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

Field Experiment Grassland 2020

Phillip Ehlert

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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 is het bepalen van risico's 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 op grasland die in 2020 werd uitgevoerd op het proefbedrijf De Marke. De agronomische effectiviteit van de biogebaseerde stikstof meststof was vergelijkbaar met die van kalkammonsalpeter. Na de oogst van de laatste snede was de voorraad minerale stikstof in de bodemlaag 0 – 90 cm bij het biogebaseerde stikstofmeststof eveneens vergelijkbaar met de voorraad bij kalkammonsalpeter.

The aim of the project Biobased Fertilisers Achterhoek ('Kunstmestvrije Achterhoek' *in Dutch*) is to make fertilisation practices more sustainable through 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 is to determine the nitrogen fertiliser replacement value of biobased fertilising products made from animal manure. A second objective is 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 with field experiments on grassland and on arable land with silage maize. This document reports the results of a field experiment on grassland which was conducted in 2020. The field experiment on grassland points on a similar agronomic effectivity of the biobased nitrogen fertilising product compared to calcium ammonium nitrate. The environmental performances of all fertilising products with equal rates of nitrogen were comparable.

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

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Photo cover: Overview of the field experiment on grassland on the Experimental Farm De Marke

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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 regional pilot Biobased Fertiliser Achterhoek (‘KunstmestVrije Achterhoek (KVA) pilot’ *in Dutch*) was to make soil fertilisation practices more sustainable by providing nitrogen, potash and sulphur fertilisation via fertilising products derived from regionally recycled resources. The pilot is part of the Sixth Action Programme of the Netherlands, which serves the Nitrates Directive. A monitoring programme within the pilot was set up by Wageningen Environmental Research (WENR) to achieve two main objectives by investigating:

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, or *‘Urean’, in Dutch*) and
2. Environmental risk assessment through analysing the risk of leaching of nitrogen from these biobased fertilising products.

The monitoring programme started in 2019 with a field experiment with silage maize on a sandy arable soil. In 2020, two field experiments were conducted: One with silage maize and a second on grassland both on sandy soils. This document reports the field experiment on grassland conducted in 2020. The biobased fertilising product used in the experimental year 2020 consisted of 99% mineral-concentrate enriched with 1% liquid fertiliser with 30% N based on urea and ammonium nitrate (UAN, called *‘Urean’ in Dutch*). Nitrogen in the BBF originated for roughly 75% from digestate and 25% from UAN. This product is referred to as BBF-basic (BBFb).

These objectives are elaborated in the following three hypotheses:

1. The magnitude of NFRV depends upon the reference N fertiliser that was 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 hypotheses were tested in 2020 in a field experiment conducted on grassland on a sandy soil.

In this field experiment, calcium ammonium nitrate (CAN) was the reference mineral fertiliser. CAN accounts for the majority of fertiliser used in the Netherlands. Due to an erroneous fertilisation of CAN on plots that also received liquid urea/ammonium nitrate (UAN), it was not possible to test UAN as a reference fertiliser and, thus, it was not possible to test the first hypothesis. Nitrogen application rates were based on the total nitrogen contents of each fertilising product.

As in 2019, the climatic conditions in 2020 were dry with elevated temperatures, which made sprinkler irrigation necessary. Although dry, grass responded to treatment with the fertilising products.

Yield
Due to the drought and despite sprinkler irrigation, only four cuts of grass were harvested with modest dry matter yields per cut and modest total yields. The yields of the first two cuts are normative, as they were higher than those for the third- and fourth cuts.

For each cut, and for the total yields, both fertilising products and application rates 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. The CAN treatment at an application rate of 125% did not result in a higher dry matter yield.

Cattle slurry (CS) brought the lowest yields, followed by the combination of CS+BBFb. BBFb and CAN generally delivered comparable dry matter yields, which were not significantly different.

Nitrogen uptake
Nitrogen fertilisation significantly increased nitrogen uptake per cut, with the exception of Cut Four, in which fertiliser treatments were not significantly different. Also, an increase in nitrogen application rate increased nitrogen uptake significantly with the exception of Cut Four. Total nitrogen uptake increased with an increase in the nitrogen application rate.

CS had a significant lower nitrogen uptake for Cuts One, Two and Four compared to other treatments at similar application rates. For Cut Three, there were no differences between CS and other treatments. The combination of CS and BBFb compared with CS at a similar application rate had significant higher nitrogen uptakes with Cuts One and Three but not for Cuts Two and Four. Overall nitrogen uptake of the combination was significantly higher than for CS.

For Cut One (BBFb) and Cut Two (CAN, BBFb), CAN and BBFb had higher uptakes than the combination (CS+BBFb) or CS. For other cuts, the uptakes were comparable. Total nitrogen uptake was ranked in the order: CS < CS+BBFb < CAN ~ BBF2 at an application rate of 75%. BBFb had higher uptake than for CAN but was not significant.

Fertilising products containing a comparable proportion of mineral nitrogen gave similar results. An increase in organically bound nitrogen lowered nitrogen uptake.

NUE
NUE of CAN at 100% and 125% application rates were higher compared to the 50% and 75% application rates (Cut One and total). In general, BBFb had similar NUE values compared to CAN. CAN and BBFb had higher NUE values for the first two cuts and total compared to CS and the combination of CS and BBFb. For Cuts Three and Four, they were comparable.

There was no indication in this field experiment that NUE declined with increased application rates. This was attributed to the fact that grass has a well-developed root-system, as well as favourable prevailing weather conditions.

NFRV
The yields of the first two cuts were normative. With these as foci, overall CS and the combination of CS+BBFb performed less well than BBFb and CAN. BBFb and CAN had comparable efficiencies of nitrogen use and BBFb, thus, had a comparable NFRV.

Stock of soil mineral nitrogen
Fertilisation led to an increase in soil mineral nitrogen stock after the last cut of grass. In general, the differences between fertilising products were small and not significantly different.

Nitrogen balance sheet
For grass without N fertilisation (0 kg N/ha) soil organic N contributed to N uptake of grass. A contribution of 26.6 kg N/ha was measured.

The difference between the stock of soil mineral N after harvest and the quantity present at the start, plus the total N uptake by grass, minus the N application rate has been used as an indicator for the contribution of nitrogen from the soil. Except for the treatment without nitrogen fertilisation (CAN 0%), all values were negative, which indicates an immobilisation of nitrogen. With an increase of the application rate the values became more negative. A major part of the residual mineral nitrogen from fertilising products not taken up by grass was not traced in the stocks of mineral nitrogen in the soil layer of 0-90 cm depth. Pathways for losses of applied mineral nitrogen are assumed to be:

- Volatilisation losses of ammonia,
- Losses through denitrification, and
- Leaching below the soil layer of 0-90 cm depth.

In conclusion

In this first field experiment on grassland on a sandy soil, which was conducted in 2020, at the experimental farm, De Marke, the effect of a biobased fertilising product on grass yield (over four cuts), N uptake, and residual fertilising product on soil N was studied. The year 2020 was a third year of drought in the Achterhoek region of the Netherlands, which was combined with elevated temperatures. The drought was severe and rendered sprinkler irrigation necessary.

This field experiment on grassland indicated that BBFb has a similar agronomic effectivity compared to CAN. CS had the lowest effectivity, and the combination of CS+BBFb achieved an agronomic effectivity somewhere between BBFb and CAN (better) and CS (poorer).

The environmental performances of all fertilising products were comparable. Fertilisation with nitrogen led to a higher residue of soil mineral nitrogen, but overall there were no differences between the fertilising products. A simple nitrogen balance sheet indicated losses of applied nitrogen, as a major proportion of residual nitrogen was not traced again in residual soil nitrogen. It is also possible that nitrogen was immobilised.

1 Introduction

The quality of groundwater and surface water in the Netherlands has improved over the past decades[1], but still requires further improvement[2] (the Netherlands, Sixth Action Programme Nitrates Directive 91/676/EEC[3]). 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 regional pilot Biobased Fertilisers Achterhoek (Sixth Action Programme of the Netherlands, 5.5.3.3, Annex 1).

The main goal of the regional pilot Biobased Fertilisers Achterhoek was to investigate the processing of animal manure at a practical level. Different manure processing technologies were reviewed and promising technologies were 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 (nitrogen, 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 on composition, agronomic effectivity and environmental effects in pilots of the Sixth Action Programme. The aim at the start 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). During the project, this aim was revised, and the focus became to meet the criteria that are set by JRC proposed RENURE[4] fertilising products within the context of the Nitrates Directive. The monitoring in this project made use of larger monitoring programmes from other projects, particularly 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 the nutrient and contaminant levels[5]. The monitoring of this project on composition, agronomic effectivity and environmental effects is a joint study by the province of Gelderland, LTO Noord Projects, ForFarmers, 'Vruchtbare Kringloop Achterhoek en Liemers' and Wageningen University and Research. There is regional cooperation with a large number of actors involved in the processing of manure at the practical level.

More specifically, the following objectives towards finding solutions for the manure surpluses in the region were formulated in the regional Biobased Fertilisers Achterhoek pilot:

- Inform, support, and facilitate local land users in their efforts to find circular solutions for manure- and mineral-related issues at their companies. Here, knowledge from the various 'manure projects' in the province was explicitly included.
- Identify the desired quality and composition of fertilising products from animal manure and sludge, becoming available for the market product through use of the best techniques available for manure and sludge processing.
- Advise manure processors, sludge processors and water boards on the desired product (quality) enabling creation of a market-oriented offer.
- Create legal space for integral sustainable solutions for the use of minerals in 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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[1] https://www.eea.europa.eu/themes/water/interactive/by-category/nitrate-directive

[2] 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

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

[4] 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.

[5] 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 regional Biobased Fertilisers Achterhoek pilot. Wageningen Environmental Research (WENR[6]) 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 by comparing 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 the desired product quality and product composition of fertilising products and monitored their performance through assessment of 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 N fertilising products based on animal manure within legal frameworks on use of animal manure and mineral fertilisers, it is important to gain insight into the NFRV of biobased fertilising products derived 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[7] and Sigurnjak et al. (2022, in prep.[8]).

The demonstration field trials[9], which constitute Point 3 of the monitoring programme, began in 2018. Results from demonstration fields studied in 2018, 2019 and 2020 have been reported (Ehlert & Van der Lippe, 2020a, 2020b; Ehlert et al., 2021). Monitoring on demonstration field trails has ended.

In 2019 and 2020, field experiments on arable land with silage maize were conducted and have been reported (Ehlert, 2020 & 2021). In 2020, a field experiment on grassland was conducted, with a second field experiment conducted on grassland in 2021. The field experiment of 2020 is reported in this study.

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

[7] 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

[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 of dairy farms. The plots were split in 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 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 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 assessed through regular soil testing. The application rates of the nutrients of these fertilisers were exactly the same. The nutrients from animal manure were taken into account in the nutrient management plan. The experiences from the field testing carried out in 2018, 2018 and 2020 were 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, as assessed 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, were years with periods of severe drought in the Achterhoek region of the Netherlands. Not all farmers there were able to apply sprinkler irrigation. Drought hampered the testing of the fertilising products and lowered the effectivity of fertilisation.

1.1 Objectives

The field experiment served two objectives. To investigate the:

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 assessment of the risk of leaching of nitrogen from these biobased fertilising products.

