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

Field Experiment Grassland 2021

Phillip Ehlert

WAGENINGEN UNIVERSITY & RESEARCH

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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 geproduceerd uit co-vergiste varkensmest. 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 tweede veldproef op grasland die in 2021 werd uitgevoerd op het proefbedrijf De Marke. De agronomische effectiviteit van de biogebaseerde stikstof meststof was vergelijkbaar met die van kalkammonsalpeter.

The aim of the project Biobased Fertilisers Achterhoek ('Kunstmestvrije Achterhoek' in *Dutch*) was to make fertilisation practices more sustainable through use of locally available nutrients that are derived 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 that are 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 which included field experiments carried out on grassland and on arable land with silage maize. This document reports the results of a second field experiment on grassland which was conducted in 2021. These results have indicated that the biobased nitrogen fertilisers tested could serve as a replacement for mineral nitrogen fertiliser.

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

The pdf file is free of charge and can be downloaded at https://doi.org/10.18174/572799 or via the website www.wur.nl/environmental-research (scroll down to Publications – Wageningen Environmental Research reports). Wageningen Environmental Research does not deliver printed versions of the Wageningen Environmental Research reports.

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Photo cover: Overview of the field experiment on grassland of the dairy farm at Wageningen

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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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Summary

The overarching objective of the Biobased Fertiliser Achterhoek regional pilot (KunstmestVrije Achterhoek (KVA) pilot in *Dutch*) was to make fertilisation practices more sustainable by supplying the nitrogen, potash and sulphur required for fertilisation through fertiliser products derived from regionally recycled resources as far as possible. The pilot is part of the Sixth Action Programme of the Netherlands which serves the Nitrates Directive. A monitoring programme was set up by Wageningen Environmental Research (WENR) as part of the pilot with two main objectives. These were to explore the:

1. Agronomic effectivity through determination of the nitrogen fertiliser replacement value (NFRV) of nitrogen of biobased fertilisers (BBF) made from co-digested animal manure mixed with a liquid blend of urea and ammonium nitrate (UAN, '*Urean' in Dutch*), and
2. Environmental risk to assess the risk of leaching of nitrogen from these biobased fertilising products.

The monitoring programme started in 2019 with a field experiment carried out on silage maize that was grown on a sandy arable soil. In 2020, two field experiments were conducted. One field experiment was conducted with silage maize as test crop and a second field experiment was conducted on grassland. Both were carried out on sandy soils as a substrate. This document reports a second field experiment on grassland which was conducted in 2021. The biobased fertilising product used in the 2021 for the field trial consisted of 99% mineral concentrate enriched with 1% liquid fertiliser, with 20% N based on urea and ammonium nitrate (UAN, called '*Urean' in Dutch*). Nitrogen in this BBF originated roughly 75% from digestate and 25% from UAN. This product is referred to as BBF-basic (BBFb). These objectives were elaborated in the following three hypotheses:

1. The magnitude of NFRV depends upon the reference N fertiliser that is used.
2. Biobased fertilising products have a similar magnitude of NFRV as the reference fertiliser.
3. Biobased fertilising products have a similar effect on residual nitrogen after the harvest of the last cut of grass as a regular nitrogen fertiliser (reference) at similar application rates.

It was planned to test the basic form of the biobased fertiliser (BBFb). After fertilisation of the first cut, the enriched type of biobased fertiliser (BBF+) was applied. BBF+ is based on 96% mineral concentrate, 2.5% liquid ammonium sulphate from an air washer, and 1.5% UAN. Nitrogen in this BBF+ originated roughly 70% from renewable sources mineral concentrate and liquid ammonium sulphate and 30% from UAN. For the subsequent cuts, the basic form of BBF was tested as there was no need for additional fertilisation with sulphur.

Due to an erroneous fertilisation practice used before the fourth cut of the grass, this report provides the results on agronomic effectivity of the first three cuts of grass only. Residual nitrogen of the fertilising products was affected by this erroneous fertilisation practice and was, therefore, not measured. Therefore, the third objective could not be tested.

For the first cut, the enriched BBF caused a slightly higher nitrogen application rate than planned. Overall, the effect of extra nitrogen on the first cut was modest (6-8 kg N/ha extra, Table 1). This was balanced by the lower nitrogen application rates associated with BBFb for the second cut (10-16 kg N/ha). The latter was caused by a difference in composition of batches of mineral concentrates used to produce BBFb.

Yield

The climatic conditions were favourable for grass growth. Due to the wet conditions during the growth of the first cut, the harvest had to be postponed until a suitable dry period. This led to about 1.5 to 2 times higher yield than was targeted for (i.e. 3.5 tonnes[1] dry matter/ha). Higher yields of first cuts were seen on many dairy farms in the Netherlands during 2021. As Cuts Two and Three had considerably lower yields than Cut One, the enriched type of biobased fertiliser (BBF+) dominated total yield. Therefore, the results were not conclusive only for BBFb, but also for the combination of BBF+ and BBFb.

[1] Metric ton

Grass responded well to nitrogen fertilisation. The yield increase diminished with increasing application rates of nitrogen, and thus, followed the law of the diminishing returns. BBF+/BBFb and CAN had, in general, comparable dry matter yields. For the first-, and highest yielding cut, there were no differences found between CAN, UAN or BBF+. UAF yielded lower than CAN for the second- and third cuts but not compared with BBFb. It is not clear what caused this difference between UAF and CAN.

CS had the lowest yields followed by the combination of CS+BBF+/BBFb, which were not significantly different with exception of the second cut, from which yields of BBFb were lower.

Nitrogen uptake

Fertilisation with nitrogen led to an increase of nitrogen uptake per cut and the totals of all three cuts following the law of diminishing returns.

For the first cut CAN, UAN and BBF+ showed similar nitrogen uptake, but for the second- and third cuts, UAN had lower uptakes which coincides with a lower dry matter yield. For BBFb, the nitrogen uptake of the second cut (75%) was significantly lower than CAN which would have been caused by the lower nitrogen application rate than targeted for (10-16 kg N/ha).

CS showed significant lower nitrogen uptake for Cut One, Two and total uptake. The combination of CS+BBF+/BBFb had uptakes between CS (lower) and BBFb (higher).

Fertilising products with comparable shares of mineral nitrogen showed similar performance. An increase in organically bound nitrogen in a fertilising product (CS and combinations of CS and BBF+ or BBFb) lowered nitrogen uptake.

NUE

NUEs are based on the actual given nitrogen fertilisation and, thus, take into account actual application rates. In general, NUE decreases with an increase in fertiliser application rate, thus, the efficiency reduces with increased application rate of nitrogen.

The effects are large for the first cut and total of three cuts, but rather modest and non-significant effects were found for the second- and third cuts. The high values for NUE for the first cut were caused by the high yields achieved with a prolonged growing period. The NUE of the treatment CAS 50% indicates a virtually complete use of applied nitrogen.

UAN had lower NUEs compared to CAN (Cuts Two, Three and total). In general, BBF+ (first cut) and BBFb (Cuts Two and Three) had similar NUEs compared with CAN. CAN and BBF+ and BBFb had higher NUE values for the first two cuts and total of three cuts compared to CS and the combination of CS and BBF+/BBFb (all cuts and total).

NFRV

The yield of the first cut was normative due to the high yield compared to yields of the second cut and third cut. With this as a focus, overall CS and the combination of CS+BBF+(first cut) and CS+BBFb (following cuts) performed less well than UAN, BBF+/BBFb and CAN. BBF+/BBFb and CAN had comparable efficiencies of nitrogen use and BBFb, thus, a comparable NFRV. NFRV of UAN was similar for the first cut but was lower for the following cuts.

Overall, the fertilising products can be ranked as:
CAS ≥ BBF+(1st cut) & BBFb(2nd & 3rd cut) > UAN > CS+BBF+(1st cut) & BBFb (2nd & 3rd cut) > CS

In conclusion

In this second field experiment on a sandy grassland on a dairy farm near Wageningen which was conducted in 2021, the effect of a biobased fertilising product on grass yield (three cuts), N uptake, NUE and NFRV was tested. The climatic conditions were favourable for testing fertilising products.

An enriched biobased fertilising product (BBF+) was applied for the fertilisation of the first cut, although it had been planned to apply the basic type. The BBFb was applied for the following two cuts. Due to an error in application of a biobased fertilising product during fertilisation of the crop prior to the fourth cut, the field experiment was discontinued. The fourth and fifth cuts could not be harvested as originally planned and the residual effects of the fertilising products on mineral nitrogen in the soil after harvest could not be measured. The third hypothesis could not be tested.

CAN and UAN performed equally for the first cut, but the performances of UAN of the second- and third cuts were considerably lower than CAN or BBFb. The cause of this was not apparent. If UAN is used as reference fertiliser, the agronomic performance of CAN or BBF+/BBFb was better. The first hypothesis, thus, tested positive.

The results of this field experiment on grassland show a similar agronomic effectivity of BBF+/BBFb compared to CAS. CS had the lowest effectivity and the agronomic effectivity of the combination of CS+BBF+/BBFb was in between BBF+/BBFb and CAS (better) and CS (poorer). This confirmed the second hypothesis.

These results have indicated that BBF made of different compositions can serve as a replacement of mineral nitrogen fertiliser.

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 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 have been reviewed and promising technologies have been implemented in practice. Processing has enabled creation of new fertilising products. The project focused on the quality aspects of these new nitrogen (N)-fertilising products which are derived from animal manure, specifically on their nutrient levels (nitrogen, N; potassium, K and sulphur, S), the agronomic effectivity, the level of contaminants (such as heavy metals), organic micro-contaminants, pathogens and other contaminants (New Emerging Contaminants (NEC)). These fertilising products were monitored on composition, agronomic effectivity and environmental effects in pilots of the Sixth Action Programme. The aim at the start of the project was to produce products that meet the requirements of the revised EU fertilising products regulation for free trade EC/2019/1009 (which is currently focused on liquid inorganic NKS fertilising products: PFC1c). During the course of the project, this aim was revised and the focus became to meet the criteria that are set by JRC proposed RENURE[5] fertilising products within the context of the Nitrates Directive. The monitoring in this project makes 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 that have also been monitored for 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. The objectives were to:

- Inform, support, and facilitate local land users in their efforts to find circular solutions for manure- and mineral-related issues at their companies. Here, the knowledge from the various "manure projects" in the province was explicitly included.
- Identify the desired quality and composition of fertilising products for market use that are derived from animal manure and sludge using 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 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

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

WENR advised on desired product quality and product composition of fertilising products and assessed and monitored their agricultural effectiveness, as well as 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 that were conducted in 2019, 2020 and 2021.
3. Demonstration field trials that were 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 N fertilising products derived from animal manure within legal frameworks on use of animal manure and mineral fertilisers, it was important to gain 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 Regelink et al., 2021[8] and Sigurnjak et al. (2022, in prep.[9]).

The demonstration field trials[10], which constitute Point 3 of the monitoring programme, began in 2018. Results of the demonstration fields carried out in 2018, 2019 and 2020 have been reported (Ehlert & Van der Lippe, 2020a, 2020b; Ehlert et al., 2021). Monitoring of these demonstration field trails has ended.

