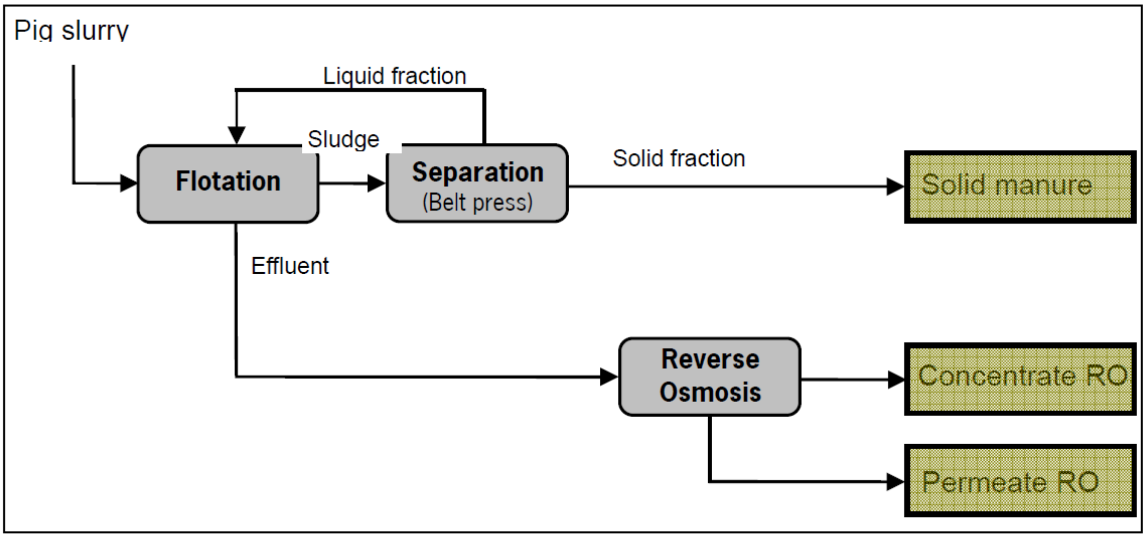

Figure 2c
Treatment scheme of plant C en F. The schemes of plants D and E are identical, except the use of an auger press for slurry separation in D and E instead of a belt filter press.

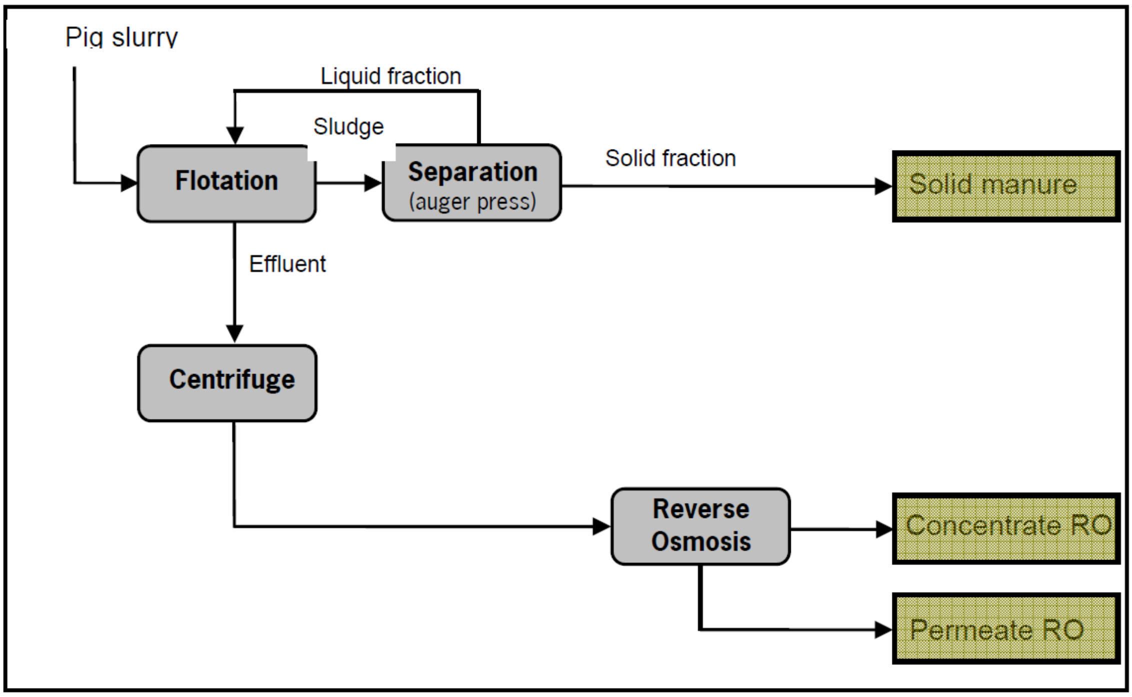

Figure 2d
Treatment scheme of plant G.

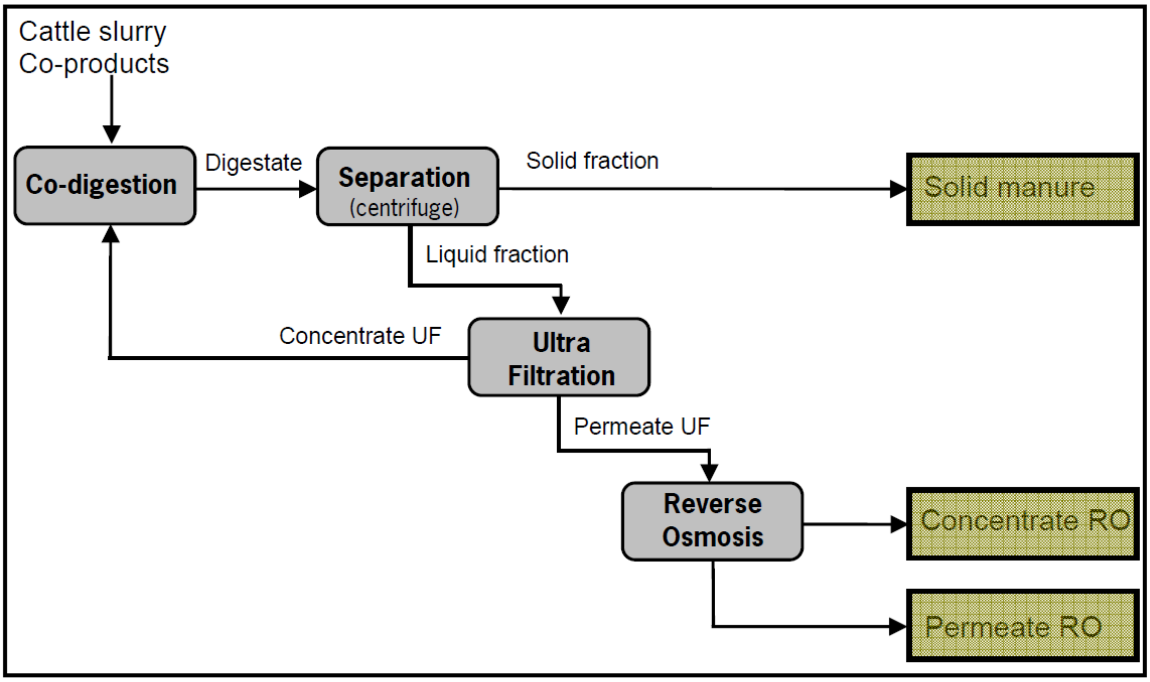

Figure 2e
Treatment scheme of plant H.

Table 1
Summary of characteristics of the eight plants.

Plant	Input	Treatment capacity (ton/year)	Techniques applied in the production process					End products
				Mechanical separation	Treatment solid fraction	Treatment liquid fraction	Reverse osmosis	
A	Pig slurry Poultry slurry Maize Co-digestion materials	67,500	Co-digestion mesophilic (38-40ºC) retention time 60 d	Centrifuge	Till September 2009: Heat Cylinder + Fluidised-Bed Dryer	Ultrafiltration Ceramic membrane	Toray, 8" TM 820-370 Surface: 896 m^2 Cap.: 12 m^3/h Pressure: 40 bar	Dry / solid manure Digestate Concentrate UF Concentrate RO Permeate RO (sewer)
B	Pig slurry	50,000	n.a.	Belt press	n.a.	Flotation	Hydranautics SWC 4+ Surface: 1728 m^2 Cap.: 17 m^3/h Pressure: 40 bar	Solid manure Concentrate RO Permeate RO (surface. water)
C	Pig slurry	25,000	n.a.	Belt press	n.a.	Flotation	Hydranautics SWC 4+ Surface: 648 m^2 Cap.: 6 m^3/h Pressure: 40 bar	Solid manure Concentrate RO Permeate RO (sewer)
D	Pig slurry	10,000	n.a.	Auger press Smicon	n.a.	Flotation	Hydranautics SWC 4+ Surface: 216 m^2 Cap.: 2 m^3/h Pressure: 40 bar	Solid manure Concentrate RO Permeate RO (own plant)
E	Pig slurry	5,000	n.a.	Auger press Smicon	n.a.	Flotation	Hydranautics SWC 4+ Surface: 216 m^2 Cap.: 2 m^3/h Pressure: 40 bar	Solid manure Concentrate RO Permeaat RO (own plant)
F	Pig slurry	25,000	n.a.	Belt press	n.a.	Flotation	Toray, 8" TM 820-370 Surface: 672 m^2 Cap.: 10 m^3/h Pressure: 45 bar	Solid manure Concentrate RO Permeate RO (sewer)
G	Pig slurry	10,000	n.a.	Belt press	n.a.	Flotation Centrifuge	Hydranautics SWC 4+ Surface: 180 m^2 Cap.: 1,8 m^3/h Pressure: 40 bar	Solid manure Concentrate RO Permeate RO (own plant)
H	Cow slurry Maize Co-products	15,000	Co-digestion mesophilic (38 - 40 ºC) retention time 60 d	Centrifuge	n.a.	Ultrafiltration Ceramic membrane	FilmTec SW 30-4040 FilmTec BW 30-4040 Surface: 285 m^2 Cap.: 2 m^3/h Pressure: 60 bar	Solid manure Concentrate UF Concentrate RO Permeate RO (surface water)

3 Monitoring of products from slurry treatment

3.1 Composition of the products

During 2009 and 2010 a monitoring was carried out on the slurry treatment plants for determining the composition of the end products and for preparing mass balances of nutrients. This chapter provides an overview of the results of 2009 and 2010 for seven of the eight plants. For plant G, which has only been operational during a few months in the first phase, no representative data were available. A detailed description of the results can be found in Hoeksma et al. (2011).

Significant differences were found in the composition of mineral concentrates of the plants (Table 2). The nitrogen content varies from an average of 4.16 g N per kg for plant E, to 11.0 g N per kg for plant H. The potassium content varies from an average of 5.53 g K per kg for plant E, to 15.7 g K per kg for plant H. The average phosphorus content is lowest for plant B (0.01 g P per kg) and highest for plant C (0.34 g P per kg).

Table 2
Average composition (in g per kg) of mineral concentrates from the plants[1].

Plant	Dry matter	Organic matter	N-total	$N\text{-}NH_4$	P	K	Number of samples
A	29.1[a]	10.5[ab]	6.41[a]	5.92[a]	0.20[a]	7.08[ab]	16
B	39.3[b]	18.2[bc]	7.17[a]	6.86[b]	0.01[b]	6.75[a]	17
C	40.2[b]	19.3[c]	8.92[b]	7.77[c]	0.34[c]	8.44[c]	22
D	25.8[ac]	7.81[a]	5.26[c]	4.72[d]	0.11[d]	6.81[a]	19
E	19.4[c]	6.32[a]	4.16[d]	3.56[e]	0.08[bd]	5.53[d]	10
F	33.9[ab]	13.7[abc]	8.12[b]	7.13[bc]	0.26[a]	8.08[bc]	13
H	113[d]	70.7[d]	11.0[e]	10.5[f]	0.27[ac]	15.7[e]	4

[1]Different letters within a column denote statistically significant differences ($P<0.05$)

The differences in composition of the mineral concentrates between the treatment plants can only for a small part be explained by differences caused by the slurry entering the treatment plant. The pretreatment technique probably has an effect on the composition of the mineral concentrates. The mineral concentrates from treatment plants with a combination of centrifugation and ultrafiltration (A and H) and with a combination of belt filter press and flotation (B, C and F) contain higher levels of nutrients than plants with a combination of mortar press and flotation (D and E). It should be stated here that in the pilot no criteria were set for the levels of nutrients in the concentrate. The plants did not optimize their process in order to reach a high nutrient content in the concentrate. Table 3 shows the average mineral composition of the concentrates and the variation for each component for different plants. The variation in composition (expressed as coefficient of variation in Table 3) is the lowest for mineral concentrates of plant C and F. It should be noted that modifications and innovations have been implemented in several plants during the pilot, which has changed the composition over the course of the pilot (resulting in a relatively high variation if the composition over the period 2009-2010 is considered). The variation in composition of mineral concentrates would probably be lower in these plants at a constant treatment the slurry.

Table 3
Mean, median, standard deviation (St.dev.), Variation coefficient (Var.coeff.) and number of observations per plant of the levels of nitrogen, ammonia, phosphorus and potassium in the mineral concentrate.

			Mean (g/kg)	Median (g/kg)	St.dev. (g/kg)	Var.coeff. (%)	Number
Plant A	N-total	g/kg	6.41	6.56	0.69	10.8	16
	$N\text{-}NH_4$	g/kg	5.92	6.28	1.03	17.4	16
	P	g/kg	0.20	0.20	0.15	71.1	16
	K	g/kg	7.08	7.42	1.38	19.5	16
Plant B	N-total	g/kg	7.12	6.43	1.33	18.7	17
	$N\text{-}NH_4$	g/kg	6.77	6.18	1.28	18.9	17
	P	g/kg	0.01	0.01	0.01	47.1	17
	K	g/kg	6.53	6.30	0.74	11.3	17
Plant C	N-total	g/kg	8.92	8.95	0.45	5.0	22
	$N\text{-}NH_4$	g/kg	7.77	7.64	0.50	6.5	22
	P	g/kg	0.34	0.34	0.05	14.9	22
	K	g/kg	8.44	8.56	0.78	9.3	22
Plant D	N-total	g/kg	5.26	5.31	0.62	11.8	19
	$N\text{-}NH_4$	g/kg	4,72	4.85	0.56	12.0	19
	P	g/kg	0.11	0.10	0.04	33.2	19
	K	g/kg	6.81	6.93	0.90	13.2	19
Plant E	N-total	g/kg	4.16	4.12	1.40	33.7	10
	$N\text{-}NH_4$	g/kg	3.56	3.60	1.37	38.6	10
	P	g/kg	0.08	0.06	0.03	43.7	10
	K	g/kg	5.53	5.24	1.91	34.6	10
Plant F	N-total	g/kg	8.12	8.17	0.34	4.2	13
	$N\text{-}NH_4$	g/kg	7.13	7.14	0.28	4.0	13
	P	g/kg	0.26	0.27	0.05	18.5	13
	K	g/kg	8.08	7.99	0.29	3.6	13
Plant H	N-total	g/kg	11.0	11.2	0.87	7.9	4
	$N\text{-}NH_4$	g/kg	10.5	10.5	0.46	4.4	4
	P	g/kg	0.27	0.28	0.06	23.5	4
	K	g/kg	15.7	15.8	1.49	9.5	4

The average composition of the mineral concentrate relative to the untreated slurry is shown in Figure 3. The levels in the untreated slurry per treatment plant in this figure are set to 100 percent. All mineral concentrates contain higher levels of potassium and ammonium than the untreated slurry. This increase ranges from about 10% to nearly 300%. The mineral concentrate from plants B, C, D, F and H also contain a higher content of total nitrogen. The levels of dry matter, organic matter and phosphorus in the mineral concentrates are lower than in the untreated slurry. Only the concentrate of plant H show a different composition, with levels of dry matter and organic matter being higher than the original slurry. This is caused by a number of factors. Plant H is the only plant that treats cattle slurry, and has a higher osmotic pressure (60 bar) than the other plants (40-45 bar; Table 1). In addition, plant H uses also co-fermentation materials, as in plant A.

The composition of the solid fraction after mechanical separation varies between the different systems. The composition is largely dependent on the separation technique, that leads to differences in moisture contents and thus to differences in nutrient contents of the solid fraction. After separation with a centrifuge and belt press the solid fraction contains higher levels of dry matter, organic matter, phosphorus and total nitrogen than after separation using a press auger (Hoeksma et al., 2011). The levels of ammonium and potassium are largely determined by the levels of these nutrients in the untreated slurry.

