Agronomic efficacy of biobased nitrogen fertilising products of co-digested pig manure

Field Experiment Silage Maize 2020

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This research was subsidised by the Dutch Ministry of Agriculture, Nature and Food Quality
(Project number BO-43-012.02-058).

Wageningen Environmental Research
Wageningen, July 2022

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Report 3174
ISSN 1566-7197

WAGENINGEN
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Ehlert, P.A.I., 2022. *Agronomic efficacy of biobased nitrogen fertilising products of co-digested pig manure; Field Experiment Silage Maize 2020.* Wageningen, Wageningen Environmental Research, Report 3174.
38 pp.; 5 fig.; 10 tab.; 11 ref.

De doelstelling van het project KunstmestVrije Achterhoek (KVA) is het verduurzamen van de bemestingspraktijk door de bemesting van grasland en bouwland zo veel mogelijk in te vullen met regionaal beschikbare nutriënten. Het project is onderdeel is van het zesde Nederlandse actieprogramma in het kader van de Nitraatrichtlijn. Een van de doelstellingen betreft het bepalen van de agronomische effectiviteit van stikstof van stikstofhoudende bemestingsproducten gebaseerd op mest. Een tweede doelstelling het bepalen van enig risico op milieubezwaarlijkheid gelet op stikstof uitspoeling. Deze doelstellingen zijn door WUR-Wageningen Environmental Research uitgewerkt in een monitoringsprogramma met veldproeven op grasland en op maisland. Dit rapport geeft de resultaten van een veldproef met snijmais die in 2020 werd uitgevoerd op het proefbedrijf De Marke.

The aim of the project Biobased Fertilisers Achterhoek (‘Kunstmestvrije Achterhoek’ in *Dutch*) is to make fertilisation practices more sustainable through the use of locally available nutrients from renewable sources. The project is part of the Sixth Action Programme of the Netherlands which serves the Nitrates Directive. One of the objectives was to determine the nitrogen fertiliser replacement value of biobased fertilising products made from animal manure. A second objective was to assess the risk of nitrogen leaching from these biobased fertilising products. These objectives were implemented by WUR-Wageningen Environmental Research in a monitoring programme that included field experiments on grassland and on arable land with silage maize. This document reports the results of a field experiment with silage maize which was conducted in 2020.

Keywords: biobased fertiliser, mineral concentrate, reverse osmosis, silage maize, nitrogen fertilisers, yield, nitrogen uptake, nitrogen use efficiency, nitrogen fertiliser replacement value, environmental risk

Wageningen Environmental Research Report 3174 | ISSN 1566-7197

Photo cover: Silage maize of the field experiment in 2020 on the experimental farm De Marke

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Verification

Report: 3174
Project number: BO-43-012.02-058

Wageningen Environmental Research (WENR) values the quality of our end products greatly. A review of the reports on scientific quality by a reviewer is a standard part of our quality policy.

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date: 25th May 2022

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Summary

The overarching objective of the Biobased Fertiliser Achterhoek regional pilot (‘KunstmestVrije Achterhoek (KVA) pilot’ in *Dutch*) is to make the fertilisation practice more sustainable by supplying the fertilisation of nitrogen, potash and sulphur - as much as possible with fertilising products from regionally recycled resources. The pilot is part of the Sixth Action Programme of the Netherlands, which serves the Nitrates Directive. Within the pilot, a monitoring programme was set up by Wageningen Environmental Research (WENR) with two main objectives:

(i) to determine the nitrogen fertiliser replacement value (NFRV) of nitrogen of biobased fertilising products made from animal manure, and
(ii) to assess the risk of leaching of nitrogen from these biobased fertilising products.

The monitoring programme started in 2019 with a field experiment conducted with silage maize that was grown on a sandy arable soil. This document reports a second field experiment with silage maize, which was conducted in 2020. The biobased fertilising product used in the 2020 trial consisted of 99% mineral-concentrate enriched with 1% liquid fertiliser with 30% N based on urea and ammonium nitrate.

As 2019, the weather conditions during the growing season of silage maize in 2020 were dry with elevated temperatures, which made sprinkler irrigation necessary.

Results showed that the type of fertilising product or application rate had no effect on the number of plants at harvest.

The dry matter yield was 14.7 tonnes[1] dry matter/ha on average with a standard deviation of 2.0 tonnes dry matter/ha. Application rate or fertilising product did not have a significant effect on the yield of dry matter.

Nitrogen (N) uptake of the maize was 147 kg N/ha on average across all treatments and ranged from 111 kg N/ha to 159 kg N/ha. Without nitrogen application (0 kg N/ha) the maize nitrogen uptake was 111 kg N/ha, which was significantly lower than the uptake from the treatments with nitrogen fertilisation. There were no significant differences between other treatments, and no interaction was found between fertiliser product and application rate.

Nitrogen use efficiency (NUE) varied from 17% for application of calcium ammonium nitrate (CAN) at a 125% application rate to 45% for application of cattle slurry (CS) at a 50% rate (Table 7). NUE of CAN declined significantly with an increase of the nitrogen application rate. At 50% of the optimum application NUE was 27% and at the application rate of 125% it was 17%. Within treatments, variation of NUE was relatively large and no significant differences between the fertilising products were found, with the exception of CS at a rate of 50%, for which the NUE was significantly larger than for other fertilising products and application rates.

NFRV showed some differences. At an application rate of 50%, NFRV values for CS and Biobased fertilising product basic (BBFb) were significantly higher compared to those for CAN. At an application rate of 75%, NFRV was significantly higher for BBFb, CS+BBFb and UAN than for CAN.

At the start of the field experiment, the soil layers of 0–30 cm, 30–60 cm and 60–90 cm depth had 19, 10 and 2 kg/ha respectively mineral nitrogen on average, with some differences between replications. On average, there were no significant differences in the stock of mineral soil nitrogen among the fertilising products. After the harvest, the stock of soil mineral nitrogen was significantly different between fertilising product treatments and application rates. An increase in application rate of CAN resulted in an increase of the stock of soil mineral N. Application rates of 0%, 100% and 125% were significantly different from each other. Without nitrogen fertilisation (0 kg N/ha) the soil layer of 0–30 cm depth and the soil layer of 0–90 cm

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[1] Metric ton

depth had a significantly lower stock of mineral nitrogen after harvest in October compared to 100% or 125%. The treatment of CAN 100% had a significant lower stock of mineral nitrogen compared to CAN 125%. For other application rates of CAN, a statistically significant difference was not found, although a trend of an increase in soil mineral nitrogen stock could be observed with an increase in application rate. Treatments with CAN and liquid urea ammonium nitrate (UAN) tended to have a lower stock of mineral nitrogen in the soil layer of 0–90 cm depth compared to BBFb, CS and the combination CS+BBFb, but no significant difference was found. The treatment CS+BBFb 100% showed a significantly higher stock of soil mineral nitrogen, which was higher compared to CAN 100% and UAN 100%. Other fertilising treatments were not significantly different. Application rates of UAN had no significant effect on soil mineral N.

Silage maize without nitrogen fertilisation (0 kg N/ha) showed a nitrogen uptake of 111 kg N/ha (Figure 5). At the start of the field experiment, the soil layer of 0–90 cm depth contained 27 kg N/ha and 62 kg N/ha after harvest. This indicated a contribution towards plant-available nitrogen with a soil organic nitrogen of 146 kg N/ha.

The difference between the stock of soil mineral nitrogen after harvest and the sum of the quantity present at the start, plus the nitrogen application rate, minus the nitrogen uptake by silage maize, is an indicator of the contribution of the soil to nitrogen taken up by the maize. This is a simple form of a partial soil nitrogen balance sheet and ignores losses through ammonia volatilisation and denitrification or immobilisation of mineral nitrogen in organic nitrogen. The apparent contributions from soil organic nitrogen were not significantly different between treatments with fertilising products at similar application rates.

The simple nitrogen balance sheet shows that the soil contributed nitrogen to the nutrition of silage maize and to the stock of mineral nitrogen after harvest. This was also found for the field experiment with silage maize in 2019 which was also conducted during a period of drought. As for 2019, sprinkler irrigation had to be used to combat drought in 2020. The effect of sprinkler irrigation in combination with elevated temperatures is thought to have had an accelerating effect on soil organic nitrogen mineralisation. The contribution of soil organic nitrogen at CAN 0% is equal to the regulatory application standard of 140 kg N/ha which may explain the absence of significant effects of increasing application rates on yield, nitrogen uptake. Under the condition of drought and a significant contribution of nitrogen by the soil, the contribution of nitrogen from a fertilising product is of less importance.

1 Introduction

The quality of groundwater and surface water in the Netherlands has improved over the past decades[2], but still requires further improvement[3] (the Netherlands, Sixth Action Programme Nitrates Directive 91/676/EEC[4]). The Sixth Action Programme of the Netherlands lists a number of measures that could contribute to this further improvement. These measures include several pilot projects, one of which is the Biobased Fertilisers Achterhoek regional pilot (Sixth Action Programme of the Netherlands, 5.5.3.3, Annex 1).

The main goal of the Biobased Fertilisers Achterhoek regional pilot was to investigate the processing of animal manure at a practical level. Different manure processing technologies were reviewed and promising technologies have been implemented in practice. Processing can lead to new fertilising products. The project focused on the quality aspects of these new nitrogen (N)-fertilising products based on animal manure, specifically on nutrient levels (N, potassium; K, and sulphur; S), the agronomic effectivity, the level of contaminants (heavy metals, organic micro-contaminants, pathogens and other contaminants (New Emerging Contaminants (NEC)). These fertilising products were monitored to explore their composition, agronomic effectivity and environmental effects in pilots of the Sixth Action Programme. The aim was to produce products that meet the requirements of the revised EU fertilising products regulation for free trade EC/2019/1009 (currently focused on liquid inorganic NKS fertilising products: PFC1c) and criteria that have been set for by JRC proposed RENURE[5] fertilising products within the context of the Nitrates Directive. The monitoring in this project made use of larger monitoring programs of other projects of individual factions of the fertilising products, such as the thick fraction, the clean water fraction, and other fractions were also monitored for the nutrient and contaminant levels[6]. The monitoring of this project on composition, agronomic effectivity and environmental effects was a joint study by the province of Gelderland, LTO Noord Projects, ForFarmers, 'Vruchtbare Kringloop Achterhoek en Liemers' and Wageningen University and Research. There was a regional cooperation with a large number of actors involved in the processing of manure at the practical level.