Field experiments on arable land with silage maize were conducted in 2019 and 2020 and were reported (Ehlert, 2020 & 2022). In 2020, a field experiment on grassland was conducted and was followed by a second field experiment on grassland in 2021. This report provides results of the second field experiment of 2021.

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

[8] Regelink, I.C., J.L. van Puffelen, P.A.I. Ehlert _ O.F. Schoumans, 2021. Evaluatie van verwerkingsinstallaties voor mest en co-vergiste mest. Wageningen. Wageningen Environmental Research, rapport 3120. https://doi.org/10.18174/554452, https://edepot.wur.nl/554452

[9] 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.

[10] Demonstration field trials were established on ten grassland plots of dairy farms. The plots were split into two blocks one receiving 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 were based on soil testing. Grass yields were estimated by measuring grass height at 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 region 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 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 the field experiments of 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 is based on measurement of the actual batch. All experimental years, 2018, 2019 and 2020 were years with 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 experiment served two objectives. These were to investigate:

1. Agronomic effectivity through determining the nitrogen fertiliser replacement value (NFRV) of nitrogen of biobased fertilisers (BBF) made from co-digested animal manure mixed with a liquid blend of urea and ammonium nitrate (UAN, '*Urean'* in *Dutch*), and
2. Environmental risk through assessing the risk of leaching of nitrogen from these biobased fertilising products.

1.2 Hypotheses

Crop available N in this study was defined as the quantity of N that is released from a fertilising product during crop growth within a growing season. Commonly, this quantity is assessed by comparison of N uptake by a crop with N from a test-product amended plots with N uptake by the crop amended with mineral N fertiliser, while correcting for the quantity of N taken up from plots without N fertilisation. A parameter that expresses this quantity is the Nitrogen Fertiliser Replacement Value (NFRV[11]).

The NFRV depends upon the four agronomic fertiliser value determining factors[12]:

- Type of fertilising product.
  - ⇨ The more crop-available N is present, the higher the NFRV is.
- Application rate.
  - ⇨ The efficacy of N taken up from a fertilising product decreases with an increase in the application rate.
- Method of application and method of placement of a fertilising product.
  - ⇨ Application methods that do not mitigate ammonia volatilisation and denitrification 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 NFRV.

The NFRV and residual nitrogen in the soil after the harvest of the last cut of grass (the fourth cut in this report) are objects of this study. Determination of the NFRV requires a reference fertiliser. In the Netherlands, calcium ammonium nitrate (CAN[13]) is used as the reference for assessing NFRV. CAN is a granular (prilled) fertiliser. Prilled fertilisers require a broadcasting fertilization technique (blanket application). As biobased N fertilising products are liquids (or suspensions), and often consist mostly of ammonium N, these fertilising products[14] are injected and not broadcasted. Due to the difference in application techniques that can affect NFRV, injection of the liquid fertiliser urea-ammonium nitrate solution (UAN) can be used as a second reference.

The following hypotheses were formulated:

1. The magnitude of NFRV depends on the reference N fertiliser that is used.
2. Biobased fertilising products have a NFRV as the reference fertiliser of nearly 100%.
3. Biobased fertilising products have a similar effect on residual nitrogen after the harvest of the last cut of grass as a regular nitrogen mineral fertiliser (reference) at similar application rates.

Biobased fertilising products (BBFs) are blends from mineral concentrate from liquid fraction of co-digested pig manure obtained from reverse osmosis and secondary raw materials: ammonium sulphate from an air scrubber, condensated ammonia water and/or mineral nitrogen fertilisers (liquid urea of a blend of liquid urea and ammonium nitrate (called *Urean*, in *Dutch*, 30%N). BBFs for the first two cuts of grassland have low N/S ratio to meet crops requirements. For following cuts, BBFs with low S content were used (and, thus,

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

[12] 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.

[13] 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.

[14] 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.

provided higher N/S ratios) as the demand of grass for sulphur was low. Due to the mixture of mineral concentrate with condensed ammonium water put previously on the grassland in the demonstration field experiments in 2019, symptoms of ammonium toxicity were observed. The composition of the biobased fertilising product (BBF) was changed in 2020 and consisted of 99% mineral concentrate and 1% liquid N fertiliser of Urea and ammonium nitrate (UAN). In this study, a similar composition of BBF to that used in 2020 was tested.

The project started in the same timeframe that 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 the JRC-study was discussed during a stakeholders' workshop at JRC in Seville, Spain. In May 2020, the final report[15] was presented for discussion within the Nitrates Expert Group[16].

The current project was stimulated by the start of the SAFEMANURE project but had another timeframe with field experiments conducted in 2019, 2020 and 2021. The data and outcomes obtained from this project serve as touchstones for the still to be implemented RENURE criteria for N fertilising products based on processed animal manure.

This report gives the results of the second experiment on grassland which was conducted in 2021. Materials and methods of the experiment are described in Chapter 2. Chapter 3 presents the main results (yield and N uptake of grass (per cut and total), nitrogen use efficiency (NUE) and NFRV. Due to the erroneous use of another biobased fertilising product based on ammonium sulphate with higher nitrogen content for the fertilisation of the fourth cut, only the results of the first three cuts have been reported. The quantity of nitrogen applied before the fourth cut was approximately five times higher than required. Results needed for the testing of the hypothesis on environmental risks based on residual soil mineral nitrogen, and an indicative nitrogen balance are therefore not given. In Chapter 4, the results are evaluated and conclusions for this second experimental year on grassland are given.

[15] 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.

[16] 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 explored the agronomic potential of a biobased fertilising product as a nitrogen source for grassland. In the Netherlands, it is common to use animal manure as a standard fertilising product that can meet a large proportion of the crop's nutrient needs. Full requirements of crops are met through additional fertilisation with mineral fertilisers. Quantities of N and phosphate have to meet 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 included three repetitions. Treatments were randomised per replication. The design incorporated a total of 39 plots. The design also included codes and application rates for four cuts. The total nitrogen application rates in kg N/ha are given in Table 1. Differences in application rate per code for BBF and CS were calculated from sampling and analysis of the actual fertilising product that was applied at fertilisation.

Table 1 *Fertilising products and application rates (code factors) of the field experiment on grassland.*

Nr.	Fertilising product	Application Rate Code(*)	Total nitrogen application, kg N/ha			
			1st cut	2nd cut	3rd cut	Total
1	Calcium ammonium nitrate (CAN), control	1	0	0	0	0
2	Calcium ammonium nitrate (CAN)	2	52	40	34	126
3	Calcium ammonium nitrate (CAN)	3	79	61	50	190
4	Calcium ammonium nitrate (CAN)	4	105	81	67	253
5	Calcium ammonium nitrate (CAN)	5	131	102	84	317
6	Liquid urea ammonium nitrate (UAN)	2	52	40	34	126
7	Liquid urea ammonium nitrate (UAN)	3	79	61	50	190
8	Cattle slurry (CS[17])	2	49	35	41	125
9	Cattle slurry (CS)	3	73	53	61	187
10	Biobased fertilising product basic (BBFb)**	2	58	30	35	123
11	Biobased fertilising product basic (BBFb)	3	87	45	53	185
12	Cattle slurry + biobased fertilising product basic (CS+BBFb)	3	90	57	61	208
13	Cattle slurry + biobased fertilising product basic (CS+BBFb)	4	134	85	92	311

*: Application rates for Codes 1, 2, 3, 4, and 5 stand for the application rates given in the table and were derived from soil fertility testing. The code for optimum fertilisation is 4 (or 100%), other codes stands respectively for 0% (Code 1), 50% (Code 2), 75% (Code 3) and 125% (Code 5). Liquid urea-ammonium nitrate fertiliser (UAN) is a liquid blend of urea and ammonium nitrate with 30%N. In the Netherlands, this fertiliser is called *'Urean'*.

**: Fertilisation before the first cut received, not planned, an BBF enriched with ammonium sulphate and UAN (BBF+), following fertilisations were conducted with the planned biobased fertilising product basic (BBFb).

[17] Cattle slurry of the dairy farm.

2.2 Soil

The field experiment was conducted on an established grassland managed under practical dairy farming near Wageningen, in the Netherlands. The initial soil fertility status of the field experiment prior to fertilisation in Spring is given in Table 2. Soil samples were taken on 22nd March 2021. For this, the soil top layer of 0–10 cm depth was sampled (40 soil cores/field experiment). The determination of the soil fertility status served towards determining the fertiliser requirements.

Table 2 *Soil fertility status of the sandy soil of the field experiments per replicate and their mean value (analyses conducted by Eurofins Agro).*

Parameter	Unit	Repetition			Mean	Method
		I	II	III		
Organic matter	%	3.9	3.5	3.8	3.7	NIRS[18]
C-inorganic	%	2.0	1.8	2.0	1.9	NIRS
Clay (< 2 µm)	%	3.0	3.0	4.0	3.3	NIRS
Silt (2-50 µm)	%	15	15	16	15	NIRS
Sand (>50 µm)	%	78	79	76	78	NIRS
CEC	mmol+/kg	53	51	60	55	NIRS
pH	-	5.5	5.3	5.3	5.4	NIRS
N-total	mg N/kg	1640	1440	1670	1583	NIRS
P-capacity (P-Al-value)	mg P_2O_5/100 g	43	34	33	37	NIRS
P-plant available (P-$CaCl_2$)	mg P/kg	1.9	1.8	1.4	1.7	CCL3
K-capacity	mmol+/kg	1.7	2.0	1.9	1.9	NIRS
K-plant available	mg K/kg	50	52	53	52	CCL3
S-total	mg S/kg	310	290	310	303	NIRS
S-plant available	mg S/kg	6.3	5.5	6.2	6.0	CCL3[19]
Ca-total	mmol+ Ca/kg	44	40	50	45	NIRS
Ca-plant available	mg Ca/kg	0.30	0.80	0.30	0.47	NIRS
Mg-total	mmol+ Mg/kg	9.00	7.40	9.30	8.57	NIRS
Mg-plant available	mg Mg/kg	117	110	127	118	CCL3

Plant available N 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 prior to fertilisation on 15th March 2021. In these soil layers, 21.5 kg N/ha, 8.1 kg N/ha and 6.3 kg N/ha was found (totalling 35.9 kg N/ha). Plots did not differ in the stock of mineral N at the start of the field experiment. Due to an error in fertilisation for the fourth cut through use of another biobased fertilising product (i.e. an ammonium sulphate was applied instead of the blend of mineral concentrate (99%) and UAN (1%)), the field experiment was discontinued. Soil mineral nitrogen after the last cut was not determined, as treatments with BBFb had received too much nitrogen (Factor 5).

2.3 Fertilising products

Fertilising products and combinations of them that were planned for use in the experiment included calcium ammonium nitrate (CAN), liquid urea-ammonium nitrate (UAN), biobased fertiliser basic (BBFb), cattle slurry (CS) and the combination[20] cattle slurry plus biobased fertiliser basic (CS+BBFb). After fertilisation, however, it was established that the first batch of BBFb was a BBF enriched with both biobased ammonium sulphate and UAN. This enriched fertilising product (BBF+) was only applied for fertilisation of the first cut of grass. For fertilisation of the subsequent cuts, BBFb was used.