The differences in composition of the end products between the plants are on the one hand due to the technical differences between the plants, and on the other hand to differences in management of the process. Process parameters such as osmotic value, use of additives and the cleaning regime of the membranes are tailored to the specific operating conditions and the market for the end products. At a higher process pressure during reverse osmosis more water is removed from the incoming fluid. The maximum process pressure of the osmosis facilities of the plants is approximately 60 bar. On most plants the process pressure is kept submaximal because of energy costs, maintenance and reliability. For larger plants (A, B, C and F), which treat slurry from third parties and have to sell end products over a relatively long distance, process tailoring on the quality of the end products is more important than for the smaller plants (D and E). These plants can dospose their end products at a relatively short distance (at relatively low cost), so tailoring of the process on the quantity and quality of the end products is less necessary than at the larger plants.

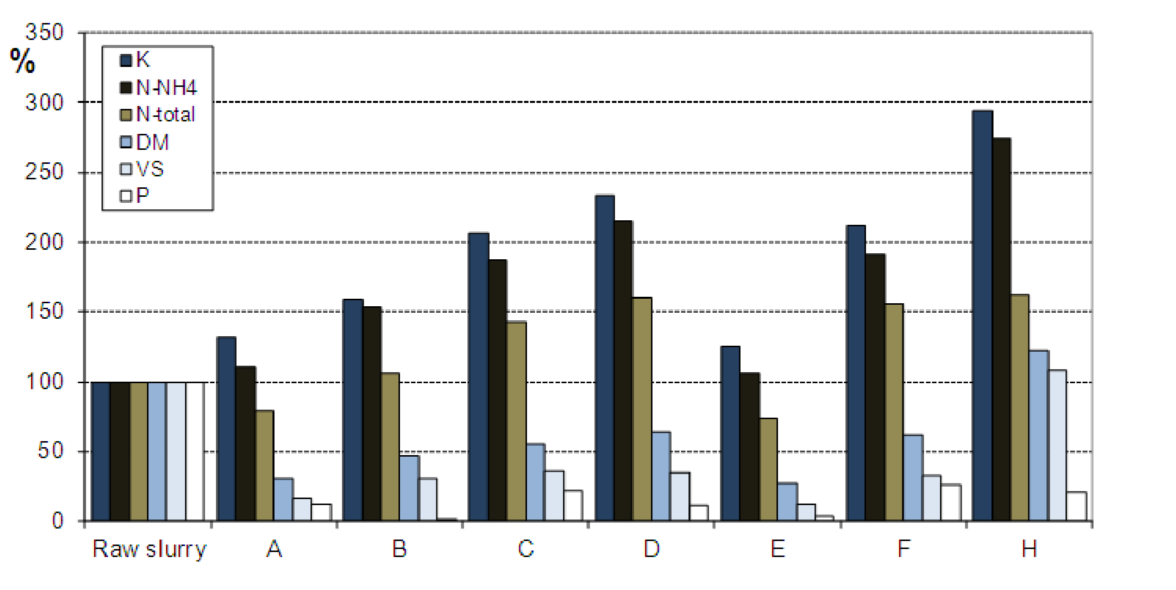

Figure 3
Relative composition of the concentrate from reverse osmosis in relation to the incoming untreated slurry per plant.

3.2 Mass balances

Based on the mass ratio between the process flows and the measured levels in these flows it was calculated how the nutrients from the incoming slurry/digestate are distributed over the end products (Table 4). Also, the difference between input and output was calculated (the balance in Table 4). The solid fraction contains more than 90% of the incoming amount of phosphorus on plants that use a belt press or screw press with flotation

(B t / F). On plants with a centrifuge and ultra filtration (A and H) 12-15 percent of the phosphorus input ends up in the concentrate of ultrafiltration (UF). The percentage of the input of total nitrogen, ammonium and potassium ending in the mineral concentrate of reverse osmosis varies greatly, but is significantly higher at plant B to F than at plants A and H. This is partly caused by some of the nitrogen and potassium ending in the ultrafiltration concentrate.

When calculating the mass distribution (Table 4) the balance for P was set to zero (Hoeksma et al., 2011). For organic matter and dry matter, the output exceeds the input. This is probably due to the use of additives such as acids, salts and flocculants during treatment. For nitrogen and ammonia the output via end products is lower than the input via incoming slurry. This points at gaseous nitrogen losses during treatment (up to 10%). For potassium the balance in six of the seven plants was slightly positive, which means that during the process small losses occurred. It should not be excluded that during the treatment potassium precipitation occurs (e.g. as potassium struvite), which is not determined so the potassium balance is not closed. The balances for nitrogen were used to estimate nitrogen losses in the LCA (Chapter 6). It should be noted that the estimated nitrogen loss based on the nitrogen balance is uncertain, because the balances of dry matter, organic matter and potassium are not closed.

3.3 Permeate

The reverse osmosis permeate is discharged into the sewer (plant A, C and F) or to surface water (systems B and H), or is used at the own farm (plant D and E). Indicative quality standards for discharges have been established by water managers. Hoeksma et al. (2011) tested if the composition of the permeate (organic matter and major elements) meets the standards. Secondary nutrients and heavy metals are excluded, because the levels of heavy metals in the permeate fell within the discharge standards. For most plants the permeate meets the discharge standards. Plant B applies ion exchange, after which the permeate meets all standards. The permeate of plant H does not meet the standards for nitrogen and ammonium.

3.4 Summary

- The nitrogen content of mineral concentrates ranges from an average of 4.16 g N per kg [plant E] to 11.0 g N per kg [plant H].
- The potassium content of mineral concentrates ranges from an average of 5.53 g K per kg [plant E] to 15.7 g K per kg [plant H].
- The average phosphorus content of mineral concentrates is the lowest for plant B (0.01 g P per kg) and highest for plant C (0.34 g P per kg).
- The differences in composition of mineral concentrate between treatment plants can only for a small part be explained by differences in the untreated slurry. The separation techniques, process management and/or the combination of both are the main factors explaining the differences in composition between plants.
- The solid fraction contains more than 90% of the phosphorus in the slurry entering the treatment on plants that use a belt press or screw press combined with flotation. On plants with a centrifuge and ultrafiltration 12-15% of the phosphorus input ends in the concentrate of ultrafiltration.
- The output of nitrogen and ammonia from slurry is equal to or lower than the input (up to 10%). This may indicate gaseous nitrogen losses during treatment. The nitrogen loss estimated from the nitrogen balance is uncertain, because the balance sheets of dry matter, organic matter and potassium are also not closed.
- For most plants the permeate meets the standards for discharge to surface waters.

Table 4
Relative mass distribution of phosphorus, organic matter, dry matter, nitrogen, ammonium and potassium over the end products of slurry treatment at the plants (in %).

		P	Organic matter	Dry matter	N-total	$N\text{-}NH_4$	K
	Raw slurry/digestate	100	100	100	100	100	100
A	Solid fraction	86	74	68	31	26	18
	Concentrate UF	12	22	23	39	38	38
	Concentrate RO	2	4	7	17	26	30
	Permeate RO	0	0	0	3	4	2
	Balance (input-output)	0	0	2	10	6	12
B	Solid fraction	100	98	95	52	35	24
	Concentrate RO	0	14	21	49	69	67
	Permeate RO	0	0	0	0	0	0
	Balance (input-output)	0	-12	-16	-1	-4	9
C	Solid fraction	92	92	84	42	26	18
	Concentrate RO	8	13	20	51	66	73
	Permeate RO	0	0	0	3	4	1
	Balance (input-output)	0	-5	-4	4	4	8
D	Solid fraction	95	90	78	40	24	12
	Concentrate RO	5	12	24	54	70	82
	Permeate RO	0	0	0	2	3	1
	Balance (input-output)	0	-2	-2	4	3	5
E	Solid fraction	96	101	87	45	27	20
	Concentrate RO	4	11	23	55	70	85
	Permeate RO	0	0	0	2	3	2
	Balance (input-output)	0	-12	-10	-2	0	-8
F	Solid fraction	93	99	89	42	26	17
	Concentrate RO	7	12	21	53	70	80
	Permeate RO	0	0	0	2	3	1
	Balance (input-output)	0	-11	-10	3	1	3
H	Solid fraction	83	69	67	36	23	20
	Concentrate UF	15	30	28	49	47	44
	Concentrate RO	2	9	9	12	21	23
	Permeate RO	0	0	0	0	0	0
	Balance (input-output)	0	-8	-4	3	9	14

4 Agronomic aspects

4.1 Assessment based on product composition

This section assesses the agricultural value of mineral concentrates based on the composition. This assessment is based on the report of Ehlert and Hoeksma (2011) and the results of the monitoring by Hoeksma et al. (2011).

Components of mineral concentrates with a agricultural value are the nutrients nitrogen (N), phosphorus (P) and potassium (K)[1], the secondary nutrients calcium (Ca), magnesium (Mg), sodium (Na) and sulfur (S), and the trace elements boron (B) , copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn). Nutrients are essential components for the crop. In addition, organic matter and acid neutralizing capacity (effect on soil acidity) may be an added value of mineral concentrates as fertilizer. These ingredients are mainly used to improve soil quality (soil biology, structure, pH). For cattle feed, the important minerals are cobalt (Co), copper (Cu), selenium (Se) and zinc (Zn). These minerals are often added to fertilizers for achieving a better distribution over a field and in the soil.

4.1.1 Nitrogen

Nitrogen is the most important nutrient determining the agricultural use of mineral concentrates (Table 5). The nitrogen in mineral concentrate is mainly found in the form of ammonium (average 90% of the N in concentrate, but there is a large spread between the treatment plants). The average content of organic nitrogen is low (average 10% of nitrogen). The pH of mineral concentrate is high (average 7.95), by which there is a risk of ammonia emission after application of mineral concentrates to soil.

The nitrogen efficiency of mineral concentrate compared with mineral fertilizer is thus determined by the effect of ammonium and organic nitrogen in the concentrate. Ammonium is immediately available for crop uptake, but some of the ammonium can volatilize as ammonia. Organically bound nitrogen becomes available for the crop after mineralization in the soil. The ratio of ammonium nitrogen to organic nitrogen varies between different mineral concentrates, so the same nitrogen application may have different agronomic effectiveness for the various concentrates.

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

[1] In this text, phosphorus and potassium are applied. Fertilization practice in the Netherlands is mostly based on the concepts of 'phosphate' and 'potassium oxide'. With phosphate, phosphorus pentoxide (P_2O_5) is meant, and with potassium oxide K_2O. This common usage, however, gives no sound picture of the chemical forms of phosphorus and potassium products of manure and is therefore not used. The conversion formulas from phosphorus to phosphate are $P_2O_5 = 2.29 * P$, for potassium to potassium oxide the formula is $K_2O = 1.205 * K$.

the mineral fertilizer Calcium Ammonium Nitrate (CAN)[1]. The coefficient is not only determined by the ammoniacal and organic nitrogen but also by:

- the rate of release by mineralization of the organic nitrogen,
- the extent to which nitrogen is denitrified to gaseous nitrogen (N_2, N_2O and NO_x),
- the extent to which inorganic nitrogen is emitted as ammonia, and
- the degree of nitrogen loss in the field via leaching or runoff.

Mineral concentrates contain more ammonium and less organic N, and have a higher pH than animal slurry. The NFRV of animal slurry may therefore not simply be applied to mineral concentrates. The solid fraction has a different composition than untreated slurry and therefore a different NFRV. The nitrogen efficiency is also determined by the application technique and the conditions under which it is applied. Ammonia emission from animal slurry applied to arable land is lowest with injection (average <5% of the applied ammonium) and highest with broadcast surface application (average 70-75% of the applied ammonium (Huijsmans et al., 2011).

Ehlert and Hoeksma (2011) estimated the NFRV of mineral concentrates from their composition. If it is assumed that part of the organic nitrogen in concentrate becomes available by mineralization for the crop (45% of organic nitrogen in pig slurry and 30% in cattle slurry), then the average NFRV compared to CAN of mineral concentrates would theoretically be 94%. Part of the ammonium in mineral concentrate (5-20%, depending on the application technique) will be lost by ammonia volatilisation. It is estimated that the NFRV of mineral concentrate will range from 76-90% on arable land and on grassland from 67-81% (depending on the amount of ammonia emission).

These calculations indicate that, due to the low content of organic nitrogen, the nitrogen efficiency of a mineral concentrate is similar to CAN if there is a low ammonia emission. The efficiency will be lower at a high ammonia emission.

Besides the presence of organic N and the risk of ammonia emission, the nitrogen form and method of application affect the nitrogen efficiency of mineral concentrates compared to CAN. CAN is broadcast as granules and the nitrogen in the CAN consists of 50% ammonium and 50% nitrate. Mineral concentrate is injected as a liquid, so the nitrogen is less well distributed in the soil than the N from broadcast applied CAN. Mineral concentrate contains ammonium compounds such as ammonium bicarbonate, ammonium chloride, ammonium sulfate and possibly ammonium-containing fatty acids. The efficiency of these nitrogen compounds may differ from ammonium nitrate in CAN (Ehlert and Hoeksma, 2011). In 2011 a pot experiment is conducted on the efficiency of various types of nitrogen fertilizer (Chapter 7).

4.1.2 Potassium

The exact chemical form in which potassium 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 sulfate and potassium-containing fatty acids. There are no reasons to believe that potassium in mineral concentrates is not fully available to the crop.

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1 In 2009, 66% of fertilizer nitrogen was applied as CAN, 18% as NP, NK, and NPK fertilizers, 5% as ammonium sulfate, 3% as urea and 8% as other fertilizer (Van Bruggen et al., 2011)

The average of nitrogen to potassium ratio in the mineral concentrates for all plants is of the same order of magnitude (mean 0.8: range 0.6 to 0.9). A ratio of 1.2 fits well with a sufficient status of potassium in the fertilizer needs of grassland (100% cut), maize, potato, sugar beet and winter wheat on clay. A ratio of 0.8 fits with sugar beet on sand.

4.1.3 Phosphorus

The phosphorus content of mineral concentrate is low and considerably lower than for nitrogen and potassium (Table 5). However, the phosphorus content of certain mineral concentrates can not be neglected (up to 21 kg P_2O_5 per ha for a nitrogen application of 100 kg N per ha).

4.1.4 Other

Mineral concentrates mainly contain nitrogen and potassium. Form the other nutrients in mineral concentrate, sulfur and sodium are of agricultural importance. The levels of sodium in mineral concentrates are approximately 20-25% of that of potassium. When using a mineral concentrate as a nitrogen fertilizer or potassium fertilizer a significant amount of sodium is applied (20-40 kg Na per ha). Sodium has significance in animal feeding, and some arable crops (e.g. sugar) reacts with a yield increase of when sodium is applied. Other crops tolerate sodium, except if very high amounts are applied. The availability of sodium in concentrate is expected to be good.

Sulfur is a valuable component of mineral concentrate. The average total sulfur application rate is low (about 4 kg S per ha at 100 kg N per ha, of which about 3 kg as sulfate). The availability for the crop of sulfur from mineral concentrate and the solid fraction of slurry is unknown.

The levels of calcium, magnesium and trace elements in concentrate are generally too low to be of agronomical importance.

Application of chloride is not an issue when using mineral concentrate if the possible supply of chloride with other fertilizers is accounted for. Early 2009 the chloride content of the mineral concentrate from one plant was high, but by an adjustment in the process the chloride content decreased significantly.

Table 5
Composition of mineral concentrates from slurry of fattening pigs (samples from seven plants) and from cattle slurry (samples of one plant).