1.2 Hypotheses

Crop available N in this study is defined as the quantity of mineral 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[10]).

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

- Type of fertilising product.
  - ⇨ The more crop available N that is present, the higher the NFRV is.
- Application rate.
  - ⇨ The efficacy of N 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 NFRV.

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

The following hypotheses were formulated:

1. The magnitude of NFRV depends upon the reference N fertiliser that is used.
2. Biobased fertilising products have an NFRV as the reference fertiliser of nearly 100%.
3. Biobased fertilising products have a similar effect on residual nitrogen after the last cut of grass to a regular mineral nitrogen 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 or a blend of liquid urea and ammonium nitrate (called '*Urean' in Dutch*, 30%N). BBFs for the first two cuts of grassland had 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 are in force and injection techniques or a blanket sheet application directly followed by incorporation in the soil are in force.

N/S ratio as per crop requirements. For following cuts, BBFs with low S content were used (and, thus, higher N/S ratios were created) as the demand of grass for sulphur is low. Due to the experience with a mixture of mineral concentrate with condensed ammonium water on grassland on the demonstration field experiments in 2019, when 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).

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), as 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[14] was presented for discussion within the Nitrates Expert Group[15].

The current project was stimulated by the start of the SAFEMANURE project but continued with field experiments in 2019, 2020 and 2021. The data and outcomes obtained in this project served 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 first experiment on grassland that was conducted in 2020. 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), nitrogen fertiliser replacement value (NFRV), residual soil mineral nitrogen, and an indicative nitrogen balance. In Chapter 4, the results are evaluated, and conclusions given for this initial experimental year on grassland.

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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 grassland. In the Netherlands, it is common to use animal manure as a standard fertilising product to fulfil a large part 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 and included three repetitions. Treatments were randomised per replication. The design created a total of 39 plots. The design, including its codes and the application rates used for four cuts, as well as the total nitrogen application rates in kg N/ha, are given in Table 1. Differences in application rate per code for BBF and CS derived from the actual given fertilising product sampled at fertilisation and the actual analyses of these samples.

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	4th cut	Total
1	Calcium ammonium nitrate (CAN), control	1	0	0	0	0	0
2	Calcium ammonium nitrate (CAN)	2	53	40	33	33	160
3	Calcium ammonium nitrate (CAN)	3	79	61	50	50	240
4	Calcium ammonium nitrate (CAN)	4	106	81	67	67	320
5	Calcium ammonium nitrate (CAN)	5	132	101	83	83	400
6	Liquid urea ammonium nitrate (UAN)	2	106	41	34	34	214
7	Liquid urea ammonium nitrate (UAN)	3	159	61	50	50	321
8	Cattle slurry (CS[16])	2	58	35	31	0	124
9	Cattle slurry (CS)	3	87	53	47	0	186
10	Biobased fertilising product basic (BBFb)	2	47	42	32	33	154
11	Biobased fertilising product basic (BBFb)	3	70	63	48	50	231
12	Cattle slurry + biobased fertilising product basic (CS+BBFb)	3	86	58	48	30	222
13	Cattle slurry + biobased fertilising product basic (CS+BBFb)	4	129	87	72	45	333

*: Application rates for Codes 1, 2, 3, 4, and 5 stand for the application rates given in the table and are derived from soil fertility testing. The code for optimum fertilisation is 4 (or 100%), other codes stand 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. In the Netherlands, this fertiliser is called '*Urean*'. Erroneously, at the fertilisation of the first cut, plots of UAN also received CAN creating higher nitrogen application rates at similar codes. Applied CS had a lower nitrogen content than a pre-analysis had indicated. This also caused lower nitrogen application rates than planned.

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[16] Cattle slurry from the experimental dairy farm, De Marke (https://www.wur.nl/nl/locatie-De-Marke.htm)

2.2 Soil

The field experiment was conducted at the experimental farm, De Marke, on a sandy soil on established grassland. The initial soil fertility status of the field experiment prior to fertilisation in Spring is given in Table 2. Soil samples were taken on 25th February 2020. 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 indicated how to determine 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	%	3.3	4.4	4.7	4.1	NIRS[17]
C-inorganic	%	1.7	2.2	2.4	2.1	NIRS
Clay (< 2 µm)	%	1	2	2	2	NIRS
Silt (2-50 µm)	%	10	15	15	13	NIRS
Sand (>50 µm)	%	86	79	78	81	NIRS
CEC	mmol+/kg	47	56	59	54	NIRS
pH	-	5.9	5.7	5.5	5.7	NIRS
N-total	mg N/kg	1320	1580	1690	1530	NIRS
P-capacity (P-Al-value)	mg P_2O_5/100 g	60	65	69	65	NIRS
P-plant available (P-$CaCl_2$)	mg P/kg	3.2	2.6	2.0	2.6	CCL3
K-capacity	mmol+/kg	1.9	2.7	3.0	2.5	NIRS
K-plant available	mg K/kg	92	99	107	99	CCL3
S-total	mg S/kg	250	290	305	282	NIRS
S-plant available	mg S/kg	<1.1	<1.1	<1.1	<1.1	CCL3[18]
Ca-total	mmol+ Ca/kg	43	46	43	44	NIRS
Ca-plant available	mg Ca/kg	1	0.4	0.7	0.7	NIRS
Mg-total	mmol+ Mg/kg	7.4	10.2	11.0	9.5	NIRS
Mg-plant available	mg Mg/kg	115	139	144	133	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 on 4th March 2020, prior to fertilisation. In these soil layers, 12 kg N/ha, 9 kg N/ha and 2 kg N/ha was found.

2.3 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). CS requires a different injection technique than a BBF and was applied independently from the BBF.

CAN and UAN are commonly used synthetic mineral nitrogen fertilisers.

The biobased fertilising product was produced at the Green Mineral Mining Centre[19] 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 biobased fertilisers and takes part in the EU H2020 project SYSTEMIC as a demonstration plant and also takes part in the Dutch MMM-2 project. Both participations lead to more in-depth monitoring of production

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[17] Eurofins Agro, method NIRS (TSC®)
[18] Eurofins Agro, method CCL3(PAE®)
[19] https://www.groenemineralencentrale.nl/nl/english

processes (Regelink et al., 2021. (*Dutch*)). The SYSTEMIC project provides a full description of the production process of biobased fertilisers[20].

The biobased fertiliser was produced from mineral concentrate obtained by processing co-digested pig slurry (digestate). This digestate is separated into a liquid and a solid fraction through the use of a decanter. Next, the liquid fraction is processed into a mineral concentrate and a permeate (clean water) through a cascade of techniques, including reverse osmosis. The mineral concentrate serves as a secondary resource for the production of biobased fertilising product. The biobased fertilising product basic (BBFb[21]) was a mixture of mineral concentrate with 1% UAN.

Table 3 gives the composition of the fertilising products (reference fertilisers CAN and UAN and BBF and CS) that were used for the field experiment on grassland. BBF and CS were sampled during fertilisation of the first three cuts (CS) or all four cuts (BBF).

2.4 Application rates

Application rates of nutrients were based on fertiliser recommendations that have been derived from soil testing. The recommendations of the Dutch Committee Fertilisation of Grassland and Fodder Crops (CBGV[22], 2020) were followed.

2.4.1 Nitrogen

The N application rate was based on the fertilisation guide (in *Dutch Bemestingswijzer grasland*) of Eurofins Agro for yield targets of 3.5 tonne[23] dry matter/ha for the first cut and 2-2.5 tonne dry matter/ha for the following cuts. For Cuts One to Four, the recommended N fertilisation rates are 126, 96, 79 and 79 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). In order to comply with this rate limit, the recommended N application rates were proportionately lowered, 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%, this correlates with Code 4 of Table 1. The response of grassland to nitrogen fertilisation application rates of CAS were 0%, 50%, 75%, 100% and 125%; of BBFb and UAN - 50% and 75%; and of the combination CS and BBFb - 75% and 100%. Table 1 provides the values for the application rates. Due to an erroneous application of the UAN treatments, grass for the first cut received both CAS and UAN, which caused higher application rates than planned. CS from the manure storage was analysed before application, as were the individual batches used for the actual fertilisation. It was found that the batches had lower nitrogen contents, which lead to lower application rates than planned.

Table 3 gives the composition of the tested products. The composition of the CS varied among the three dosages. The NH_4/N ratio varied between 47 and 65%. The BBFb is the mixture of mineral concentrate and UAN containing 10.0 – 10.8 kg N/ton, mostly as N-NH_4. The urea content could not be measured. No measurements were performed on the mineral concentrate prior to adding UAN but the composition of mineral concentrate is 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 as proposed for RENURE fertilising products.

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[20] https://systemicproject.eu/plants/demonstration-plants/groot-zevert-the-netherlands/

[21] 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.

[22] https://www.bemestingsadvies.nl/nl/bemestingsadvies.htm

[23] Metric ton

Table 3 *Composition of reference fertilisers CAN and UAN, biobased fertilising product (BBFb)* [1] *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[24], 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	8.0	80.0	19.7	998	7.2	3.8	2.2	*	*	0.40	4.1	0.59	0.5	0.49	0.9	7.6
	2nd	7.4	79.7	18.5	1005	6.9	3.4	1.6	*	*	0.36	4.0	0.54	0.39	0.40	0.9	8.7
	3rd	7.2	79.4	18.6	1015	7.0	3.1	1.7	*	*	0.37	4.3	0.59	0.4	0.39	0.7	7.8
Biobased fertilising product. basic (BBFb)	1st	3.8	24.0	73.7	1041	8.2	10.0	8.0	0.7	*	0.058	8.17	0.072	1.79	4.8	1.2	5.6
	2nd	3.6	21.3	77.5	1030	8.7	10.8	8.7	0.6	*	0.027	8.44	0.039	1.91	4.3	1.3	5.7
	3rd	3.6	21.1	77.9	1046	8.7	10.3	9.2	0.5	*	0.020	8.52	0.044	1.79	4.1	1.2	5.8
	4th	3.5	21.3	74.7	1039	8.8	10.2	9.3	0.24	*	0.023	7.98	0.035	1.77	4.2	1.3	5.8

[1] CAN and UAN were analysed by Lufa Nord West[25] (Germany); CS and BBF were analysed by Wageningen UR - Chemical Biological Soil Laboratory[26] (CBLB).

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[24] Biuret content was 0.22%

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

[26] 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 first 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	95	60
Magnesium	kg MgO/ha	40	40 (only 2nd cut)
Sulphur	kg SO_3/ha	35	25
Sodium	Kg Na_2O/ha	35	35 (only 2nd cut)

BBFb and CS contain other nutrients in addition to N. These were taken into account by applying the *Ceteris Paribus* Principle[27]. Therefore, each treatment received the same quantity of phosphate, 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 ($CaSO_4.2\ H_2O$). And sodium was applied as sodium chloride. Although the magnesium status of the soil was adequate, with the application of biobased fertilising products and cattle slurry Mg was also added. 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.

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

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[27] 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 of the N-fertiliser was conducted on 6th February, 20th May, 25th June and 19th August 2020.

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 which was used for application of the liquid mineral nitrogen fertiliser, UAN.*

The application of biobased fertilising products required an injection technique and equipment that can handle application rates of 2-5 m^3/ha. For this purpose, an injector was designed and built (Photo 2).