More specifically, the following objectives were formulated in the Biobased Fertilisers Achterhoek regional pilot to find solutions for the manure surpluses in the region. These objectives were included to:

- Inform, support, and facilitate local land users in their efforts to find circular solutions for manure- and mineral-related issues. Here, the knowledge from the various "manure projects" in the province can be explicitly included.
- Identify the desired quality and composition of emerging fertilising products derived from animal manure and sludge that have been produced by the best techniques available for processing.
- Advise manure processors, sludge processors and water boards on the desired product (quality), creating a market-oriented offer.
- Create legal space for integral sustainable solutions for the use of minerals in the vegetable- and arable production areas, and in the animal sector with grassland and arable land as fodder crops. As a matter of policy, manure and products from manure and sludge must be positioned as valuable secondary raw materials for a circular agricultural practice.

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[2] https://www.eea.europa.eu/themes/water/interactive/by-category/nitrate-directive

[3] Van Grinsven et al., 2016.

[4] EC Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates for agricultural sources.

[5] RENURE stands for "REcovered Nitrogen from manURE". RENURE is proposed by JRC in its study SAFEMANURE. RENURE is defined by JRC as any nitrogen containing substance fully or partially derived from livestock manure through processing that can be used in areas with water pollution by nitrogen following otherwise identical provisions applied to nitrogen containing chemical fertilisers as defined in the Nitrates Directive (91/676/EEC), while ensuring the achievement of the Nitrates Directive's objective and providing adequate agronomic benefits to enhance plant growth.

[6] Monitoring is conducted within the H2020 European project Systemic (https://systemicproject.eu/) and the Dutch project Meerwaarde Mest en Mineralen 2 (https://www.wur.nl/nl/project/Meerwaarde-Mest-en-Mineralen-2.htm)

LTO-Noord was the project leader of the Biobased Fertilisers Achterhoek regional pilot. Wageningen Environmental Research (WENR[7]) of Wageningen University and Research supported this project with a monitoring programme. WENR's monitoring programme was focused on a safe introduction of nitrogen (N) fertilising products in the Achterhoek region of the Netherlands through comparison of the nitrogen fertiliser replacement value (NFRV; a measure for nitrogen use efficiency) to that of regular mineral (synthetic, chemical) nitrogen fertilisers and study of the risk of nitrate leaching.

WENR advised on desired product quality and product composition of fertilising products and assessed and monitored their agricultural effectiveness, and the associated risk of nitrate leaching. The monitoring programme consisted of five parts:

1. Assessment of risks associated with blending of fertilising products based on animal manure, sewage sludge, and mixtures of these.
2. Field experiments conducted in 2019, 2020 and 2021.
3. Demonstration field trials conducted in 2018, 2019 and 2020.
4. Annual technical reports on risk assessment, field experiments and demonstration trials.
5. Synthesis report of parts 1 – 4.

For the positioning of the nitrogen fertilising products based on animal manure within legal frameworks on use of animal manure and mineral fertilisers, it was important to obtain insight into the NFRV of biobased fertilising products from processed animal manure and their risk on nitrate leaching.

Risks associated with blending of fertilising products from mixtures with animal manure and other (renewable) nitrogen sources have been reported by Sigurnjak et al. (2022, in prep.[8]).

The demonstration field trials[9], which constitute Point 3 of the monitoring programme, started in 2018. Results of demonstration fields carried out in 2018, 2019 and 2020 have been reported (Ehlert & Van der Lippe, 2020a, 2020b; Ehlert et al., 2020). The monitoring of demonstration field trials part has ended.

In 2020, a field experiment on grassland was conducted and was followed by a second field experiment on grassland in 2021. These field experiments have been reported in two separate reports. A field experiment on arable land with silage maize was also conducted in 2019 and was reported (Ehlert, 2020). The results of a second field experiment on arable land with silage maize of 2020 are reported in this report.

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[7] WENR is one of the research institutes of Wageningen University & Research

[8] Sigurnjak, I., Brienza, C., Egene, C., Regelink, I., G. Reuland, Satvar, M., L. Hongzhen, Massimo, Z. Meers, E., 2022. Document on product characteristics, lab results and field trials (year 4). SYSTEMIC Deliverable D1.13. www.systemicproject.eu/downloads.

[9] Demonstration field trials were established on ten grassland plots at dairy farms. The plots were split into two blocks. One received a biobased fertilising product, while the other received a blend of mineral NKS fertilisers. The application rate of N, K and S was based on regular fertiliser recommendations for grassland in the Netherlands, which are based on soil testing. Grass yields were estimated by measuring grass height about 15 days after fertilisation and 10 days before the actual harvest. The quantity mineral nitrogen was measured in three soil layers (of 0-30, 30-60 and 60-90 cm depths) before fertilisation started and after the harvest of the last (fifth) cut. Grassland use followed agricultural practices in the Achterhoek where cattle slurry is used for fertilising three of the five cuts of grass. Therefore, the biobased fertilising product and the blend were additional fertilisers in the nutrient management plan, which was also based on regular soil testing. The application rates of the nutrients of these fertilisers were exactly the same. The nutrients of animal manure were taken into account in the nutrient management plan. The experience from 2018, 2018 and 2020 was that the agronomic performance of the biobased fertilising product approached the effectivity of the blend of mineral fertilisers in both yield and residual soil nitrogen after the last harvest, provided that ammonia toxicity was avoided, and the nitrogen application rate was based on measurement of the actual batch. All experimental years, 2018, 2019 and 2020 included periods of severe drought in the Achterhoek region. Not all farmers were able to use sprinkler irrigation. Drought hampered testing of fertilising products and lowered the effectivity of fertilisation.

1.1 Objectives

The field experiments started in 2019 with one field experiment conducted on grassland and one field experiment conducted with silage maize. These field experiments have served two objectives to measure:

1. Agronomic effectivity through determining the NFRV of the biobased fertilising products by means of field experiments.
2. Environmental risk through determining and comparing the risk of nitrate leaching when using nitrogen biobased fertilising products as a substitute for mineral nitrogen fertilisers (such as those which are synthetic or chemical).

1.2 Hypotheses

Crop available nitrogen in this study is defined as the quantity of nitrogen that is released from a fertilising product during crop growth within a growing season. Commonly, this quantity is assessed by comparison of nitrogen uptake by a crop with nitrogen from a test-product amended plot with nitrogen uptake by the crop amended with mineral nitrogen fertiliser, while correcting for the quantity of nitrogen taken up from plots without nitrogen fertilisation. A parameter that expresses this quantity is the NFRV[10].

The NFRV depends upon the four agronomic fertiliser value determining factors[11]:

- Type of fertilising product.
  - ⇨ The more crop available nitrogen is present, the higher the NFRV is.
- Application rate.
  - ⇨ The efficacy of nitrogen taken up from a fertilising product decreases with an increase of the application rate.
- Method of application and method of placement of a fertilising product.
  - ⇨ Application methods that do not mitigate ammonia volatilisation and denitrification will have a lower NFRV.
- Application timing of a fertilising product.
  - ⇨ A period of application well before crop growth, increases the risk of nutrient losses to the environment (volatilisation, denitrification and leaching) and will lower the NFRV.

The NFRV and residual nitrogen in the soil after the harvest of silage maize were objects of this study. Determination of the NFRV requires a reference fertiliser. In the Netherlands, calcium ammonium nitrate (CAN[12]) is used as the reference for assessing NFRV. CAN is a prilled fertiliser. Prilled fertilisers require a broadcasting fertilisation technique (blanket application). As biobased nitrogen fertilising products are liquids (or suspensions) and often consist mostly of ammonium nitrogen these fertilising products are commonly[13] injected rather than broadcasted. These differences in application techniques can affect NFRV. Therefore, injection of the liquid fertiliser urea-ammonium nitrate solution (UAN) was used as a second reference.

The following hypotheses were formulated:

1. The magnitude of NFRV depends upon the reference nitrogen fertiliser that is used.
2. Biobased fertilising products have a similar magnitude of NRFV to the reference fertiliser.
3. Biobased fertilising products have a similar effect on residual nitrogen after the harvest of silage maize as a regular nitrogen fertiliser at similar application rates.

In the study of 2020, one type of biobased fertilising products was tested, namely a type with a low sulphur content and, thus, a relatively high N/S ratio of 5.7 (Biobased fertilising product (BBFb)). This type has significance for fertilisation of grassland after the first two cuts, where the crop demand for sulphur is low,

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[10] Also called 'Mineral Fertiliser Equivalent' (Jensen, 2013).

[11] Also known as the 4R's of nutrient stewardship: right fertiliser type, right application rate, right method of fertiliser application and right period of fertilising.

[12] Calcium ammonium nitrate is a directly available nitrogen fertiliser. Other names are Nitro-limestone or nitrochalk. The fertiliser is a mixture of ammonium nitrate and lime.

[13] In the Netherlands, legal restrictions on ammonia emission of fertilising products based on manure, and injection techniques or a blanket sheet application directly followed by incorporation in the soil are in force.

and was specifically tailored for use later in the growing season. Adding ammonium sulphate can help decrease the N/S ratio of the fertiliser product to lower values that serve the nutrient requirements of the first two cuts of grassland. This addition of ammonium sulphate, however, was not tested in this experiment, as the production of a BBF with a low sulphur content creates a basis for the production of other, derivative BBFs, with different sulphur contents and N/S ratios.

The secondary raw materials mineral concentrate, and condensed ammonium water served as compounds for these biobased fertilising products. Due to previous experience with a mixture of mineral concentrate and condensed ammonium water on grassland, in which symptoms of ammonium toxicity were observed, the composition of the BBFb was changed in 2020 and consisted of 99% mineral concentrate and 1% liquid nitrogen fertiliser of urea and ammonium nitrate (UAN, '*Urean' in Dutch*, 30% N).

The project started in the same timeframe when the Joint Research Centre (JRC) was carrying out its SAFEMANURE project. The aim of the JRC project is the development of criteria for the safe use of processed N-containing fertilising products from manure in vulnerable zones (areas sensitive to nitrate leaching), established by the Nitrates Directive. In January 2020, a pre-final report of this study was discussed during a stakeholders' workshop at JRC in Seville, Spain. In May 2020, the final report[14] was presented for discussion within the Nitrates Expert Group[15].

The current project was stimulated by the start of the SAFEMANURE project but has another timeframe. Its field experiments were conducted in 2019, but also in 2020 and 2021. The data and outcomes obtained in this project serve as touchstones for the, still to be implemented, RENURE criterions for nitrogen fertilising products which are based on processed animal manure.

The results of the second silage maize experiment of 2020 are reported here. Materials and methods of the experiment are described in Chapter 2. Chapter 3 presents the main results (yield and nitrogen uptake of maize, nitrogen use efficiency (NUE), NFRV, residual soil mineral nitrogen, and an indicative nitrogen balance). In Chapter 4, the results are evaluated and conclusions for this second experimental year with silage maize are reported.

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[14] Huygens D., G. Orveillon, E. Lugato, S. Tavazzi, S. Comero, A. Jones, B. Gawlik and HG.M. Saveyn, 2019. Technical proposals for the safe use of processed manure above the threshold established for Nitrate Vulnerable Zones by the Nitrates Directive (91/676/EEC). EUR 30363 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21539-4, doi:10.2760/373351, JRC121636.