CAN and UAN are commonly used synthetic mineral nitrogen fertilisers.

[18] Eurofins Agro, method NIRS (TSC®)
[19] Eurofins Agro, method CCL3(PAE®)
[20] CS and BBF were not blended as both fertilising products require different application methods.

The biobased nitrogen fertilising products were produced by the Green Mineral Mining Centre[21] of Groot Zevert Vergisting (GZV) B.V. in Beltrum, the Netherlands. The Green Mineral Mining Centre began the production of biobased fertilising products in early 2019. The plant uses innovative techniques for the production of biobased fertilisers and participates in the EU H2020 project SYSTEMIC as a demonstration plant, as well as the Dutch MMM-2 project. Both participations lead to more in depth monitoring of production processes (Regelink et al., 2021 In *Dutch*). The SYSTEMIC project gives a full description of the production process of biobased fertilisers[22].

The biobased fertilisers were produced from mineral concentrate obtained through processing co-digested pig slurry (digestate). This digestate was separated into a liquid and a solid fraction by 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 served as a secondary resource for the production of biobased fertilising product. The biobased fertilising product basic (BBFb[23]) was a mixture of mineral concentrate with 1% UAN. This mixture (blend) was made on location in Wageningen from mineral concentrate (99%) and UAN (1%) to prevent the risk of denitrification of nitrate nitrogen. About 25% of N in the BBFb product originated from UAN and the remaining 75% from the mineral concentrate. Per cut, a BBFb was made from a batch of mineral concentrate. All BBF's were analysed. The first batch of mineral concentrate appeared to be not mineral concentrate, but the enriched fertilising product that the Green Mining Centre uses for fertilisation of the first cuts of grassland. This product is enriched with liquid biobased ammonium sulphate via an air wash with composting sewage sludge (8% N). For the following cuts, BBFb was produced from a new batch of mineral concentrate without the addition of any other nitrogen sources. Table 3 gives the composition of the fertilising products (reference fertilisers CAS and UAN and test-products BBF+, BBFb and CS) that were used for the field experiment on grassland.

2.4 Application rates

Application rates of nutrients were based on fertiliser recommendations derived from soil testing. The recommendations of the Dutch Committee Fertilisation of Grassland and Fodder Crops (CBGV[24], 2020) were followed.

2.4.1 Nitrogen

The N application rate was based on Eurofins Agro's fertilisation guide ('*Bemestingswijzer grasland'* in *Dutch*) for yield targets of 3.5 tonnes dry matter/ha for the first cut and 2-2.5 tonne dry matter/ha for the following cuts. For Cuts One – Four, the recommendations are 119, 92, 76 and 76 kg N/ha respectively. In addition, the legal N application rate limit of the Netherlands was taken into account, which amounted to 320 kg N/ha (sandy soil, total per year). In order to comply with this rate limit, the recommended N application rates were lowered proportionately, so that the sum of the four applications equalled 320 kg N/ha. Nitrogen fertiliser recommendation adapted to the legal conditions of use was set at 100%. Table 1 gives the values for the application rates.

Table 3 gives the composition of the tested products. The composition of the CS varied among the three dosages and the NH_4/N ratio was remarkably low in the CS applied for the first cut (27% NH_4/TN) but higher (52-59%) in the subsequent applications. The BBF+ was characterised by a high nitrogen and sulphur content due to the fact that ammonium sulphate was added to the mineral concentrate alongside UAN. The BBFb refers to the mixture of mineral concentrate and UAN containing 11.3 to 11.9 kg N/ton mostly as N-NH_4. Urea content could not be measured. No measurements were taken from the mineral concentrate prior to adding UAN because the composition of the mineral concentrate is already well-known from other monitoring programmes at the GZV plant. Monitoring in this period showed that the reverse osmosis (RO) concentrate contained on average 7.6 g N/kg which was >90% present as NH_4 (Regelink et al. 2021). Hence, the RO concentrate complied with the NH_4/TN criteria proposed for RENURE fertilising products.

[21] https://www.groenemineralencentrale.nl/nl/english
[22] https://systemicproject.eu/plants/demonstration-plants/groot-zevert-the-netherlands/
[23] Another type of BBF was enriched with ammonium sulphate which causes higher nitrogen content and was used in practice for the fertilisation of the first two cuts of grass.
[24] https://www.bemestingsadvies.nl/nl/bemestingsadvies.htm

Table 3 *Composition¹ of reference fertilisers CAN and UAN, biobased fertilising products (BBF+, BBFb) and cattle slurry (CS).*

Fertilising product	**Cut**	**Dry matter, %**	**Organic matter, % in dry matter**	**EC, mS/cm**	**Bulk-density, kg/L**	**pH [-]**	**N-total, g N/kg**	**NH_4-N, g N/kg**	**NO_3-N, g N/kg**	**Urea-N[25], g N/kg**	**P, g P/kg**	**K, g K/kg**	**Mg, g Mg/kg**	**S, g S/kg**	**Na, g Na/kg**	**N/K, g/kg/ g/kg**	**N/S, g/kg/ g/kg**
Calcium ammonium nitrate (CAN)	All	*	*	*	*	*	275	142.5	132.5	*	*	*	*	*	*	*	*
Liquid Urea-ammonium nitrate (UAN)	All	*	*	*	*	*	297.6	71.1	76.8	153	*	*	*	*	*	*	*
Cattle slurry (CS)	1st	10.7	68.6	16.6	1000	7.0	3.7	1.0	0.0	*	0.75	4.16	0.86	0.52	0.67	0.90	7.60
	2nd	9.2	53.1	17.0	1001	7.1	3.2	1.9	0.0	*	0.68	4.10	0.49	0.54	0.64	0.90	8.70
	3rd	6.6	74.0	18.8	1016	7.5	3.8	2.0	*	*	0.49	3.90	0.76	0.37	0.39	0.70	7.80
Biobased fertilising product, enriched with ammonium sulphate (BBF+)	1st	5.3	38.0	98.0	1048	8.0	15.2	11.5	0.7	*	0.07	9.46	0.07	5.30	3.02	1.20	5.60
Biobased fertilising product, basic (BBFb)	2nd	3.7	19.6	78.3	1027	8.0	11.3	9.2	0.1	*	0.06	9.00	0.0001	1.53	2.85	1.30	5.70
Biobased fertilising product, basic (BBFb)	3rd	3.8	28.5	78.7	1035	8.2	11.9	8.8	0.8	*	0.06	8.70	0.0001	1.85	2.84	1.20	5.80
	4th	*	*	*	*	*	275	142.5	132.5	*	*	*	*	*	*	*	*

¹ CAN and UAN were analysed by Lufa Nord West[26] (Germany); CS and BBF were analysed by Wageningen UR - Chemical Biological Soil Laboratory[27] (CBLB).

[25] Biuret content was 0.22%

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

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

2.4.2 Other nutrients

The application rates of other nutrients were based on the same fertilisation guide and are given in Table 4.

Table 4 *Recommended application rates for phosphate, potassium, sulphur and magnesium, and sodium for the 1st cut and subsequent cuts. Recommendations follow the guidelines of the Committee for Fertilisation of Grassland and Fodder crops.*

Nutrient	Unit	1st Cut	Subsequent cuts
Phosphate	kg P_2O_5/ha	15	25
Potassium	kg K_2O/ha	85	60
Magnesium	kg MgO/ha	50	50 (only 2nd cut)
Sulphur	kg SO_3/ha	35	0
Sodium	Kg Na_2O/ha	30	0

BBF+, BBFb and CS contain other nutrients in addition to N. These were taken into account by applying the *Ceteris Paribus* Principle[28]. Therefore, each treatment received the same quantity of phosphate (P), potassium (K), magnesium (Mg), sodium (Na) and sulphur (S). Phosphate was applied as Triple superphosphate. Potassium was applied as potassium chloride (60%). Magnesium was applied as magnesium sulphate (Kieserite). Sulphur was applied as gypsum ($CaSO_4$.2 H_2O). Sodium was applied as sodium chloride. 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 dosage of a particular nutrient via CS of BBFb determined its compensation application rate. Soil testing showed that there was no need for additional fertilisation with micronutrients (data not given).

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

2.5 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). Fertilisation for the first three cuts was conducted on 19th and 22nd March, 5th and 6th June and 12th and 13th August 2021.

Granular (prilled) mineral fertilisers were applied by hand.

The liquid mineral fertiliser UAN was applied with a field sprayer (Photo 1).

Photo 1 *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 for this purpose (Photo 2).

Photo 2 *Injector designed for biobased fertilising products. The injector was built by Slootsmid[29] in 2020 and was designed for use specifically in field experiments and/or fertilisation of small plots. The design aims to mitigate/minimise ammonia losses.*

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

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 3). For application on grassland nozzles and injection slots were distanced at 25 cm from each other.

Photo 3 *Injector of WUR Unifarm which was designed for the application of animal slurries. The injector was adjusted for application of cattle slurry on grassland with slots distanced at 25 cm in this photograph.*

2.6 Sampling soil, harvest and sampling crop

2.6.1 Sampling soil

Sampling of the grass sods (of 0 – 10 cm depth) occurred on 22nd March 2021. 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 to assess the availability of macro-nutrients that determine the application rates of N, P, K, Mg, Na and S.

2.6.2 Crop and harvest

Three cuts of grass were mowed with the Haldrup on 31st May, 6th July and 11th August. Fresh and dry yields were determined.

2.7 Analytical methods

2.7.1 Fertilising products

CAN and UAN fertilisers were analysed for N 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. Methods used were total Nitrogen VDLUFA II, 3.5.2.7.: 1995; ammonical 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 based on the ISO-17025 standard. CBLB follows internal methods based 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 a mixture of 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.

2.7.2 Soil samples

Soil samples from the plough layer of 0 – 10 cm depth were analysed by Eurofins Agro BV according to its analysis package for grassland[30]. Eurofins Agro Testing Wageningen BV is an accredited[31] laboratory.

The mineral N content was determined for the individual soil layers after extraction of field-moist soil with 1 M KCl (1:2.5 w/v). The analyses were performed by Wageningen UR – CBLB. The method is an internal standard adapted from ISO/TS 14256-1:2003 en.

2.7.3 Crop samples

Two samples of grass per plot were taken. One set of samples served the determination of the dry matter content (24 h., 105°C). The other set of samples of grass was dried overnight at 70°C and ground up. Next, these samples were analysed for nutrient content after destruction with H_2SO_4-H_2O_2-Se followed by photometric determination of N and P on a segmented flow analyser (SFA) and K on a flame-atomic emission spectroscope (F-AES). These analyses were conducted by CBLB.

2.8 Calculations

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

$$NUE = 100 * (U_N - U_0) / F_N \quad (1)$$

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 N demand and the release of N from the fertilising product.

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

$$NFRV = 100 * NUE_{\text{Biobased fertilising product}} / NUE_{\text{Calcium ammonium nitrate}} \quad (2)$$

With:
$NUE_{\text{Biobased fertilising product}}$ = Nitrogen use efficiency or apparent recovery of biobased fertilising product (%).
$NUE_{\text{Calcium ammonium nitrate}}$ = 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.