Type of concentrate	Parameter	Unit	Average	Median	Minimum	Maximum	Standard deviation	Number of samples
Pig slurry	Specific gravity	kg/l	1.03	1.03	1.02	1.04	0.001	95
	Dry matter	g/kg	33.0	33.5	15.2	58.2	0.879	101
	Organic matter (calculated)	g/kg	13.5	13.0	0	34.7	0.629	102
	pH		7.95	7.93	7.25	8.62	0.025	101
	Nitrogen total	g N/kg	6.99	6.86	3.13	11.0	0.179	101
	Ammonium-N	g N/kg	6.27	6.65	1.78	9.53	0.160	101
	Phosphorus	g P/kg	0.18	0.15	0	0.6	0.013	101
	Potassium	g K/kg	7.33	7.51	4.16	9.80	0.130	101
	Calcium	g Ca/kg	0.23	0.18	0.02	1.17	0.020	95
	Magnesium	g Mg/kg	0.09	0.03	0	0.68	0.015	95
	Sodium	g Na/kg	1.77	1.80	0.77	4.46	0.047	97
	Sulfur	g S/kg	1.07	0.29	0.12	9.71	0.200	95
	Sulfate	g SO_4^{2-}/kg	2.91	0.21	0	19.2	0.694	69
Cattle slurry	Specific gravity	kg/l	1.06	1.06	1.05	1.07	0.004	4
	Dry matter	g/kg	90.9	87.3	68.3	120	11.70	4
	Organic matter (calculated)	g/kg	48.9	45.4	30.2	74.9	10.19	4
	pH		7.01	6.91	6.78	7.43	0.145	4
	Nitrogen total	g N/kg	11.0	11.2	9.73	11.7	0.435	4
	Ammonium-N	g N/kg	10.5	10.5	10.0	11.0	0.230	4
	Phosphorus	g P/kg	0.27	0.28	0.19	0.34	0.032	4
	Potassium	g K/kg	15.7	15.9	13.8	17.2	0.745	4
	Calcium	g Ca/kg	0.34	0.34	0.26			4
	Magnesium	g Mg/kg	0.06	0.06	0.03			4
	Sodium	g Na/kg	2.06	2.08	1.80			4
	Sulfur	g S/kg	15.4	15.4	10.2			4
	Sulfate	g SO_4^{2-}/kg	39.3	43.9	23.1			4

4.2 Nitrogen efficiency of mineral concentrates on arable land

4.2.1 Experiments in the pilot

Van Geel et al. (2011) performed two experiments with potatoes in 2009 and 2010. In both years one experiment was done with ware potato on clay soil in Lelystad (Flevoland) and one with starch potato on sandy soil in Rolde (Drenthe). In the four experiments, the use of mineral concentrate was examined both before planting (basal dressing) and after planting (top dressing before creating ridges and at tuber setting). In all experiments, three mineral concentrates were compared with CAN. CAN and the mineral concentrates were tested at different nitrogen application rates before planting. Applications after planting were tested at only one nitrogen level. To determine whether the application form and technique have an effect on the nitrogen efficiency, the effect of different levels of liquid ammonium nitrate was examined in 2010, applied before planting. In the experiments with concentrate a control was included, in which the injection coulters were pulled through the soil without concentrate being applied. This was carried out to assess whether there is an effect of soil disturbance by the coulters on yield. In 2010, one of the concentrates was acidified in order to assess the extent to which ammonia emission plays a role in the N efficiency. The concentrates and liquid ammonium nitrate were applied with a machine developed for field experiments, with which the products were applied via low-emission injection coulters. When applied before planting the distance between the coulters was 17 cm, when applied after planting the concentrates were injected in the middle between the ridges.

The NFRVs of the mineral concentrates were calculated for the marketable yield, dry matter yield and nitrogen in the tubers. The statistical analysis showed that generally the yield curve for nitrogen in the tuber fitted better than the curves for marketable yield and dry matter. Furthermore, nitrogen uptake is the most direct measure to compare fertilizers based on their nitrogen efficiency or on the probability of nitrogen loss. Therefore, this report examines the NFRV based on nitrogen uptake by the potatoes (Table 6).

No statistically significant differences in yield were found between the three mineral concentrates and, therefore, only the average results of the mineral concentrates are given. The average NFRV of mineral concentrates ranged on clay soil from 78% (2009) to 81% (2010) and on sandy soil from 86% (2009) to 98% (2010). On sandy soil there was no significant difference in nitrogen efficiency between mineral concentrates and CAN. Averaged over both experimental years the NFRV was 80% on clay and 92% on sandy soil, the average of all four experiments was 86%.

When liquid ammonium nitrate was used as basal dressing on clay soil at Lelystad nitrogen uptake was significantly lower than with KAS, and comparable to the uptake from mineral concentrates. The average NFRV of liquid ammonium nitrate compared to CAN was 65%. The average NFRV of the mineral concentrate compared to liquid ammonium nitrate was 117%. The difference in the efficiency of nitrogen from mineral concentrate and from liquid ammonium nitrate was statistically not significant.

The results of application of mineral concentrate via top dressing at tuber setting were variable between years. In 2009, a low NFRV was found (40-58%) and in 2010 a high NFRV (> 100%). Since for application after planting the NFRV was determined at only one nitrogen level, the NFRV could be determined less accurately than when it was applied before planting (which was done at different N rates).

The acidification of mineral concentrate to a pH of 6.7 (Rolde) and 7.2 (Lelystad) in Lelystad, did not lead to a statistically significant increase in NFRV. In Rolde a higher NFRV was found, the difference was nearly significant.

In conclusion, the NFRV of mineral concentrate applied before the planting of potatoes averaged 80% on clay (78% in 2009 and 81% in 2010) and 92% on sand (86% in 2009 and 98% in 2010). The NFRV on the sandy soil corresponded to the theoretically calculated value in the case of deep injection on arable land, and on clay soil the NFRV was slightly lower than calculated. The NFRV of top dressing with mineral concentrate varied greatly (40-58% in 2009 and over

100% in 2010), but due to the chosen experimental design the NFRV of top dressing could be determined less than accurately than for base fertilizing. On clay soil, the nitrogen efficiency of the mineral concentrate was equivalent to that of liquid ammonium nitrate (not significantly different).

Table 6
NFRV *(%) compared to calcium ammonium nitrate (CAN) of mineral concentrate and liquid ammonium nitrate, based on of nitrogen in the tubers (Van Geel et al., 2011).*

Fertilizer	Time of application	Lelystad		Rolde	
		2009	2010	2009	2010
Mineral concentrate	Basal dressing	78	81	86 (n.s.)	98 (n.s.)
Liquid ammonium nitrate	Basal dressing	–	65	–	–
Mineral concentrate	Creating ridges	58 (n.s.)[1]	121 (n.s.)	–	–
Mineral concentrate	Tuber setting	44 (n.s.)	104 (n.s.)	40	112 (n.s.)

[1] n.s. = not significanty different from CAN (i.e. of 100)

4.2.2 Additional research

In the ongoing study of Schroder et al. (2011) the efficiency of different organic nitrogen fertilizers is determined in a field experiment with maize on sandy soil in Achterveld. In this experiment, the NFRV compared to CAN is determined for mineral concentrate, pig slurry, cattle slurry, solid fraction of separated pig slurry, and cattle slurry. All fertilizers were tested at different nitrogen levels. Liquid fertilizers were applied with a deep injector for arable land (approximately 5-10 cm depth and distance of 26 cm) combined with a disc harrow. Solid fertilizers were applied with a spreader for solid manure. The NFRV of mineral concentrate was 77%, 65% for pig slurry, 60% for cattle slurry, 64% for the solid fraction of separated pig slurry, and 33% for cattle slurry. The study is repeated in 2011.

In 2009 and 2010, experiments were carried out with starch potatoes on reclaimed peat soil, winter wheat on heavy clay, and spring barley on reclaimed peat soil (2009) and sand (2010). Further experiments were done in 2010 on sandy soil and marine clay with ware potatoes, and on sandy soil with maize. This research is described in several reports. Van Geel et al. (2011b) summarized the results of all experiments from this additional survey in 2009 and 2010. Below a summary is given of the NFRV found in the various experiments.

Table 7 shows the NFRV compared to CAN of mineral concentrate in the various experiments. If the nitrogen efficiency of the mineral concentrate is not statistically different from CAN, it is assessed as similar to CAN. The values of NFRV found varied between crops, years and application methods. This variation is partly due to growth and weather conditions. In addition, when interpreting the results it should be considered that a small difference in nitrogen uptake may already give a large difference in the calculated NFRV. In most experiments described in Table 7 the NFRV of mineral concentrate is based on only one level of nitrogen, and this value is compared with a nitrogen response curve determined at different levels of CAN. In that case the field variation has a greater impact than in an experiment in which the mineral concentrate was also applied at different levels. In an experiment with more application rates, a nitrogen response curve for the mineral concentrate would be compared with a nitrogen response curve for CAN, and the influence of field variation would be less. In the experiments of the pilot, the three mineral concentrates weres applied as basal dressing at different nitrogen levels (Section 4.2.1). In the study by Schroder et al. (2011), the mineral concentrate was also applied at different levels. Thus, in the potato experiments by Van Geel et al. (2011a) and in the maize experiment by Schröder et al. (2011), the NFRV was determined more accurately than in the experiments from the additional study (Van Geel et al., 2011b).

The findings from additional studies (Van Geel et al., 2011b):

- When using mineral concentrate via deep injection before planting or sowing of crops, the nitrogen efficiency of the mineral concentrate was in most experiments similar to the efficiency of CAN. Only exception was the spring barley trial on sand in 2010.
- When using mineral concentrate as a second application in winter with a slit coulter, the nitrogen efficiency in the trial of 2009 was lower than that of CAN. This was as expected, since the risk of ammonia volatilisation when applied with a slit coulter is higher than for deep injection. In the 2010 trial there was no difference with CAN.
- Top dressing of mineral concentrate with a hose machine in the potato trials gave a nitrogen efficiency similar to CAN in the 2010 experiments on sand and reclaimed peat soil. On the clay soil, the nitrogen efficiency was lower than for CAN, which is possibly due to less soil cover by foliage in the clay trial than in the experiments on sand and reclaimed peat soil (the less coverage by foliage, the higher the risk of ammonia volatilisation from the hose-applied mineral concentrate).
- Application of mineral concentrate with the hose machine in winter wheat in 2009 gave a result similar to CAN, in 2010 the nitrogen efficiency was lower.
- Surface application of mineral concentrate (not within the soil) to spring barley in 2009 gave a result similar to CAN (as deep injection), but in 2010 the nitrogen efficiency was considerably lower.
- Application of mineral concentrate mixed with slurry resulted in a lower nitrogen efficiency of the concentrate than when the mineral concentrate was applied separate.
- When using mineral concentrate in early spring on clay, there is a risk of damage to soil structure, as is the case is with application of raw slurry. Risk of soil degradation by application in ealry spring on clay remains a bottleneck when applying mineral concentrate in stead of slurry.

4.3 Nitrogen efficiency of mineral concentrate on grassland

4.3.1 Experiments in the pilot

Van Middelkoop and Holshof (2011) carried out experiments in 2009 and 2010 on permanent grassland on sand (Heino) and clay (Lelystad). Mineral concentrates were applied with a machine developed for experiments that cuts the coulters through the sod, after which the liquid fertilizer is placed in the slit that was made. For grassland the coulters were set at five cm below ground level, similar to a well-adjusted sod injector. The distance between coulters was 17 cm.

In 2009, three mineral concentrates, liquid ammonium nitrate and CAN were applied at three nitrogen levels. On grassland the same mineral concentrates were used as in the study on arable land by Van Geel et al. (2011a). On all objects five grass cuttings were harvested. In 2010, in addition to the objects from 2009, new objects were installed, including an object with acidified concentrate and an object with dissolved ammonium chloride. The purpose of acidifying the concentrate was to determine whether ammonia volatilisation was a cause of the relatively low nitrogen efficiency of mineral concentrates in 2009. The object with ammonium chloride solution was included to determine whether the nitrogen form has an effect on the nitrogen efficiency. The NFRVs are calculated based on the dry matter yields and nitrogen yields of all cuts (annual yields) and nitrogen applications. The NFRV of nitrogen yield is most meaningful in the current study, because this is an indicator of differences between fertilizers in nitrogen efficiency and the risk of nitrogen loss.

The NFRV of mineral concentrate compared to CAN, averaged over both years, both locations and all mineral concentrates, was 58% (varying between years and mineral concentrates from 43% to 69%). There was no statistically significant difference in NFRV between the two locations. The average NFRV of 58% was lower than the value of 70-80% that was calculated based on the composition of the concentrates (see Section 4.1.1).

The NFRV compared to liquid ammonium nitrate ranged from 76 to 115% (average 96%). The efficiency of concentrates on grassland is thus almost as good as of liquid ammonium nitrate, when applied with the same equipment.

Acidification of the concentrate had no effect on the nitrogen efficiency. Cutting itself, without application of concentrate, did not affect the yield, both with and without nitrogen fertilization.

The yield obtain with (dissolved) ammonium chloride was small and samller t
han for mineral concentrates. The NFRV compared to CAN of ammonium chloride was 49% in 2010 (for mineral concentrate it was on average 63% in that year). The low effect of ammonium chloride may be the result of a high application of chlorine.

Conclusions:

- The average NFRV compared to CAN of the concentrates on grassland was 58% (based on two years, both locations and all mineral concentrates). The coefficient varied between years and mineral concentrates from 43% to 69%. No statistically significant difference between the two locations was found.
- The NFRV compared to liquid ammonium nitrate was on average 96% (76-115%). The mineral concentrates were almost as efficient on grassland as the liquid ammonium nitrate.

4.3.2 Additional research

The report by Van Geel et al (2011b) describes the results of additional research on grassland. In an experiment with grassland on sandy soil, the nitrogen efficiency was examined of mineral concentrate given either in addition to a slurry application, or as a mixture of mineral concentrate and slurry. The concentrate and the mixture of slurry and concentrate were applied with a sod injector. The reference was a basal dressing of cattle slurry with different levels of CAN. For all fertilizers the nitrogen was applied in four doses distributed over the growing season. The nitrogen efficiency of mineral concentrate was equivalent to that of CAN in this grassland experiment. Application of mineral concentrate mixed with slurry led to lower nitrogen efficiency than when the mineral concentrate was applied separately (Table 8).

Table 7
The NFRV of mineral concentrates in the various experiments on arable land, done as additional research (Van Geel et al., 2011b).

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
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
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

Table 8
The NFRV of mineral concentrates in the various experiments on grassland as part of the additional research (Van Geel et al., 2011b).

Experiment	Moment of application	Method of application	NFRV, %	Rating
Grassland SE sand, 2010	before each cut, apart from slurry	sod injection	110	similar to CAN
	before each cut, mixed with slurry	sod injection	82	similar to CAN

4.4 Survey of experiences of users of mineral concentrates

De Hoop et al. (2011) have conducted a survey to gain insight into the experiences of users of mineral concentrates within the Mineral Concentrates Pilot in 2009 and 2010. In September 2009 and September 2010, the survey was distributed to participants. In both years, the usable survey response rates were 62% (103 out of 166 customers in 2009 and 169 of the 274 customers in 2010).

In both 2009 and 2010, mineral concentrate was most often used on grassland, followed by maize and ware potatoes. Minerals concentrate is, to a lesser extent, also used on other crops such as sugar beet, cereals and vegetables.

On grassland mineral concentrate was mostly applied as a mixture of concentrate and slurry (in 70% of the fertilizations with mineral concentrate it was applied as a mixture of concentrate and cattle slurry, in 30% only concentrate was applied). The main reason for mixing concentrate is that it is easier to distribute with existing application techniques, such as sod injection. In addition, by mixing with mineral concentrate the slurry becomes thinner and therefore easier to handle. Users of concentrate on grassland appreciate the product as a good fertilizer for both yield (55 and 60% of users in 2009 and 2010, respectively assess concentrate as good) and quality (70 and 78% of users in 2009 and 2010, respectively). Of the users on grassland, almost all users indicate that nitrogen is a valuable component of the concentrate, and 39% considers potassium as also important. Only a small proportion of the users (<5%) experienced a bad effect on crop quality or crop yield. These farmers have suffered from drought or wet periods. In some cases burning of the grass was found after the application of concentrate (not mixed with slurry).

On maize mineral concentrate is usually applied as a basal dressing. In 2010, 27% of the concentrate was applied as a top dressing. The most common method of application on maize was deep injection. In 2010, 15% of the applications of concentrate was done with aboveground hose application, which was permitted in that year. In over half of all fertilizations concentrate was mixed with slurry. The average application level of concentrate was about 8.5 tons per hectare. Among the users of mineral concentrate on forage maize about 80% considers potassium a major constituent of mineral concentrate, for nitrogen this is about 85%. In both years the use of mineral concentrate was experienced as positive.

On ware potatoes, fertilization with mineral concentrate was in 2009 usually given before planting as a base fertilizer. In 2010, in 21% of the applications to potatoes concentrate was added as a mixture with slurry. In most cases, the concentrate was applied as a base fertilizer and applied by the slurry injector. Top dressing of potatoes has become more attractive in 2010 since a band place system with tubes was allowed that year. The majority of the users of mineral concentrate on ware potatoes consider nitrogen and potassium as important. On average, approximately 10.5 tons of concentrate per hectare per year is used on potatoes. The experiences with using mineral concentrate as fertilizer for ware potatoes are good.

Some users indicate that there is a need for a higher nitrogen content of the mineral concentrate. Most users on grassland indicate that potassium levels should be lower. By contrast, for users on arable crops (especially ware potatoes and sugar beet) a higher potassium content is favourable.