[15] The Expert Group for the implementation of the Nitrates Directive provides an informal forum of discussion between DG Environment and the Member States on technical aspects linked to the implementation of the Nitrates Directive and nutrients policy.

2 Materials and methods

2.1 Design of the field experiment

This study explores the agronomic potential of a biobased fertilising product as a nitrogen source for silage maize.

In the Netherlands, it is common to use animal manure as a standard fertilising product to fulfil a large proportion of the crop's nutrient needs. Full crop nutrient requirements are met through additional fertilisation with mineral fertilisers. Quantities of nitrogen and phosphate used must meet the application standards of the Fertiliser Act of the Netherlands (see Section 2.4).

The field experiment followed an orthogonal design with fertilising product and application rate as factors. It also included three repetitions. Treatments (Table 1) were randomised per replication. The design involved a total of 39 plots.

Table 1 *Fertilising products and application rates (code factors) of the field experiment with silage maize.*

Nr.	Fertilising product	Application Rate[a] (Code)
1	Calcium ammonium nitrate (CAN)	1
2	Calcium ammonium nitrate (CAN)	2
3	Calcium ammonium nitrate (CAN)	3
4	Calcium ammonium nitrate (CAN)	4
5	Calcium ammonium nitrate (CAN)	5
6	Liquid urea ammonium nitrate (UAN[16])	2
7	Liquid urea ammonium nitrate (UAN)	3
8	Cattle slurry (CS[17])	2
9	Cattle slurry (CS)	3
10	Biobased fertilising product basic (BBFb)	2
11	Biobased fertilising product basic (BBFb)	3
12	Cattle slurry + biobased fertilising product basic (CS+BBFb)	3
13	Cattle slurry + biobased fertilising product basic (CS+BBFb)	4

[a]: application rates for Codes 1, 2, 3, 4, and 5 are respectively 0, 93, 140, 186, and 233 kg N/ha. The optimum application rate was 186 kg N/ha which was set at 100% (Code 4). Other application rates were 0% (Code 1). 50% (Code 2). 75% (Code 3) or 125% (Code 5).

2.2 Crop

Silage maize was sown with a target of 100,000 seeds/ha. The row distance was 75 cm.

2.3 Soil

The field experiment was conducted on a sandy soil at the experimental farm, De Marke, on a different plot from the one used previously for the field experiment of 2019. The initial soil fertility status of the field experiment prior to fertilisation in spring is given in Table 2. For this, the soil top layer of 0–25 cm depth was sampled (40 soil cores/field experiment). The determination of the soil fertility status served in determining the fertiliser requirements.

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[16] Liquid urea-ammonium nitrate fertiliser (UAN) is a mixture of urea and ammonium nitrate. In the Netherlands this fertiliser is called 'Urean'.

[17] Cattle slurry of the experimental dairy farm, De Marke (https://www.wur.nl/nl/locatie-De-Marke.html).

Table 2 *Soil fertility status of the sandy soil used in the field experiments.*

Parameter	Unit	Value	Method
Organic matter	%	4.9	NIRS[18]
C-inorganic	%	2.4	NIRS
Clay (< 2 µm)	%	2	NIRS
Silt (2-50 µm)	%	10	NIRS
Sand (>50 µm)	%	84	NIRS
CEC	mmol+/kg	57	NIRS
pH	-	5.3	NIRS
N-total	mg N/kg	1663	NIRS
P-capacity (P-Al-value)	mg P_2O_5/100 g	33	NIRS
P-plant available (P-$CaCl_2$)	mg P/kg	0.5	CCL3
K-capacity	mmol+/kg	2.1	NIRS
K-plant available	mg K/kg	78	CCL3
S-total	mg S/kg	297	NIRS
S-plant available	mg S/kg	2.5	CCL3[19]
Ca-total	mmol+ Ca/kg	44	NIRS
Ca-plant available	mg Ca/kg	0.1	NIRS
Mg-total	mmol+ Mg/kg	9.0	NIRS
Mg-plant available	mg Mg/kg	130	CCL3

Plant available nitrogen was measured in soil layers of 0-30 cm. 30-60 and 60-90 cm depths with 1 M KCl (1:2.5 w/v) extraction on 8th April 2020 prior to sowing. In these soil layers, 21 kg N/ha, 11 kg N/ha and 2 kg N/ha were found.

2.4 Fertilising products

Fertilising products and combinations used in the experiment were calcium ammonium nitrate (CAN), liquid urea-ammonium nitrate (UAN), biobased fertiliser basic (BBFb), cattle slurry (CS) and cattle slurry plus biobased fertiliser basic (CS+BBFb). CAN and UAN are commonly used mineral nitrogen fertilisers.

The biobased fertilising product was produced by the Green Mineral Mining Centre[20] of Groot Zevert Vergisting (GZV) B.V. in Beltrum, the Netherlands. The Green Mineral Mining Centre started the production of biobased fertilising products in early 2019. The plant uses innovative techniques for the production of these biobased fertilisers and participates in the EU H2020 project Systemic, by providing a demonstration plant, and the Dutch MMM-2 project. Both participations lead to more in-depth monitoring of production processes. The Systemic project has provided a full description of the production process of biobased fertilisers[21].

The biobased fertiliser was produced from mineral concentrate obtained by processing co-digested pig slurry (digestate). This digestate was separated into a liquid and a solid fraction through the use of a decanter. Next, the liquid fraction was processed into a mineral concentrate and a permeate (clean water) via a cascade of techniques, including reverse osmosis. The mineral concentrate serves as a secondary resource for the production of biobased fertilising product. The BBFb[22] was a mixture of mineral concentrate with 1% UAN.

Table 3 gives an overview of the composition of the fertilising products (reference fertilisers and biobased fertilising products) that were used in the current field experiment with silage maize.

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[18] Eurofins Agro, method NIRS (TSC®)
[19] Eurofins Agro, method CCL3(PAE®)
[20] https://www.groenemineralencentrale.nl/nl/english
[21] https://systemicproject.eu/plants/demonstration-plants/groot-zevert-the-netherlands/
[22] Another type of BBF is enriched with ammonium sulphate which causes higher nitrogen content and is used in practice on grassland for the fertilisation of the first two cuts of grass.

Table 3 *Composition of reference fertilisers CAN and UAN, biobased fertilising product (BBF) and cattle slurry (CS).*

Fertilising product	Dry matter, %	Organic matter, %DS	EC, mS	Bulk-density, kg/L	pH [-]	N-total, g N/kg	NH_4-N, g N/kg	NO_3-N, g N/kg	Urea-N[23], g N/kg	P, g P/kg	K, g K/kg	Mg, g Mg/kg	S, g S/kg	N/S, g/kg/ g/kg	N/K, g/kg/ g/kg	Laboratory
Calcium ammonium nitrate (CAN)	*	*	*	*	*	275	142.5	132.5	*	*	*	*	*	*	*	1
Liquid Urea-ammonium nitrate (UAN)	*	*	*	*	*	297.6	71.1	76.8	153	*	*	*	*	*	*	1
Cattle slurry (CS)	8.1	80.4	18.16	1006	6.97	3.87	1.9	*	*	0.44	4.06	0.66	0.51	7.6	1.0	2
Biobased fertilising product basic (BBFb)	3.8	23.3	74.5	1044	8.35	10.39	8.2	0.7	*	0.047	8.29	0.057	1.83	5.7	1.3	2

Laboratory 1: Lufa Nord West[24]. Germany.

Laboratory 2: Wageningen UR - Chemical Biological Soil Laboratory[25] (CBLB).

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[23] Biuret content was 0.22%

[24] https://www.lufa-nord-west.com/

[25] https://www.wur.nl/en/Research-Results/Research-Institutes/Environmental-Research/Facilities-Products/Environmental-Sciences-Laboratories/Chemical-Biological-Soil-Laboratory-CBLB.htm

2.5 Application rates

Application rates of nutrients were based on fertiliser recommendations that were derived from soil testing. The recommendations of the Dutch Committee Fertilisation of Grassland and Fodder Crops (CBGV[26], 2020) were followed.

2.5.1 Nitrogen

The nitrogen application rate was based on the quantity of mineral nitrogen in de soil layers of 0-30 cm and 30-60 cm depth, and the 1.0 M KCl (1:2.5 w/v) extraction. The optimum (recommended) nitrogen application rate was set at 190 kg N/ha. In the Netherlands, the Fertiliser Act sets application standards for all agricultural crops and maintains a 140 kg N/ha application standard for silage maize. This regulatory application standard is set as a starting point in designating the actual application rate. The application standard is set at 75%. The application rates 0%, 50%, 75%, 100% and 125% followed, therefore, 0, 93, 140, 186 and 233 kg N/ha (Table 1).

2.5.2 Other nutrients

The application rates of other nutrients were based on the results of the soil sample of the soil layer of 0-25 cm depth. The recommended application rates are given in Table 4.

Table 4 *Recommended application rates for phosphate, potassium, sulphur and magnesium, and application rate after applying the Ceteris Paribus Principle with compensation for nutrients from all fertilising products.*

Nutrient	Unit	Recommended application rate	Actual application rate with compensation
Phosphate	kg P_2O_5/ha	90	90
Potassium	kg K_2O/ha	300	350
Magnesium	kg MgO/ha	0	40
Sulphur	kg SO_3/ha	15	350

Biobased fertilising products and cattle slurry contain other nutrients in addition to N. These are taken into account by applying the *Ceteris Paribus* Principle[27]. Therefore, each treatment received the same quantity of phosphate, K, magnesium (Mg) and sulphur (S). Phosphate was applied as Triple superphosphate. K was applied as potassium sulphate. Mg was applied as magnesium sulphate (Kieserite). Although the Mg status of the soil was adequate, Mg was also added with the application of biobased fertilising products and cattle slurry. Therefore, Mg applications were equalised over treatments by the use of Kieserite. The highest quantity nutrients determined the compensation application rate.

The micronutrient status of the soil was adequate. Soil testing showed that there was no need for additional fertilisation with micronutrients (data not shown).

2.6 Fertilisation techniques

Fertilisation techniques differed per fertilising product. The equipment used was specifically designed for fertilisation of field experiments with small plots (e.g. 3 x 10 m).

Granular mineral fertilisers were applied with a spreader adapted for experiment field use (Photo 1).

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[26] https://www.bemestingsadvies.nl/nl/bemestingsadvies.html

[27] Ceteris Paribus Principle: All other factors being unchanged or constant. For the field experiment: applications of all nutrients other than nitrogen were kept constant. Table 4 gives the maximum application of the other nutrients.

Photo 1 *Equipment of WUR Unifarm for application of granular fertiliser CAN.*

The liquid mineral fertiliser UAN was applied with a field sprayer (Photo 2).