[30] https://www.eurofins-agro.com/nl-nl/bemestingswijzer
[31] https://www.rva.nl/en/accredited-organisations/all-accredited-bodies nr. L122.

2.9 Statistical analyses

Cattle slurry (CS) and biobased fertilising product (BBF) were applied at levels of 50% and 75% of the recommended N application rate. The combinations with cattle slurry and biobased fertilising product was applied at levels of 75% and 100%. Treatments with BBF+ (1st cut) and BBFb (2nd and 3rd cut) were treated as one combination.

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

$$\text{Model} = \text{Block} + \text{Fertiliser} + \text{Application rate} + \text{Fertiliser} * \text{Application rate} \tag{3}$$

With:

Model: parameter (Dry matter yield, N-uptake, NUE) to be analysed statistically.
Block: repetition (=3).

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

Fertiliser: Fertiliser treatments control (no N fertilisation), calcium ammonium nitrate (CAN), biobased fertiliser basic (BBFb), cattle slurry (CS) and cattle slurry plus biobased fertiliser basic (CS+BBFb).

Application rate: Table 1.

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

Both NUE and NFRV were calculated per treatment and per replicate. NUE was reported with its LSD values. The variance in the N uptake at various N 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 climate of 2021 was favourable for grass growth. Temperature followed the thirty-year average, although in March, April and May, the temperature was lower but slightly higher in June (Figure 1, Table 5). The Spring was drier than the thirty-year average, while the Summer was wetter (Figure 2, Table 6). The wet summer delayed the harvest of the first cut. Due to ample moisture and modest temperatures, the yield was higher than anticipated, as the grass was too wet to mow. In general, the first cut of grass on dairy farms in the Netherlands were (way) above expectations: i.e. despite yields of 3.5 tonnes dry matter as the original target, yields of 6 tonnes/ha were commonly seen.

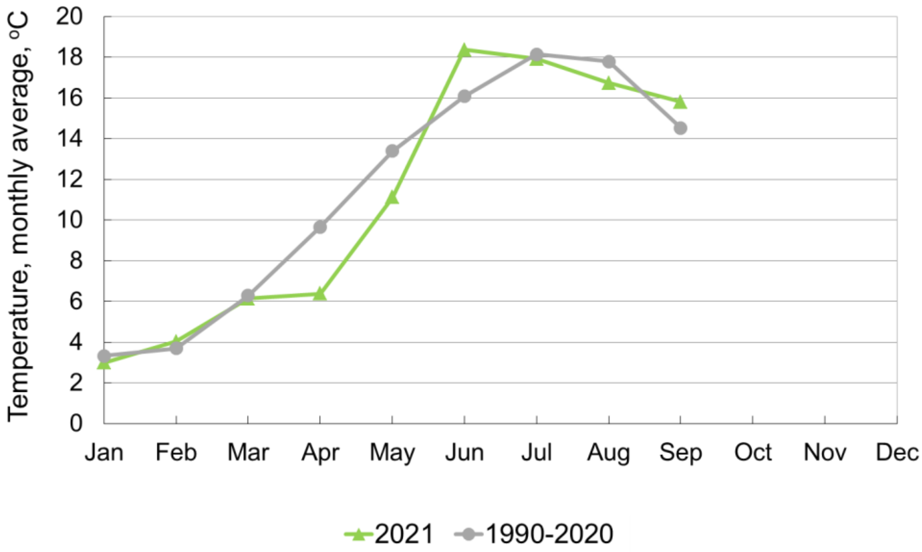

Figure 1 *Temperature, monthly average in degrees Celsius for the grass experiment on sandy soil near Wageningen with the long-term average for the period 1990-2020 of the region (date KNMI De Bilt and Deelen, mean values).*

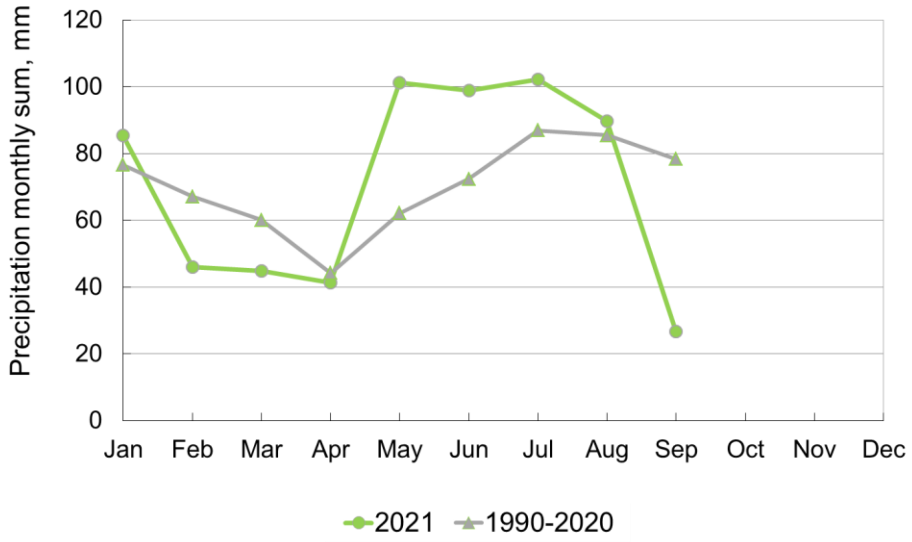

Figure 2 *Precipitation, monthly sum in mm for the for the grass experiment on sandy soil near Wageningen 2021 compared with the long-term average for the period 1990-2020 of the region (date KNMI De Bilt and Deelen, mean values).*

Table 5 *Monthly temperatures for 2021 in °C presented as monthly average, averages of decades I, II and III and monthly minimum and maximum values (data KNMI De Bilt and Deelen, mean values).*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Monthly average	3.0	4.0	6.1	6.4	11.1	18.4	17.9	16.7	15.8
Long-term monthly average	3.3	3.7	6.3	9.7	13.4	16.1	18.1	17.8	14.5
Decade I	1.9	0.9	3.9	5.4	9.6	18.7	17.4	16.4	17.5
Decade II	3.8	2.7	5.6	6.0	11.4	19.9	18.5	17.0	15.5
Decade III	3.2	9.6	8.6	7.7	12.2	16.5	17.8	16.8	14.4
Monthly minimum	-5.4	-13.6	-6.8	-4.0	-1.2	6.3	7.9	8.3	3.7
Monthly maximum	12.0	18.7	24.2	19.0	26.4	32.2	27.2	25.6	26.9

Table 6 *Monthly precipitation for 2021 in mm. Long-term averages, and days with rain categorised to quantities of precipitation (data KNMI De Bilt and Deelen, mean values).*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Monthly total	85	46	45	41	101	99	102	90	27
Long term monthly average	77	67	60	44	62	72	87	85	78
Days with rain	23	23	12	6	9	15	19	20	13
Decade I	9	33	8	24	21	40	20	48	6
Days with rain	7	8	3	4	7	2	6	8	1
Decade II	38	14	32	3	41	26	30	13	3
Days with rain	8	4	9	4	9	3	4	4	3
Decade III	39	0	5	14	40	33	53	29	18
Days with rain	9	0	4	2	7	7	8	8	3
Days with rain									
0 mm	8	17	16	20	9	19	14	12	24
› 0 mm	23	11	15	10	22	11	17	19	6
› 1 mm	8	6	8	5	9	4	7	8	1
› 5 mm	2	2	2	2	8	2	3	4	2
› 10 mm	4	1	1	2	2	3	4	3	1

3.2 Dry matter yield

The favourable weather conditions supported three good yields of grass. Due to the wet conditions, the harvest of the first cut was postponed until favourable dry weather conditions. This led to yields of up to 7 tonnes dry matter/ha for the first cut, which was way above the original target of 3.5 tonnes dry matter/ha (Table 7, Figure 3). All data are given in Annex 1.

For each cut, and for the totals, both fertilising product and application rate had a significant effect on the dry matter yield. Application of a fertilising product with nitrogen resulted in a higher dry matter yield, i.e. the grass responded to nitrogen fertilisation. For the treatment with CAS, an application rate of 100% and 125% did not result in a significant higher dry matter yield than an application rate of 75%. UAF yielded for the second and third cuts and total (CAS 75%) significantly lower than CAN% (Table 7, Figure 4). This was not found for BBF+ (first cut) and BBFb (third cut) but the second cut with BBFb (75%) yielded lower than CAN (75%). Over all three cuts, yields of CAN and (BBF+ & BBFb) at similar application rates were not significantly different. This finding was conditioned by the use of an enriched BBF+ for fertilisation of the first cut causing a slightly higher application rate of nitrogen (6-8 kg N/ha) than planned (Table 1). For the second cut, the application rate was lower than planned (10-16 kg N/ha). Overall, the nitrogen application rates for BBFb met targeted rates.

CS had the lowest yields followed by the combination of CS+BBFb.

Table 7 *Yield per cut and their totals in tonnes dry matter/ha for CAN, Biobased fertilisers enriched (BBF+ (1st cut) or basic BBFb (2nd and 3rd cut), Cattle Slurry (CS) and the combination with CS and BBF+ or BBFb and application rates of nitrogen of 0%, 50%, 75%, 100% and 125% with their least square differences for comparison of unfertilised treatment with fertilising products and combinations and for comparison between fertilising products and combinations.*

Cut	Fertilising Product	Application rate					LSD	LSD
		0%	50%	75%	100%	125%	Unfertilised *versus* fertilised	Fertilised
1	CAN	4.4	6.4	6.7	7.2	6.6	0.5	0.6
1	UAN	*	6.4	6.8	*	*		
1	BBF+	*	6.6	6.6	*	*		
1	CS	*	4.7	5.6	*	*		
1	CS+BBF+	*	*	6.1	6.4	*		
2	CAN	0.9	1.8	2.3	2.2	2.2	0.1	0.2
2	UAN	*	1.4	1.7	*	*		
2	BBFb	*	1.5	1.8	*	*		
2	CS	*	1.0	1.2	*	*		
2	CS+BBFb	*	*	1.3	1.4	*		
3	CAN	0.6	1.5	1.7	1.7	2.0	0.1	0.2
3	UAN	*	1.1	1.4	*	*		
3	BBFb	*	1.4	1.8	*	*		
3	CS	*	1.1	1.2	*	*		
3	CS+BBFb	*	*	1.3	1.6	*		
Total	CAN	5.8	9.7	10.7	11.1	10.8	0.5	0.7
Total	UAN	*	9.0	9.9	*	*		
Total	BBF+/ BBFb	*	9.5	10.2	*	*		
Total	CS	*	6.8	7.9	*	*		
Total	CS+BBF+/BBFb	*	*	8.6	9.4	*		