Photo 2 *Injector designed for biobased fertilising products. Injector was built by Slootsmid*[28] *in 2020 and was designed for specific use in field experiments and/or fertilisation of small plots. The design aims to mitigate/minimise ammonia losses.*

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[28] 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. Here, it was adjusted for application of cattle slurry on grassland with slots distanced at 25 cm.*

2.6 Sampling soil, harvest and sampling crop

2.6.1 Sampling soil

Soil samples were taken at three times during the experimental period. Before fertilisation (on 26th February 2020), the grass sod (of 0-10 cm depth) of the experimental field was sampled. A standard sampling protocol was followed for the field experiment. Forty soil cores were extracted manually from a random distribution and pooled. The pooled soil sample was used to assess the availability of macro-nutrients which determine the application rates of N, P, K, Mg, Na and S.

On the 3rd and 4th March 2020, the soil layers of 0 – 30 cm, 30 – 60 cm and 60 – 90 cm depths of each plot in the field experiment were sampled individually, using a motorised drill. In total, 12 soil cores per individual plot were taken to assess the quantity of mineral N in the soil.

This was repeated at the end of the experiment (on 31st October and 1st November 2020) to assess the amount of mineral N remaining in the soil at the end of the growing season.

2.6.2 Crop and harvest

Four cuts of grass were mowed with the Haldrup on 18th May, 22nd June, 18th August and 5th November 2020, and fresh and dry yield from these cuts 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; 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 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). Electrical conductivity was based on NEN-EN 13038:2011 and bulk density followed an internal standard.

2.7.2 Soil samples

Soil samples of the plough layer of 0 – 10 cm depth were analysed by Eurofins Agro BV following its analysis package for grassland[29]. Eurofins Agro Testing Wageningen BV is an accredited[30] 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 were taken from each plot. One set of samples served to determine 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):

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

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 upon the congruence between plant N demand and the release of N from the fertilising product.

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

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

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.

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 were applied at levels of 75% and 100%. The treatments with UAN erroneously also received CAN for the first cut. Hence, these treatments received a double amount of mineral nitrogen from two different mineral nitrogen fertilising sources. UAN could, therefore, not be used as a reference fertiliser in analysing these treatments. The statistical analyses were, therefore, based on data without UAN.

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:

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

With:
Model: parameter (Dry matter yield, N-uptake, NUE, soil stock N mineral) 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 (BBF), cattle slurry (CS) and cattle slurry plus biobased fertiliser (CS+BBF).

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 stated otherwise.

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

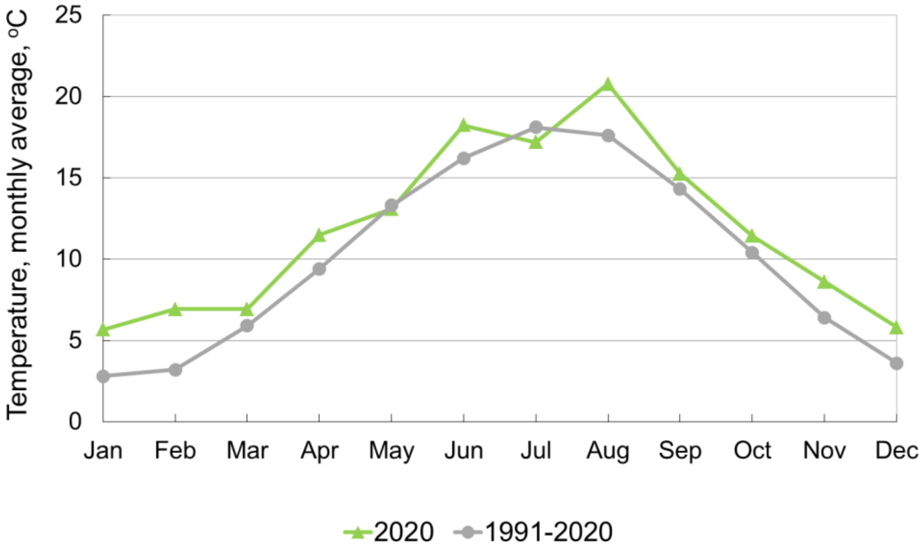

Figure 1 *Temperature, monthly average in degrees Celsius for the experimental farm, De Marke, in 2020 compared with the long-term average for the period 1991-2020 of the region*[31] *(data provided by G.J. Hilhorst).*

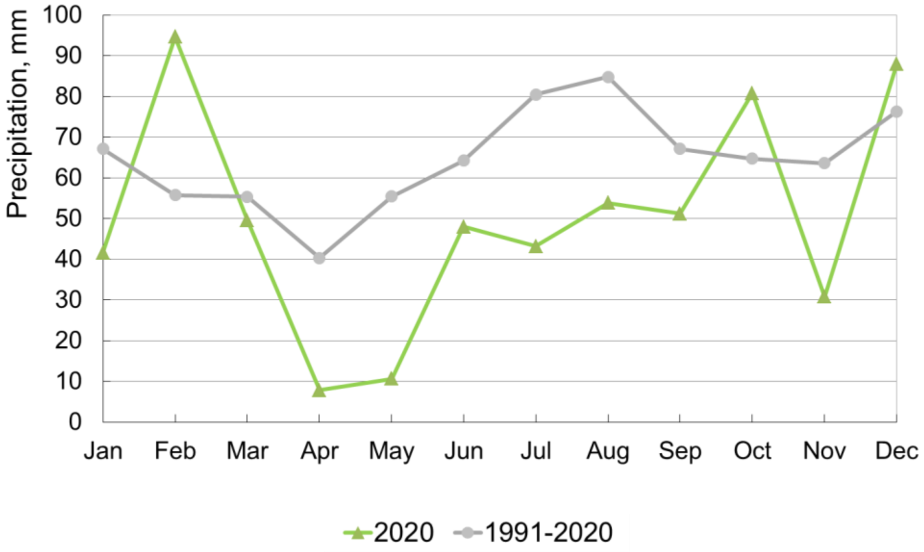

Figure 2 *Precipitation, monthly sum in mm for the experimental farm, De Marke, in 2020, compared with the long-term average for the period 1991-2020 in the region (data provided by G.J. Hilhorst).*

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

During the growing season of 2020, the monthly average temperatures were equal to or slightly higher than average during the first three months of May, June and July, but during ripening in the months August and September, temperatures were elevated from average (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 is 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 decade 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 andnd 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 that soil moisture content decreased below 10%. About eleven sprinkler irrigations with on average 22 mm water (range 10-38 mm) were applied during the growing season.

3.2 Dry matter yield

Due to the drought and despite sprinkler irrigation, only four cuts of grass were harvested with modest dry matter yields (Table 7, Figure 3). The total yield of dry matter was also modest (Table 7, Figure 4). All data are given in Annex 1.

The treatments with UAN mistakenly received a similar additional application of nitrogen as CAN for the first cut (Figures 3 and 4). These treatments received a double amount of mineral nitrogen which resulted in an increased yield for the first two cuts. UAN could, therefore, not be used as a reference fertiliser. The statistical analyses were, therefore, based on data without UAN. 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. grass responded to nitrogen fertilisation. For the treatment with CAN, an application rate of 125% did not result in a higher dry matter yield.

CS had the lowest yields, followed by the combination of CS+BBFb. In general, BBFb and CAN had comparable dry matter yields that were not significantly different. CS received less nitrogen than planned due to lower nitrogen contents of consecutive batches used for fertilisation of 1st, 2nd and 3rd cuts of grass. Although the application rate of CS 75% was higher than CAS 50% (Table 1), dry matter yields of CS 75% were lower than CAS 50%. The fourth cut at application rate 50% was an exception, in which BBFb had a significantly higher yield.

Table 7 *Yield per cut and their totals in tonne dry matter/ha for CAN, Biobased fertiliser basic (BBFb), Cattle Slurry (CS) and the combination with CS and 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	0.4	1.8	2.2	3.1	3.2	0.5	0.6
1	BBFb	*	1.6	2.4	*	*		
1	CS	*	1.0	1.1	*	*		
1	CS+BBFb	*	*	2.0	2.2	*		
2	CAN	0.6	2.3	2.7	3.6	4.0	0.3	0.4
2	BBFb	*	2.3	2.6	*	*		
2	CS	*	1.1	1.9	*	*		
2	CS+BBFb	*	*	1.8	2.6	*		
3	CAN	0.2	0.5	0.7	1.1	0.9	0.2	0.2
3	BBFb	*	0.5	0.5	*	*		
3	CS	*	0.5	0.8	*	*		
3	CS+BBFb	*	*	0.7	0.9	*		
4	CAN	0.2	0.4	0.8	1.2	0.9	0.3	0.4
4	BBFb	*	1.0	1.0	*	*		
4	CS	*	0.4	0.5	*	*		
4	CS+BBFb	*	*	0.7	1.2	*		
Total	CAN	1.3	5.0	6.4	8.9	9.0	0.7	0.8
Total	BBFb	*	5.3	6.5	*	*		
Total	CS	*	2.9	4.2	*	*		
Total	CS+BBFb	*	*	5.1	6.9	*		

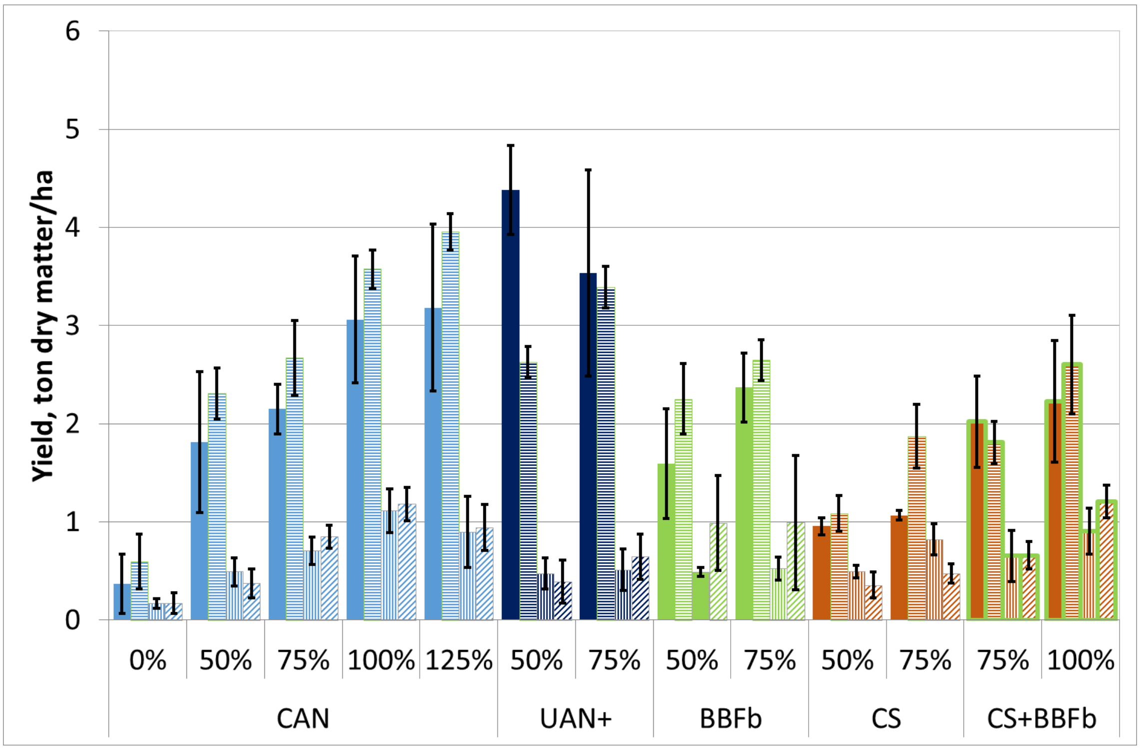

Figure 3 *Yield in tonne dry matter/ha of four cuts grass for CAN, UAN, Biobased fertiliser (BBFb), Cattle Slurry (CS), and the combination with CS and BBFb at application rates of application rates of nitrogen of 0%, 50%, 75%, 100% and 125%. Vertical bars represent standard deviations. First cut - no pattern, second cut - horizontal pattern, third cut - vertical pattern, and forth cut -diagonal pattern. UAN mistakenly received CAN also for the fertilisation of the first cut, hence the code is UAN+.*