Photo 2 *Field sprayer of WUR Unifarm used for application of the liquid mineral nitrogen fertiliser UAN.*

The application of biobased fertilising products requires an injection technique and equipment that can supply application rates of 2-5 m^3/ha. An injector was designed and built specifically for this purpose (Photo 3).

Photo 3 *Injector designed for biobased fertilising products. Injector was built by Slootsmid[28] in 2020 and is designed for specific use in field experiments and/or fertilisation of small plots. The design was aimed at mitigating/minimising ammonia losses.*

Cattle slurry is commonly applied with a field injector that can handle larger volumes than those used for the more concentrated biobased fertilising products. For this field experiment, the equipment of WUR Unifarm was used (Photo 4).

Photo 4 *Injector of WUR Unifarm which was designed for the application of animal slurries. It was adjusted for application of cattle slurry on grassland with slots distanced at 25 cm in this photograph.*

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[28] https://www.slootsmid.nl/

For application on arable land and silage, maize nozzles and injection slots are distanced at 75 cm from each other.

Fertilisation was carried out on 28th and 29th of April 2020.

2.7 Sampling soil, harvest and sampling crop

2.7.1 Sampling soil

The soil was sampled three times.

Sampling of the plough layer (of 0 – 25 cm depth) took place on 3rd April 2020, before the sowing of the silage maize. A standard sampling protocol was followed: 40 soil cores of the field experiment were taken manually with a random distribution and pooled. This pooled soil sample was used for the determination of the application rates of P, K, Mg and S.

On 7th and 8th April 2020, the soil layers of 0–30 cm, 30–60 cm and 60–90 cm depth of the field experiment were sampled individually, using a motorised drill. In total, 12 soil cores per plot were taken to assess the quantity of mineral nitrogen in the soil and to derive the nitrogen application rates.

Also on 8th April 2020, the three soil layers of each individual plot (total of 39 plots with 12 soil cores per plot) were sampled in the same way to assess the quantity of mineral nitrogen in the soil at the start of the field experiment, before fertilisation and cultivation of silage maize. This practice was repeated at the end of the experiment (12th & 13th October 2020) to assess the amount of nitrogen remaining in the soil.

2.7.2 Crop and harvest

Silage maize (cultivar LG 31.211) was sown on 28th April 2020 with a seeding density of 100,000 seeds/ha.

Before harvest, the numbers of plants per plot were counted. Next, 20 plants per plot were sampled for the determination of dry matter content and nutrient content (N, P and K). This was followed by the determination of the yield of the whole plant.

2.8 Analytical methods

2.8.1 Fertilising products

CAN and UAN fertilisers were analysed for nitrogen content and forms by Lufa Nord West, Germany. Lufa Nord West is an accredited laboratory and has a quality system based on the ISO-17025 standard. The methods used were total Nitrogen VDLUFA II, 3.5.2.7.: 1995; ammoniacal N, DIN EN ISO 11732 (e23): 2005-05; #6 and Nitrate N, DIN EN ISO 13395; 1996-12; #6; Carbamide N, VDLUFA II.1, 3.9.2, 1995 AND Biuret VDLUFA II.1, 3.9.2; 1995.

Other fertilising products were analysed by Wageningen UR - Chemical Biological Soil Laboratory (CBLB). CBLB has a quality system that is based on the ISO-17025 standard. CBLB follows internal methods bases on the following standards: dry matter NEN 7432:1998; organic matter, NEN 5754;2014 (loss on ignition); pH, NEN 5704. Nutrient contents (N, P, K, and Mg) were determined after destruction with sulphuric acid, hydrogen peroxide, and selenium. Sulphur content was determined after aqua regia destruction (microwave method). Electric conductivity was based on NEN-EN 13038:2011 and bulk density followed an internal standard.

2.8.2 Soil samples

Soil samples of the plough layer of 0–25 cm depth were analysed by Eurofins Agro BV and followed its analysis package for arable land[29]. Eurofins Agro Testing Wageningen BV is an accredited[30] laboratory.

The mineral nitrogen content in the soil samples of individual soil layers was determined after an extraction with 1 M KCl (1:2.5 w/v) by CBLB. The method is an internal standard adapted from ISO/TS 14256-1:2003 en.

2.8.3 Crop samples

Samples of silage maize plants were shredded, dried overnight at 70 °C, and ground up. Next, samples were analysed for nutrient concentration by destruction with H_2SO_4-H_2O_2-Se followed by photometric determination of nitrogen and P on a segmented flow analyser (SFA) and K on a flame-atomic emission spectroscope (F-AES). These analyses were conducted by CBLB.

2.9 Calculations

The nitrogen use efficiency (NUE) of the fertilising products was calculated according to Dobermann (2007):

$$\mathrm{NUE} = 100 * (U_N - U_0) / F_N \qquad (1)$$

With:

NUE = Nitrogen use efficiency or apparent recovery of nitrogen as percentage (%).

U_N = Uptake of nitrogen of fertiliser treatment (kg N/ha).

U_0 = Uptake of nitrogen of control treatment without nitrogen fertilisation (kg N/ha).

F_N = Application rate fertiliser treatment (kg N/ha).

The NUE depends on the congruence between plant nitrogen demand and the release of nitrogen from the fertilising product.

The nitrogen fertiliser replacement value (NFRV) of a biobased fertilising product can be calculated as follows:

$$\mathrm{NFRV} = 100 * \mathrm{NUE}_{\text{Biobased fertilising product}} / \mathrm{NUE}_{\text{Calcium ammonium nitrate}} \qquad (2)$$

With:

$\mathrm{NUE}_{\text{Biobased fertilising product}}$ = Nitrogen use efficiency or apparent recovery of biobased fertilising product (%).

$\mathrm{NUE}_{\text{Calcium ammonium nitrate}}$ = Nitrogen use efficiency or apparent recovery of calcium ammonium nitrate (%).

By this definition, the NFRV of calcium ammonium nitrate is 100%. This does not mean that this chemical fertiliser is 100% effective though.

2.10 Statistical analyses

Liquid urea-ammonium nitrate (UAN), cattle slurry (CS), biobased fertilising product basic (BBFb) were applied at levels 50% and 75%. The combinations with cattle slurry and biobased fertilising product was applied at levels of 75% and 100%.

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[29] https://www.eurofins-agro.com/nl-nl/bemestingswijzer

[30] https://www.rva.nl/en/accredited-organisations/all-accredited-bodies nr. L122.

The response of maize to nitrogen fertilisation was analysed using linear regression with both experimental factors (fertiliser treatment and application rate) and their interaction as explanatory variables:

$$\text{Model} = \text{Block} + \text{Fertiliser} + \text{Application rate} + \text{Fertiliser} * \text{Application rate} \qquad (3)$$

With:
Model: parameter (Number of plants, Dry matter yield, N-uptake, NUE, soil stock nitrogen mineral) statistically to be analysed.
Block: repetition (=3).

Equation (3) was adapted for the stock of mineral nitrogen by including the time of sampling.

Fertiliser: Fertiliser treatments control (no nitrogen fertilisation), calcium ammonium nitrate (CAN), liquid urea-ammonium nitrate (UAN), biobased fertiliser (BBFb), cattle slurry (CS) and cattle slurry plus biobased fertiliser (CS+BBFb).

Application rate: 0, 93, 140, 186 and 233 kg N/ha.

Tests on pairwise differences of means were based on Least Significant Differences (LSD's) and probabilities of 95% ($\alpha = 0.05$, two sided), unless stated otherwise.

Both NUE and NFRV were calculated per treatment and per replicate. NUE was reported with its LSD values. The variance in the nitrogen uptake at various nitrogen application rates of fertilising product was taken into account when calculating the standard error of NFRV. Pooled standard errors of these predictions were reported.

The statistical analyses were carried out with the general-purpose statistical package GenStat Nineteenth Edition (VSN, 2019).

3 Results

3.1 Weather conditions

The year 2020 was the third consecutive year that the *De* Achterhoek region experienced a dry growing season. With exception of May and July all other months had on average a higher-than-average temperature (Figure 1). From March until September, the precipitation in the region was below average for the years 1991-2020 (Figure 2).

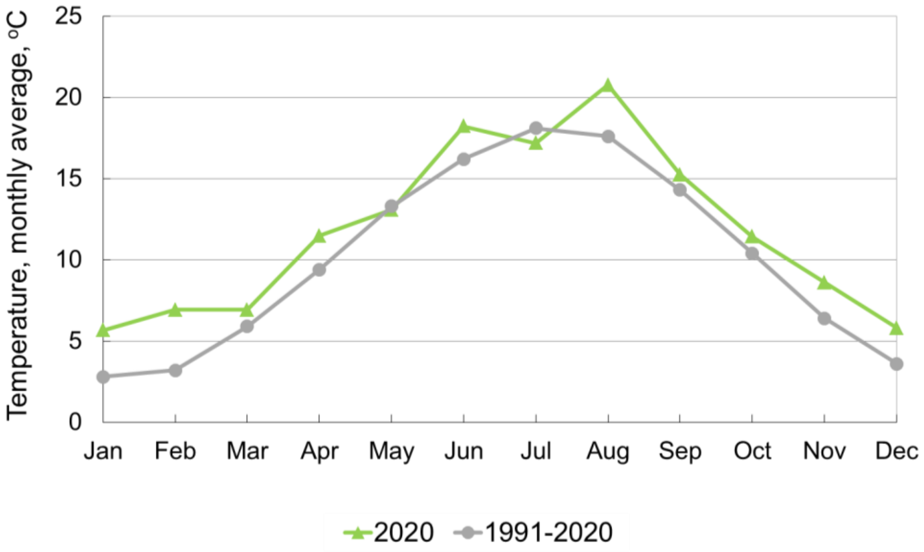

Figure 1 *Temperature, monthly average in degrees Celsius for the experimental farm, De Marke, in 2020 compared with the long-term average for the period 1991-2020 for the region*[31] *(data provided by G.J. Hilhorst).*

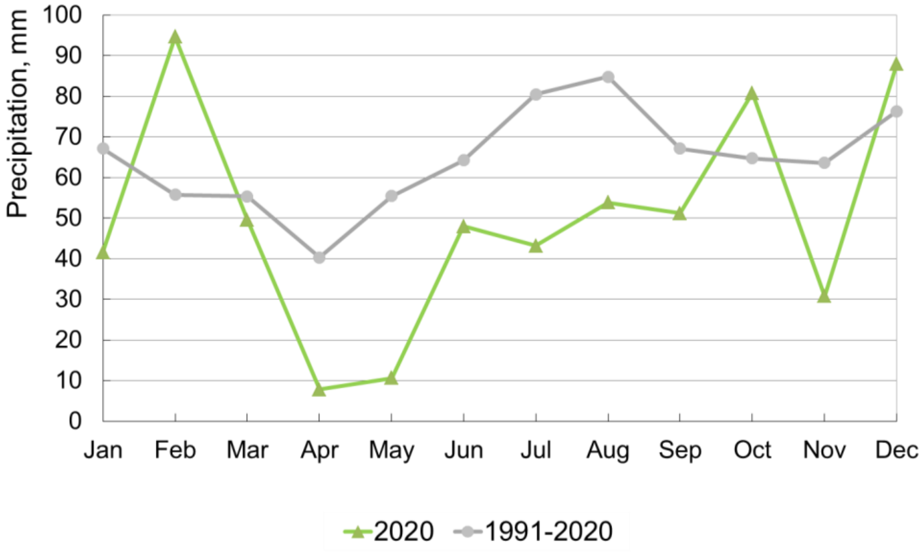

Figure 2 *Precipitation, monthly sum in mm for the experimental farm, De Marke, in 2020 compared with the long-term average for the period 1991-2020 for the region (data provided by G.J. Hilhorst).*

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[31] The Royal Netherlands Meteorological Institute (Koninklijk Nederlands Meteorologisch Instituut (KNMI)), Weather Station Hupsel.