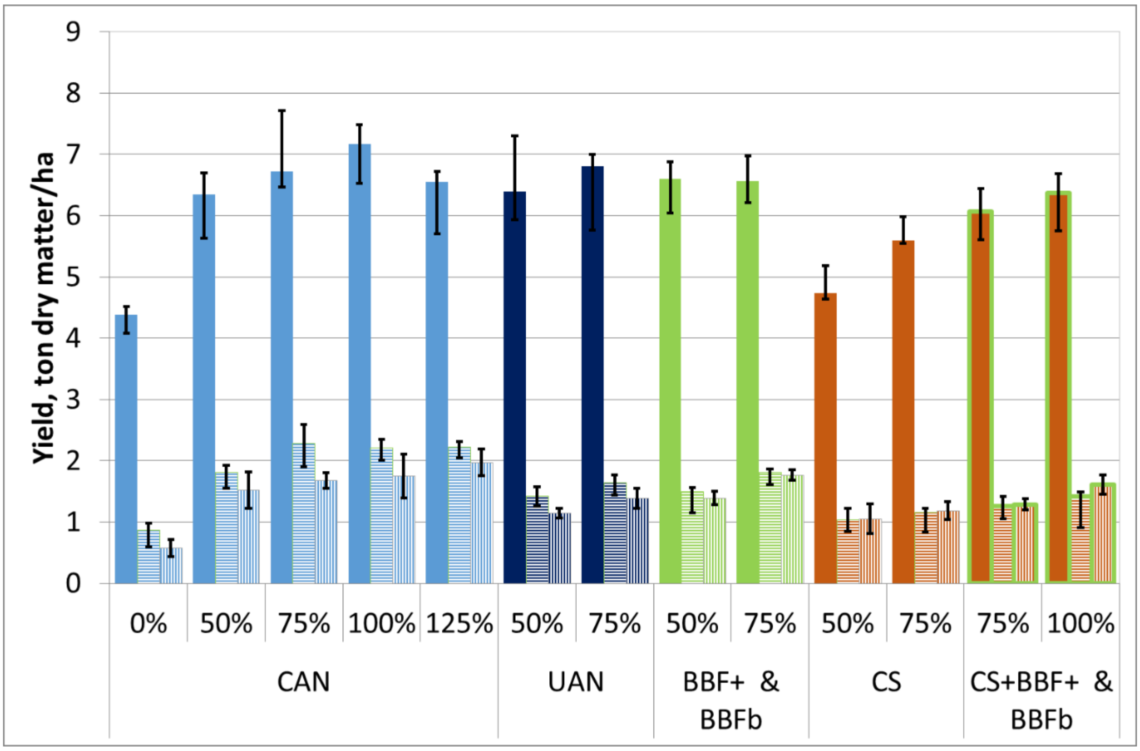

Figure 3 *Yield in tonne dry matter/ha of three cuts grass for CAN, UAN, Biobased fertilisers BBF+ (1st cut), BBFb (2nd and 3rd cut), Cattle Slurry (CS), and the combination with CS and BBF+/BBFb at application rates of nitrogen of 0%, 50%, 75%, 100% and 125%. Vertical bars represent standard deviations. First cut - no pattern. Second cut - horizontal pattern. Third cut - vertical pattern.*

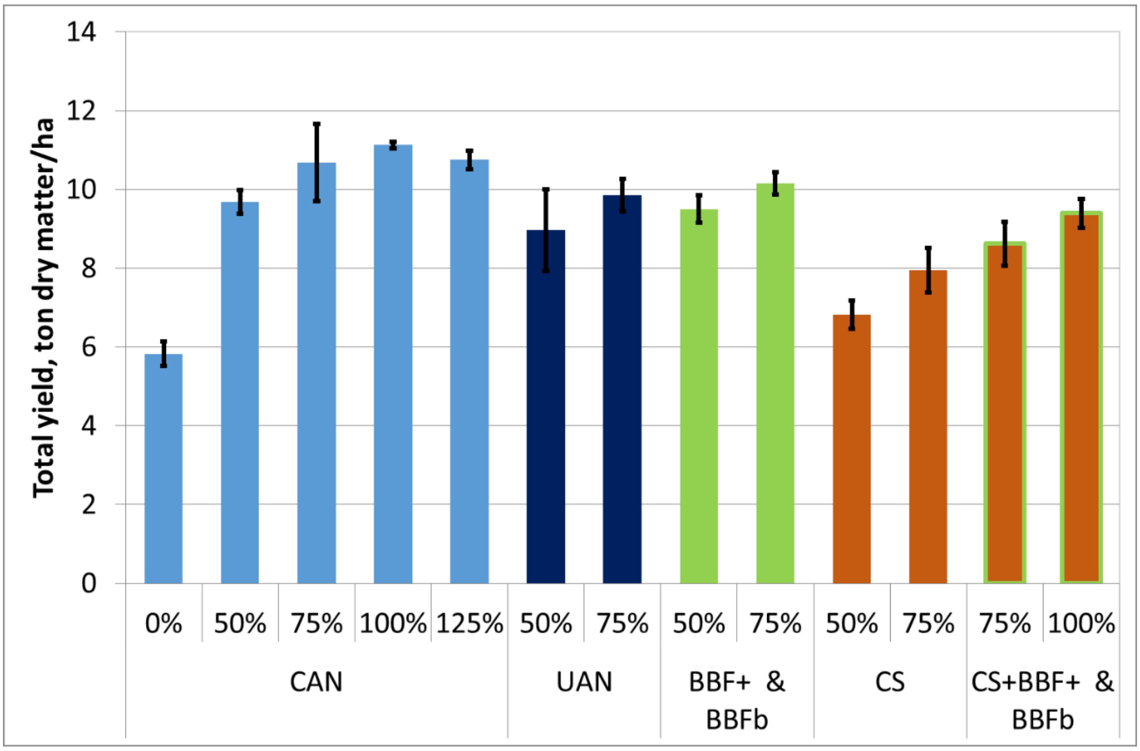

Figure 4 *Total yield of grass in tonne dry matter/ha for CAN, UAN, Biobased fertilisers BBF+ (1st cut), BBFb (2nd and 3rd cut), Cattle Slurry (CS) and the combination with CS and BBF+/BBFb at application rates of nitrogen of 0%, 50%, 75%, 100% and 125%. Vertical bars represent standard deviations.*

3.3 Nitrogen uptake and efficacy

3.3.1 Nitrogen uptake

Nitrogen uptake of the three cuts and their totals are given in Table 8, and with the standard deviations in Figures 5 and 6. All data are given in Annex 1.

Table 8 *Nitrogen uptake per cut and their totals in kg N/ha for CAN, Biobased fertilisers enriched (BBF+) and basic (BBFb), Cattle Slurry (CS) and the combination with CS and BBF+/BBFb at application rates of nitrogen of 0%, 50%, 75%, 100% and 125% with their least square differences for comparison of unfertilised treatment with fertilising products and combinations and for comparison between fertilising products and combinations.*

Cut	Fertilising product	Application rate					LSD	LSD
		0%	50%	75%	100%	125%	Unfertilised *versus* fertilised	Fertilised
1	CAN	57.5	105.9	117.6	130.6	129.7	12.5	16.0
1	UAN	*	104.1	108.3	*	*		
1	BBF+	*	103.9	122.9	*	*		
1	CS	0.0	66.5	77.7	*	*		
1	CS+BBF+	*	*	94.7	116.1	*		
2	CAN	14.2	33.9	52.7	61.7	72.7	3.3	4.3
2	UAN	*	25.1	32.7	*	*		
2	BBFb	*	31.4	40.9	*	*		
2	CS	*	19.4	23.0	*	*		
2	CS+BBFb	*	*	28.3	34.8	*		
3	CAN	11.1	35.2	41.9	50.9	61.6	5.9	7.6
3	UAN	*	23.9	31.6	*	*		
3	BBFb	*	31.6	42.9	*	*		
3	CS	*	21.2	25.7	*	*		
3	CS+BBFb	*	*	30.9	38.6	*		
Total	CAN	82.8	175.0	212.2	243.2	264.0	16.7	21.4
Total	UAN	*	153.1	172.6	*	*		
Total	BBF+ / BBFb	*	166.9	206.7	*	*		
Total	CS	*	107.2	126.3	*	*		
Total	CS+BBF+/ BBFb	*	*	154.0	189.5	*		

For each cut, nitrogen fertilisation significantly increased nitrogen uptake. Also, the total nitrogen uptake of fertilised treatments was significantly higher after application of nitrogen. An increase in nitrogen application rate increased nitrogen uptake but was not always significant for each cut. Although the totalised differences between application rates became significantly higher as the application rate increased.

CS had a significantly lower nitrogen uptake for the first cut, the second cut and the total uptake. UAN had an equal nitrogen uptake at the first cut, but subsequent cuts had lower nitrogen uptakes at similar application rates compared to CAN. BBF+ and BBFb had a similar nitrogen uptake compared to similar application rates of CAN, with the exception of the second cut at a 75% application rate, in which the uptake for the BBFb treatment was lower. The combination of CS+BBF+ and CS+BBFb had uptakes between CS (lower) and BBF+ or BBFb (higher).

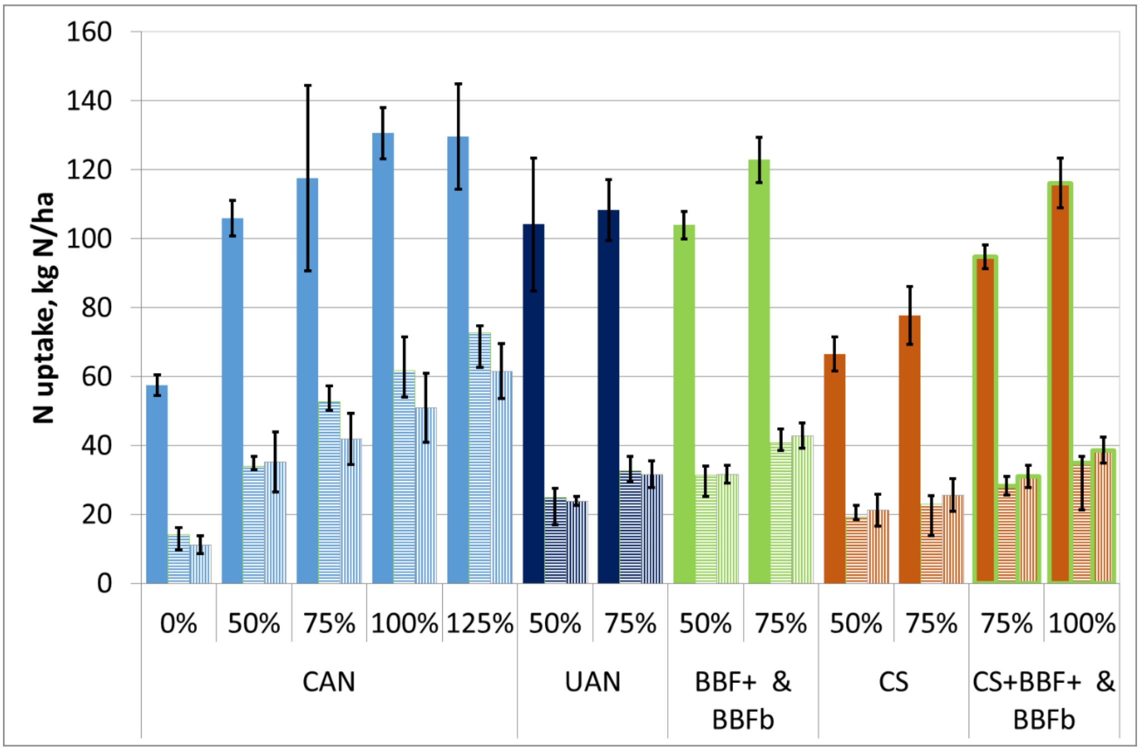

Figure 5 *Nitrogen uptake by grass in kg N/ha of three cuts for CAN, UAN, Biobased fertilisers (BBF+ for 1st cut, BBFb for 2nd and 3rd cut), cattle slurry (CS), and the combination with CS and BBF+/BBFb at application rates of nitrogen of 0%, 50%, 75%, 100% and 125%. Vertical bars represent standard deviations. First cut - no pattern. Second cut - horizontal pattern. Third cut - vertical pattern.*