4.5 User experience in projects Cows and Opportunities and Farming with Future

Verloop et al. (2011) conducted a survey on the use of mineral concentrates in practice on dairy farms and arable farms. The aims of this study was to determine the advantages and disadvantages of using concentrates, the identification of potential problems in using concentrate, and finding solutions. This project also had the aim of promoting communication about experiences using mineral concentrates. The research took place on farms that participate in the projects 'Cows and Opportunities' and 'Farming with Future'. A summary of the key findings is given below.

User assessment of concentrate

- Application of mineral concentrates has the best prospects in sugar beet, winter wheat, barley, maize, dwarf French Bean, carrots and potatoes (arable) and grass (dairy).
- The N efficiency of concentrate as fertilizer depends on the way of application of mineral concentrate (application technique, level, time of application, place of application, etc.), as with other fertilizers. More experience is needed to optimize the use of mineral concentrates.

Potassium and phosphorus

- For the use of concentrates in dairy farming the highest possible nitrogen/phosphorus ratio is required. The phosphate content of some products is too high accoring to some users.
- The supply of potassium with mineral concentrate limits the possibilities for application of mineral concentrate as nitrogen fertilizer on dairy farms when the potassium status of the soil is sufficient or higher.
- On many crops mineral concentrate can largely meet the potassium needs. The presence of potassium in the concentrate therefore contributes significantly to the possibility of using mineral concentrate as mineral fertilizer.

Crop yield

- Applications by farmers and experiments on small plots are by their nature in general not suitable for determining nitrogen efficiency, but do give an impression. The general impression of yields when using concentrates in agriculture is positive. There are little or no observable differences between crops treated with concentrates and treated with mineral fertilizer.
- The effect on grass yield is variable but mostly positive. The nitrogen yield of grass fertilized with mineral concentrate is usually slightly lower than for fertilization with CAN.

Application techniques

- Some users are seeing opportunities in the application of a mixture of concentrate and slurry (see also Section 4.4). The mixing is done in a silo or tank. The possibilities for mixing mineral concentrate with slurry are limited on arable farms and mixed farms with pigs.
- Separate use of mineral concentrate instead of mixed with mineral fertilizer allows fine tuning of nitrogen application, but leads to higher subcontracting costs. In addition, the grass is cut twice (for application of slurry and for application of concentrates). There is a need for application techniques that allow low doses (<10 tonnes per ha) of mineral concentrate.

Environmental effects

- Due to the low level of organic nitrogen in mineral concentrate there is little residual effect of nitrogen through mineralization. The probability of nitrogen release through mineralization in autumn and winter is therefore limited. This can lead to a lower risk of nitrate leaching.

4.6 Perspectives of the solid fraction

4.6.1 Nitrogen

The solid fraction of pig slurry has an average nitrogen content of 11.8 g per kg, and on average 45% of this nitrogen is ammonium (Ehlert and Hoeksma, 2011). Based on this composition an average NFRV is calculated of 69% (61-79%, depending on the composition; Ehlert and Hoeksma, 2011). The calculated NFRV of the solid fraction is lower than that of the mineral concentrate, because the proportion of ammonium in the nitrogen of the solid fraction is lower than in mineral concentrate. In addition, the solid fraction can not be injected but is applied on the soil surface and then incorporated. This way of application results in a higher risk of ammonia emission than with injection.

Van Geel et al. (2011a) performed two expermiments with potatoes in 2009 and 2010, in which both mineral concentrates (see Section 4.2.1) and the solid fraction were tested. The ammonium fraction of total nitrogen in the solid fraction was 42% in 2009 and 53% in 2010. In all experiments, the solid fraction was compared with CAN at different nitrogen levels. The solid fraction was distributed before planting and incorporated with a harrow. In three of the four experiments a low NFRV compared to CAN was found for the solid fraction: 32 to 34% (Table 9). In the trial in Rolde in 2009 a NFRV of 55% was found. The NFRV found in these experiments is lower than the value of 69% calculated theoretically (Ehlert and Hoeksma, 2011). The cause of the low NFRV is unclear. Possibly ammonia emission after application played a role, since the product is first applied on the soil surface and then incorporated by harrows in a separate track.

Table 9
NFRV compared to CAN (in %) of solid fraction based on N-uptake in de tubers (Van Geel et al., 2011a).

Fertilizer	Time of application	Lelystad		Rolde	
		2009	2010	2009	2010
Solid fraction	Basal dressing	34	32	55	34

In the ongoing study of Schröder et al. (2011) the nitrogen efficiency of different organic fertilizers is determined in a field trial with maize on sandy soil in Achterveld (see Section 4.2.2). The nitrogen efficiency of the solid fraction and CAN is tested at various levels of nitrogen. The solid fractions are applied with a manure spreader. The ammonium fraction of total nitrogen in the solid fraction was 38% in 2010. The NFRV of the solid fraction was 64% and is higher than that found by Van Geel et al. (2011a). It is not clear why the NFRV of the solid fraction was higher in the study by Schröder et al. (2011) than in Van Geel et al. (2011a).

4.6.2 Phosphorus

The solid fraction is relatively rich in phosphorus and organic matter (Ehlert and Hoeksma, 2011) and therefore attractive for use as fertilizer on arable land. The phosphorus efficiency of the solid fractions was examined by an incubation with soil by Schröder et al. (2010). The phosphorus efficiency was derived from changes in the phosphate status of the soil over time. The phosphate status was determined using methods of soil analysis used for fertilizer advice. When using gentle extraction methods the phosphorus efficiency of the solid fraction was similar to that of animal slurry. Using more aggressive extraction methods more phosphate was found in comparison to animal slurry. Flocculants and coagulants containing iron led to an increase in the iron content in the solid fraction, which decreased the availability of phosphate.

4.6.3 Other nutrients

The solid fraction contains potassium and magnesium. The magnesium content in the solid fraction is higher than that in mineral concentrates. It is expected that both the potassium and magnesium are available to the crop. When using the solid fraction as phosphate fertilizer, however, a limited amount of potassium and magnesium is applied. The sodium content in the solid fraction is considerably lower than in mineral concentrates and has little agronomic significance. The sulfur content in the solid fraction is higher than the sulphate content. This indicates the presence of reduced forms of sulfur. The availability of sulfur from solid manure fractions is unknown, but it is expected that the sulfur will be available to the crop after soil application. The sulfur applied with the solid fraction almost fully meets the crop demand.

The solid fraction is a source of trace elements. Application of iron and manganese to the soil is not a fertilization purpose, and the amount of molybdenum applied is too small to assign any agronomic value to it. The amounts of boron, copper and zinc should be considered when fertilization is planned.

4.6.4 User experiments

The survey of De Hoop et al. (2011) also contained questions about the use of the solid fraction. The solid fraction produced in various treatment plants varies in composition. Besides differences in the separation process itself and the differences in composition of the incoming slurry, operations as sanitizing, drying and composting may have an effect on attractiveness for farmers.

When a solid fraction that is not further treated is to be disposed for application in arable farming, the price is mainly determined by the costs of transport and administration. There is little difference between the selling prices of solid fractions of slurries as the price is determined for an important part by transportation costs, which are calculated per cubic meter. Not the composition, but the amount determines the price. Disposal of solid fraction to Dutch arable farming mainly occurs in Flevoland and Zeeland, and to a lesser extent in Drenthe. The solid fraction is especially popular on clay soils.

Besides sales to Dutch arable farming, the product is also delivered to companies for composting and biogas production. Disposal of solid fraction to foreign agriculture is only possible after sanitizing. During a composting process the solid fraction is made ready for export, mainly to arable farmers in Northern France.

4.7 Summary

Composition

- Nitrogen is the nutrient that mainly determines the agricultural use of mineral concentrates. The nitrogen in mineral concentrate occurs mainly in the ammonium form (average 90% of the N in concentrate, but there is a large variation between the plants).
- The pH of mineral concentrate from pig slurry is on average 7.95, making it likely that ammonia emission from the mineral concentrates applied to soil may occur.
- Based on the composition it is estimated that the NFRV compared to CAN of mineral concentrate will range from 76-90% on arable land and from 67-81% on grassland (depending on the amount of ammonia emission).
- There are no reasons to assume that the potassium in mineral concentrates is not fully available to the crop.
- The phosphorus content in mineral concentrate is low and considerably lower than the nitrogen and potassium content. However, the phosphate content of some mineral concentrates can not be neglected (up to 21 kg P_2O_5 per ha when nitrogen is applied at 100 kg N per ha).
- Of the other nutrients in mineral concentrate sodium and sulfur can be of agronomic significance.
- The levels of calcium, magnesium and trace elements in concentrate are generally too low to be of agronomic significance.
- The application of chloride is not an issue when using mineral concentrate when the possible supply of chloride with other fertilizers is taken into account.

Arable land

- The NFRV of mineral concentrate as basal dressing of potatoes averaged 80% on clay (78% in 2009 and 81% in 2010), and 92% on sand (86% in 2009 and 98% in 2010).
- The NFRV of top dressing with mineral concentrate varied greatly (40-58% in 2009, and higher than 100% in 2010), but the experimental design chosen made it more difficult to determine the NFRV accurately than with basal dressing.
- The NFRV of liquid ammonium nitrate compared to CAN for potatoes on clay in Lelystad was 65%. The NFRV compared to liquid ammonium nitrate of mineral concentrate was 117%. Thus, the N efficiency of mineral concentrate was similar to those of liquid ammonium nitrate.
- The NFRV compared to CAN of mineral concentrate was 77% when applied to forage maize on sandy soil. The NFRV was 65% for pig slurry, and 64% for the solid fraction of separated pig slurry.
- In the additional experiments it was found that the nitrogen efficiency of mineral concentrate was similar to that of CAN in 14 of the 21 experiments (NFRV higher than 95%). In seven experiments it was worse (NFRV 9-70%). The low NFRV was in part of the experiments related to the application method and the time of fertilization. In the additional study the NFRV could be determined less accurately than in the pilot study, because only one application rate of mineral concentrates was tested. In the pilot experiments, the concentrates were tested at several rates.
- The highest NFRVs of mineral concentrates were usually obtained from deep injection as base fertilizer.
- Application of mineral concentrate mixed with slurry resulted in a lower nitrogen efficiency than when mineral concentrate was applied separately.

Grassland

- The NFRV compared to CAN of mineral concentrate on pasture averaged 58%. The coefficient varied between years and mineral concentrates from 43 to 69%. There was no statistically significant difference in NFRV between the two grassland sites.
- The calculated NFRV compared to liquid ammonium nitrate was on average 96% (76-115%). Thus, the N efficiency of mineral concentrates was simila to that of liquid ammonium nitrate on grassland. In one additional test the nitrogen efficiency of mineral concentrate was equivalent to that of KAS. Application of mineral concentrate mixed with slurry resulted in a lower nitrogen efficiency than when mineral concentrate was applied separately.

User experiences

- Both in 2009 and 2010, mineral concentrate was most often used on grassland, followed by maize and ware potatoes.
- Mineral concentrate was usually applied on grassland as a mixture of mineral concentrate and slurry. The main reason for applying mineral concentrate mixed, is that it is easier to distribute with existing application techniques. On maize, mineral concentrates were applied in more than half of the cases mixed with cattle slurry, and on potatoes in about 20% of the cases.
- Almost all users on grassland consider nitrogen as a valuable component of concentrate. Potassium application with mineral concentrate limits the possibilities of applying mineral concentrate as nitrogen fertilizer on dairy farms, when the potassium status of the soil is sufficient or higher.
- Most of the users of mineral concentrate on ware potatoes found that both nitrogen and potassium are important. The experiences with using mineral concentrate as fertilizer on ware potatoes are good.
- For many arable crops and maize mineral concentrate can largely meet the potassium needs. The presence of potassium in the concentrate therefore contributes significantly to the possibilities of using concentrate as mineral fertilizer replacement.

Solid fraction

- The NFRV compared to CAN of the solid fraction was 32 to 55% in the four trials with potatoes, and 64% in the experiment with maize.
- The application of iron flocculants and/or coagulants during slurry separation reduces the phosphate efficiency of the solid fraction.
- The solid fraction is deposited in the arable areas in the Netherlands and northern France.

5 Economical aspects

5.1 Prices for mineral concentrate and solid fraction

The survey by De Hoop et al. (2011) shows that the average price paid for mineral concentrate was € 1.25 per ton in 2009 and € 1.19 per ton in 2010. There was a wide variation in the price mentioned by the users. In 2009 there was a difference of € 6 and in 2010 of € 16.50 between the lowest and highest price. The price to be paid for the concentrate is closely linked to the price of mineral fertilizer. The value of total nitrogen and potassium in the concentrate, based on mineral fertilizer prices (Figure 4) is much higher than what was paid on average. The lower nitrogen efficiency of the concentrate than CAN, the higher cost of spreading, and the relationship that is still being experienced with the prices of slurry, are factors causing that most customers are (yet) not prepared to pay a fertilizer derived price for the delivered minerals. In addition, farmers generally do not attach importance to potassium, since they usually have enough potassium from the slurry of their own herd.

In 2010, 52% of the customers indicated that the maximum price they are willing to pay for concentrate is higher than the price they actually paid in 2010. The permission to use the concentrate as a mineral fertilizer, implicating that concentrate is not included in the application standard of animal manure, is an important prerequisite. The market on grassland farms will almost completely disappear if regulations do not permit to use mineral concentrate as mineral fertilizer above the standard for manure. Also the sales to arable farms will become more difficult because then the concentrate should be fully competitive with slurry. For many arable farmers slurry application is an additional source of income since they are paid for application.

The costs of direct disposal of untreated solid fraction to agriculture in the Netherlands during the fertilization period, are estimated by the producers and their intermediaries as between € 7 and € 20 per ton. This includes the cost of transportation, weighing, sampling, and compensation for the intervening by the intermediary. The amount that a customer receives for accepting the solid fraction, ranges from € 0 to € 2.5 per ton of solid fraction. In periods when application is not possible immediately, disposal costs are higher, because storage and intervening costs are higher.

The costs of discharging permeate vary from € 0 to € 2 per m^3. The possibility to discharge permeate into the surface water or sewer depends on how clean the permeate is, and on the regulations of the water authority involved. For companies that have their own cattle and land it is often cheaper to distribute the permeate on their own land or to use it for cleaning stables.

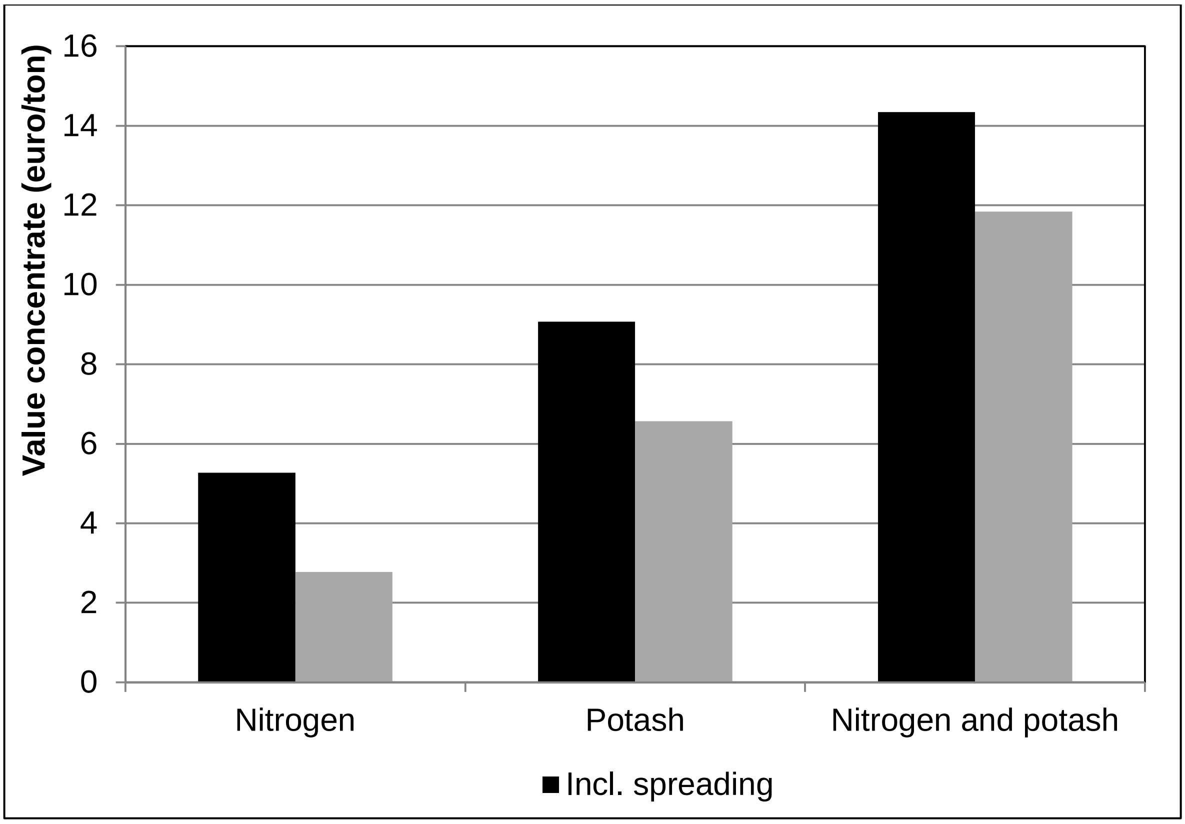


Figure 4
Value of mineral concentrate by adding a value to nitrogen, potassium or both, assuming a price of € 20 per 100 kg CAN, and of € 60 per 100 kg of KCl (60% K2O). The calculation was based on a nitrogen content of 7.12 kg N, and a potassium content of 9.07 kg K2O per ton of mineral concentrate. Costs of spreading were either included or excluded, and taken as € 2.5 per ton.