During the growing season of the silage maize, the first three monthly average temperatures (May, June and July) were equal to, or slightly higher than the long-term average, but in August and September, during ripening, the 2020 temperatures were elevated further (Table 5). The months May, June, July, August September had lower precipitation than the long-term monthly average (Table 6). During the growing season (May – September) 156 mm precipitation was registered, which was 129 mm less than the long-term average of 285 mm. The difference in total precipitation in 2020 compared to the long-term total was 175 mm for the whole year.

Table 5 *Monthly temperatures in °C presented as monthly average, averages of decades I, II and III and monthly minimum and maximum values (data from experimental farm, De Marke).*

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Monthly average	5.7	6.9	6.9	11.5	13.1	18.2	17.2	20.7	15.2	11.4	8.6	5.8
Long term monthly average	2.8	3.2	5.9	9.4	13.3	16.2	18.1	17.6	14.3	10.4	6.4	3.6
Decade I	6.1	7.0	6.7	10.8	11.9	15.0	16.5	22.2	15.5	12.5	9.8	3.7
Decade II	6.3	7.4	8.8	11.1	11.0	19.2	16.9	23.2	16.4	8.9	10.5	7.7
Decade III	4.7	6.3	5.4	12.6	16.1	20.4	18.0	17.2	13.9	12.7	5.5	6.0
Monthly minimum	-0.8	2.7	2.7	3.9	7.0	9.9	13.7	14.9	11.6	7.7	-0.2	-0.4
Monthly maximum	11.5	12.9	11.1	15.9	19.3	25.1	23.7	27.2	21.7	15.4	16.6	11.6

Table 6 *Monthly precipitation for 2020 in mm, long-term averages, and days with rain categorised to quantities of precipitation (data from experimental farm, De Marke).*

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Tot**
Monthly total	41.6	94.6	49.6	7.8	10.6	48.0	43.2	53.8	51.2	80.8	30.8	88.0	600
Long term monthly average	67.1	55.7	55.3	40.3	55.4	64.2	80.5	84.8	67.1	64.7	63.6	76.3	775
Days with rain	23	23	12	6	9	15	19	20	13	24	18	25	207
Decade I	13.6	17.0	35.6	0.8	6.2	17.0	34.4	2.8	14.6	37.6	6.2	18.8	205
Days with rain	8	7	7	1	4	4	8	2	6	9	4	8	68
Decade II	12.8	32.8	13.4	2.0	1.4	19.2	7.2	23.6	0	6.2	11.8	17	147
Days with rain	8	8	4	2	2	7	6	7	0	5	8	7	64
Decade III	15.2	44.8	0.6	5.0	3.0	11.8	1.6	27.4	36.6	37	12.8	52.2	248
Days with rain	7	8	1	3	3	4	5	11	7	10	6	10	75
Days with rain													
0 mm	8	6	19	24	22	15	12	11	17	7	12	6	159
› 0 mm	23	23	12	6	9	15	19	20	13	24	18	25	207
› 1 mm	13	16	8	2	3	6	10	12	8	15	6	16	115
› 5 mm	1	6	5	0	0	4	3	3	3	5	2	7	39
› 10 mm	0	2	1	0	0	1	1	1	1	2	0	2	11

To combat drought, sprinkler irrigation was applied whenever there was a risk of soil moisture content decreasing below 10%.

3.2 Plant density

At harvest, a plant count yielded 93.8 thousand plants per ha (with a standard deviation of 3.8 thousand). The type of fertilising product or application rate had no effect on the number of plants (Figure 3).

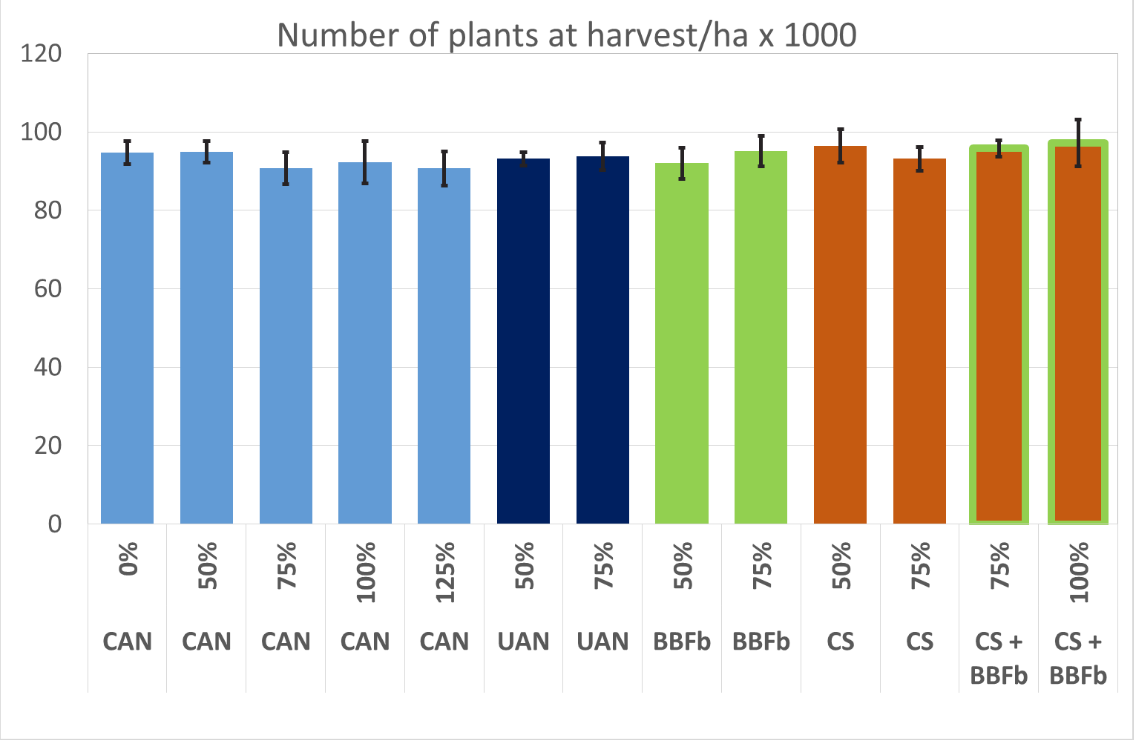

Figure 3 *Number of plants per ha at harvest (x 1000) for CAN, UAN, Cattle Slurry (CS), Biobased fertiliser basic (BBFb) and the combination Cattle Slurry with Biobased fertiliser basic (CS+BBFb) at application rates of nitrogen of 0%, 50%, 75%, 100% and 125%. Vertical bars represent standard deviations.*

3.3 Dry matter yield

Variation between repetitions was as large as (or larger than) differences between fertilising products and application rates (Figure 4). The dry matter yield was 14.7 tonne[32]/ha on average with a standard deviation of 2.0 t/ha. Dry matter yields varied from 13.3 t/ha for treatment CAN at rate of 0% to 15.8 t/ha for treatment CS at a rate of 50% (Figure 4). Neither application rate or fertilising product had a significant effect on dry matter yield. Comparison of dry matter yields of fertilising products at similar application rates showed no significant differences. All data are given in Annex 1.

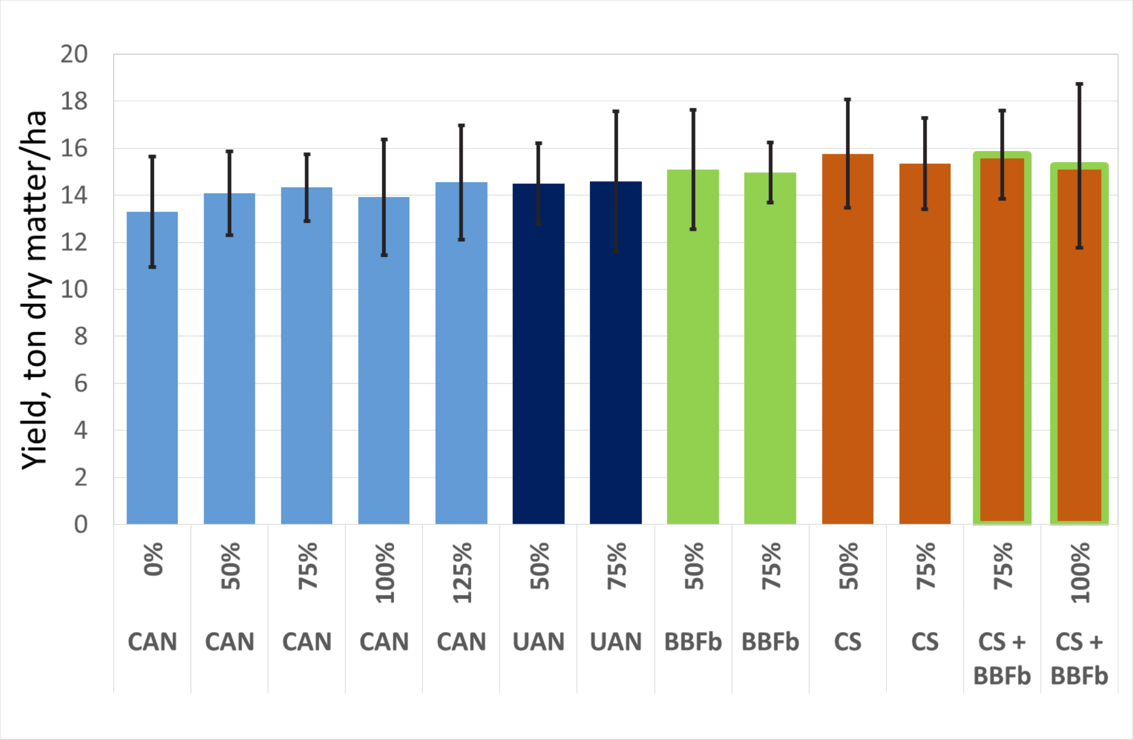

Figure 4 *Yield in t/ha for CAN, UAN, Cattle Slurry (CS), Biobased fertiliser basic (BBFb) and the combination with cattle slurry and BBFb. Codes 1, 2, 3, 4 and 5 at application rates of nitrogen of 0%, 50%, 75%, 100% and 125%. Vertical bars represent standard deviations.*

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[32] Metric ton

3.4 Nitrogen uptake and efficacy

3.4.1 Nitrogen uptake

Nitrogen uptake of the third repetition was higher than of the other two repetitions. On average, it was 180 kg N/ha, while the two other replicates averaged a nitrogen uptake of 130 kg N/ha. The differences between the replicates were similar to those between fertilising products and application rates.