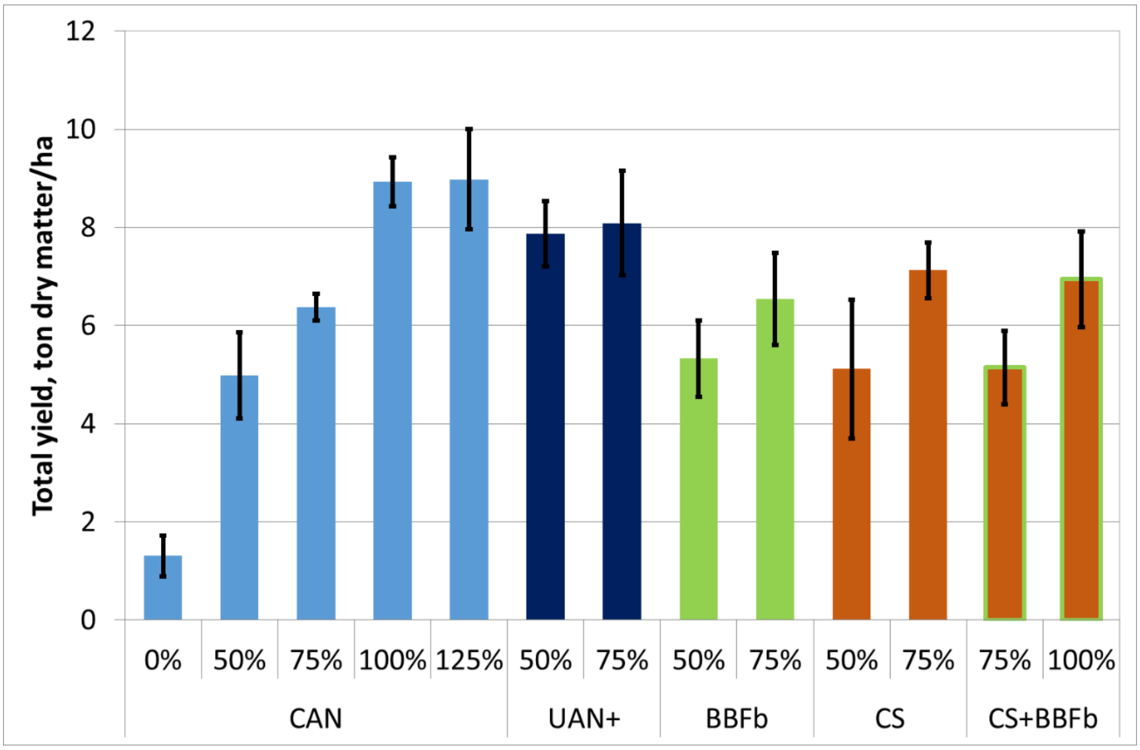

Figure 4 *Total yield of grass in tonne dry matter/ha for CAN, UAN, Biobased fertiliser (BBFb), Cattle Slurry (CS) and the combination with CS and BBFb at application rates of nitrogen of 0%, 50%, 75%, 100% and 125%. Vertical bars represent standard deviations. UAN mistakenly received CAN also for the fertilisation of the first cut, hence the code is UAN+.*

3.3 Nitrogen uptake and efficacy

3.3.1 Nitrogen uptake

Nitrogen uptake of the four cuts and their totals are given in Table 8 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 fertiliser basic (BBFb), Cattle Slurry (CS) and the combination with CS and 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	4.9	28.2	38.8	61.5	90.7	7.5	9.2
1	BBFb	*	23.1	43.4	*	*		
1	CS	*	13.2	16.8	*	*		
1	CS+BBFb	*	*	33.8	42.0	*		
2	CAN	8.7	37.0	47.5	62.5	84.6	7.7	9.4
2	BBFb	*	32.3	46.3	*	*		
2	CS	*	18.1	33.1	*	*		
2	CS+BBFb	*	*	31.6	48.1	*		
3	CAN	4.2	13.1	19.6	32.5	30.4	4.4	5.4
3	BBFb	*	12.9	14.7	*	*		
3	CS	*	13.8	23.7	*	*		
3	CS+BBFb	*	*	18.2	28.1	*		
4	CAN	4.5	10.9	23.2	34.5	28.6	10.0	12.3
4	BBFb	*	31.7	33.1	*	*		
4	CS	*	10.6	13.9	*	*		
4	CS+BBFb	*	*	19.3	33.8	*		
Total	CAN	22.3	89.2	129.2	191.1	234.4	14.3	17.6
Total	BBFb	*	100.0	137.5	*	*		
Total	CS	*	55.7	87.4	*	*		
Total	CS+BBFb	*	*	102.8	152.0	*		

Nitrogen fertilisation significantly increased nitrogen uptake per cut, with the exception of Cut Four, which was not significantly different. The total nitrogen uptake of fertilised treatments was also significantly higher. An increase in nitrogen application rate significantly increased nitrogen uptake with the exception of Cut Four. Total nitrogen uptake increased with an increase of the nitrogen application rate.

CS had a significantly lower nitrogen uptake for Cuts One, Two and Four compared to other treatments at similar application rates. For Cut Three there were no differences between CS and other treatments. The combination of CS and BBFb was compared with CS at a similar application rate had a significantly higher nitrogen uptake at Cuts One and Three, but not for Cuts Two and Four. Overall, nitrogen uptake of the combination was significantly higher than for CS. Treatments with CS received less nitrogen than planned (Table 1). Treatments with CS at application rate code 75% received more nitrogen than CAN at application rate code 50%. Although more nitrogen was applied at 75% (Table 1), less nitrogen was taken up than treatments with CAS 50%.

For Cut One (BBFb) and Cut Two (CAN, BBFb), CAN and BBFb had higher uptakes than the combination (CS+BBFb) or CS. For other cuts, the uptake was comparable. Total nitrogen uptake ranked CS < CS+BBFb < CAN ~ BBF2 at an application rate of 75%. BBFb had higher uptake than for CAN but was not significant.

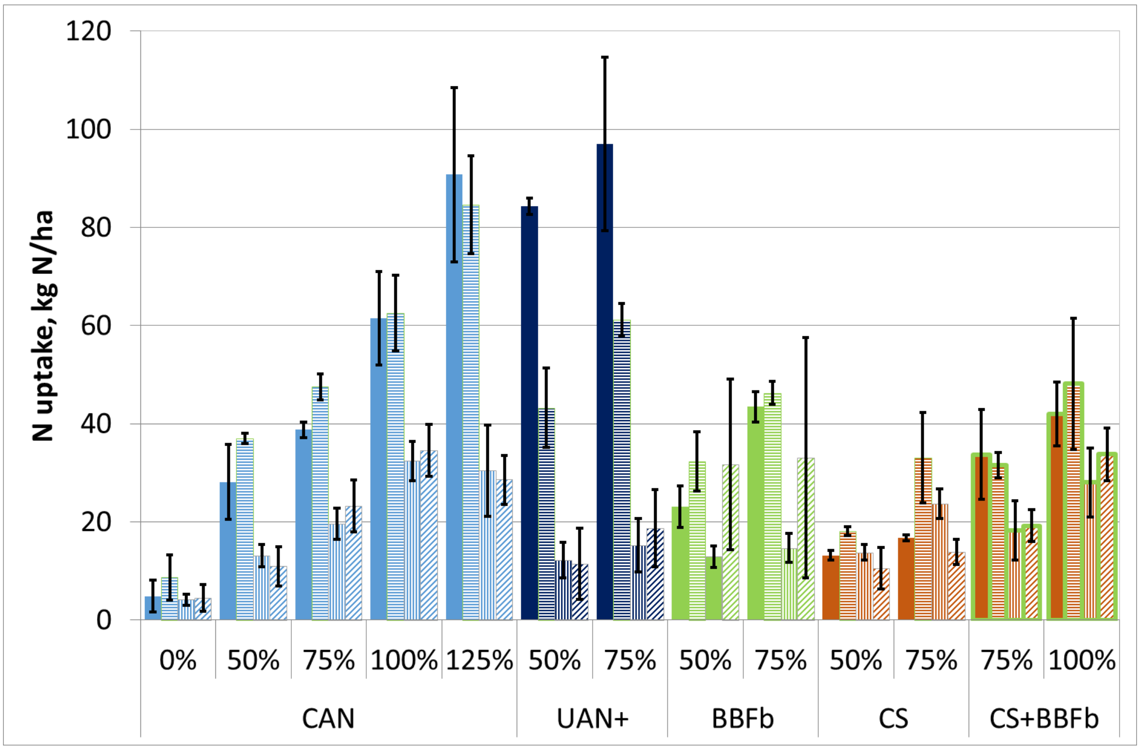

Figure 5 *Nitrogen uptake by grass in kg N/ha of four cuts for CAN, UAN, Biobased fertiliser (BBFb), Cattle Slurry (CS), and the combination with CS and BBFb at application rates of 0%, 50%, 75%, 100% and 125%. Vertical bars represent standard deviations. First cut - no pattern, second cut - horizontal pattern, third cut - vertical pattern and forth cut - diagonal pattern. UAN mistakenly received CAN also for the fertilisation of the first cut, hence the code is UAN+.*