5.2 Economic analysis of the treatment plants

De Hoop et al. (2011) performed a cost-benefit analysis based on information delivered by the eight treatment plants participating in the pilot on mineral concentrates. The producers of mineral concentrate delivered data on what the investments would be in case they would rebuild their facilities at the same size. They also reported their variable costs (energy, labor, additives, etc.) to run the installation.

Figure 5 shows the results of the economic analysis. The plants are grouped here by way of slurry separation. As mentioned in Section 2.2, the plants A and H digest slurry and separate the slurry with a decanter/centrifuge. The plants B, C, F and G use a belt press to separate slurry, and the (smaller) plants D and E use an auger press. Three types of costs or profits are distincted:

- Variable costs: these costs include materials (including additives), electricity and gas, maintenance, labor, any charges for administration, management, water, and not specified costs. Profit: reduction in nitrogen fertilizer applied on the farm by using mineral concentrate.
- Fixed costs: these costs include the depreciation of the plant. It assumes a lifespan of ten years and a calculated interest (6% annually over half the investment, resulting in 3% of investment).
- Costs or profits of disposing the end products mineral concentrate, permeate and solid fraction.

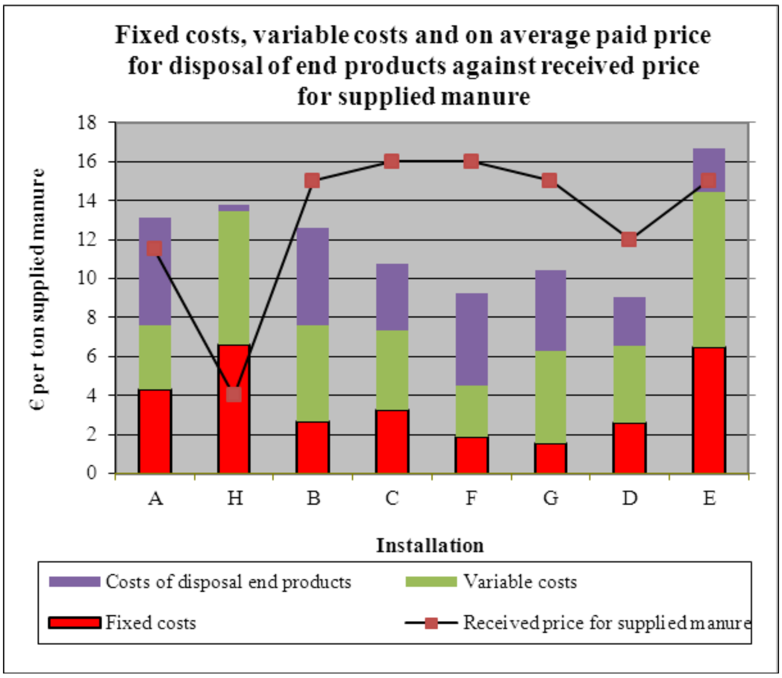
Figure 5 shows that the net amount received for treatment slurry was € 12-16 per ton (excluding plant H). The fixed and variable costs of the plants plus the costs of disposing end products amount to 9-13 per ton (excluding plant E).

The plants B, C, F, G and D are profitable for the data and assumptions used, plant E is not. The plants A and H are not profitable without digestion (Figure 5, top) but are profitable with digestion (Figure 5, bottom).

The economic viability of the plants for treatment animal slurry with reverse osmosis heavily depends on mineral fertilizer prices, the price received from the providers of slurry, the prices of end products and of competitive products from slurry and fertilizers. With the current settings of the plants for producing mineral concentrates, the costs of the installation units are on average € 7 to 8 per ton of slurry treated. This applies to a lifespan of 10 years. The variability of the end products (low or high water content, much or little solid fraction) significantly affects profitability. Some producers are working or have plans to further increasing the nutrient concentration of mineral concentrate. This could reduce the transport costs of the mineral concentrates, because less water has to be transported. Other factors affecting profitability, are the further treatment of the solid fraction and digestion of slurry. When the price paid by the providers of slurry is around € 15 per ton or higher, the plants are profitable. Here, the cost of transport to the plant, weighing and sampling of the slurry are paid by the slurry supplier.

5.3 Summary

- The average price paid for the mineral concentrate was € 1.25 per ton in 2009 and € 1.19 per ton in 2010, but there was a wide variation.
- The value of the nitrogen and potassium in the concentrate, based on mineral fertilizer prices, is much higher than the average paid for the concentrate.
- The cost of direct disposal of the untreated solid fraction of slurries on arable land in the Netherlands during the fertilization period, were estimated by the producers and their intermediaries at € 7 to € 20 per ton.
- The cost of discharging permeate range from € 0 to € 2 per cubic meter. The potential for discharge of permeate (and the related costs), depend on how clean the water is and on the regulations of the water authority involved.
- The economic viability of a treatment plant is highly dependent on the price paid by the providers of slurry and the prices of end products and of competitive products, slurry and fertilizers.
- Seven of the eight plants are profitable for the data and assumptions used, with two installations being only profitable if the slurry is digested.



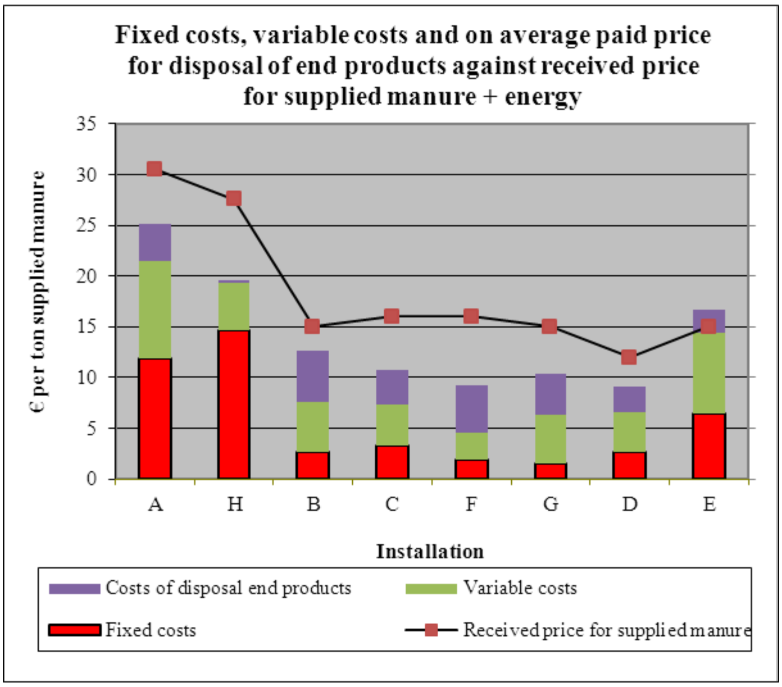


Figure 5
Total cost and average price paid for the disposal of end products per ton of fertilizer treated by the eight plants versus the price received from the providers of slurry. In the upper figure a calculation was performed for companies A and H without slurry digestion and in the lower figure the income from energy production from slurry digestion are included for companies A and H.

6 Environmental aspects

6.1 Heavy metals and organic contaminants

Generally, the mineral concentrates met the environmental criteria for heavy metals (97% of the samples; Ehlert and Hoeksma, 2011). Three products did not meet these criteria, because of an excess of the levels of zinc (zinc exceeded the maximum allowable load by a factor of 1.3 to 7.1). However, exceeding the zinc levels were incidents. The general picture is that the levels of heavy metals (Cd, Cr, Ni, Pb and As) are not a concern for agricultural use of mineral concentrates.

The solid fractions of fattening pigs generally not meet the environmental criteria. This is caused by contents of copper and zinc. Copper and zinc are therefore a concern when using the solid fraction of pig slurry, but this does not differ from untreated slurry. The solid fraction of cattle meets the environmental criteria.

A survey was conducted on the presence of organic contaminants in mineral concentrates at four plants (A, B, C and D) (Hoeksma et al., 2011). Per plant two samples of mineral concentrate were analyzed on levels of organic micro-pollutants indicated in the Fertilisers Act[5]. Hydrocarbons are calculated as diesel (C10-C24) and a mineral oil (C25-C56). The results of the analyses show 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. None of the organic micro-pollutants exceeds the requirements of the Dutch Fertiliser Act. The survey shows that organic micropollutants in mineral concentrates do not harm the environment when applied within the application standards of nitrogen, phosphorus, and manure used in agriculture.

6.2 Nitrate leaching

In the field trial with maize of Schröder et al. (2011, see Section 4.2.2) the nitrate concentration in the upper groundwater was measured in all objects in early 2011. With nitrogen applications of 100 and 150 kg effective N per hectare nitrate concentrations in groundwater for mineral concentrate were significantly lower than those for CAN (Table 10). The nitrate concentration for mineral concentrate were similar to those for solid fraction of slurry, and lower than those for untreated pig slurry. In this experiment the NFRV compared to CAN of mineral concentrate was 77%; Section 4.2.2). The lower nitrogen efficiency of concentrate did not result in more leaching. When mineral concentrate was applied at the same rate of effective N as CAN, the amount of mineral nitrogen in the soil after harvest of maize was about 40 kg N per ha lower than with CAN. In this experiment the lower nitrogen efficiency of mineral concentrate did not lead to accumulation of mineral nitrogen in the soil and thus to higher nitrate leaching. This indicates that the ineffective nitrogen from mineral concentrate was lost to the atmosphere in gaseous form nitrogen is (ammonia emission and/or denitrification) or was immobilized in the soil. Section 8.4.1. discusses the fate of the ineffective nitrogen from mineral concentrates. The field trial with maize is continued in 2011.

[5] The organic contaminants of the Fertilisers act are ΣPCDD/PCDF, α-HCH, β-HCH, γ-HCH (lindane), HCB, Aldrin, Dieldrin, ΣAldrin + Dieldrin, Endrin, Isodrin, ΣEndrin+Isodrin, ΣDDT+DDD+DDE, PCB-28, PCB-52, PCB-101, PCB-118, PCB-138, PCB-153, PCB-180, naphthalene, phenanthrene, anthracene, fluoranthene, benzo (a) anthracene, chrysene, benzo (k) fluoranthene, benzo (a) pyrene, benzo (g, h, i) perylene, indeno (1,2,3-c, d) pyrene, Σ10-PAH and mineral oil

Table 10
Average nitrate concentration in mg NO_3-N per liter in the field experiment by Schröder et al. (2011)

Type of fertilizer	Estimated effective N, kg/ha			
	0	50	100	150
CAN	8.1	7.3	11.5	22.6
Mineral concentrate	6.5	6.1	6.2	13.6
Pig slurry	9.6	7.1	16.1	17.1
Solid fraction	8.0	6.3	9.4	13.3
Least Significant Difference (LS) (*P*<0.05): 4.2				

The amount of mineral nitrogen in the soil after harvest is an indicator for the nitrogen leaching during winter. Part of the nitrogen in the soil after harvest will leach during winter and part will be denitrified. The risk of leaching depends on soil type and groundwater table. The risk of leaching is largest in dry sandy soils and lowest in peat and clay soils.

In field trials with potatoes in Lelystad by Van Geel et al. (2011a), the amount of mineral nitrogen in the soil after harvest was in 2009 approximately 10 kg N per hectare higher with mineral concentrate than with CAN (this difference was statistically significant). In 2010, there was no difference in Lelystad. In Rolde there was no difference in mineral nitrogen between mineral concentrate and CAN in both years. In 2010, the wet autumn may have led to early leveling of differences in mineral nitrogen.

No difference in the amount of mineral nitrogen in autumn was found in the four grassland experiments by Van Middelkoop and Holshof (2011). A difference was expected, because the nitrogen uptake by grassland from mineral concentrate was lower than from CAN. The results of the amount of mineral nitrogen in autumn indicate that mineral concentrate has not led to an increased risk of nitrate leaching compared to CAN in the four experiments on grassland.

6.3 Ammonia emission

6.3.1 Results of incubation experiments

Velthof and Hummelink (2011) performed three incubation experiments to determine the risk of ammonia and nitrous oxide emission from the soil when applying mineral concentrate compared to other fertilizers (mineral fertilizers, untreated pig slurry and solid fraction from slurry separation). Laboratory studies give an impression of the differences in gaseous emissions between fertilizers, but provide no quantitative estimate of emissions that occur under field conditions.

The emission of ammonia from mineral concentrate incorporated in the soil was negligible and similar to that of surface-applied CAN. The ammonia emission from the surface-applied mineral fertilizer urea was higher than from low-emission applied mineral concentrate. Urea is a fertilizer with a high risk of ammonia emission.

Ammonia emission from surface applied mineral concentrate was comparable to, or higher than emission from surface applied pig slurry. Mineral concentrate is thus a fertilizer with a high risk of ammonia emission. This is caused by the combination of a high ammonium content and a high pH (above 7.5). Low-emission application of mineral concentrate led to a sharp reduction in ammonia emission, like with pig slurry. Averaged over all incubation experiments, the

ammonia emission from mineral concentrate applied with low-emission technique was statistically significant smaller than that of pig slurry applied with a low-emission technique. With a proper application technique ammonia emission from mineral concentrates can be reduced strongly.
Differences were found in ammonia emission between the mineral concentrates tested, but no relationship was found between the composition of the mineral concentrates and ammonia emission. The number of concentrates tested was too small to determine a relationship between composition and emission. Soil type had no effect on ammonia emission.

By comparing the results of the incubation experimentent of mineral concentrate with reference fertilizers and untreated pig slurry, some conclusions can be drawn that will also be applicable under field conditions:

- Mineral concentrate is a fertilizer with a high risk of ammonia emission. When low-emission techniques are not, or insufficiently applied, the ammonia emission will be high, resulting in a relatively low nitrogen efficiency.
- The ammonia emission after application of concentrate is similar to that of pig slurry, at the same application rate of total nitrogen.
- For deep injection (a technique resulting in a strong reduction in ammonia emission), the emission from mineral concentrate will be similar to that of surface applied CAN. When techniques are applied that reduce emission less, ammonia emission from mineral concentrate will be higher than from CAN.
- The ammonia emission from surface applied urea is higher than that from mineral concentrate applied with a low-emission technique.
- On average, ammonia emission from surface applied solid slurry fraction was lower than from surface applied pig slurry and mineral concentrate, but not negligible. Ammonia emission from surface applied solid fraction was higher than from incorporated pig slurry. Incorporating the solid fraction leads to a reduction in ammonia emission.

6.3.2 Results of field experiments

Huijsmans and Hol (2011) performed different field experiments in 2010, in which ammonia emission was determined after application of mineral concentrate. Two experiments were carried out with cereals, two with potatoes and two with grassland. Ammonia emission is highly dependent on weather conditions, so it is not possible to derive ammonia emission factors from measurements during only one year. The results give an indication of ammonia emission after application of mineral concentrate.

Measurements of ammonia emission from arable land with cereals were carried out after application of mineral concentrate with a drag hose dosing machine or a sod injector. With the drag hose dosing machine mineral concentrate is applied in strips on the soil between the plants (band placement). The average ammonia emission after sod injection was 3% of the applied ammonium nitrogen and 12% when applied via the drag hose dosing machine.

The ammonia emission after application with a sod injector of mineral concentrate and cattle slurry to grassland averaged 8% of the applied ammonium for mineral concentrate, and 26% for cattle slurry. It should be noted that the ammonium content of concentrate (approximately 90% of total nitrogen) is much higher than that of cattle slurry (approximately 50% of total nitrogen). The difference between concentrate and cattle slurry in total ammonia emission was thus smaller than the difference in emission based on the amount of ammonium applied.