Nitrogen uptake of the maize was 147 kg N/ha on average across all treatments and ranged from 111 kg N/ha to 159 kg N/ha. Without nitrogen application (0 kg N/ha), the maize nitrogen uptake was 111 kg N/ha, which was significantly lower than the uptake from the treatments with nitrogen fertilisation. Other differences between fertilising products and application rates were not significant, and neither was their interaction (Figure 5).

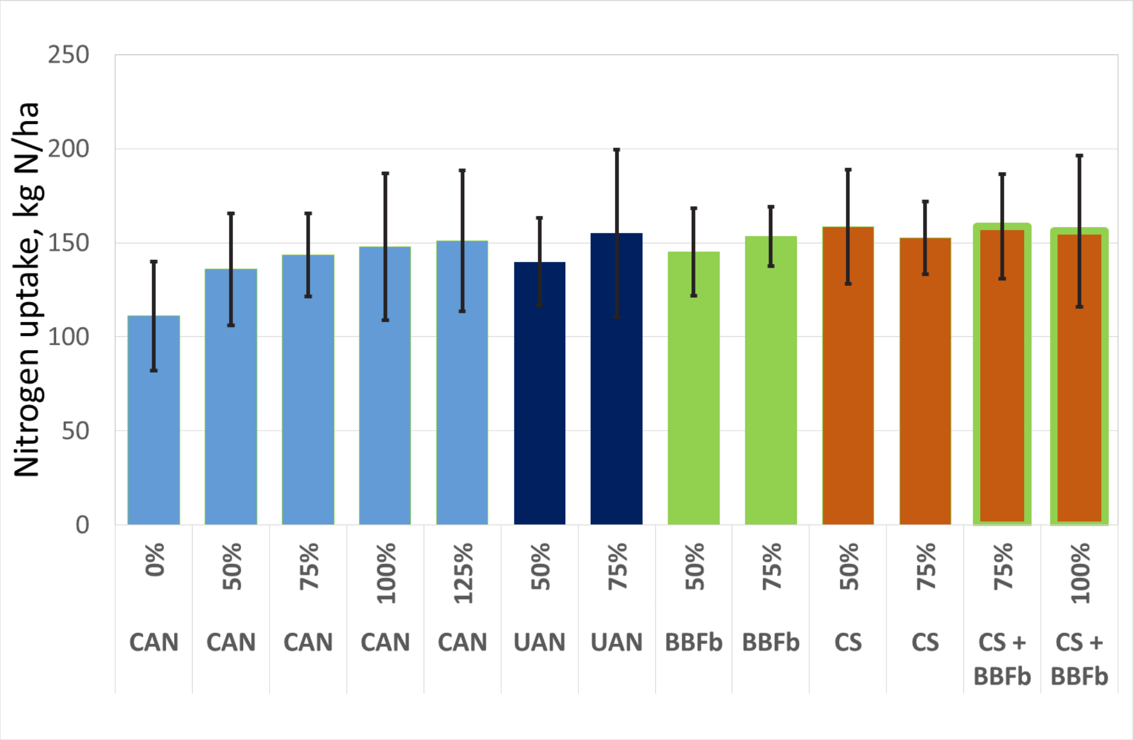

Figure 5 *Nitrogen uptake in kg N/ha for CAN, UAN, Cattle Slurry (CS), Biobased fertiliser basic (BBFb) and the combination of cattle slurry and BBFb (CS+BBFb) at application rates of nitrogen of 0%, 50%, 75%, 100% and 125%. Vertical bars represent standard deviation.*

3.4.2 Efficacy

In this report, efficacy of nitrogen has been expressed as Nitrogen Use Efficiency (NUE) and Nitrogen Fertiliser Replacement Value (NFRV).

3.4.2.1 Nitrogen Use Efficiency (NUE)

NUE varied from 17% for application CAN at a 125% application rate to 45% for application of CS at a 50% rate (Table 7). NUE declined significantly with an increase of the nitrogen application rate. The results for CAN clearly show this decline. At 50% of the optimum application NUE was 27% and at the application rate of 125% it was 17%. Within treatments, variation of NUE was relatively large, which is reflected in the large value of the LSD. Hence, no significant differences between the fertilising products were found with the exemption of the NUE for CS 50%, which was significantly larger than other fertilising products and application rates.

Table 7 *Nitrogen use efficiency in percent (%) of CAN, UAN, CS, BBFb and CS+BBFb (100% = 186 kg N/ha).*

Fertilising product	Application rate				LSD
	50%	75%	100%	125%	(5%)
CAN	27	23	20	17	11
UAN	31	31	*	*	
CS	45	27	*	*	
BBFb	39	33	*	*	
CS+BBFb	*	36	23	*	

3.4.2.2 Nitrogen Fertiliser Replacement Value (NFRV)

NFRV was calculated according to the equation [2] of Paragraph 2.8 per level of application rates. NFRV was calculated for each fertilising product per application rate with CAN as reference fertiliser (Table 8). Standard errors of means (SE) were pooled based on SE of nitrogen uptake of the reference fertiliser CAN and the SE of the fertilising product treatment.

Table 8 *Mean values with their standard error between brackets (SE[33]) for Nitrogen fertiliser replacement value (NFRV) in percent (%) for CAN, UAN, CS, BBFb and CS+BBFb per application rate (100%=186 kg N/ha). CAN served as the reference nitrogen fertiliser.*

Fertilising product	Application rate		
	50%	75%	100%
CAN	100 (0.9)	100 (7.0)	100 (9.9)
UAN	114 (9.1)	134 (12.6)	*
CS	169 (9.3)	114 (11.3)	*
BBFb	147 (6.5)	140 (11.2)	*
CS+BBFb	*	154 (5.0)	114 (9.3)

Based on SE a confidence interval can be calculated. SE values were in the range of 1 – 13%. At an application rate of 50%, NFRV values of CS and BBFb were significantly higher compared to CAN. At an application rate of 75% BBFb, CS+BBFb and UAN were significantly higher.

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[33] Confidence interval can be estimated Mean value ± t x SE with a Student-t value 2.78 (n = 4).

3.5 Soil mineral nitrogen

3.5.1 Soil mineral nitrogen at start and after harvest

At the start of the field experiment, the soil layers of 0–30 cm, 30–60 cm and 60–90 cm depths contained respectively 19, 10 and 2 kg mineral N/ha on average (Table 9) amounting to a total of 31 kg N/ha in the 0-90 cm depth soil layer. Nitrogen stocks in Repetition 3 were 6–8 kg N/ha higher than in the other two repetitions at the start of the experiment. At the start of the experimental period, some differences in soil mineral nitrogen within a treatment of a fertilising product were found (Table 9). On average however, there were no significant differences in the stock of mineral soil nitrogen among the fertilising products. All data are given in Annex 2.

After the harvest, the stock of soil mineral nitrogen was significantly different between fertilising product treatments and application rates (Table 9). An increase in application rate of CAN resulted in an increase of the stock of soil mineral N. Application rates of 0%, 100% and 125% were significantly different from each other. Without nitrogen fertilisation (0 kg N/ha) the soil layer of 0–30 cm depth and the soil layer of 0–90 cm depth had a significantly lower stock of mineral nitrogen after harvest in October than in April compared to 100% or 125%. The treatment of CAN 100% had a significant lower stock of mineral nitrogen compared to CAN 125%. For others, application rates of CAN, although the soil mineral nitrogen stock increased with higher application rates, no statistically significant difference was found. Treatments with CAN and UAN tended to have a lower stock of mineral nitrogen in the soil layer of 0–90 cm depth compared to BBFb, CS and the combination of CS+BBFb, although these were not significantly different. The treatment with CS+BBFb 100% had a significant higher stock of soil mineral nitrogen higher than CAN 100% and UAN 100%. Other fertilising treatments were not significantly different.

Application rates of UAN had no significant effect on soil mineral N.

3.5.2 Nitrogen balance sheet

Silage maize without nitrogen fertilisation (0 kg N/ha) had a nitrogen uptake of 111 kg N/ha (Figure 5). At the start of the field experiment, the soil layer of 0–90 cm depth contained 27 kg N/ha and after harvest 62 kg N/ha. This points towards a contribution of soil organic nitrogen to maize nitrogen uptake of 111 + (62 – 27) = 146 kg N/ha.

The difference between the stock of soil mineral nitrogen after harvest and the quantity present at the start, plus the nitrogen uptake by silage maize, minus the nitrogen application rate is an indicator for the contribution of the soil (Table 10). This is a simple form of a partial soil nitrogen balance sheet and ignores losses through ammonia volatilisation and denitrification.

The calculated contributions from soil organic nitrogen were not significantly different between treatments with fertilising products at similar application rates.

The simple nitrogen balance sheet shows that the soil contributed substantial amounts of nitrogen to the nutrition of silage maize and to the stock of mineral nitrogen after harvest. This was also found for the 2019 field experiment with silage maize, which was also carried out during a period of drought. As per 2019, sprinkler irrigation had to be used in 2020 to combat the drought. The effect of sprinkler irrigation in combination with elevated temperatures is thought to have accelerated soil organic nitrogen mineralisation. The contribution of soil organic nitrogen at CAN 0% is equal to the application standard of 140 kg N/ha, which may explain the absence of significant effects of increasing application rates on yield, nitrogen uptake.