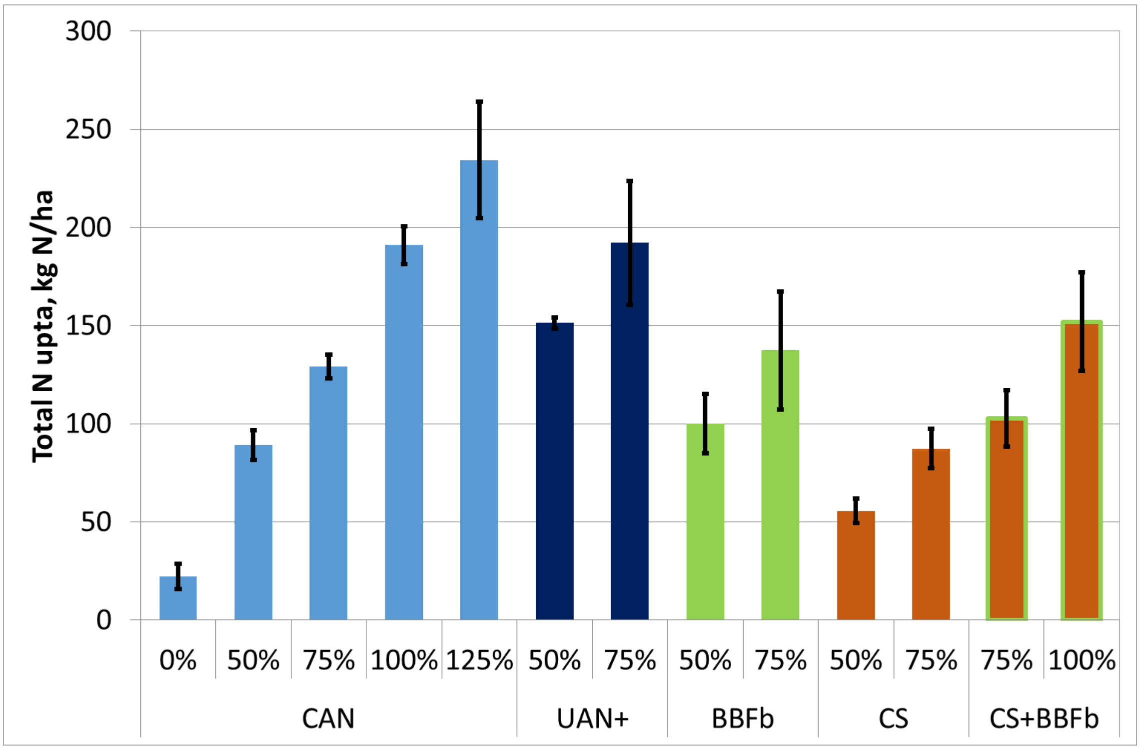

Figure 6 *Nitrogen uptake by grass in kg N/ha for CAN, UAN, Biobased fertiliser (BBFb), Cattle Slurry (CS) and the combination with CS and BBFb at application rates of nitrogen of 0%, 50%, 75%, 100% and 125%. Vertical bars represent standard deviations. UAN mistakenly received CAN also for the fertilisation of the first cut, hence the code is UAN+.*

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 to nitrogen fertilisation, and with an increase in fertilisation rate, more nitrogen was taken up (3.2.2). NUE of CAN at 100% and 125% application rates were higher compared to the 50 and 75% application rates (Cut 1 and total), which was unexpected. In general, BBFb had similar NUE compared to CAN. CAN and BBFb had higher NUE values for the first two cuts and total compared to CS and the combination of CS and BBFb. For Cuts Three and Four, they were comparable (Table 9).

Table 9 *Nitrogen Use Efficiency (NUE) per cut and their totals in percent for CAN, Biobased fertiliser basic (BBFb), Cattle Slurry (CS), and the combination with CS and 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
		50%	75%	100%	125%	Fertilised
1	CAN	44	43	54	65	11
1	BBFb	39	55	*	*	
1	CS (*)	14	14	*	*	
1	CS+BBFb	*	34	29	*	
2	CAN	77	64	67	75	16
2	BBFb	63	60	*	*	
2	CS	35	46	*	*	
2	CS+BBFb	*	39	45	*	
3	CAN	25	31	42	31	9
3	BBFb	25	25	*	*	
3	CS	29	42	*	*	
3	CS+BBFb	*	29	33	*	
4	CAN	24	37	45	29	32
4	BBFb	87	57	*	*	
4	CS	*	*	*	*	
4	CS+BBFb(**)	*	49	65	*	
Total	CAN	42	45	53	53	8
Total	BBFb	51	50	*	*	
Total	CS	27	35	*	*	
Total	CS+BBFb	*	36	39	*	

(*) CS was applied three times: First Cut, Second Cut and Third Cut.

(**) CS was applied three times: First Cut, Second Cut and Third Cut. For the fourth cut, only BBFb was applied with rates given in Table 1.

3.3.2.2 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 10). Standard errs 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 with their standard error between brackets (SE[32]) for Nitrogen fertiliser replacement value (NFRV) in percent (%) for CAN, BBFb, CS and CS+BBFb per application rate per cut and for the total of all cuts and fertilisation. CAN serves as reference nitrogen fertiliser.*

Cut	Fertilising product	Application rate		
		50%	75%	100%
1	CAN	100 (11.8)	100 (6.8)	100 (7.5)
1	BBFb	88 (13.2)	128 (6.8)	*
1	CS	33 (10.0)	32 (5.5)	*
1	CS+BBFb	*	78 (11.0)	54 (6)
2	CAN	100 (4.6)	100 (11.7)	100 (5.3)
2	BBFb	82 (15.0)	93 (12.5)	*
2	CS	45 (3.3)	72 (23.1)	*
2	CS+BBFb	*	61 (11.1)	68 (10.3)
3	CAN	100 (8.2)	100 (9.0)	100 (5.3)
3	BBFb	102 (8.2)	80 (11.1)	*
3	CS	116 (7.3)	135 (7.3)	*
3	CS+BBFb	*	95 (12.9)	78 (9.6)
4	CAN	100 (15.8)	100 (12.9)	100 (9.1)
4	BBFb	360 (45.6)	154 (41.7)	*
4	CS(¹)	*	*	*
4	CS+BBFb(²)	*	107 (22.5)	75 (17.5)
Total	CAN	100 (6.7)	100 (1.2)	100 (1.6)
Total	BBFb	121 (6.9)	112 (9.3)	*
Total	CS	64 (4.7)	79 (7.7)	*
Total	CS+BBFb	*	81 (3.2)	74 (5.1)

1. CS was applied for the first three cuts only.
2. CS was applied for the first three cuts, the fourth cut received BBFb only.

Based on SE a confidence interval can be calculated. SE values were in the range of 3 – 46%. At an application rate of 50%, NFRV values of CS and the combination of CS+BBFb were significantly lower compared to CAN. BBFb was significantly higher. At an application rate of 75% BBFb and CAN were significantly higher compared to CS or the combination. At this rate, BBFb did not differ from in NFRV. The fourth cut showed a difference between BBFb and CAN at the 50% application rate. The fourth cut had a modest yield. Overall, BBFb performed equal to CAN.

3.4 Soil mineral nitrogen

3.4.1 Soil mineral nitrogen at start and after the last harvest

At the start of the field experiment, the soil layers of 0 – 30 cm, 30 – 60 cm and 60 – 90 cm depths had 12, 9 and 2 kg/ha mineral N on average respectively (Table 11). The total amount in the soil layer of 0 – 90 cm depth was 23 kg N/ha. Some small differences in soil mineral nitrogen were found within a treatment of a fertilising product (Table 11), which, although just statistically significant, had no practical consequences. All data are given in Annex 2.

After the harvest of the last (fourth) cut, the stock of soil mineral N was not significantly different between fertilising product treatments and application rates in the soil layer of 0 – 30 cm depth (Table 11). In the soil layer of 30-60 cm depth, UAN, and in the soil layer of 60-90 cm depth, BBFb had slightly higher stocks of

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

mineral nitrogen. Overall, fertilising products did not differ in November in total mineral nitrogen stocks in the soil layer of 0 – 90 cm depth, with the exception of UAN, which had a slightly but significant higher stock due to the erroneous application of CAN for the first cut (Table 11, Figure 7). The stock of mineral nitrogen in November was significantly higher than in March but fertilising products per application rate in general did not differ significantly.

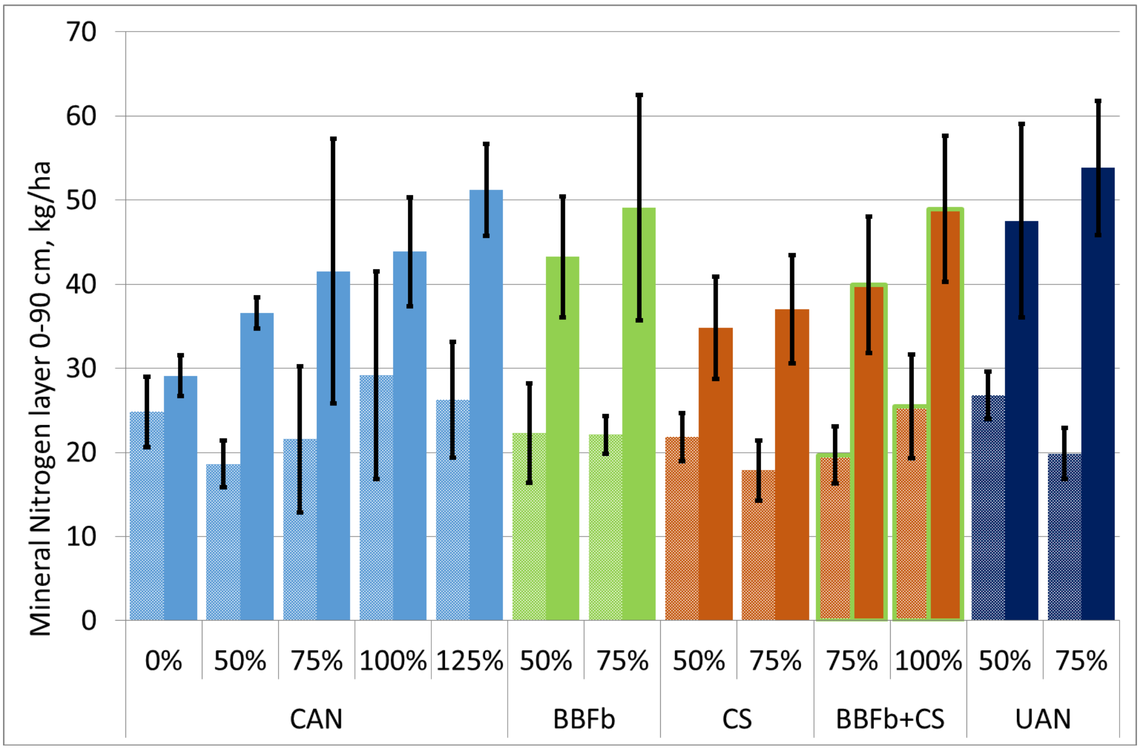

Figure 7 *Stocks of mineral nitrogen before fertilisation with nitrogen in March (light colour) and after the harvest of the last cut of grass in November 2020 (dark colour) for CAN, UAN, BBFb, CS and the combination of CS + BBFb at application rates of nitrogen of 0%, 50%, 75%, 100% and 125%. UAN mistakenly received CAN also for the first cut, hence UAN+.*

3.4.2 Nitrogen balance sheet

Grass without N fertilisation (0 kg N/ha) had a total nitrogen uptake of 22.3 kg N/ha (Table 8). At the start of the field experiment, the soil layer of 0 – 90 cm depth contained 24.8 kg N/ha, and after the last cut it contained 29.1 kg N/ha. This points towards a contribution of soil organic N to N uptake of grass of 22.3 + (29.1 –24.8) = 26.6 kg N/ha.

The difference between the stock of soil mineral N after harvest and the quantity present at the start, plus the total N uptake by grass minus the N application rate is an indicator for the contribution of N by the soil (Table 12). This is a simple form of a partial soil N balance sheet and ignores losses through ammonia volatilisation and denitrification.

Except for the treatment without nitrogen fertilisation (CAN 0%), all values are negative. With an increase of the application rate the values become more negative. This is an indication of immobilisation of nitrogen in soil. A major part of the residual mineral nitrogen from fertilising products not taken up by grass was not traced in the stocks of mineral nitrogen in the soil layer of 0-90 cm depth. Pathways for losses of applied mineral nitrogen are assumed to be:

- Volatilisation losses of ammonia,
- losses through denitrification, and
- leaching below the soil layer of 0-90 cm depth.