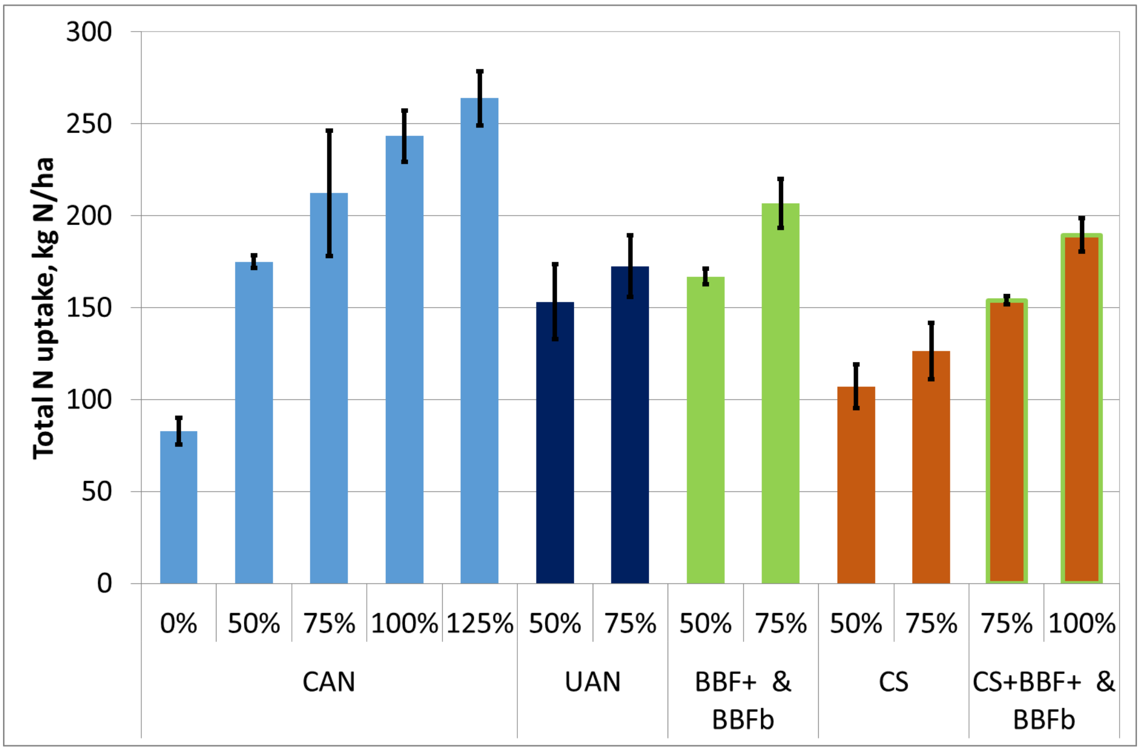

Figure 6 *Nitrogen uptake by grass in kg N/ha for CAN, UAN, Biobased fertiliser (BBF+ 1st cut, BBFb 2nd and 3rd cut), cattle slurry (CS) and the combination with CS and BBF+/BBFb at application rates of nitrogen of 0%, 50%, 75%, 100% and 125%. Vertical bars represent standard deviations.*

3.3.2 Efficacy

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

3.3.2.1 Nitrogen Use Efficiency (NUE)

Grass responded on nitrogen fertilisation and with an increase in application rate, more nitrogen was taken up (3.2.2). NUE are given in Table 9. NUE of CAN at 100% and 125% application rates were lower compared to the 50 and 75% application rates (Cut One and total). UAN had lower NUEs compared to CAN (Cuts Two, Three and total). In general, BBF+ and BBFb had similar NUEs compared with CAN. CAN and BBF+ / BBFb had higher NUE values for the first two cuts and total compared to CS and the combination of CS and BBF+ or BBFb (all cuts and total).

Table 9 *Nitrogen Use Efficiency (NUE) per cut and their totals in percent for CAN, Biobased fertilisers enriched (BBF+) and basic (BBFb), cattle slurry (CS) and the combination with CS and BBF+/BBFb and application rates of nitrogen of 0%, 50%, 75%, 100% and 125% with their least square differences for comparison of unfertilised treatment with fertilising products and combinations and for comparison between fertilising products and combinations.*

Cut	Fertilising Product	Application rate				LSD
		50%	75%	100%	125%	Fertilised
1	CAN	96	79	72	57	23
1	UAN	93	67	*	*	
1	BBF+	83	77	*	*	
1	CS	23	31	*	*	
1	CS+BBF+	*	44	45	*	
2	CAN	54	66	61	59	7
2	UAN	32	33	*	*	
2	BBFb	63	63	*	*	
2	CS	20	20	*	*	
2	CS+BBFb	*	28	26	*	
3	CAN	77	66	63	63	15
3	UAN	44	45	*	*	
3	BBFb	65	64	*	*	
3	CS	30	27	*	*	
3	CS+BBFb	*	36	32	*	
Total	CAN	78	71	66	59	12
Total	UAN	60	51	*	*	
Total	BBF+ / BBFb	73	70	*	*	
Total	CS	25	27	*	*	
Total	CS+BBF+/BBFb	*	37	36	*	

3.3.2.2 Nitrogen Fertiliser Replacement Value (NFRV)

NFRV was calculated according to 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 10). 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 10 *Mean values for nitrogen fertiliser replacement value (NFRV) with their standard error between brackets (SE[32]) in percent (%) for CAN, BBF+, BBFb, CS, CS+BBF+ and CS+BBFb per application rate per cut and for the total of all three cuts and fertilisation. CAN served as reference nitrogen fertiliser.*

Cut	**Fertilising Product**	**Application rate**		
		50%	**75%**	**100%**
1	CAN	100 (12.3)	100 (42.0)	100 (8.6)
1	UAN	96 (32.9)	85 (31.3)	*
1	BBF+	87 (10.5)	98 (30.4)	*
1	CS	24 (12.3)	39 (31.3)	*
1	CS+BBF+	*	56 (30.3)	73 (7.6)
2	CAN	100 (9.3)	100 (9.0)	100 (4.8)
2	UAN	59 (8.5)	50 (8.2)	*
2	BBFb	118 (10.0)	96 (9.8)	*
2	CS	37 (10.4)	30 (7.6)	*
2	CS+BBFb	*	42 (7.6)	43 (10.6)
3	CAN	100 (31.1)	100 (18.2)	100 (18.3)
3	UAN	57 (22.3)	69(14.5)	*
3	BBFb	84 (22.9)	97 (14.3)	*
3	CS	39 (24.0)	42 (14.5)	*
3	CS+BBFb	*	55 (13.7)	57 (13.4)
Total	CAN	100 (3.5)	100 (22.1)	100 (6.7)
Total	UAN	78 (14.2)	72 (17.4)	*
Total	BBF+ / BBFb	94 (4.0)	98 (16.8)	*
Total	CS	33 (8.7)	37 (17.2)	*
Total	CS+BBF+/ BBFb	*	52 (15.6)	55 (5.4)

Based on SE, a confidence interval can be calculated. SE values were in the range of 3.5–42%. Larger values of SE limits the means for assessing significant differences, although values of NFRVs were lower than 100%. NFRVs of BBF+ or BBFb were not significantly different from CAN for any of the three cuts and for their totals. This was also found for UAN with the exception of the second cut, in which NFRV was significant lower. CS had significant lower NFRV for the first cut (50%), second cut (50%, 75%), third cut (75%) and total (50% and 75%). The combination of CS+BBF+ had a significantly lower NFRV compared to CAN for the first cut (75%) and the combination of CS+BBFb for the second and third cuts. The pooled combination CS+BBF+/BBFb had also a significant lower NFRV compared to 100% of CAS based on the totals of three cuts (50%, 75%).

Table 10 summarises all results of the BBFs. The type of BBFb used for the first cut was, however, the enriched type (enriched with ammonium sulphate and UAN). Biobased fertiliser basic (enriched only with 1% UAN) was used for fertilisation of grass grown for Cuts Two and Three which had considerably lower yields than Cut One. Thus, the enriched type dominated total yield and total nitrogen uptake. Therefore, the results of NFRV were not conclusive for BBFb but were for the combination of BBF+ and BBFb. The results indicated that BBF made of different compositions can serve as a replacement of mineral nitrogen fertiliser.

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

4 Evaluation and conclusions

Biobased fertilising products can be tailored to crop requirements by the addition of nitrogen and/or sulphur sources to optimise ratios between nitrogen and sulphur to meet crop requirements. In 2021, sources were mineral concentrate and a solution of mineral fertilisers (urea and ammonium nitrate (UAN); '*Urean'* in *Dutch*). In this study, a basic type of a tailored biobased fertilising products was tested in a field experiment on grassland. It consisted of 99% mineral concentrate and 1% UAN. The field experiment served two objectives. These were to investigate:

1. Agronomic effectivity through determination of the nitrogen fertiliser replacement value (NFRV) of nitrogen of biobased fertilisers (BBF) made from co-digested animal manure mixed with a liquid blend of urea and ammonium nitrate (UAN, '*Urean'* in Dutch), and
2. Environmental risk through assessing the risk of leaching of nitrogen from these biobased fertilising products.

These objectives led to three hypotheses:

1. The magnitude of NFRV depends on the reference N fertiliser that is used.
2. Biobased fertilising products have a NFRV as the reference fertiliser of nearly 100%.
3. Biobased fertilising products have a similar effect on residual nitrogen after the harvest of the last cut of grass as a regular nitrogen mineral fertiliser (reference) at similar application rates.

The objectives and hypotheses were tested in 2021 in a field experiment on grassland grown on a sandy soil on a dairy farm.

It was planned to test the basic form of the biobased fertiliser which was a blend of 99% mineral concentrate and 1% UAN. After fertilisation of the first cut, it was established that the fertilising material that was applied was the enriched type of biobased fertiliser (enriched with ammonium sulphate and UAN). For the two subsequent cuts, the basic form was tested, as there was no need for additional fertilisation with sulphur.

For the first cut, the use of the enriched BBF+ caused a slightly higher nitrogen application rate than was anticipated. Overall, the effect of extra nitrogen for the first cut was modest (6-8 kg N/ha extra, Table 1) and was balanced by the lower nitrogen application rates with BBFb for the second cut (10-16 kg N/ha, Table 1).