Table 9 *Mean values for the quantity of mineral soil nitrogen in kg N/ha in soil layers of 0–30 cm, 30–60 cm and 60–90 cm depth before the start of the field experiment in April and after the harvest of silage maize in October for fertilising products CAN, UAN, CS, BBFb and CS+BBFb per application rate (100% = 140 kg N/ha).*

Product	**Soil layer. cm**	**April**					**Oct. 0%**				
		0%	**50%**	**75%**	**100%**	**125%**		**50%**	**75%**	**100%**	**125%**
CAN	0 - 30	16	17	17	25	21	34	44	58	78	114
	30 - 60	9	10	6	12	10	17	35	46	59	96
	60 - 90	2	2	1	2	2	11	10	20	9	11
	0 - 90	27	29	24	39	33	62	89	124	146	221
UAN	0 - 30	*	18	18	*	*	*	63	55	*	*
	30 - 60	*	10	9	*	*	*	37	38	*	*
	60 - 90	*	2	2	*	*	*	6	8	*	*
	0 - 90	*	30	29	*	*	*	107	101	*	*
CS	0 - 30	*	23	14	*	*	*	46	87	*	*
	30 - 60	*	12	9	*	*	*	33	55	*	*
	60 - 90	*	2	2	*	*	*	5	8	*	*
	0 - 90	*	37	25	*	*	*	83	150	*	*
BBFb	0 - 30	*	17	23	*	*	*	57	89	*	*
	30 - 60	*	9	16	*	*	*	38	58	*	*
	60 - 90	*	2	2	*	*	*	5	8	*	*
	0 - 90	*	27	41	*	*	*	99	156	*	*
CS+BBFb	0 - 30	*	*	18	18	*	*	*	71	110	*
	30 - 60	*	*	10	10	*	*	*	48	64	*
	60 - 90	*	*	2	2	*	*	*	9	12	*
	0 - 90	*	*	29	30	*	*	*	128	187	*
LSD (α=0.05) Per sampling	0 - 30			6					23		
	30 - 60			4					16		
	60 - 90			1					13		
	0 - 90			7					40		
LSD (α=0.05) between sampling times	0 - 30						17				
	30 - 60						14				
	60 - 90						9				
	0 - 90						41				

Table 10 *Mean values the contribution of the soil to crops nutrition in kg N/ha for CAN, UAN, CS, BBFb and CS+BBFb per application rate (100% = 186 kg N/ha) based on a simple nitrogen balance sheet.*

Fertilising product	**Application rate.**				
	0%	**50%**	**75%**	**100%**	**125%**
CAN	146	103	103	69	107
UAN	*	123	86	*	*
CS	*	100	121	*	*
BBFb	*	131	139	*	*
CS+BBFb	*	*	125	114	*
LSD (α = 0.05)	43				

4 Evaluation and conclusions

Biobased fertilising products can be tailored to crop requirements through the addition of extra nitrogen and/or sulphur sources to optimise N/S ratios. In 2020, sources of these nutrients were ammonium sulphate from ammonium stripping of air from a compositing process of sewage sludge, urea or a mixture of urea and ammonium nitrate (UAN, or '*Urean' in Dutch*). In this study, a basic type of tailored biobased fertilising products that consisted of 99% mineral concentrate and 1% UAN was tested in a field experiment with silage maize. The current field experiment served two objectives and working hypotheses which have been given in the introduction to this report. These objectives and hypotheses were tested in 2020 in a field experiment with silage maize grown on a sandy soil.

As in 2019, the climatic conditions in 2020 were dry with elevated temperatures, which made sprinkler irrigation necessary.

Number of plants at harvest
The type of fertilising product used in the trial conducted in 2020 had no effect on the number of plants at harvest.

Yield
Significant effects of fertilising products and application rates were not found. The lack of a response in dry matter yield of silage maize was attributed to the climatic conditions with elevated temperatures and sprinkler irrigation that led to a supply of nitrogen for organic soil nitrogen sources. Without nitrogen fertilisation (CAN 0%), a contribution of soil organic nitrogen of 146 kg N/ha was calculated, which is lower compared to the optimum nitrogen application rate (186 kg N/ha) but meets the regulatory application standard of 140 kg N/ha. The supply by the soil was high and equalled the average nitrogen uptake. This supply most likely caused the poor response of silage maize on nitrogen fertilisation.

Nitrogen uptake
Nitrogen uptake of the whole plant was on average 147 kg N/ha and ranged from 111 to 159 kg N/ha. Without nitrogen application (0 kg N/ha), the nitrogen uptake was 111 kg N/ha which is significantly lower than the uptake from the treatments with nitrogen fertilisation, but differences between fertilising products and other application rates were not significant (Figure 5). Again, this is attributed to the supply of nitrogen by the soil.

NUE
Nitrogen Use Efficiency (NUE) values varied from 17% to 27% (Table 7). With an increase of the nitrogen application rate (for CAN), NUE declined. Due to the large variation in NUE, no significant differences between the fertilising products were found with the exception of CS 50%, which was significantly larger than other fertilising products and application rates. Variation between the replicates was found: the third replicate had a much higher nitrogen uptake and a higher nitrogen contribution of the soil, which coincides with a slightly higher soil mineral nitrogen stock measured at the start of the experiment.

NFRV
Nitrogen Fertiliser Replacement Value (NFRV) was calculated for each fertilising product per application rate with CAN as reference fertiliser (Table 8). At an application rate of 50% NFRV values of CS and BBFb were significantly higher compared to CAN. At an application rate of 75% BBFb, CS+BBFb and UAN were significantly higher. CAN was used as reference fertiliser and was broadcasted on the soil surface, whereas CS and BBFb were both injected near the seed of silage maize, thus, acting as a form of row placement. The nutrients applied in a row were placed deeper (~12-15 cm) in the soil which made them less vulnerable to drought and nearer to the developing roots of silage maize. Row placement can also prevent emission of ammonia. Results of the NFRV indicated that the method of application of a fertilising product combined with sprinkler irrigation may have had a beneficial effect.

Stock of soil mineral nitrogen

At the start, the total amount of mineral nitrogen in the soil layer of 0–90 cm depth was on average 31 kg N/ha and after the harvest 127 kg N/ha averaged over all treatments. After the harvest, soil mineral nitrogen was significantly different between application rates and increased with increasing application rates ranging from 62 to 221 kg N/ha in the soil layer of 0–90 cm depth (Table 9). Without nitrogen fertilisation (0 kg N/ha) the soil layer of 0–90 cm depth had at the start 27 kg mineral N/ha, whereas after the harvest, 62 kg N/ha was measured, indicating a contribution of mineralisation of soil organic nitrogen that was not used by the crop. Per application rate differences between fertilising products were not significant, which points to other (climatic) conditions determining the stock of mineral nitrogen than the fertilising product.

Nitrogen balance sheet

A simple nitrogen balance sheet based on the stocks of mineral nitrogen at start of the field experiment before fertilisation, nitrogen application rate, nitrogen uptake by silage maize and the stock of mineral nitrogen after harvest showed effects of fertilising products and application rates, but above all, the effect of contribution of nitrogen from the soil due to drought combined with sprinkler irrigation. Fertiliser treatments followed the ranking:
BBFb > CS+BBFb > CS > CAN ~ UAN. With an increase of the application rate, the contribution of the soil decreased.

In conclusion

In this second field experiment conducted on a sandy soil of the experimental farm, De Marke, in 2020, the effect of a biobased fertilising product on maize yield, nitrogen uptake and residual nitrogen from fertilising products on soil nitrogen cycling was studied. The year 2020 was a third consecutive year of drought in the Achterhoek region, which again was combined with elevated temperatures. The drought was severe and made sprinkler irrigation necessary. The consequence of sprinkler irrigation and elevated temperatures was that the mineralisation of soil organic nitrogen was stimulated to an extent to which the quantity of mineralised nitrogen already roughly met fertilisation criteria for optimal nitrogen fertilisation of silage maize. Treatments with CS and BBFb effectively showed higher nitrogen uptake efficiency compared to the reference fertiliser, CAN. It is assumed that was caused by the method of application (row placement of CS and BBFb vs. broadcasting (blanket sheet dressing) of CAN) combined with effects of sprinkler irrigation to combat effects of drought.

Furthermore, under the conditions of drought and a significant contribution of nitrogen from the soil, the possible effects of nitrogen addition from fertilising products were more difficult to detect.

Stocks of soil mineral nitrogen after the harvest of silage maize were affected by application rate but not by the fertilising product when comparing same application rates. The higher the application rate, the higher the stock of mineral N. This field experiment shows that biobased nitrogen fertilising products have a similar risk of nitrogen leaching as CAN at similar application rates.

5 Acknowledgements

Biobased fertilising products were produced by Groot Zevert Vergisting (GZV) B.V. in Beltrum, the Netherlands. We thank Arjan Prinsen. Sander Bruil and Roel Beunk for the production. The application of these fertilising product was made possible by Bert Ebbekink of Slootsmid in joint cooperation with Evert Jan Haalboom, Andries Siepel and John van der Lippe of WUR Unifarm. Gerjan Hilhorst and Zwier van der Vegte are gratefully thanked for their supervision of the experimental field at the experimental farm, De Marke, in Hengelo (Gelderland) the Netherlands.

References

Commissie Bemesting Grasland en Voedergewassen (CBGV). 2020. Bemestingsadvies. version 2019. c/o Wageningen Livestock Research. Postbus 338. 6700 AH Wageningen. E-mail webmaster.asg@wur.nl. Internet http://www.bemestingsadvies.nl

Dobermann. A.. 2007. Nutrient use efficiency – measurement and management. In: Fertilizer Best Management Practices. General principles. strategy for their adopt ion and voluntary initiatives vs. regulations. International Fertilizer Industry Association IFA. Paris. France. 1-28. ISBN 2-9523139-2-X

Ehlert, P.A.I & J. van der Lippe, 2020a. Toetsing van de Groene Weide Meststof in de praktijk; Demovelden van de gebiedsgerichte pilot Kunstmestvrije Achterhoek, 2018. Wageningen, Wageningen Environmental Research, Rapport 3007. https://edepot.wur.nl/522575

Ehlert, P.A.I & J. van der Lippe, 2020b. Toetsing van de Groene Weide Meststof in de praktijk; Demovelden van de gebiedsgerichte pilot Kunstmestvrije Achterhoek, 2019. Wageningen, Wageningen Environmental Research, Rapport 3034. https://edepot.wur.nl/532700

Ehlert, P.A.I., 2020. Agronomic efficacy of nitrogen biobased fertilising products of co-digested pig manure. Field experiment with silage maize 2019. Wageningen. Wageningen Environmental Research, report 3033, https://edepot.wur.nl/532699

Huygens. Dries. Glenn Orveillon. Emanuele Lugato. Simona Tavazzi. Sara Comero. Arwyn Jones. Bernd Gawlik & Hans Saveyn. 2020. SAFEMANURE - Developing criteria for safe use of processed manure in Nitrates Vulnerable Zones above the threshold established by the Nitrates Directive. Final Report. European Commission DG Joint Research Centre (JRC) September 2020.

Jensen. L.S.. 2013. Animal manure fertiliser value. crop utilization and soil quality impacts. In: Sommer. S.G.. M.L. Christensen. T. Schimdit & L.S. Jensen (deds). Animal manure recycling: treatment and management. Wiley. Chichester.