Which pathway dominates, cannot be addressed with this research. Immobilisation of nitrogen will have also had an effect on the concentration of mineral nitrogen after the last harvest.

Table 11 *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 depths before the start of the field experiment in March and after the harvest of the last cut of grass in November for fertilising products CAN, UAN, CS, BBFb and CS+BBFb per application rate.*

Product	**Soil layer. cm**	**March**					**Nov.**				
		0%	**50%**	**75%**	**100%**	**125%**	**0%**	**50%**	**75%**	**100%**	**125%**
CAN	0 - 30	10	10	12	19	15	12	19	23	23	26
	30 - 60	12	7	9	8	10	13	13	14	16	18
	60 - 90	3	2	1	2	2	4	4	4	5	8
	0 - 90	25	19	22	29	26	29	37	42	44	51
UAN	0 - 30	*	15	10	*	*	*	23	20	*	*
	30 - 60	*	10	8	*	*	*	17	28	*	*
	60 - 90	*	2	2	*	*	*	8	5	*	*
	0 - 90	*	27	20	*	*	*	48	54	*	*
CS	0 - 30	*	11	9	*	*	*	17	18	*	*
	30 - 60	*	8	7	*	*	*	13	15	*	*
	60 - 90	*	3	2	*	*	*	5	4	*	*
	0 - 90	*	25	18	*	*	*	35	37	*	*
BBFb	0 - 30	*	12	10	*	*	*	20	20	*	*
	30 - 60	*	7	9	*	*	*	15	17	*	*
	60 - 90	*	2	3	*	*	*	9	13	*	*
	0 - 90	*	22	22	*	*	*	43	49	*	*
CS+BBFb	0 - 30	*	*	9	12	*	*	*	19	23	*
	30 - 60	*	*	8	11	*	*	*	16	20	*
	60 - 90	*	*	3	2	*	*	*	5	6	*
	0 - 90	*	*	20	25	*	*	*	40	49	*
LSD (α=0.05) Per sampling	0 - 30					6					7
	30 - 60					2					5
	60 - 90					0.8					3
	0 - 90					7					10
LSD (α=0.05) between sampling times	0 - 30										5
	30 - 60										4
	60 - 90										2
	0 - 90										7

Table 12 *Mean values for a simple partial soil N balance sheet in kg N/ha for CAN, UAN, CS, BBFb and CS+BBFb per application rate based on a simple nitrogen balance sheet.*

Fertilising product	**Application rate.**				
	0%	**50%**	**75%**	**100%**	**125%**
CAN	27	-53	-91	-114	-140
UAN	*	-42	-95	*	*
CS	*	-55	-80	*	*
BBFb	*	-33	-66	*	*
CS+BBFb	*	*	-99	-157	*
LSD (α = 0.05)	17				

4 Evaluation and conclusions

Biobased fertilising products can be tailored to crop requirements through addition of extra nitrogen and/or sulphur sources to optimize the ratios between nitrogen and sulphur. In 2020, sources were mineral concentrate and a solution of mineral fertilisers (urea and ammonium nitrate; '*Urean' in Dutch*). In this study, basic types of tailored biobased fertilising products were tested in a field experiment on grassland consisting of 99% mineral concentrate and 1% UAN (≈25-30% N from UAN). The current field experiment served two objectives, to ascertain the:

1. Agronomic effectivity through determining the NFRV of the biobased fertilising products.
2. Environmental risk assessment through determination and comparison of the risk of nitrate leaching when using nitrogen biobased fertilising products as a substitute for mineral (synthetic. chemical) nitrogen fertilisers.

These objectives led to 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 NRFV to the reference fertiliser.
3. Biobased fertilising products have a similar effect on residual nitrogen after the last cut of grass as a regular nitrogen fertiliser at similar application rates.

The objectives and hypotheses were tested in a field experiment conducted on grassland that was grown on a sandy soil in 2020.

Due to an erroneous fertilisation of UAN on plots which also received CAN, it was not possible to test UAN as reference fertiliser.

As in 2019, the climatical conditions in the test region 2020 were dry with elevated temperatures which made sprinkler irrigation necessary. Although conditions were dry, the grass responded to the treatments with fertilising products.

Yield

Due to the drought and despite sprinkler irrigation, only four cuts of grass were harvested with modest dry matter yields per cut and total yields (Table 7, Figure 3 & 4). Yields of the first two cuts were larger than those for the third- and fourth cut. The yields of the first two cuts were within the normal range, whereas yields of the later cuts were below average.

For each cut and for the total yield, fertilising product and application rate had a significant effect on the dry matter yield. Application of nitrogen with a fertilising product resulted in a higher dry matter yield as compared to treatment receiving no nitrogen fertiliser, i.e. grass responded to nitrogen fertilisation. For the treatment with CAN, an application rate of 125% did not result in a higher dry matter yield as compared to the CAN treatment with an application rate of 100%.

CS had the lowest yields followed by the combination of CS+BBFb. BBFb and CAN had in general comparable dry matter yields which were not significantly different at similar application rates. An exception was the fourth cut at an application rate of 50%: BBFb had a significantly higher yield.

Nitrogen uptake

Nitrogen fertilisation significantly increased nitrogen uptake per cut, with the exception of Cut Four in which fertiliser treatments were not significantly different. Also the total nitrogen uptake over the four cuts increased with increasing N application rate.

CS had significantly lower nitrogen uptake for Cuts One, Two and Four compared to other treatments at similar application rates of total N. For Cut Three, there were no differences between CS and other treatments. The combination of CS and BBFb had at a similar application rate comparable, not significantly different, uptake of nitrogen compared to CS except Cut One when the combination had a higher uptake compared to CS. Except for Cut One (BBFb) and Cut Two (CAN, BBFb) with higher uptakes than the combination, for other cuts the uptake of other treatments was comparable with those of CAN and BBFb. Total nitrogen uptake increased in the order CS ~ CS+BBFb < CAN ~ BBFb at an application rate of 75% of the recommended N application rate. Hence, uptake of nitrogen by grass fertilised with CAN was higher than for CS. BBFb had higher uptake than for CAN but was not significant.

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

NUE

Grass responded to nitrogen fertilisation, and with an increase in rate, more nitrogen was taken up (3.2.2). NUE of CAN at 100% and 125% application rates were higher compared to the 50 and 75% application rates (Cut One and total). In general, BBFb had a similar NUE compared with CAN. CAN and BBFb had higher NUE values for the first two cuts and total compared to CS and the combination of CS and BBFb. For Cuts Three- and Four they were comparable (Table 9).

It this field experiment, NUE did not decline with increased application rate. This is attributed to the structure of grass as a plant with its well-developed root system.

NFRV

The yields of the first two cuts were normative. With this as a focus, overall CS and the combination of CS+BBFb performed less well than BBFb and CAN. BBFb and CAN had comparable efficiencies of nitrogen use and BBFb, and thus, a comparable NFRV.

Due to the erroneous treatments with UAN, only CAN could serve as a reference fertiliser. The first hypothesis could not be tested.

De second hypothesis could be tested. Results indicated that the biobased fertilising product had a similar NRFV to the reference fertiliser.

Stock of soil mineral nitrogen

Fertilisation led to an increase of soil mineral nitrogen stock, but in general, differences between fertilising products were small. This confirms the third hypothesis that the biobased fertilising product had a similar effect on residual nitrogen after the harvest of the last cut of grass to a regular nitrogen mineral fertiliser supplied at similar application rates.

Nitrogen balance sheet

Grass without N fertilisation (0 kg N/ha) had a contribution of soil organic N to N uptake of grass of 26.6 kg N/ha.

The difference between the stock of soil mineral N after harvest and the quantity present at the start, plus the total N uptake by grass, minus the N application rate was used as an indicator for the contribution of nitrogen from the soil (Table 12). Except for the treatment without nitrogen fertilisation (CAN 0%), all values were negative indicating nitrogen immobilisation. With an increase of the application rate the values became more negative. However, mineral nitrogen stocks after the last cut of grass did not reflect an increase of mineral nitrogen in a comparable magnitude. A major part of the mineral nitrogen from fertilising products was not traced in the stocks of mineral nitrogen in the soil layer of 0-90 cm depth. Pathways for losses of applied mineral nitrogen were assumed to be:

- Volatilisation losses of ammonia,
- losses through denitrification, and
- leaching below the soil layer of 0-90 cm depth.

Which pathway dominated cannot be addressed with this research. Pathways will differ between fertilising products. Overall, leaching was assumed not to be a major factor considering the dry growing period. The performance of the BBFb and CS injectors to minimize ammonia volatilisation was not known but was assumed to be manageable i.e. small losses. Under warm weather conditions, sprinkler irrigation might have stimulated mineralisation of organic matter and decomposition of grass roots and, thus, might have contributed to immobilisation. Sprinkler irrigation might have promoted denitrification.

In conclusion

In this first field experiment conducted on sandy grassland at the experimental farm, De Marke, in 2020, the effect of a biobased fertilising product on grass yield (four cuts), N uptake and residual effect of nitrogen from fertilising products on soil N cycling was studied.

The year 2020 was a third year of drought in the Achterhoek region, which was again combined with elevated temperatures. The drought was severe and made sprinkler irrigation necessary.

This field experiment on grassland shows a similar agronomic effectivity of BBFb compared to CAN. CS had the lowest effectivity, and the combination of CS+BBFb performed somewhere in between BBFb and CAN (better) and CS (poorer) in terms of agronomic effectivity. This result met the first objective and the second working hypothesis tested positive.

The environmental performance achieved by all the fertilising products were comparable. Fertilisation with nitrogen led to a higher residue of soil mineral nitrogen, but overall there were no differences between the fertilising products. This result meets the second objective and the third working hypothesis tested positive.

The consequence of sprinkler irrigation and elevated temperatures was that the mineralisation of soil organic N was stimulated and or denitrification was most likely promoted but also immobilisation. A simple nitrogen balance sheet indicated losses of applied nitrogen or immobilisation, as a major part was not traced again in residual soil nitrogen.