On potatoes, measurements of ammonia emission were carried out after application of mineral concentrate with a drag hose dosing machine immediately after closing of the crop. With the drag hose dosing machine the concentrate was applied between potato ridges. The ammonia emision ranged from 16 to 20% of the applied ammonia. The ammonia emission was therefore higher than in the experiments on cereal. Possible explanations of the relatively high ammonia emission on potatoes could be the warm weather and the accumulation of concentrate between the ridges.

6.4 Nitrous oxide emission

In the incubation experiments of Velthof and Hummelink (2011), the nitrous oxide emission was determined after applying mineral concentrate in comparison with other fertilizers (mineral fertilizers, untreated pig slurry and solid fraction from slurry separation). The incorporation of concentrates led, as with incorporated untreated pig slurry, to higher nitrous oxide emissions than surface application. Averaged over all experiments, incorporated concentrate resulted in a statistically significant higher nitrous oxide emission than surface- applied CAN. There was no statistically significant difference in nitrous oxide emission from incorporated concentrate and surface applied urea and urean. Averaged over all experiments and application techniques, the nitrous oxide emission from mineral concentrate was approximately 1.5-fold higher than from untreated pig slurry.

Many factors play a role in nitrous oxide emission from soils, so no clear explanation can be given for the relatively high nitrous oxide emission after applying mineral concentrate. Differences in nitrous oxide emission will be related to the form and content of nitrogen, pH, presence of organic matter and all other factors that influence the microbial processes nitrification and denitrification.

Nitrous oxide is formed during nitrification and denitrification. During the processes in which nitrous oxide is formed, other gaseous nitrogen compounds are also formed, namely nitrogen gas (N_2) and nitrogen oxides (NO_x). High losses of gaseous nitrogen compounds from a fertilizer result in a lower nitrogen efficiency.

6.5 Life Cycle Assessment (LCA)

De Vries et al. (2011) performed a life cycle assessment (LCA). The LCA methodology is an internationally recognized method for determining the environmental impact of a product or a service from the beginning to the end of its life cycle (from cradle to grave or cradle to cradle). The purpose of the LCA study was to answer the research question: '*What is the change in the environmental impact (greenhouse gas and ammonia emissions, nitrate leaching, particulate emissions and fossil energy use) of the production and use of the end products from the pilot mineral concentrate in combination with slurry and fertilizer, compared with using only slurry and fertilizer?*

To calculate the change in the environmental impact, four scenarios were assessed (see page 56). The results of these scenarios were compared with a reference situation for fattening pig and dairy cattle slurries, which reflect current practice. In the slurry treatment scenarios, only the fraction of slurry or digestate is treated that in the reference situation is deposited outside the region (i.e., 'the surplus slurry'). In a sensitivity analysis, the effect of a number of parameters and underlying assumptions was assessed. This sensitivity analysis included treatment of all produced slurry or digestate in the considered region.

In the LCA, the environmental impact of the production and use of mineral concentrates was quantified for the emissions of greenhouse gases (CO_2, N_2O and CH_4), ammonia (NH_3) and particulate matter (PM10), the leaching of nitrate (NO_3) and the use of fossil energy. The environmental impact was expressed per ton of untreated slurry with the same composition for the references as well as the scenarios to enable comparison (i.e., the functional unit (FU)).

Crucial to any LCA are the chosen system boundaries and the underlying assumptions. The boundaries and assumptions in this LCA were based on discussions within the project group and with external experts, and on the literature. The system boundary of the manure chain were defined from the storage of untreated slurry until the application of the end products. The nitrogen, greenhouse gas and fine particle emissions and the consumptions of fossil energy in the system were included in the analysis. It was assumed that livestock production was not affected by the treatment of slurry and therefore livestock production was excluded from the system boundary.

After storage and transport of the untreated slurry, the treatment and digestion of the slurry and solid fraction followed (for cattle slurry combined with the digestion of the concentrate from ultrafiltration) (see page 56). Electricity produced during digestion is sold to the electricity grid and was assumed to avoid fossil based electricity. Electricity is used for treatment of slurry or digestate. After treatment, the end products (mineral concentrate, solid fraction, digestate and concentrate from ultrafiltration) are stored, transported and applied to the field. The transport and application of mineral concentrates is divided into four routes to represent distribution and transport distances: i) local application on arable land on arable or dairy farms, ii) local application on grassland on a dairy farm, iii) application on arable farms elsewhere in the Netherlands, and iv) application on arable farms outside the Netherlands. It was assumed that fattening pig slurry was applied only on arable land, whereas dairy cattle slurry was applied on grassland and arable land. It was assumed that the demand for nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) was identical in the references and the scenarios. The maximum legally permitted amounts of N and P_2O_5 from animal slurry were applied. It was permissible to apply mineral concentrate above the limit for animal slurry, but the permissible limit for total N and P_2O_5 application still held. The mineral concentrate was used in the local area. The other slurry products were applied in the local area as much as possible, depending on the application limits. If not all products could be applied locally, they were applied outside the area and, if necessary, outside the Netherlands.

The LCA used data obtained in the sub-studies of the pilot project, augmented with data from the literature and expert judgement. Mass balances were calculated in order to map all the mass and nutrient flows. The mineral fertilizer applications in the reference were calculated on the basis of two defined standard farms: one arable and one dairy farm. Mineral fertilizer application in the scenarios was calculated by subtracting the nutrients applied in slurry products in the scenario from the total nutrient application as calculated in the reference. Emission data related to processes such as electricity supply, production of mineral fertilizer, application of products and transportation were derived from the Ecoinvent database.

Results showed that the use of mineral concentrate resulted in replacement of mineral fertilizers in the vicinity of the treatment plant. The export of slurry to arable areas outside the area with livestock systems decreased as a result of using mineral concentrate locally. More mineral fertilizer was required in the arable areas to match the crop demand for nitrogen. This resulted in a similar use of mineral fertilizer compared to the references (Table 11).

In the fattening pig scenario without digestion (Sc1V) the environmental impact showed little or no change compared to the reference (Table 12). When the solid fraction was anaerobically digested (Sc2V), greenhouse gas emissions decreased by 12% and fossil energy use fell by 22%. Digestion of solid fraction and concentrate from ultrafiltration (Sc3V) reduced this by 15% and 34% respectively. In the scenario with dairy cattle slurry (Sc1R), shorter slurry storage and anaerobic digestion resulted in greenhouse gas emissions decreasing by 67%. Fossil energy use decreased by 107%, meaning a net energy production, because there was no need to use electricity generated from fossil fuel.

In the pig slurry scenarios, ammonia emission, particulate matter emission and nitrate leaching changed very little (<3%) compared to the reference situation. In the dairy cattle slurry scenario the ammonia emission increased by 27%. This was mainly due to storage and application of digestate an in lesser extent due to emissions from treatment, storage, and application of the end products. Ammonia emissions increased when digestate was applied, because digestate contained more mineral nitrogen than undigested slurry. Furthermore, as ammonia is a precursor of particulate matter formation, the emission of particulate matter in the scenario was 16% higher than the emission from the reference.

From the sensitivity analysis it was concluded that treatment of all fattening pig slurry without anaerobic digestion increased the environmental impact, except for nitrate leaching. Ammonia emissions were 13 to 20% higher compared to the reference. When anaerobic digestion was included, greenhouse gas emission and fossil energy use remained lower than in the reference system. Assuming higher ammonia emission during treatment increased ammonia and particulate matter emission in the scenarios compared to current agricultural practice. Furthermore, when longer storage of slurry from fattening pigs was assumed (Sc1V), greenhouse gas emissions were higher compared to current practice.

Scenarios

Fattening pig slurry:

- *Reference (RefV): untreated slurry is used in combination with mineral fertilizer according to current farming practices.*
- *Scenario 1 (Sc1V): treatment of the slurry surplus in a cooperative plant (based on plants B through F) by means of mechanical separation, floatation, and reverse osmosis into end products: mineral concentrate, solid fraction and permeate. After treatment, the end products are transported and applied. Permeate is discharged to a water purification plant.Scenario 2 (Sc2V): the same as Sc1V but including the anaerobic digestion of the solid fraction. The biogas is used in a combined heat and power plant for electricity production (CHP).*
- *Scenario 3 (Sc3V): treatment of the slurry surplus in a cooperative plant (based on plant A) by decanting (centrifugation), ultrafiltration and reverse osmosis. In addition the solid fraction and concentrate from ultrafiltration are anaerobically digested. This results in the end products: mineral concentrate, digestate and permeate. After treatment, the en products are transported and applied. The biogas is used in a CHP for electricity production.*

Dairy cattle slurry:

- *Reference (Refr): untreated cattle slurry is applied in combination with mineral fertilizer according to current farming practices.*
- *Scenario 1 (Sc1R): anaerobic digestion of all the slurry and treatment of the surplus of digestate by means of decanting, ultrafiltration and reverse osmosis into end products: mineral concentrate, digestate, solid fraction, concentrate from ultrafiltration and permeate from reverse osmosis. After treatment, the end products are transported and applied. The biogas is used in a CHP for electricity production.*

Table 11
Calculated use of nitrogen fertilizer per ton of slurry (FU) for each application route in the references and the scenarios.

Scenario	Total (kg N/ FU)	Route		
		Region (kg N/ FU)	Outside region (kg N/ FU)	Outside NL (kg N/ FU)
Fattening pig slurry				
Reference (RefV)	4.9	3.2	1.6	0.12
Scenario 1 (Sc1V)	5.0	2.0	2.8	0.23
Scenario 2 (Sc2V)	4.9	2.0	2.7	0.23
Scenario 3 (Sc3V)	4.7	2.6	1.9	0.17
Dairy cattle slurry				
Reference (RefR)	2.5	2.1	0.37	-
Scenario 1 (Sc1R)	2.6	2.0	0.59	-

Table 12
Environmental impact per ton of slurry (FU) in the references and the scenarios.

Scenario	Greenhouse gas emission	Ammonia emission	Nitrate leaching	Particulate matter emission	Fossile energy use
	kg CO_2-eq/ FU	kg/ FU	kg/ FU	g PM_{10}-eq/ FU	kg oil-eq/ FU
Fattening pig slurry					
Reference (RefV)	179	2.4	8.6	870	11.4
Scenario 1 (Sc1V)	175	2.5	8.5	896	11.3
Scenario 2 (Sc2V)	157	2.5	8.6	877	8.9
Scenario 3 (Sc3V)	152	2.4	8.6	854	7.5
Dairy cattle slurry					
Reference (RefR)	141	0.75	2.1	284	4.6
Scenario 1 (Sc1R)	47	0.95	2.1	330	-0.3

6.6 Summary

- Heavy metals and organic micro-pollutants in mineral concentrate are not a concern for responsible agricultural use of mineral concentrate.
- Both on arable land and grassland the use of mineral concentrate does lead to an increased risk of nitrate leaching compared to CAN.

- Ammonia emission
    - Mineral concentrate have a high risk of ammonia emission. With low ammonia emission appication techniques, the ammonia emission from mineral concentrates can be strongly reduced.
    - The ammonia emission from applied concentrate is similar to that of pig slurry at the same total nitrogen application rate.
    - With deep injection (a technique that results in a strong reduction in ammonia emission), the ammonia emission from mineral concentrate will be similar to that of surface applied CAN. When application techniques are used that reduce emission less effectively, ammonia emission will be higher for mineral concentrate than for CAN.
    - Ammonia emission from surface-applied urea is higher than from mineral concentrates applied with a low ammonia emission application technique.
    - Ammonia emission from sod injection on cereals in 2010 were on average 3% of the ammonium nitrogen applied with concentrate, and the emissions were 12% when applied via the drag hose dosing machine.
    - Ammonia emission from sod injection on grasland averaged 8% of the applied ammonia for concentrate and 26% for cattle slurry in 2010.
    - Ammonia emission from sod injection on potatoes were 16-20% of the applied ammonia with a hose dosing machine in 2010.
    - Ammonia emission is highly dependent on the weather conditions, so it is not possible to derive emission factors from measurements during one year. The results give an indication of the ammonia emission after application of mineral concentrates.

- Greenhouse gas emission
    - Incorporation of mineral concentrate resulted in to higher nitrous oxide emissions than surface application, which is also found for incorporation of untreated pig slurry.
    - Averaged over all trials, incorporated concentrate resulted in a statistically significant higher nitrous oxide emission than surface-applied CAN.

    - Averaged over all incubation experiments and application techniques, the nitrous oxide emission from concentrate were approximately 1.5-fold higher than from untreated pig slurry.
    - During the processes in which nitrous oxide is formed (nitrification and denitrification) also other gaseous nitrogen compounds are formed (N_2 and NO_x). High losses of gaseous nitrogen compounds from a nitrogen fertilizer result in a lower nitrogen efficiency.

- The LCA shows:
    - The use of mineral concentrate leads to replacement of mineral fertilizers only in the vicinity of the treatment plant. The export of slurry to arable areas located further away from the livestock systems decreases because of the use of mineral concentrates near the treatment plant. In the arable areas the use of mineral fertilizers will increase to match crop demamd for N, resulting in a similar use of fertilizer compared to the references.
    - Treatment the surplus of slurry from fattening pigs without applying anaerobic digestion hardly changed the environmental impact.
    - Anaerobic digestion resulted in a smaller greenhouse gas emission and fossil energy use. Waste heat utilization further decreased greenhouse gas emissions and fossil energy use.
    - In the scenarios with pig slurry, ammonia and particulate matter emission and nitrate leaching changed very little (maximum of 3%) when only the slurry surplus was treated.
    - When all pig slurry was treated, instead of only the slurry surplus, ammonia emission was 13 to 20% higher than the reference. Furthermore, emissions of particulate matter and greenhouse gases and the use of fossil energy were higher than the reference as a result of treatment all the slurry.

7 Research in 2011

At the end of 2010, the pilot was extended by a year until the end of 2011. In 2011 a few studies will be carried out. Partly it is a continuation of ongoing research and partly research aiming to find an explanation for the sometimes low nitrogen efficiency of mineral concentrate on grasland. The following research is carried out in 2011:

- Monitoring of the treatment plants (continuation of the monitoring described in Chapter 3). Mineral concentrates contain organic matter, in what form is not well known. In 2011, also the level of fatty acids in the concentrates is measured.
- Field trial for determining the nitrogen efficiency of mineral concentrate on grassland (follow-up of the trial of Van Middelkoop and Holshof, 2011).
- Field trial for determining the nitrogen efficiency of mineral concentrate on maize (follow-up of the trial of Schröder et al., 2011).
- Incubation experiment to test the hypothesis that the presence of (biodegradable) organic matter and ammonia nitrogen in mineral concentrate - temporarily - increases the immobilization of nitrogen in the soil. Part of the mineral nitrogen in the soil or in the mineral concentrate is therefore (temporarily) unavailable to the crop. If this is established, then this is a cause for the lower NFRV of nitrogen from mineral concentrate.
- Incubation experiment to test the hypothesis that the presence of organic matter in mineral concentrate - temporarily - increases the denitrification of nitrate already present in the soil when spreading mineral concentrate. The stock of mineral nitrogen in the soil is thereby reduced. If this is established, then this is a cause for the lower NFRV of nitrogen from mineral concentrate.
- Pot experiment to determine if the ammonium forms in mineral concentrate are as effective as nitrogen from mineral fertilizers, and thus determine the NFRV. Based on the current insights, it can be reasoned that the nitrogen efficiency of mineral concentrate is the result of the efficiency of ammonium bicarbonate, ammonium chloride and ammonium sulfate, with potential contributions from ammonium-containing fatty acids and mineralization of organic nitrogen compounds. It is known from literature and experiments on grassland in 2010 (Ehlert et al., 2011; Van Middelkoop and Holshof, 2011) that the efficiency of ammonium fertilizers is often lower than that of CAN. Also the form (liquid versus granular) plays a role in the nitrogen efficiency. In the pot experiment the nitrogen uptake by grass and an arable crop is measured after application of CAN, ammonium sulfate, ammonium chloride, ammonium nitrate, urea, two mineral concentrates strongly differing in composition, and fattening pig slurry. All fertilizers are applied in liquid form, but CAN is applied as granules.
- The Scientific Committee of the Manure Act (CDM) explores the effects of large-scale use of mineral concentrate in the Netherlands on nitrogen and phosphate surpluses, nitrate leaching, and emissions of ammonia and greenhouse gas. It will also determine whether widespread use of mineral concentrate will create room for a larger livestock population, since part of the slurry is calculated as mineral fertilizer.