As Cuts Two and Three had considerably lower yields than cut one, the enriched type dominated total yield and total nitrogen uptake. Therefore, the results on NFRV were not conclusive for BBFb but were for the combination of BBF+ and BBFb.

Due to an error in fertilisation of the grass before the fourth cut through use of an undesignated biobased fertilising product, the field experiment could not test the third hypothesis.

The climatic conditions were favourable for grass growth. Due to the wet conditions during the growth of the first cut, the harvest had to be postponed until a suitable dry period. This led to about 1.5 – 2 times higher yields than was anticipated for (i.e. tonnes dry matter/ha). These higher yields were also seen in the first cut of dairy farms across the Netherlands in 2021[33].

Yield

Grass responded well to nitrogen fertilisation. Each nitrogen fertilising product tested yielded higher compared to the non-fertilised treatment (CAN 0%). Treatment with CAN at application rates of 100% and 125% did not result in a significantly higher dry matter yield than at an application rate of 75%. Yield increase diminished with increasing application rates, thus, following the law of the diminishing returns. In general, BBF+ or BBFb and CAN showed comparable dry matter yields per cut. For the first and highest

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[33] Bases on personal information from farmers of the Biobased Fertilsers project.

yielding cut, no differences were found between CAN, UAN or BBF+. UAF yielded lower than CAN for the second and third cuts, but not significantly for BBFb. It was not clear what caused this difference.

CS had the lowest yields followed by the combination of CS+BBFb; which were not significantly different with exception of the second cut, in which yields of BBFb were lower.

Overall fertilising products can be ranked as:
CAS ≥ BBF+/BBFb > UAN > CS+BBF+/BBFb > CS.

Nitrogen uptake
Fertilisation with nitrogen led to an increase of nitrogen uptake per cut and in the totals of the three cuts. Thus, grass responded well to nitrogen fertilisation. An increase in nitrogen application rate increased nitrogen uptake but was not consistently significant per cut. Although when totalised, the differences between applications rates were significantly higher when the application rate increased. Again, this follows the law of diminishing returns.

For the first cut, CAN, UAN and BBF+ were similar in the nitrogen uptake, but for the second and third cuts, UAN had lower uptakes which coincided with the lower dry matter yield. For BBFb (75%), the nitrogen uptake of the second cut was significantly lower than CAN which was caused by the lower nitrogen application rate than targeted for (10-16 kg N/ha).

CS had significant lower nitrogen uptake for Cuts One, Two and total uptake. The combination of CS+BBF+ or CS+BBFb had uptakes between CS (lower) and BBF+ or BBFb (higher).

Overall fertilising products can be ranked as:
CAS ≥ BBF+/BBFb > UAN > CS+BBF+/BBFb > CS.

Fertilising products with comparable shares of mineral nitrogen acted similarly. An increase in organically bound nitrogen lowered nitrogen uptake.

NUE
NUEs were based on the actual given nitrogen fertilisation and, thus, took into account the differences between targeted application rates and realised application rates.

In general, NUE values declined with increased fertiliser application rate: the efficiency decreased with increased application rate.

This general effect was also found for CAS with NUE of CAN at 100% and 125% application rates lower compared to the 50 and 75% application rates (Cut 1 and total). The effects were large for the first cut and total of three cuts, but for the second- and third cuts, the effects were rather modest or not found. The high values for NUE for the first cut were caused by the high yields resulting from a prolonged growing period. CAS 50% points to a virtually complete use of applied nitrogen.

Grass with its dense rooting is assumed to explore soil nitrogen well and may have caused the modest decline in NUE value with increasing application rate.

UAN had lower NUEs compared to CAN (Cuts Two, Three and total). In general, BBF+/BBFb had similar NUEs compared with CAN. CAN and BBF+/BBFb had higher NUE values for the first two cuts and total compared to CS and the combination of CS and BBFb (all cuts and total).

Overall fertilising products can be ranked as:
CAS ≥ BBF+/BBFb > UAN > CS+BBF+/BBFb > CS.

NFRV
The yield of the first cut of this field experiment was normative due to the high yield. With this as a focus, overall CS and the combination of CS+BBF+/BBFb performed less well than UAN, BBF+/BBFb and CAN.

BBF+/BBFb and CAN had comparable efficiencies of nitrogen use and BBF+/BBFb, thus, had a NFRV of 100%. UAN was similar for the first cut but lagged behind for the following cuts. The cause of this was unclear.

Overall fertilising products can be ranked as:
CAS ≥ BBF+/BBFb > UAN > CS+BBF+/BBFb > CS.

In conclusion
In this second field experiment on a sandy grassland on a dairy farm near Wageningen, in the Netherlands, which was conducted in 2021, the effects of a biobased fertiliser product on grass yield (three cuts), N uptake, NUE and NFRV were measured. The climatic conditions were favourable for testing fertilising products.

The results of this field experiment on grassland point to a similar agronomic effectivity of BBF+/BBFb compared to CAS. CS had the lowest effectivity and the combination of CS+BBF+/BBFb was in between BBF+/BBFb and CAS (better) and CS (poorer) in agronomic effectivity. In this experiment, UAN performed less well than CAN. If UAN was taken as reference fertiliser results for NFRV of CAN and BBF+/BBFb would exceed 100% and, thus, the first hypothesis and second hypothesis tested positive.

As measurements on residual effects of nitrogen fertilising products were not available due to the erroneous fertilisation of grass for the fourth cut, the third hypothesis cannot be tested.

These results point out that BBFs made of different compositions can serve as a replacement of mineral nitrogen fertiliser.

5 Acknowledgements

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Annex 1 Yield data and chemical composition of crop

Number	Parameter	Unit
1	Plot	[-]
2	fertilising product	[-]
3	code application rate	[-]
4	Repetition	[-]
5	Code treatment	[-]
6	Application rate 1st cut	kg N/ha
7	Application rate 2nd cut	kg N/ha
8	Application rate 3rd cut	kg N/ha
9	Application rate total all cuts	kg N/ha
10	Yield, 1st cut fresh	tonnes fresh/ha
11	Yield, 2nd cut fresh	tonnes fresh/ha
12	Yield, 3rd cut fresh	tonnes fresh/ha
13	Yield, 1st cut dry matter	tonnes dry matter/ha
14	Yield, 2nd cut dry matter	tonnes dry matter/ha
15	Yield, 3rd cut dry matter	tonnes dry matter/ha
16	Total yield dry matter	tonnes dry matter/ha
17	N content, 1st cut	g N/kg
18	P content, 1st cut	g P/kg
19	Moisture content (70-105°C), 1st cut	% oven dry
20	Moisture content (fresh-105°C), 1st cut	% fresh
21	N content, 2nd cut	g N/kg
22	P content, 2nd cut	g P/kg
23	Moisture content (70-105°C), 2nd cut	% oven dry
24	Moisture content (fresh-105°C), 2nd cut	% fresh
25	N content, 3rd cut	g N/kg
26	P content, 3rd cut	g P/kg
27	Moisture content (70-105°C), 3rd cut	% oven dry
28	Moisture content (fresh-105°C), 3rd cut	% fresh
29	N uptake, 1st cut	kg N/ha
30	N uptake, 2nd cut	kg N/ha
31	N uptake, 3rd cut	kg N/ha
32	N uptake total	kg N/ha
33	P uptake, 1st cut	kg P/ha
34	P uptake, 2nd cut	kg P/ha
35	P uptake, 3rd cut	kg P/ha
36	P uptake total	kg P/ha

1	2	3		4	5	6	7	8	9
1	CS	50	2	1	108	76	35	41	125
2	CAN	75	3	1	103	79	61	50	190
3	BBFb	75	3	1	111	87	45	53	185
4	CAN	50	2	1	102	52	40	34	126
5	CS+BBFb	100	4	1	113	134	85	92	311
6	CAN	100	4	1	104	105	81	67	253
7	CS+BBFb	75	3	1	112	90	57	61	208
8	CAN	0	1	1	101	0	0	0	0
9	UAN	50	2	1	106	52	40	34	126
10	UAN	75	3	1	107	79	61	50	190
11	CAN	125	5	1	105	131	102	84	317
12	CS	75	3	1	109	73	53	61	187
13	BBFb	50	2	1	110	58	30	35	123
14	CS+BBFb	75	3	2	212	90	57	61	208
15	CS+BBFb	100	4	2	213	134	85	92	311
16	CAN	100	4	2	204	105	81	67	253
17	CAN	50	2	2	202	52	40	34	126
18	CAN	75	3	2	203	79	61	50	190
19	CS	75	3	2	209	73	53	61	187
20	CS	50	2	2	208	49	35	41	125
21	BBFb	50	2	2	210	58	30	35	123
22	CAN	125	5	2	205	131	102	84	317
23	UAN	75	3	2	207	79	61	50	190
24	BBFb	75	3	2	211	87	45	53	185
25	UAN	50	2	2	206	52	40	34	126
26	CAN	0	1	2	201	0	0	0	0
27	BBFb	50	2	3	310	58	30	35	123
28	CS+BBFb	75	3	3	312	90	57	61	208
29	CAN	0	1	3	301	0	0	0	0
30	BBFb	75	3	3	311	87	45	53	185
31	CAN	100	4	3	304	105	81	67	253
32	UAN	75	3	3	307	79	61	50	190
33	CS	75	3	3	309	73	53	61	187
34	CS+BBFb	100	4	3	313	134	85	92	311
35	CAN	50	2	3	302	52	40	34	126
36	UAN	50	2	3	306	52	40	34	126
37	CAN	75	3	3	303	79	61	50	190
38	CS	50	2	3	308	49	35	41	125
39	CAN	125	5	3	305	131	102	84	317

1	10	11	12	13	14	15	16
1	27.0	4.9	7.7	5.1	1.0	1.1	7.2
2	45.0	18.5	17.8	6.5	2.6	1.8	10.9
3	44.7	12.5	14.1	7.0	1.8	1.7	10.4
4	37.7	11.7	13.5	6.1	1.9	1.8	9.8
5	42.0	9.1	13.8	6.5	1.4	1.8	9.6
6	49.3	18.1	20.3	6.8	2.2	2.2	11.2
7	39.3	8.6	12.0	6.5	1.3	1.4	9.2
8	20.7	3.9	4.3	4.3	0.8	0.4	5.5
9	41.0	6.1	9.7	6.7	1.3	1.2	9.2
10	40.7	9.1	11.7	6.6	1.5	1.2	9.4
11	50.3	19.0	20.3	6.6	2.3	2.1	11.0
12	25.0	5.5	8.0	5.2	1.1	1.0	7.3
13	38.0	9.3	12.7	6.3	1.6	1.3	9.2
14	35.0	6.6	11.0	5.8	1.1	1.2	8.1
15	39.0	8.3	14.0	6.0	1.4	1.6	9.0
16	49.7	16.3	18.7	7.4	2.1	1.6	11.0
17	39.0	9.7	13.0	6.7	1.7	1.4	9.9
18	49.7	14.5	17.0	7.8	2.0	1.7	11.5
19	30.7	6.1	10.3	5.8	1.1	1.3	8.3
20	24.3	4.3	7.0	4.9	0.9	0.8	6.5
21	43.7	8.9	13.0	6.9	1.5	1.5	9.9
22	50.0	17.7	20.3	6.4	2.2	2.1	10.7
23	44.7	9.3	11.0	7.0	1.6	1.4	10.1
24	46.0	11.5	14.7	6.6	1.8	1.8	10.2
25	44.0	8.1	8.7	7.1	1.6	1.2	9.9
26	22.0	4.1	4.0	4.5	0.9	0.6	6.0
27	42.0	9.2	10.3	6.6	1.5	1.3	9.4
28	36.7	8.0	10.3	5.9	1.4	1.3	8.6
29	20.7	4.3	6.0	4.3	1.0	0.7	6.0
30	44.0	12.3	17.3	6.2	1.9	1.8	9.9
31	50.3	17.7	17.7	7.3	2.3	1.5	11.2
32	45.0	10.7	15.3	6.8	1.8	1.5	10.1
33	32.7	6.5	10.3	5.8	1.2	1.2	8.3
34	43.7	10.2	13.7	6.6	1.5	1.5	9.6
35	44.0	12.1	12.0	6.2	1.8	1.3	9.3
36	38.0	7.5	8.3	5.4	1.4	1.1	7.8
37	42.7	14.3	14.0	5.8	2.2	1.5	9.6
38	23.3	6.4	9.7	4.2	1.2	1.2	6.7
39	49.3	16.2	19.0	6.7	2.1	1.7	10.5