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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 4th cut	kg N/ha
10	Application rate total all cuts	kg N/ha
11	Yield, 1st cut fresh	tonne fresh/ha
12	Yield, 2nd cut fresh	tonne fresh/ha
13	Yield, 3rd cut fresh	tonne fresh/ha
14	Yield, 4th cut fresh	tonne fresh/ha
15	Yield, 1st cut dry matter	tonne dry matter/ha
16	Yield, 2nd cut dry matter	tonne dry matter/ha
17	Yield, 3rd cut dry matter	tonne dry matter/ha
18	Yield, 4th cut dry matter	tonne dry matter/ha
19	Total yield dry matter	tonne dry matter/ha
20	K content, 1st cut	g K/kg
21	N content, 1st cut	g N/kg
22	P content, 1st cut	g P/kg
23	Moisture content (70-105°C), 1st cut	% oven dry
24	Moisture content (fresh-105°C), 1st cut	% fresh
25	K content, 2nd cut	g K/kg
26	N content, 2nd cut	g N/kg
27	P content, 2nd cut	g P/kg
28	Moisture content (70-105°C), 2nd cut	% oven dry
29	Moisture content (fresh-105°C), 2nd cut	% fresh
30	K content, 3rd cut	g K/kg
31	N content, 3rd cut	g N/kg
32	P content, 3rd cut	g P/kg
33	Moisture content (70-105°C), 3rd cut	% oven dry
34	Moisture content (fresh-105°C), 3rd cut	% fresh
35	K content, 4th cut	g K/kg
36	N content, 4th cut	g N/kg
37	P content, 4th cut	g P/kg
38	Moisture content (70-105°C), 4th cut	% oven dry
39	Moisture content (fresh-105°C), 4th cut	% fresh
40	N uptake, 1st cut	kg N/ha
41	N uptake, 2nd cut	kg N/ha
42	N uptake, 3rd cut	kg N/ha
43	N uptake, 4th cut	kg N/ha
44	N uptake total	kg N/ha
45	P uptake, 1st cut	kg P/ha
46	P uptake, 2nd cut	kg P/ha
47	P uptake, 3rd cut	kg P/ha
48	P uptake, 4th cut	kg P/ha
49	P uptake total	kg P/ha
50	K uptake, 1st cut	kg K/ha
51	K uptake, 2Kd cut	kg K/ha
52	K uptake, 3rd cut	kg K/ha
53	K uptake, 4th cut	kg K/ha
54	K uptake total	kg K/ha

1	2	3	4	5	6	7	8	9	10
1	CAN	4	1	104	105.6	80.9	66.8	66.8	320.1
2	CS	3	1	109	86.5	52.8	46.7	0	186
3	CS	2	1	108	57.7	35.2	31.2	0	124.1
4	CAN	2	1	102	52.8	40.4	33.3	33.3	159.8
5	CS+BBFb	3	1	112	86.1	57.9	48	29.9	221.9
6	CAN	1	1	101	0	0	0	0	0
7	UAN	2	1	106	106.3	40.8	33.6	33.6	214.3
8	CS+BBFb	4	1	113	129.1	86.8	72	44.8	332.7
9	CAN	3	1	103	79.2	60.5	50.1	50.1	239.9
10	BBFb	3	1	111	70.4	62.7	47.9	49.7	230.7
11	UAN	3	1	107	159.1	61.3	50.4	50.4	321.2
12	CAN	5	1	105	132.3	100.9	83.3	83.3	399.8
13	BBFb	2	1	110	47	41.8	31.9	33.1	153.8
14	CAN	1	2	201	0	0	0	0	0
15	CAN	4	2	204	105.6	80.9	66.8	66.8	320.1
16	CAN	5	2	205	132.3	100.9	83.3	83.3	399.8
17	CAN	3	2	203	79.2	60.5	50.1	50.1	239.9
18	UAN	3	2	207	159.1	61.3	50.4	50.4	321.2
19	BBFb	3	2	211	70.4	62.7	47.9	49.7	230.7
20	CS+BBFb	3	2	212	86.1	57.9	48	29.9	221.9
21	UAN	2	2	206	106.3	40.8	33.6	33.6	214.3
22	BBFb	2	2	210	47	41.8	31.9	33.1	153.8
23	CS	2	2	208	57.7	35.2	31.2	0	124.1
24	CS	3	2	209	86.5	52.8	46.7	0	186
25	CS+BBFb	4	2	213	129.1	86.8	72	44.8	332.7
26	CAN	2	2	202	52.8	40.4	33.3	33.3	159.8
27	CS	3	3	309	86.5	52.8	46.7	0	186
28	CAN	3	3	303	79.2	60.5	50.1	50.1	239.9
29	CS+BBFb	3	3	312	86.1	57.9	48	29.9	221.9
30	CAN	4	3	304	105.6	80.9	66.8	66.8	320.1
31	CAN	2	3	302	52.8	40.4	33.3	33.3	159.8
32	CS+BBFb	4	3	313	129.1	86.8	72	44.8	332.7
33	CAN	5	3	305	132.3	100.9	83.3	83.3	399.8
34	CAN	1	3	301	0	0	0	0	0
35	UAN	2	3	306	106.3	40.8	33.6	33.6	214.3
36	BBFb	2	3	310	47	41.8	31.9	33.1	153.8
37	CS	2	3	308	57.7	35.2	31.2	0	124.1
38	BBFb	3	3	311	70.4	62.7	47.9	49.7	230.7
39	UAN	3	3	307	159.1	61.3	50.4	50.4	321.2

1	11	12	13	14	15	16	17	18	19
1	13.7	19.3	3.3	9.3	2.8	3.5	1.2	1.3	8.7
2	4.3	10.0	3.3	2.7	1.1	2.3	0.9	0.4	4.7
3	3.0	3.7	1.7	1.3	0.9	0.9	0.4	0.2	2.4
4	7.0	8.7	1.3	1.7	1.8	2.0	0.4	0.3	4.4
5	6.7	8.0	1.7	3.3	1.6	1.8	0.4	0.6	4.3
6	0.7	1.3	0.7	0.5	0.2	0.3	0.2	0.1	0.8
7	20.7	14.3	1.0	1.3	3.9	2.7	0.3	0.2	7.1
8	9.7	9.0	2.7	6.3	2.2	2.1	0.7	1.0	6.0
9	9.0	14.0	2.3	4.7	2.2	3.1	0.6	0.8	6.7
10	8.3	13.3	1.3	1.3	2.0	2.9	0.4	0.2	5.5
11	13.0	19.0	1.0	3.0	2.4	3.6	0.3	0.5	6.9
12	13.7	22.7	2.7	9.0	2.6	4.1	0.5	1.2	8.4
13	4.0	11.3	1.3	2.7	1.1	2.6	0.5	0.4	4.6
14	0.7	3.3	0.3	1.7	0.2	0.9	0.1	0.3	1.5
15	12.3	19.7	3.0	9.3	2.6	3.8	0.9	1.3	8.6
16	13.7	21.0	3.3	6.7	2.8	3.8	0.9	0.9	8.4
17	9.3	12.7	2.3	5.7	2.4	2.4	0.7	0.8	6.2
18	24.3	16.0	1.7	3.3	4.5	3.2	0.5	0.5	8.6
19	12.7	12.3	2.0	9.7	2.7	2.5	0.5	1.2	6.9
20	10.0	9.0	2.7	4.0	2.5	2.0	0.7	0.6	5.8
21	23.3	11.0	2.0	4.3	4.7	2.4	0.6	0.6	8.4
22	8.3	10.0	2.0	9.0	2.2	2.2	0.5	1.2	6.2
23	3.7	4.7	2.0	3.3	1.0	1.2	0.5	0.5	3.2
24	3.7	7.0	2.7	3.7	1.0	1.7	0.6	0.6	3.9
25	6.7	15.3	3.7	9.0	1.6	3.1	0.9	1.3	6.9
26	4.0	10.3	1.3	3.3	1.1	2.4	0.4	0.5	4.5
27	4.0	7.3	3.3	2.3	1.1	1.7	1.0	0.4	4.2
28	7.7	12.7	3.0	7.0	1.9	2.5	0.9	1.0	6.2
29	7.7	7.0	3.3	5.3	1.9	1.6	0.9	0.8	5.3
30	17.7	17.3	5.0	7.0	3.8	3.4	1.3	1.0	9.5
31	10.0	10.0	2.0	2.0	2.6	2.5	0.7	0.3	6.0
32	12.7	13.0	5.3	9.7	2.9	2.7	1.1	1.3	7.9
33	22.7	21.0	5.3	5.7	4.1	4.0	1.3	0.8	10.2
34	2.3	2.0	0.7	0.7	0.7	0.6	0.2	0.1	1.6
35	21.3	11.7	1.7	1.7	4.6	2.7	0.6	0.3	8.1
36	5.7	8.0	1.7	9.3	1.5	1.9	0.4	1.3	5.2
37	3.3	4.7	2.0	2.0	1.0	1.2	0.5	0.3	3.1
38	10.7	13.0	2.0	13.0	2.5	2.6	0.6	1.5	7.3
39	19.0	17.0	3.0	6.3	3.7	3.4	0.7	0.9	8.8

1	20	21	22	23	24	25	26	27	28	29	30	31	32
1	33.2	18.7	2.52	1.80	79.6	30.0	15.4	3.07	1.35	81.8	22.2	29.4	2.75
2	25.2	14.5	2.14	1.86	74.6	31.1	19.0	4.17	1.61	77.5	25.9	29.1	3.35
3	22.0	14.0	2.42	1.76	71.1	29.0	19.8	4.35	2.04	76.0	24.8	27.7	4.03
4	25.5	15.5	2.20	1.66	74.9	30.8	18.5	3.38	2.10	76.8	22.9	28.8	2.78
5	23.2	15.4	2.12	2.04	76.0	29.6	18.3	3.56	2.41	77.7	27.5	30.2	3.48
6	19.8	13.8	2.63	1.97	70.7	24.1	14.9	4.25	2.40	74.7	19.6	22.5	3.75
7	34.6	21.1	2.99	2.36	81.3	31.2	18.8	3.66	2.20	81.0	22.5	26.6	3.20
8	27.8	18.5	2.62	1.81	77.0	27.1	15.8	3.54	2.24	76.9	28.9	29.7	3.32
9	25.9	16.9	2.56	1.57	75.3	29.8	15.8	3.39	2.14	77.8	26.2	26.3	3.74
10	29.0	19.9	2.51	1.49	76.2	30.0	16.1	3.11	1.86	78.5	23.6	27.7	2.89
11	34.7	31.1	2.80	1.78	81.4	30.7	15.8	3.04	1.94	81.1	24.3	30.8	2.78
12	32.6	28.9	2.83	1.78	81.3	30.8	17.4	3.20	2.28	81.8	30.0	36.8	2.85
13	24.9	17.7	2.52	1.69	73.2	26.3	14.4	3.38	2.22	76.9	23.7	28.9	3.12
14	21.7	16.0	2.44	1.49	70.6	22.8	15.3	3.45	1.93	73.2	23.4	25.1	2.76
15	31.3	22.5	2.57	1.88	78.9	33.0	18.1	3.16	2.16	80.7	26.1	31.1	2.78
16	37.0	30.0	2.48	2.00	79.2	34.5	24.2	3.13	1.83	82.1	29.3	34.7	2.57
17	26.0	16.9	2.14	1.77	74.7	35.1	19.3	3.06	2.24	81.0	29.1	29.8	2.93
18	35.4	23.5	2.56	1.86	81.5	31.5	18.9	2.92	2.26	80.2	25.0	30.0	3.01
19	29.2	16.9	2.35	1.87	78.9	30.9	17.4	3.25	2.30	80.1	24.7	27.2	3.16
20	27.4	16.9	2.34	1.79	74.8	28.2	15.7	3.29	2.08	77.4	28.0	26.7	3.66
21	30.5	17.3	2.59	2.09	79.8	27.0	14.9	3.27	1.86	77.8	25.9	23.9	3.27
22	24.0	12.4	2.09	1.92	73.8	28.7	14.0	3.19	2.05	77.6	26.4	24.9	3.49
23	22.1	13.4	2.01	1.66	71.5	25.7	14.8	3.50	2.00	75.3	26.6	26.9	3.52
24	23.8	16.2	2.28	1.62	72.5	27.0	15.4	3.70	2.32	76.3	28.9	30.6	3.51
25	27.0	21.7	2.47	1.75	75.8	34.5	19.1	3.75	2.02	79.9	28.6	31.3	3.05
26	22.5	18.1	2.17	1.76	71.8	26.0	14.6	3.27	1.99	76.6	19.9	26.9	3.55
27	21.7	15.7	2.12	1.66	72.7	28.4	17.0	3.52	2.00	76.7	26.0	24.9	3.36
28	29.5	19.8	2.30	1.60	75.6	30.3	17.6	2.84	2.25	80.3	26.7	25.1	3.12
29	26.0	16.5	2.29	1.82	74.6	29.0	17.4	3.27	2.05	77.0	28.0	25.8	3.39
30	31.6	18.6	2.44	1.69	78.5	32.7	17.9	3.07	2.16	80.3	27.1	25.7	2.80
31	25.5	13.8	2.23	1.79	74.4	25.3	14.5	2.94	2.03	75.0	21.9	23.2	3.04
32	28.2	16.7	2.48	2.03	77.5	30.7	18.7	3.32	2.22	79.6	32.2	29.3	3.68
33	35.4	25.9	2.36	2.33	81.7	32.9	21.5	3.01	2.26	81.0	29.5	29.7	2.87
34	18.9	11.8	1.90	1.72	69.1	22.9	12.6	3.57	2.15	72.3	25.4	25.2	4.70
35	30.8	18.5	2.52	2.13	78.6	27.4	14.6	2.80	1.76	76.7	23.1	25.0	3.81
36	23.6	14.3	2.17	1.71	73.0	26.6	13.6	3.02	2.04	76.2	23.6	22.8	2.77
37	21.7	13.3	2.17	1.81	71.4	25.2	15.3	3.16	2.04	73.7	26.5	26.5	3.35
38	28.6	17.7	2.36	1.80	77.0	32.2	17.9	3.32	2.35	79.8	24.2	26.7	2.68
39	35.2	28.3	2.60	2.09	80.6	31.9	18.4	2.92	2.50	79.9	19.9	27.4	2.67