8 Discussion

8.1 Mineral concentrate as fertilizer: legal aspects

The European Nitrates Directive (91/676/EEC) aims to reduce the leaching of nitrate from agriculture to groundwater and surface water. The Nitrates Directive contains measures that member states must take in nitrate vulnerable zones to reduce nitrate leaching. The Netherlands is fully designated as sensitive to nitrate leaching. The Nitrates Directive dictates that the maximum amount of manure that can be applied is 170 kg N per ha. States may allow application of more manure when it is shown that this does not lead to an increased risk of nitrate leaching (derogation). The Netherlands has a derogation of 250 kg N per ha for manure from grazing livestock on farms with more than 70% grassland. Furthermore, the Nitrates Directive states that nitrogen should be based on the nitrogen needs of crops, taking into account the nitrogen supply from soil, manure, mineral fertilizers and other organic fertilizers. The Netherlands has implemented this measure through an application standard for total nitrogen (expressed as active nitrogen). In addition, the Netherlands has a system of phosphate application standards. The three types of application standards are part of the Dutch action program in the context of the Nitrates Directive.

The Mineral Concentrates Pilot is designed to examine whether mineral concentrates can be used as fertilizer. This means that mineral concentratescan be applied on top of the application standard for manure, but within the standard for total nitrogen application. This fits in attempts on reaching responsible use of animal manure and in the quest for further closing nutrient cycles.

The agricultural, economic and environmental impacts of production and use of mineral concentrate to replace fertilizer were investigated in the pilot. The study was done with the consent of the European Commission. Participants in the pilot could use mineral concentrate as fertilizer on top of the application standard for manure (but within the standard for total nitrogen). The data from the pilot will be used in consultations with the European Commission on a possible permanent permission to use mineral concentrate as fertilizer replacement.

Article 2 of the Nitrates Directive contains the following definitions for fertilizers:

(e) 'fertilizer`: means any substance containing a nitrogen compound or nitrogen compounds utilized on land to enhance growth of vegetation; it may include livestock manure, the residues from fish farms and sewage sludge;
(f) 'chemical fertilizer`: means any fertilizer which is manufactured by an industrial process;
(g) 'livestock manure`: means waste products excreted by livestock or a mixture of litter and waste products excreted by livestock, even in processed form;

A mineral concentrate is produced through high-tech slurry treatment techniques, using reverse osmosis as the last treatment step, and can be seen as a fertilizer which is manufactured by an industrial process. A mineral concentrate would then be defined in the Nitrates Directive as 'fertilizer'. However, a mineral concentrate is produced from slurry products and is therefore 'manure according to the Nitrates Directive. Thus, the definitions of fertilizers in the Nitrates Directive give no criterion by which it can be tested if a mineral concentrate can be considered as 'fertilizer'.

The EU Regulation 2003/2003 applies to products such as fertilizers to be traded as 'EC fertilizer'. This Regulation gives requirements for the composition of all types of fertilizer.The term is used in this Regulation is inorganic fertilizer:

(e) 'Inorganic fertiliser' means a fertiliser in which the declared nutrients are in the form of minerals obtained by extraction or by physical and/or chemical industrial processes. Calcium cyanamide, urea and its condensation and association products, and fertilisers containing chelated or complexed micro-nutrients may, by convention, be classed as inorganic fertilisers.

The Regulation 2003/2003 contains a list of approved fertilizers, recording for each fertilizer the preparation method and the minimum levels of nutrients. It also contains the tolerated deviations and the methods of sampling and analysis for the control of fertilizers.

A mineral concentrate is a NK fertilizer with a low phosphorus content (Chapters 3 and 4). The Regulation 2003/2003 defines NP, NK, PK and NPK fertilizer types and gives descriptions and requirements for the composition. For all solutions containing N, P and / or K the Regulation dictates that no organic nutrients of animal or vegetable origin may be present.[6] A mineral concentrate contains organic nutrients of animal origin and thus it does not comply with the definitions set to NK-fertilizers in Regulation 2003/2003. Thus, the mineral concentrate can not meet the conditions placed on EC fertilizers by EU Regulation 2003/2003, since

- the levels of nitrogen, phosphorus and potassium are lower than the minimum requirement of EU regulation (see Table 13);
- mineral concentrate contains organic nutrients of animal origin.

It is possible to add new products or a new group of products to the Regulation 2003/2003. The admission of new products is determined by the European Commission and EU Member States. Mineral concentrates and other products from slurry may be included in Regulation 2003/2003, if adequately supported by the European Commission and EU Member States. There will be requirements for mineral concentrates on nutrient contents and the variation in these levels, related to the minimum requirement for nutrients (lower contents of nutrients than the required content is not allowed, a certain spread around a guaranteed level is permitted).

The variation in composition of mineral concentrates is large when all measurements are considered (Table 5 in Chapter 4). However, Table 3 in Chapter 3 shows that a portion of the slurry treatment plants is able to produce mineral concentrate with a stable composition over time. It should be noted that several companies have made changes and innovations during the pilot, so the composition changed during the pilot (resulting in a relatively high spread). The variation in composition of mineral concentrate from these plants is probably lower in a continuous stream of slurry treatment. The results show that it is possible to produce mineral concentrate with a constant composition.

The possible inclusion of mineral concentrates as EC-fertilizer in Regulation 2003/2003 does not automatically imply that the fertilizer is recognized in the Nitrates Directive as fertilizer, given the definitions for fertilizers in Article 2 of that directive.

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[6] Definitions NK-fertilizer in EU Regulation 2003/2003:

NK fertilizer: *Product obtained chemically or by blending, without addition of organic nutrients of animal or vegetable origin.*

Soluble NK fertilizer: *Product obtained chemically and by dissolution in water, in a form stable at atmospheric pressure, without addition of organic nutrients of animal or vegetable origin.*

Table 13
Composition of mineral concentrates (all samples of all plants with treatment of pig slurry in 2009 and 2010) compared with the requirements for nutrients according to EC Regulation 2003/2003 in percent[1].

Parameter	Average	Median	Minimum	Maximum	Minimum required by regulation 2003/2003	
					Single N	Composed NK, NP, PK or NPK[2]
N	0.70	0.69	0.31	1.10	15	3
P_2O_5	0.04	0.03	0.00	0.14		5
K_2O	0.88	0.90	0.50	1.18		5
Sum N+K	1.6					18
Sum N+P	0.7					18
Sum N+P+K	1.6					20

[1] Percent in the product itself
[2] Required minimum content for each nutrient for composed fertilizers and minimum required for two or three nutrients

8.2 Agronomic value mineral concentrate

8.2.1 Composition

Mineral concentrate is a liquid nitrogen-potassium fertilizer, with low levels of phosphate. The content of nitrogen in mineral concentrates from pig slurry averaged 6.99 g N per kg, of which on average 90% as ammonium nitrogen (Table 5). The average concentration of potassium is 7.33 g K per kg, and of phosphorus 0.18 g P per kg (Table 5). The composition varies between plants (Table 3). The average pH of mineral concentrate from pig slurry was 7.95. In one installation (plat H) mineral concentrate was produced from cattle slurry. The contents of this concentrate were higher than those from pig slurry: 11 g N per kg, of which on average 95% as ammonium nitrogen, 15.7 g K per kg and 0.27 g P per kg. It should be noted that plant H also uses co-fermentated materials, and that the osmotic pressure during reverse osmosis was higher in plant H than in other plants. The differences in composition between plant H and the other facilities are thus not only related to the type of slurry.

Slurry treatment plants use high-tech techniques to separate the slurry in liquid and solid fractions, so that the cleanest possible solution can be used for the reverse osmosis (Hoeksma et al., 2011). More than 80% of the phosphorus from the incoming slurry ends up in the solid fraction. The phosphate-rich solid fraction can be deposited on arable land, or can be treated and then the phosphate can be recovered. Some mineral concentrates still contain phosphate. This can be a disadvantage when applying mineral concentrate as nitrogen and/or potassium fertilizer, as the phosphate application standards will be tightened the coming years.

The production of mineral concentrate and solid fractions using high-tech separation techniques make it possible to improve the use of nitrogen, potassium and phosphorus from animal slurry.

8.2.2 Nitrogen efficiency of mineral concentrate

The nitrogen fertilizer replacement value (NFRV) of organic fertilizers indicates the percentage of a nitrogen application that is as effective as a single application of mineral nitrogen. In the Netherlands, the NFRV is usually expressed relative to the most common fertilizer, calcium ammonium nitrate (CAN). The NFRV is a relative measure (relative to mineral nitrogen) and does not indicate the amount of nitrogen taken up by crops. Nitrogen is also lost when mineral fertilizers are used. Based on the composition, it was estimated that the NFRV of mineral concentrate will range from 76-90% for arable land and from 67-81% for grassland (Section 4.4.1). The NFRV is highly dependent on the amount of ammonia emission and therefore on the application technique used and the weather conditions during application.

The experiments during the pilot showed that the NFRV of mineral concentrate compared to CAN of basal dressing of potatoes averaged 80% on clay soil, and on sandy soil 92%. In the study on maize by Schröder et al. (2011) the NFRV of mineral concentrate was 77%, which was higher than that of pig slurry (65%) and of cattle slurry (60%). In an additional project, the nitrogen efficiency of mineral concentrate was similar to CAN in 14 of the 21 experiments (NFRV > 95%). In seven experiments it was lower (9-70%). In part of the experiments the low NFRV was related to the application method and the time of fertilization. In the additional experiments (Van Geel et al., 2011b) the NFRV could be determined less accurately than in the experiments of the pilot (Van Geel et al., 2011a) and Schröder et al. (2011), because only one rate of mineral concentrate was tested and not as a series as donce by Van Geel et al. (2011a) and Schröder et al. (2011). The highest NFRV values of mineral concentrates were mostly obtained from deep injection at basal dressing on arable land.

In the field trial on clay soil, the NFRV of mineral concentrates applied to potatoes was equal to that of liquid ammonium nitrate applied with the same equipment (Van Geel et al., 2011a). Liquid ammonium nitrate contains 50% ammonium and 50% nitrate, like in CAN. With CAN the nitrogen is distributed in granules on the soil surface and is mixed with soil during the construction of the potato ridges. The nitrogen in mineral concentrate and in liquid ammonium nitrate is injected in rows (spaced 17 cm) at a depth of 8 to 10 cm, and is mixed with soil during the construction of the potato ridges. The distribution of nitrogen thus differs between application of CAN and of liquid fertilizers, and this could be a factor that played a role in the differences in nitrogen efficiency between CAN and the liquid fertilizers. In addition, the amount of ammonia volatilized and the fraction of organic nitrogen will determine the nitrogen efficiency of mineral concentrate.

The NFRV of mineral concentrate was obviously lower in the four grassland experiments of the pilot than on arable land. The NFRV of mineral concentrate averaged 58% (there was no difference between sand and clay). In one trial under the additional study, the of nitrogen efficiency of mineral concentrate was equivalent to CAN. On grassland, the NFRV of liquid ammonium nitrogen was also lower than that of CAN. The calculated NFRV of mineral concentrate compared to liquid ammonium nitrate ranged from 76 to 115% and averaged 96%. On grassland the concentrates worked almost as well as the liquid ammonium nitrate, when applied with the same application equipment. Apparently the distribution of nitrogen in grassland has a major effect on grass yield. Ehlert and Hoeksma (2011) indicate in their literature study that the injection of liquid fertilizers often leads to a lower nitrogen efficiency than spreading of solid fertilizers. This will partly be caused by a poor distribution of nitrogen in the soil. In addition, the locally high concentration of salts in the slit with liquid fertilizer may lead to inhibition of grass growth, because after injection the grass roots may have direct contact with the injected concentrate. The survey on user experience with mineral concentrate (Section 4.4) shows that some users have observed phenomena of root burn caused by salt damage to grass. In the field trials with grass, no root burn was observed. Furthermore, the amount of ammonia emission and the size of the organic nitrogen fraction will determine the nitrogen efficiency of mineral concentrate on grassland.

The type of ammonium compounds in the concentrate may also influence the nitrogen efficiency. In the grassland study by Van Middelkoop and Holshof (2011), the NFRV of ammonium chloride compared to CAN was 49% in 2010, and for mineral concentrate it was 63%. The lower NFRV of ammonium chloride may be due to a high amount of chlorine. Mineral concentrates are probably a mixture of ammonium bicarbonate, ammonium chloride, ammonium sulfate and ammonium-containing fatty acids. In 2011 a pot experiment will be carried out with grass and arable crops, to study the nitrogen efficiency of different types of liquid nitrogen fertilizers as compared with CAN granules (Chapter 7).

It is concluded that the NFRV of mineral concentrates compared to CAN is on average about 80-90% on arable land (for basal dressing via deep injection) and 58% on grassland. The variation in NFRV is large, and in some experiments the efficiency of mineral concentrate is similar to that of CAN. In the pilot the same experiments were carried out on sand and clay soils. For arable land, the NFRV on sandy soil (92%) was higher than on clay soil (80%), but for pasture no statistical difference was found between soil types (average 58%). It cannot be clearly explained why soil type had an effect on arable land but not on grassland. The NFRV of mineral concentrate is similar to that of liquid ammonium nitrate for grassland and for arable land on clay. In 2011, the nitrogen efficiency of mineral concentrates will be further studied in pot and field experiments. Insights from this research can be used to optimize the application of mineral concentrates and to increase their nitrogen efficiency.

8.2.3 Application of mineral concentrate and solid fraction in practice

The survey by De Hoop et al. (2011) on the experiences of users of mineral concentrate in the pilot showed that mineral concentrate is most often used on grassland as a mixture of mineral concentrate and slurry. The main reason for applying mineral concentrate mixed with slurry, is that a mixture can be applied more easily with existing application equipment. On maize, mineral concentrate was mixed with cattle slurry in more than half of the cases, and on potatoes in about 20% of the cases. Within the pilot no studies were done on the agricultural effectiveness and environmental impacts of using mixtures of mineral concentrate and slurry. The additional study by Van Geel et al. (2011b) showed that the efficiency of a mixture of slurry and mineral concentrate was lower than that of concentrate alone. The efficiency of a mixture of concentrate and slurry will depend on the composition of the slurry and the application method.

If the mineral concentrate is recognized as mineral fertilizer, then its nitrogen is not included in the application standard for manure, but in the application standard for total nitrogen which is based on effective nitrogen. Within the legal application standard for total nitrogen, the effectiveness of mineral fertilizer is taken as 100%, that of pig slurry as 60-70%, that of the liquid fraction as 80%, and that of solid pig manure as 55%. No distinction is being made between types of mineral N fertilizer, thus also the nitrogen in fertilizers with a lower nitrogen efficiency than CAN (like urea or liquid fertilizers) are for 100% included in the application standard. The NFRV of mineral concentrate compared to CAN is less than 100%. For a given nitrogen application standard, less effective nitrogen will thus be applied with mineral concentrate than with CAN, since the nitrogen efficiency in practice is lower than the 100% assumed in the regulation.

Mineral concentrate also contains potassium and the supply of potassium to crops leads to savings in the amount of potassium fertilizer needed. This is particularly true for crops with a high demand for potassium, such as potatoes, maize and some arable crops. Grassland also requires a lot of potassium, but this is partly covered by the cattle slurry that is produced on the farm. Supply of potassium in mineral concentrate to a dairy farm where the soil has a good potassium status (and therefore needs little potassium) can cause an excess of potassium.

Within the trials the variation in nitrogen efficiency of mineral concentrate was large, and in some of the trials the efficiency was similar to that of CAN. The sometimes high efficiency of nitrogen in mineral concentrate shows that there are perspectives to increase the nitrogen efficiency of mineral concentrate. Moreover, improvement of application techniques may be possible, but low ammonia emission application technique must be used to prevent high emission of ammonia.

During the production of mineral concentrate a solid fraction is formed. This can be used in agriculture as a source of phosphate and organic matter. The application of iron flocculants and/or coagulants in slurry will reduce the phosphate efficiency of the solid fraction (Schröder et al., 2010). During the production of mineral concentrate 31 to 52% of the nitrogen input will end up in the solid fraction (Table 4). Of this, 45% of the nitrogen is present as ammonium. The NFRV of the solid fraction compared to CAN was 32 to 55% in the four trials with potatoes (Van Geel et al., 2011a), and 64% in the experiment with maize (Schroeder et al., 2011).

The legal NFRV of solid manure is 55%. The risk of ammonia 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 ammonia emission and may increase the nitrogen efficiency. 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 solide fraction is exported (e.g. to arable land in Northern France).