1	17	18	19	20	21	22	23	24	25	26	27	28
1	13.7	2.6	1.7	81.2	18.1	3.5	2.1	79.0	18.8	3.8	2.4	85.3
2	18.6	3.2	1.9	85.5	22.1	3.9	2.2	85.9	26.0	4.3	2.2	90.0
3	17.8	3.3	2.0	84.4	21.9	4.2	2.1	85.8	24.3	4.5	2.2	88.2
4	16.5	3.0	1.9	83.8	17.4	3.4	1.8	83.7	24.0	4.4	2.2	86.3
5	18.0	3.0	2.4	84.5	25.8	3.7	2.0	85.1	23.9	3.7	2.3	87.1
6	20.4	3.5	2.1	86.2	25.8	4.2	2.1	87.7	28.5	4.5	2.5	89.4
7	14.2	2.8	2.0	83.5	22.8	4.3	2.1	84.8	24.8	4.4	2.9	88.4
8	12.9	2.5	1.8	79.3	16.6	3.6	2.1	80.6	20.4	4.6	2.8	89.9
9	16.0	3.0	2.3	83.6	17.4	3.6	2.1	78.9	21.5	4.3	2.7	87.9
10	15.0	3.1	2.2	83.7	19.2	4.0	2.1	83.0	22.6	4.6	2.6	89.6
11	22.2	4.0	2.6	86.8	32.3	4.3	2.5	87.9	28.1	4.2	2.2	89.9
12	13.2	2.6	2.2	79.4	18.3	3.8	2.3	79.9	19.8	4.1	1.8	87.0
13	16.2	3.2	2.6	83.4	20.0	4.1	2.3	83.2	22.5	4.6	1.7	89.4
14	17.1	3.2	2.2	83.5	22.9	4.4	2.2	83.4	23.3	4.5	1.2	88.9
15	18.0	3.5	2.5	84.6	23.7	4.0	2.0	83.4	24.0	4.0	1.1	88.7
16	17.1	2.8	2.4	85.2	26.6	4.2	2.0	87.4	30.7	4.3	1.4	91.3
17	15.7	2.9	2.3	82.7	18.5	3.5	1.5	82.5	23.9	4.3	1.7	89.0
18	18.3	3.2	2.5	84.3	24.5	4.1	1.8	86.2	26.8	4.1	1.8	89.9
19	14.3	2.9	2.1	81.1	20.9	3.8	1.7	81.1	22.5	4.2	2.3	87.2
20	12.5	2.6	2.1	79.9	19.5	4.1	1.9	80.2	21.4	4.6	2.5	88.9
21	15.8	3.2	2.0	84.3	19.2	4.0	1.9	83.1	22.7	4.5	2.6	88.3
22	19.1	3.7	2.2	87.3	31.4	4.0	2.0	87.3	33.1	4.3	2.4	89.5
23	15.4	3.0	2.4	84.3	19.0	4.1	2.3	82.4	22.5	4.5	2.8	87.0
24	17.6	3.6	2.2	85.7	21.2	4.1	2.0	84.1	22.8	4.4	2.3	87.8
25	17.2	3.2	2.1	83.9	17.2	3.8	2.1	80.6	19.8	3.9	2.7	86.0
26	12.4	2.5	1.7	79.4	15.7	3.3	1.9	78.3	18.2	4.0	2.7	85.6
27	15.2	3.1	2.1	84.2	23.5	4.6	2.4	84.2	23.0	4.5	2.5	87.3
28	15.7	2.9	2.1	83.8	21.6	4.2	2.3	82.6	23.9	4.4	2.4	87.9
29	14.0	2.6	2.3	79.0	16.8	3.5	2.2	77.8	19.8	4.1	2.4	88.2
30	20.9	3.7	2.3	86.0	24.4	4.4	2.3	84.8	25.7	4.4	2.2	89.4
31	17.3	3.2	2.2	85.4	31.1	4.5	2.0	86.8	28.3	4.4	2.1	91.7
32	17.3	3.4	2.2	84.9	21.0	4.3	2.1	83.4	22.9	4.4	2.1	90.0
33	14.1	3.0	1.9	82.1	20.2	4.2	2.3	80.9	22.2	4.4	2.3	88.4
34	18.6	3.3	2.1	84.9	24.5	4.2	2.2	85.3	23.8	4.2	2.2	89.2
35	17.9	3.4	1.9	85.9	20.1	4.2	2.2	84.7	21.1	4.3	3.1	89.3
36	15.6	3.1	1.8	85.9	18.3	3.7	2.2	81.0	21.2	4.4	2.6	87.3
37	15.2	3.4	2.0	86.3	23.0	4.1	2.3	84.5	21.6	4.4	2.8	89.0
38	16.3	3.1	2.0	81.9	18.7	4.1	2.3	80.8	20.7	4.2	3.1	87.1
39	18.1	3.1	2.1	86.5	34.3	4.0	2.3	86.8	32.6	4.3	2.4	90.9

1	29	30	31	32	33	34	35	36
1	69.7	18.5	21.1	109	13.2	3.5	4.1	21
2	121.7	57.7	46.4	226	20.6	10.0	7.6	38
3	124.4	38.7	40.6	204	22.2	7.3	7.3	37
4	100.8	33.1	44.3	178	18.2	6.4	7.9	32
5	117.3	34.9	42.6	195	18.9	4.9	6.4	30
6	139.1	57.4	61.4	258	23.6	9.1	9.5	42
7	92.1	29.8	34.6	156	18.1	5.5	6.0	30
8	55.3	12.4	8.9	77	10.7	2.6	1.9	15
9	107.4	22.2	25.1	155	19.8	4.5	4.9	29
10	99.6	29.6	27.4	157	20.2	6.0	5.4	32
11	147.3	74.3	57.7	279	25.8	9.5	8.4	44
12	67.9	20.1	20.5	109	13.3	4.0	4.2	22
13	102.3	31.1	30.2	164	19.7	6.3	6.0	32
14	98.7	25.1	28.4	152	18.3	4.8	5.4	28
15	108.4	32.8	37.9	179	20.4	5.5	6.3	32
16	125.8	54.8	49.9	230	20.0	8.4	6.9	35
17	105.7	31.3	34.2	171	19.4	5.9	6.0	31
18	142.3	49.2	46.0	237	24.6	8.0	6.9	39
19	82.9	23.9	29.8	137	16.2	4.3	5.4	26
20	60.9	16.7	16.7	94	12.6	3.5	3.5	20
21	108.5	28.9	34.5	172	21.6	5.9	6.7	34
22	121.4	70.5	70.6	263	22.9	8.8	9.0	41
23	107.8	31.3	32.2	171	20.4	6.5	6.3	33
24	115.7	38.7	40.9	195	23.1	7.4	7.7	38
25	121.5	27.1	24.1	173	22.5	5.9	4.6	33
26	56.2	14.1	10.5	81	11.2	2.9	2.3	16
27	101.0	34.1	30.1	165	19.9	6.5	5.7	32
28	93.4	30.1	29.8	153	16.9	5.7	5.3	28
29	60.9	16.1	14.0	91	11.2	3.3	2.8	17
30	128.6	45.4	47.2	221	22.0	8.1	8.0	38
31	127.0	72.9	41.5	241	22.7	10.4	6.3	39
32	117.4	37.3	35.1	190	22.6	7.4	6.5	37
33	82.3	24.9	26.6	134	17.0	5.1	5.2	27
34	122.6	36.8	35.2	195	21.2	6.2	6.1	34
35	111.3	37.2	27.2	176	20.9	7.6	5.3	34
36	83.5	26.0	22.5	132	16.4	5.1	4.6	26
37	88.8	51.2	33.3	173	19.4	8.9	6.7	35
38	69.0	23.0	25.9	118	12.9	5.0	5.0	23
39	120.4	73.3	56.3	250	20.4	8.3	7.2	36

Annex 2 Mineral nitrogen in soil

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

1	2	3	4	5	6	7	8
1	CS	50	1	30	9	10	49
2	CAN	75	1	19	9	6	34
3	BBFb	75	1	27	11	7	44
4	CAN	50	1	32	11	8	51
5	CS+BBFb	100	1	58	11	7	75
6	CAN	100	1	16	13	8	37
7	CS+BBFb	75	1	28	8	6	42
8	CAN	0	1	24	7	4	34
9	UAN	50	1	16	12	4	31
10	UAN	75	1	27	6	5	38
11	CAN	125	1	18	7	7	32
12	CS	75	1	13	6	10	28
13	BBFb	50	1	17	10	14	40
14	CS+BBFb	75	2	17	6	5	29
15	CS+BBFb	100	2	20	7	7	33
16	CAN	100	2	20	7	6	33
17	CAN	50	2	28	6	4	39
18	CAN	75	2	20	6	4	30
19	CS	75	2	21	9	6	35
20	CS	50	2	26	9	10	45
21	BBFb	50	2	15	9	4	28
22	CAN	125	2	13	5	6	25
23	UAN	75	2	16	7	6	30
24	BBFb	75	2	13	9	10	33
25	UAN	50	2	27	13	6	46
26	CAN	0	2	16	6	5	27
27	BBFb	50	3	26	8	5	39
28	CS+BBFb	75	3	29	8	6	43
29	CAN	0	3	17	7	5	30
30	BBFb	75	3	19	9	8	36
31	CAN	100	3	19	10	4	32
32	UAN	75	3	18	13	7	38
33	CS	75	3	30	10	8	48
34	CS+BBFb	100	3	18	5	5	28
35	CAN	50	3	17	4	4	25
36	UAN	50	3	12	6	6	24
37	CAN	75	3	23	7	5	35
38	CS	50	3	18	7	5	30
39	CAN	125	3	17	6	5	28

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