1	40	41	42	43	44	45	46	47	48	49	50	51	52
1	53.1	54.9	35.0	37.0	180.0	7.2	11.0	3.3	5.5	26.9	94.3	107.0	26.4
2	16.3	43.4	26.1	12.9	98.7	2.4	9.5	3.0	2.1	17.0	28.3	71.1	23.3
3	12.4	17.8	12.0	6.6	48.7	2.1	3.9	1.7	1.1	8.9	19.4	26.1	10.7
4	27.7	38.0	11.4	7.8	84.9	3.9	6.9	1.1	1.3	13.3	45.6	63.3	9.0
5	25.2	33.5	12.1	16.0	86.6	3.5	6.5	1.4	2.7	14.1	37.9	54.1	11.0
6	2.7	5.1	4.9	2.4	15.1	0.5	1.5	0.8	0.4	3.2	3.9	8.3	4.3
7	83.5	52.4	8.1	6.3	150.3	11.8	10.2	1.0	1.3	24.3	136.9	86.9	6.8
8	41.9	33.6	20.4	27.6	123.5	5.9	7.5	2.3	5.1	20.9	62.9	57.6	19.9
9	38.2	50.2	16.1	17.9	122.3	5.8	10.8	2.3	3.5	22.3	58.5	94.6	16.0
10	40.1	47.0	11.5	5.7	104.3	5.1	9.1	1.2	1.2	16.5	58.4	87.6	9.8
11	76.6	57.9	10.1	13.2	157.7	6.9	11.1	0.9	2.4	21.3	85.4	112.4	8.0
12	75.2	73.5	20.3	34.3	203.3	7.4	13.5	1.6	5.8	28.2	84.8	130.0	16.6
13	19.3	38.6	14.5	11.7	84.1	2.7	9.0	1.6	2.3	15.7	27.2	70.4	11.9
14	3.2	13.9	2.9	7.5	27.5	0.5	3.1	0.3	1.3	5.3	4.3	20.8	2.7
15	59.7	70.2	27.8	38.2	195.9	6.8	12.3	2.5	5.4	27.0	83.0	128.0	23.4
16	87.0	92.7	32.3	25.9	237.9	7.2	12.0	2.4	3.7	25.3	107.3	132.1	27.3
17	40.6	47.5	20.5	23.2	131.8	5.1	7.5	2.0	3.8	18.5	62.5	86.4	20.0
18	107.8	61.3	14.7	15.2	198.9	11.7	9.5	1.5	2.4	25.1	162.4	102.1	12.3
19	46.0	43.7	15.0	40.4	145.1	6.4	8.2	1.7	4.8	21.1	79.5	77.6	13.6
20	43.4	32.6	18.5	19.3	113.8	6.0	6.8	2.5	2.7	18.0	70.3	58.6	19.4
21	83.3	37.1	14.5	19.8	154.6	12.5	8.1	2.0	2.5	25.1	146.8	67.2	15.7
22	27.6	32.0	13.8	40.7	114.1	4.7	7.3	1.9	5.0	18.9	53.4	65.6	14.7
23	14.2	17.4	14.6	15.0	61.3	2.1	4.1	1.9	2.4	10.5	23.5	30.2	14.5
24	16.6	26.2	20.3	16.7	79.8	2.3	6.3	2.3	3.2	14.1	24.4	45.9	19.2
25	35.6	60.1	29.4	37.0	162.0	4.1	11.8	2.9	6.3	25.0	44.3	108.5	26.8
26	20.8	36.0	12.4	15.4	84.6	2.5	8.1	1.6	3.2	15.4	25.8	64.1	9.2
27	17.4	29.6	24.5	12.0	83.6	2.4	6.1	3.3	1.6	13.4	24.1	49.5	25.6
28	37.6	44.9	22.4	28.5	133.5	4.4	7.2	2.8	3.7	18.1	56.1	77.3	23.8
29	32.7	28.6	24.1	22.5	107.9	4.5	5.4	3.2	3.2	16.3	51.6	47.7	26.1
30	71.9	62.5	34.5	28.5	197.3	9.4	10.7	3.8	3.7	27.6	122.1	114.1	36.4
31	36.0	37.0	15.6	9.5	98.1	5.8	7.5	2.0	1.3	16.7	66.5	64.6	14.7
32	48.6	50.7	34.3	36.8	170.5	7.2	9.0	4.3	4.9	25.5	82.0	83.3	37.7
33	110.0	87.8	38.6	25.6	262.0	10.0	12.3	3.7	3.0	29.0	150.3	134.3	38.4
34	8.7	7.1	4.8	3.7	24.4	1.4	2.0	0.9	0.6	4.9	13.9	13.0	4.9
35	86.3	40.4	14.2	8.5	149.3	11.8	7.7	2.2	1.2	22.9	143.7	75.8	13.1
36	22.3	26.4	10.4	42.7	101.9	3.4	5.9	1.3	4.6	15.1	36.7	51.7	10.8
37	12.9	19.2	14.7	10.2	57.0	2.1	4.0	1.9	1.5	9.4	21.1	31.6	14.7
38	44.2	48.1	17.4	53.1	162.9	5.9	8.9	1.8	6.3	22.9	71.5	86.6	15.8
39	106.5	64.5	20.9	27.8	219.7	9.8	10.2	2.0	4.8	26.9	132.5	111.8	15.2

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 0 - 30 cm depth Autumn, kg N/ha
7	Layer of 30 - 60 cm depth Spring, kg N/ha
8	Layer of 30 - 60 cm depth Autumn, kg N/ha
9	Layer of 60 - 90 cm depth Spring, kg N/ha
10	Layer of 60 - 90 cm depth Autumn, kg N/ha
11	Layer of 0 - 90 cm depth Spring, kg N/ha
12	Layer of 0 - 90 cm depth Autumn, kg N/ha

1	2	3	4	5	6	7	8	9	10	11	12
1	CAN	4	1	14	23	10.4	12.6	1.8	2.9	25.9	38.3
2	CS	3	1	11	18	8.5	12.4	1.8	3.3	21.7	33.5
3	CS	2	1	13	17	8.1	9.0	1.8	1.9	22.4	28.1
4	CAN	2	1	10	18	9.0	13.1	1.8	3.4	20.3	34.8
5	CS+BBFb	3	1	12	16	7.8	14.0	2.7	3.8	22.4	34.2
6	CAN	1	1	12	12	9.4	14.5	2.7	4.3	23.7	30.9
7	UAN	2	1	14	22	9.4	12.9	1.3	4.3	24.4	39.4
8	CS+BBFb	4	1	17	19	13.0	13.5	1.8	6.7	31.6	39.1
9	CAN	3	1	19	14	9.8	11.3	1.8	3.8	31.0	29.6
10	BBFb	3	1	10	13	7.8	14.4	1.8	6.7	19.5	34.4
11	UAN	3	1	10	20	8.2	40.6	2.3	2.9	20.8	63.0
12	CAN	5	1	14	31	8.2	13.5	1.4	6.7	23.7	51.5
13	BBFb	2	1	11	16	6.0	14.5	1.3	4.8	18.6	35.7
14	CAN	1	2	8	12	10.9	11.8	2.2	2.4	21.3	26.3
15	CAN	4	2	9	24	8.9	14.8	1.3	3.8	18.7	42.3
16	CAN	5	2	19	21	13.3	19.8	1.3	4.8	34.0	45.7
17	CAN	3	2	8	18	10.3	14.3	1.3	3.8	19.7	35.7
18	UAN	3	2	6	18	7.8	24.9	2.2	7.2	16.4	49.6
19	BBFb	3	2	11	19	9.5	18.8	3.5	22.7	23.8	60.8
20	CS+BBFb	3	2	8	16	8.9	14.0	3.8	6.6	20.8	36.3
21	UAN	2	2	13	27	10.2	24.2	2.6	9.1	26.0	60.7
22	BBFb	2	2	16	24	10.8	15.2	2.6	10.6	29.1	50.1
23	CS	2	2	7	15	8.3	16.6	3.5	4.9	18.6	36.5
24	CS	3	2	8	22	7.4	18.3	1.8	4.3	17.3	44.4
25	CS+BBFb	4	2	12	19	12.3	27.4	1.3	5.8	25.4	52.1
26	CAN	2	2	10	20	7.6	14.0	2.2	4.3	20.1	38.5
27	CS	3	3	7	16	6.0	13.6	1.8	3.8	14.6	33.1
28	CAN	3	3	7	38	5.5	16.6	1.3	4.3	14.0	59.3
29	CS+BBFb	3	3	8	25	6.3	20.3	1.8	4.3	15.9	49.2
30	CAN	4	3	36	22	4.8	19.4	2.2	9.5	42.8	51.0
31	CAN	2	3	10	18	4.4	13.2	1.3	5.3	15.4	36.3
32	CS+BBFb	4	3	8	32	8.4	19.1	2.6	4.7	19.4	55.6
33	CAN	5	3	10	24	8.2	19.8	2.6	12.4	21.1	56.6
34	CAN	1	3	12	13	14.4	13.0	3.5	4.3	29.4	30.0
35	UAN	2	3	17	19	10.5	14.2	2.2	9.3	29.9	42.6
36	BBFb	2	3	10	20	5.6	14.1	3.5	10.2	19.1	43.9
37	CS	2	3	13	18	9.0	14.7	2.6	6.8	24.3	39.9
38	BBFb	3	3	9	27	10.9	17.2	2.7	8.3	22.9	52.1
39	UAN	3	3	13	24	7.5	18.8	2.2	5.8	22.3	48.8

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