8.2.4 Technological developments in slurry treatment

In most plants the slurry treatment 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). For quality improvement new techniques are needed, whether or not connected to the system of reverse osmosis. Examples include using another type of membrane resulting in higher nitrogen and potassium contents in the mineral concentrate. Higher contents can also be achieved by evaporating the concentrate, for example by using heat from air from housing. In order to further increase the use of nutrients excreted by livestock, the concentrate could be splitted in nitrogen and potassium fertilizers, e.g. by stripping. The feasibility of these techniques (technical, economic, agricultural and environmental) demands further investigation.

Further increasing the concentration of nutrients in mineral concentrates will reduce the costs for transport 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.

8.3 Economic viability

The economic analysis (Chapter 7) shows that, given the current assumptions, most plants are profitable (note that two plants are only profitable if the slurry is digested). At slurry supply rates of around € 15 per tonne or higher slurry treatment plants can be profitable. The economic viability of the plant strongly depends on fertilizer prices. This involves both the slurry supply rate and the disposal prices of end products from slurry, including the mineral concentrate. Also the prices of competing products from slurry and of fertilizers are important in the sales of mineral concentrate and for the profitability of the treatment plants.

The prices of slurry and slurry products highly depend on developments in the manure market, while the height of the nitrogen, phosphorus, and manure application standards, the total manure production in the Netherlands, developments in the reduction of nitrogen and phosphate excretion (by diet changes), slurry treatment and export are of major importance. Another factor is the fertilizer price. The prices for nitrogen, phosphate and potassium fertilizers have fluctuated greatly in recent years, in which energy prices and potential shortages of raw materials played a role. The value of the nitrogen and potassium in the concentrate, based on fertilizer prices, is much higher than the average price paid by the users of the mineral concentrate (De Hoop et al., 2011). The lower nitrogen efficiency of the concentrate when compared to CAN, the higher cost of application and the relationship that is still being experienced by the farmers with the prices of slurry, suggests that most users of mineral concentrates are not (yet) prepared to pay a price derived from the price of fertilizers. If the mineral concentrate is recognized as fertilizer and the agricultural efficiency is similar to fertilizer, then the willingness to pay higher prices for mineral concentrate will increase. This can lead to higher profitability of slurry treatment plants.

8.4 Environmental effects

8.4.1 Fate of nitrogen from mineral concentrates

Mineral concentrates are liquid nitrogen fertilizers and have a lower nitrogen efficiency than CAN, which is applied as granules. Liquid ammonium nitrate also has a lower efficiency than CAN on grassland and on arable land on clay. Section 8.2.2 discussed the possible causes of the lower nitrogen efficiency. Less nitrogen is taken up by the crop from mineral concentrate and liquid ammonium nitrate than from CAN. Various nitrogen losses can take place:

- Nitrogen is lost via ammonia emission;
- Nitrogen is lost via denitrification and/or nitrification as nitrogen (N_2), nitrous oxide (N_2O) and/or nitrogen oxides (NO_x);
- Nitrogen leaches to groundwater and/or surface water;

Moreover, nitrogen remains in the soil in organic or inorganic form (including immobilization).

Ammonia emission

Mineral concentrate is an ammonium-containing fertilizer with a high pH. It is therefore a fertilizer with a risk of ammonia emission, as shown in incubation experiments by Velthof and Hummelink (2011) and field trials by Huijsmans and Hol (2011). Emission-reducing application of mineral concentrate will therefore result in a strong reduction in ammonia emission. Weather conditions have a major effect, ammonia emission is highest in dry, sunny and windy weather. The research of Huijsmans and Hol (2011) for one year shows that the ammonia emission after sod fertilization was 3% on cereals and 8% on grassland. There are not enough emission measurements available to deduce an emission factor, but it is expected that after low-emission application of mineral concentrate less than 10% of the applied nitrogen is lost. In incubation experiments no clear effect of soil type on ammonia emission was found (Velthof and Hummelink, 2011). Part of the lower nitrogen efficiency of mineral concentrate compared to CAN can thus be explained by ammonia emission.

Denitrification and nitrification after application

Nitrification is the process by which ammonium is converted to nitrate. Nitrification occurs under oxygen rich conditions, but under relatively wet conditions gaseous nitrogen compounds such as nitrous oxide are formed during nitrification. Denitrification is the process in which nitrate is decomposed to gaseous nitrogen compounds under anoxic conditions. Denitrifying bacteria need an energy source, in agricultural soils formed by easily degradable organic matter. This may be soil organic matter, but also organic matter from slurry or mineral concentrate.

Velthof and Hummelink (2011) concluded that nitrous oxide emission after application of mineral concentrate was relatively high when compared to CAN. Both nitrification and denitrification could play a role in this. High ammonia concentrations in soil may inhibit nitrification, while nitrous oxide is formed. Mineral concentrate may contain volatile fatty acids which lead to denitrification of soil nitrate after application. In 2011 further investigation will be done on the presence of fatty acids in mineral concentrate and on the effect of application of mineral concentrate on denitrification.

The amount of nitrogen lost via nitrous oxide emissions is low (usually less than 2% of the applied nitrogen; Velthof and Mosquera, 2011). Similar amounts of nitrogen will be lost in the form of NO_x. Emissions of N_2 can be high under wet conditions. In the field experiments done by Van Geel et al. (2011a) and by Van Middelkoop and Holshof (2011) mineral concentrate was not applied under very wet conditions, so in these experiments total losses via denitrification will be limited (estimated as less than 10%).

Nitrogen leaching

The nitrate concentrations in the upper groundwater using mineral concentrate were similar to, or lower than when CAN was used in the field experiment with maize (Table 10). Leaching of nitrogen takes place during winter (when there is a rainfall surplus). The amount of mineral nitrogen in the soil in autumn is an indicator of leaching and denitrification that will occur in winter. Measurements of mineral nitrogen in the soil in autumn in the field trials showed no difference between mineral concentrate and CAN. In one experiment the amount of mineral nitrogen was higher for mineral concentrate (Van Geel et al., 2011), and in one experiment it was lower (Schroeder et al., 2011) than for CAN. In the other experiments on arable land, and in all grassland experiments (Van Middelkoop and Holshof, 2011) there was no difference between mineral concentrate and CAN. There is no evidence that the lower nitrogen efficiency of mineral concentrate resulted in a higher nitrogen leaching than with CAN.

Immobilization in the soil
Part of the nitrogen in mineral concentrate is present as organic nitrogen (average 10% of nitrogen). Part of this organic nitrogen will mineralize during the growing season and become available for crop uptake, and partly it remains in the soil as organic nitrogen. The remaining part is only a few percent of the total nitrogen in mineral concentrate. This organic nitrogen will also mineralize in the long-term (several years), and, consequently, the long-term nitrogen efficiency of mineral concentrate will be higher than that obtained in the first year. However, the differences between first-year and long-term efficiency will be small, because the levels of organic nitrogen in mineral concentrates are low.

Ammonium can be bound to clay particles and organic matter in the soil. This could partly have caused the lower nitrogen efficiency on clay than on sandy soils found in the study by Van Geel et al. (2011). However, it is unlikely that ammonium fixation in soils explains all the difference in nitrogen efficiency between sand and clay soils.

Mineral concentrate contains ammonium and organic matter. Upon decomposition of organic matter, part of the released energy is consumed by soil organisms. Organic compounds and nitrogen compounds are transformed by soil organisms into living biomass. The nitrogen is hereby fixed by the micro-organisms, also called nitrogen immobilization. The nitrogen immobilization is usually temporary, by dying of biomass and subsequent nitrogen mineralization the immbiliized nitrogen may become available to the crop. The combination of organic matter (probably fatty acids) and ammonium in mineral concentrate may result in nitrogen immobilization. In 2011 it will be investigated whether application of mineral concentrate can cause nitrogen immobilization (Chapter 7).

As indicated above, there are several possible mechanisms resulting in fixation of nitrogen from mineral concentrate in the soil in organic or inorganic form. However, it is not expected that nitrogen immobilization explains an important part of the lower nitrogen efficiency of mineral concentrate.

Table S1 summarizes the average NFRV and the fate of the ineffective nitrogen from mineral concentrates. Based on the above reasoning it is concluded that the ineffective nitrogen of mineral concentrate can partly be explained by organic nitrogen from concentrate that does not mineralize (approximately 5%), part of the nitrogen is lost through ammonia emission, nitrification and denitrification, and some nitrogen is (temporarily) fixed in the soil. Although it is not found in the experiments, it may not be excluded that Nitrogen leaching may occur sometimes. The size of individual pathways of nitrogen loss is probably limited.

The nitrogen efficiency of mineral concentrate is lower on grassland than on arable land. The chance of ammonia emission after sod fertilization (applied to grassland) is higher than for deep injection on arable land (Huijsmans et al., 2011). It is possible that denitrification and immobilization are also higher on grassland than on arable land, because the content of degradable organic matter in grassland is higher than in arable land. Because of the increased risk of denitrification and immobilization in grassland it is likely that leaching is lower on grassland than on arable land. Based on the available results it can not be indicated whether there are other mechanisms in grassland causing loss or immobilization of nitrogen from mineral concentrate than occuring on arable land. There are no results that indicate differences between clay and sandy soil in nitrogen immobilization immobilizationor losses from low-emission applied mineral concentrate.

Table 14
Summary of Nitrogen Fertilizer Replacement Values (NFRW)[1] and the fate of ineffective nitrogen from mineral concentrates[1].

		Arable land	Grassland
NFRW	**Compared to CAN**	84%	58%
	Effect of soil type	yes potato sand: 92% potatoes clayi: 80%	no
	Compared to liquid ammonium nitrate	117%	96%
Fate of ineffective nitrogen from mineral concentrates	**Non-mineralized organic N**	On average 5% of applied N	
	Ammonia emission	< 10% of applied N Chance sod injection grassland > deep injection Chance calcareous clay soil > sandy soil	
	Gaseous loss by nitrification and denitrification	< 10% of applied N Chance on grassland > arable land	
	Leaching	< 5% of applied N Chance on sandy soil > clay soil Chance on arable land > grassland	
	Immobilization in soil	< 10% of applied N Chance on grassland > arable land	

[1] The NFRV values in this table are based on field experiments in which mineral concentrates were tested at different nitrogen application rates: four trials with basal dressing on potatoes on sandy and clay soil by Van Geel et al. (2011a), one trial with maize on sandy soil by Schroder et al. (2011), and four trials with grassland on sandy and clay soil by Van Middelkoop and Holshof (2011). The fate of the inactive nitrogen is partly based on results from the experiments and partly on estimates

8.4.2 Changes in environmental impact by production and use of mineral concentrates

Losses of nitrogen may occur during the production of mineral concentrate and when used as fertilizer. Nitrogen balances of slurry treatment systems show a nitrogen loss during slurry treatment between 0 and 10% (Table 4), but this estimate has a large uncertainty. It is not clear in what form nitrogen is lost during slurry treatment, but most likely it will be in the form of ammonia and a small part will be lost through denitrification. During the storage of untreated slurry also nitrogen will be lost (Mosquera et al., 2010).

The LCA study provides insight in how environmental impact changes when mineral concentrate as produced in the pilot are used above the application standard for animal manure (De Vries et al., 2011). The analysis focused on the whole life cycle including production, storage and application of the products (cradle to grave). The study used the most recent data on emissions of greenhouse gases and ammonia during the lifecycle of slurry (resulting from the other studies, literature and expert judgement). When the application methods and method of treatment changes, emissions will also change. With the development of new technology or applying existing technology (e.g. scrubbers), the emission of ammonia during treatment and application of slurry products may decrease.

The influence of change in seven parameters and underlying assumptions on the final results were examined in a sensitivity analysis. The analysis showed that the amount of treated slurry has a significant impact on the environment. When more slurry than the calculated surplus is treated, the emissions of ammonia and particulates are expected to rise.

The production of a nitrogen-potassium mineral concentrate aimes at replacing nitrogen and potassium fertilizer, while mineral concentrate can be applied above the application standard for manure. In the LCA study it was assumed that the need for nitrogen, phosphorus and potassium will remain the same for all application routes in both the reference situation and in the scenarios. This means that any differences in nutrient availability compared with the reference situation must be compensated. It is assumed that this is done with mineral N fertilizers. In the overall system, this will not lead to nitrogen fertilizer replacement, but to a shift of fertilizer use between different areas instead. In other words: the local demand for fertilizer (around the treatment plant) decreases, but the fertilizer demand will increase at other locations outside the region or even outside the Netherlands. Therefore, local available nutrients are used more effectively as the mineral concentrate is applied there.

In 2011 the Scientific Committee of the Manure Act (CDM) will study the effects of large-scale application of mineral concentrate in the Netherlands on emissions into the environment. Several scenarios will be evaluated.

Use of mineral concentrate as fertilizer does not lead to an unacceptable loading of the soil with heavy metals and organic micropollutants (Ehlert et al., 2009).

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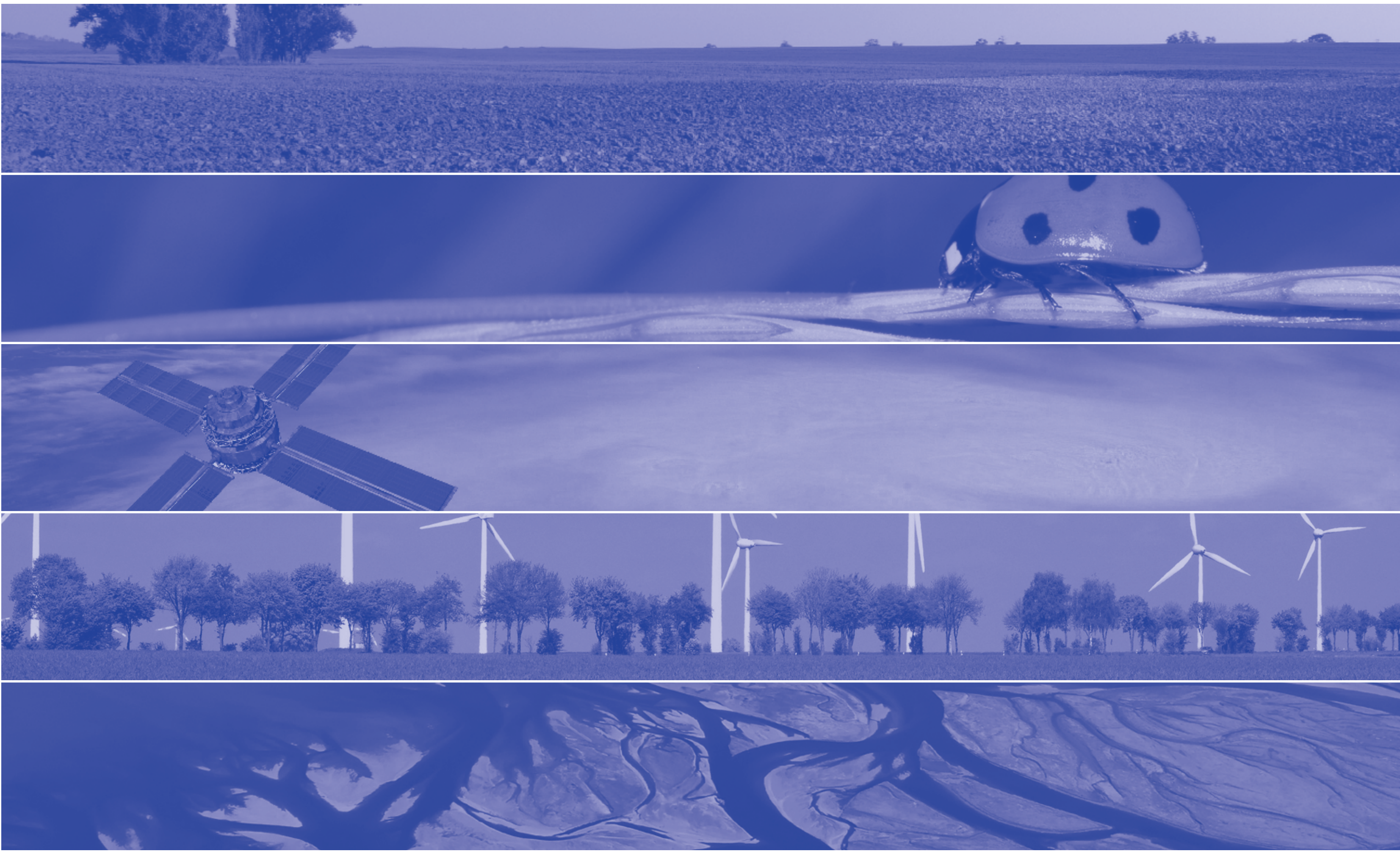

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