Schröder. J.. 2005. Revisiting the agronomic benefits of manure: a correct assessment and exploitation of its fertilizer value spares the environment. Bioresource Technology 96: 253-261. https://doi.org:10.1016/j.biortech.2004.05.015.

Schröder. W. De Visser. F.B.T. Assinck. G.L. Velthof. W. Van Geel. & W. van Dijk. 2014. Nitrogen Fertilizer replacement Value of the Liquid Fraction of Separated Livestock Slurries Applied to Potatoes and Silage Maize. Communications in Soil Science and Plant Analysis. 45:1. 73-85. https://doi.org/10.1080/00103624.2013.848881.

Van Grinsven Hans J.M.. Aaldrik Tiktak. Carin W. Rougoor. 2016. Review. Evaluation of the Dutch implementation of the nitrates directive. the water framework directive and the national emission ceilings directive. NJAS - Wageningen Journal of Life Sciences. 78: 69-84. https://doi.org/10.1016/j.njas.2016.03.010

VSN International (2019). Genstat *for Windows* 20th Edition. VSN International. Hemel Hempstead. UK. Web page: Genstat.co.uk.

Annex 1 Yield data and chemical composition of crop

Column	Parameter	Unit
1	Field	*
2	Fertilising product	*
3	Code application rate	*
4	Repetition	*
5	N application rate	kg N/ha
6	Count plants	plants/ha
7	Yield	tonne fresh/ha
8	Yield	tonne dry matter (DM)/ha
9	N-total	g N/kg DM
10	P-total	g P/kg DM
11	K-total	g K/kg DM
12	N-uptake	kg N/ha
13	P-uptake	kg P/ha
14	K-uptake	kg K/ha

1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	BBFb	2	1	86	96000	40.00	14.81	8.77	1.15	11.22	130	17	166
2	CS	2	1	105	93333	40.67	14.49	9.07	1.08	10.60	131	16	154
3	CAN	1	1	0	93333	32.67	12.56	7.56	1.14	8.78	95	14	110
4	UAN	3	1	141	96667	36.67	13.64	9.78	1.15	10.09	134	16	138
5	UAN	2	1	94	91333	35.33	13.55	8.97	1.13	9.08	122	15	123
6	CAN	4	1	186	98000	37.33	14.18	9.89	1.33	9.99	140	19	142
7	CS-BBFb	4	1	199	93333	40.00	14.68	9.81	1.23	10.32	144	18	151
8	CAN	3	1	139	88667	36.67	13.64	9.37	1.18	10.29	128	16	140
9	CAN	2	1	93	97333	38.00	13.95	8.54	1.07	9.46	119	15	132
10	CS	3	1	157	90000	38.67	13.62	9.70	1.38	10.21	132	19	139
11	BBFb	3	1	129	90667	40.67	15.03	9.98	1.31	9.07	150	20	136
12	CS-BBFb	3	1	133	94000	40.67	15.13	9.47	1.29	10.18	143	20	154
13	CAN	5	1	232	94667	40.00	14.82	9.18	1.14	9.08	136	17	134
14	CAN	5	2	232	91333	30.67	12.01	10.29	1.34	9.98	124	16	120
15	CAN	2	2	93	95333	32.00	12.36	9.58	1.20	9.38	118	15	116
16	CS-BBFb	3	2	133	95333	36.67	14.23	9.98	1.22	10.90	142	17	155
17	CS	3	2	157	96000	38.00	14.97	10.40	1.31	11.01	156	20	165
18	CAN	3	2	139	95333	35.33	13.39	10.00	1.08	10.72	134	14	143
19	UAN	2	2	94	94667	32.67	13.46	9.79	1.19	8.98	132	16	121
20	CS-BBFb	4	2	199	94000	31.33	12.08	10.21	1.21	10.00	123	15	121
21	CAN	4	2	186	91333	30.67	11.32	10.01	1.13	10.52	113	13	119
22	CS	2	2	105	94667	36.00	14.37	10.62	1.32	9.60	153	19	138
23	BBFb	3	2	129	98000	35.33	13.66	10.20	1.17	10.50	139	16	143
24	UAN	3	2	141	94667	33.33	12.19	10.28	1.11	11.09	125	14	135
25	BBFb	2	2	86	88000	33.33	12.72	10.50	1.26	10.40	134	16	132
26	CAN	1	2	0	98000	30.00	11.39	8.24	1.15	10.68	94	13	122
27	CAN	3	3	139	88000	38.67	15.95	10.58	1.33	9.67	169	21	154
28	CAN	1	3	0	92667	40.00	15.92	9.08	1.43	9.59	145	23	153
29	CAN	4	3	186	87333	44.00	16.23	11.72	1.57	10.40	190	25	169
30	CS	2	3	105	101333	48.00	18.42	10.39	1.35	9.98	191	25	184
31	CAN	5	3	232	86000	45.33	16.84	11.50	1.41	10.28	194	24	173
32	BBFb	3	3	129	96667	46.00	16.20	10.52	1.35	10.11	170	22	164
33	CS-BBFb	3	3	133	98000	47.33	17.84	10.70	1.39	9.48	191	25	169
34	CAN	2	3	93	92000	42.00	15.93	10.69	1.49	8.86	170	24	141
35	UAN	3	3	141	90000	43.33	17.91	11.51	1.54	7.64	206	28	137
36	UAN	2	3	94	93333	44.67	16.47	10.08	1.34	9.98	166	22	164
37	CS-BBFb	4	3	199	104000	50.67	18.99	10.59	1.52	9.47	201	29	180
38	CS	3	3	157	93333	48.00	17.44	9.76	1.49	9.97	170	26	174
39	BBFb	2	3	86	92000	44.67	17.76	9.67	1.52	9.77	172	27	173

Annex 2 Mineral nitrogen in soil

Column	Parameter
1	Field
2	Fertilising product
3	Code application rate
4	Repetition
5	N application. kg N/ha
6	Layer of 0 - 30 cm depth Spring, kg N/ha
7	Layer of 0 - 30 cm depth Autumn, kg N/ha
8	Layer of 30 - 60 cm depth Spring, kg N/ha
9	Layer of 30 - 60 cm depth Autumn, kg N/ha
10	Layer of 60 - 90 cm depth Spring, kg N/ha
11	Layer of 60 - 90 cm depth Autumn, kg N/ha
12	Layer of 0 - 90 cm depth Spring, kg N/ha
13	Layer of 0 - 90 cm Autumn, kg N/ha

1	2	3	4	5	6	7	8	9	10	11	12	13
1	BBFb	2	1	86	15.8	51.1	7.5	37.7	2.6	5.3	25.9	94.1
2	CS	2	1	105	23.9	37.8	14.0	25.6	2.2	3.5	40.2	66.9
3	CAN	1	1	0	19.2	38.3	7.8	2.9	1.8	22.1	28.8	63.3
4	UAN	3	1	141	19.5	48.5	8.2	31.8	1.8	3.1	29.5	83.4
5	UAN	2	1	94	23.6	70.8	7.8	49.6	1.3	4.9	32.7	125.3
6	CAN	4	1	186	18.2	77.0	13.1	47.8	1.8	4.0	33.1	128.8
7	CS-BBFb	4	1	199	15.2	81.9	6.8	50.7	0.9	6.2	23.0	138.8
8	CAN	3	1	139	17.6	53.9	7.3	48.2	1.8	3.5	26.7	105.6
9	CAN	2	1	93	19.8	52.9	10.5	32.4	1.3	2.6	31.7	88.0
10	CS	3	1	157	11.8	69.7	9.2	58.4	1.3	6.6	22.3	134.7
11	BBFb	3	1	129	20.3	89.5	11.4	44.3	2.2	3.5	33.9	137.3
12	CS-BBFb	3	1	133	16.2	58.8	8.7	34.8	1.3	3.5	26.3	97.2
13	CAN	5	1	232	16.5	117.7	8.3	82.4	1.3	5.3	26.2	205.3
14	CAN	5	2	232	19.9	103.6	6.7	101.6	2.2	12.5	28.8	217.7
15	CAN	2	2	93	15.7	42.1	5.9	40.7	1.3	8.5	22.9	91.3
16	CS-BBFb	3	2	133	21.1	50.8	7.1	37.5	1.3	4.9	29.5	93.2
17	CS	3	2	157	14.2	58.0	7.8	40.7	1.3	6.2	23.3	104.9
18	CAN	3	2	139	15.4	55.6	5.0	54.4	1.3	53.4	21.7	163.5
19	UAN	2	2	94	11.9	73.3	5.4	34.9	1.3	5.8	18.6	113.9
20	CS-BBFb	4	2	199	16.2	123.9	8.6	76.9	1.8	14.6	26.6	215.4
21	CAN	4	2	186	35.5	51.3	10.7	46.2	2.7	15.6	48.9	113.1
22	CS	2	2	105	18.9	49.4	8.8	34.1	2.2	4.0	29.9	87.5
23	BBFb	3	2	129	22.5	78.1	12.7	59.2	2.2	5.3	37.5	142.7
24	UAN	3	2	141	17.4	66.9	8.7	47.4	1.8	7.1	27.9	121.4
25	BBFb	2	2	86	16.5	60.0	10.6	40.4	1.8	5.3	28.8	105.7
26	CAN	1	2	0	11.8	30.4	7.1	23.0	1.3	6.7	20.3	60.1
27	CAN	3	3	139	16.6	63.2	6.2	36.2	1.3	2.2	24.1	101.6
28	CAN	1	3	0	17.5	33.5	12.5	26.1	2.1	3.4	32.1	63.0
29	CAN	4	3	186	21.7	105.9	12.4	82.0	1.3	7.7	35.4	195.6
30	CS	2	3	105	26.5	51.1	13.4	38.4	1.3	6.4	41.2	95.8
31	CAN	5	3	232	25.5	121.4	15.7	103.8	3.3	14.9	44.5	240.1
32	BBFb	3	3	129	25.6	99.2	23.1	71.7	2.5	16.3	51.2	187.2
33	CS-BBFb	3	3	133	16.1	103.0	13.0	73.0	2.1	17.1	31.3	193.2
34	CAN	2	3	93	15.5	36.5	13.3	31.4	3.2	18.6	32.1	86.5
35	UAN	3	3	141	16.3	48.9	10.4	35.5	3.3	14.1	30.0	98.5
36	UAN	2	3	94	17.8	45.7	17.1	27.8	3.3	8.2	38.2	81.7
37	CS-BBFb	4	3	199	22.6	125.7	15.5	64.8	2.8	15.9	41.0	206.4
38	CS	3	3	157	17.4	133.9	10.3	65.5	2.5	12.0	30.2	211.4
39	BBFb	2	3	86	18.0	59.0	7.8	34.6	1.7	4.2	27.5	97.8

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Report 3174
ISSN 1566-7197

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Report 3174
ISSN 1566-7197

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