Limits to nitrogen fertilizer on grassland

Promotor: ir. M.L. 't Hart, oud-hoogleraar in de leer van de landbouwplantenteelt en het grasland

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W.H. Prins

Limits to nitrogen fertilizer on grassland

Proefschrift
ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector-magnificus,
dr. C.C. Oosterlee,
hoogleraar in de veeteeltwetenschap,
in het openbaar te verdedigen
op vrijdag 11 maart 1983
des namiddags te vier uur in de aula
van de Landbouwhogeschool te Wageningen

Abstract

Prins W.H. (1983) Limits to nitrogen fertilizer on grassland.
Doctoral thesis, Wageningen. (x) + 44 p., 1 table, 9 figs, 57 refs, Eng, and Dutch summaries, 6 annexes plus papers in:
Proc. int. Symp. Eur. Grassl. Fed. Wageningen (1980): 35-49;
Proc. 13th int. Grassl. Congress Leipzig (1977): 971-978;
Proc. 14th int. Grassl. Congress Lexington (1981): 305-308;
Fertilizer Research 1 (1980): 51-63; 2 (1981): 309-327; 4 (1983): 101-113;
Neth. J. agric. Sci. 29 (1982): 245-258

The effect of nitrogen fertilizer on seasonal response of grassland, sward quality and productivity, herbage nitrate content, and soil mineral nitrogen status was studied in cutting trials lasting from one to six years. Rates of nitrogen application ranged from 0 to 160 kg N per ha per cut, totalling up to about 1000 kg N per ha per year. Plots were cut whenever a yield level of 2 to 2.5 t dry matter per ha was reached.

The response to nitrogen was strongest in the first half of the season and decreased gradually thereafter. The response was influenced by residual nitrogen from previously applied nitrogen fertilizer. In the first year a positive response was obtained to higher rates of nitrogen application than in subsequent years. At rates exceeding about 500 kg N per ha per year sward quality deteriorated to such an extent that productivity decreased in the following year.

As 'optimum' application a quantity of, on average, 420 kg N per ha per year was calculated. At this rate herbage nitrate content did not exceed 0.75% NO_3 and accumulation of soil mineral nitrogen was minimal.

STELLINGEN

1. Stikstofbemesting op grasland heeft naast een economische ook een fysieke grens. Bij overschrijden van deze grens neemt de produktiviteit van het grasland af, wat gepaard gaat met een verhoging van het nitraatgehalte van het gras en van de hoeveelheid minerale stikstof in de grond.

   Dit proefschrift.

2. Alleen veeljarige proeven kunnen een juist beeld geven van de stikstofreactie van grasland op lange termijn.

   Dit proefschrift.

3. De resultaten van bemestingsproeven op grasland worden sterk bepaald door het gekozen maaischema, hetgeen vaak niet wordt onderkend.

   Dit proefschrift.
   K.P. Dawson, O.R. Jewiss & J. Morrison (1982) 9th General Meeting European Grassland Federation, Reading, preprint 058.

4. Het feit dat de voorraad minerale stikstof in de grond bij het begin van de grasgroei vaak nauwelijks de reactie van de eerste snede op stikstofbemesting beinvloedt, stemt pessimistisch ten aanzien van een mogelijke verfijning van het stikstofadvies voor de eerste snede op basis van grondonderzoek.

   W.H. Prins & J. Postmus (1979) Stikstof nr. 91, 220-225.
   W.H. Prins (1980) Stikstof nr. 94, 314-317.
   Projectverslagen Instituut voor Bodemvruchtbaarheid, Haren, 1981.

5. In Nederland en omringende landen is op melkveebedrijven waar een zo hoog mogelijke opbrengst van het grasland moet worden behaald, geen plaats voor klaver.

   J.S. Brockman & B.M. Camm (1981) Winter Meeting British Grassland Society on Legumes and fertilizers in grassland systems, Londen, 4.1-4.10.

6. Het vinden van een goede ureaseremmer, die bovendien kan worden toegevoegd aan ureum tijdens de fabricage, zal een doorbraak zijn bij het streven de stikstofverliezen bij het gebruik van ureum als meststof te beperken.

   P.L.G. Vlek & E.T. Crasswell (1981) Fertilizer Research 2, 227-245.

7. Bij de natte rijstbouw kan het rendement van ureum sterk worden verbeterd door de meststof diep te plaatsen. Grootscheeps onderzoek naar apparatuur voor toediening op diepte en naar de toepasbaarheid daarvan is gerechtvaardigd.

D.L. McCune & P.L. Stangel (1982) 12th International Congress of Soil Science, New Delhi, 5, 181-211.
International Workshop on Nitrogen management, Fuzchou, China, 1982.

8. Een landbouwsysteem in de tropen op basis van mais en een niet-agressief vlinderbloemig voedergewas, in Zambia bijvoorbeeld Siratro (*Macroptilium atropurpureum* [DC.] Urb.), verschaft stikstof voor de gewassen, graan voor de boer en voer voor het vee.

Annual Report Research Branch, Republic of Zambia, 1971-1973.

9. Het Bijbelse: "Als iemand kennis vermeerdert, vermeerdert hij smart" is zeker van toepassing op berichten over al dan niet vermeende schadelijke effecten van voedings- en genotmiddelen.

10. Organisatoren van congressen moeten er rekening mee houden dat congresgangers vooral geinteresseerd zijn in discussies met collega's in de wandelgangen, om zo op de hoogte te blijven van ontwikkelingen op hun vakgebied, die via de nog steeds groeiende stroom publikaties niet meer bij te houden zijn.

J.J. van Cuilenburg, Intermediair 12 november 1982.

11. Het verdient aanbeveling op 3 november 1984 te gedenken dat honderd jaar geleden Apie Prins geboren werd.

Winkler Prins (1975) deel 15, p 697.

12. Middelen om de stank van mest te bestrijden zijn vaak produkten waar een luchtje aan is.

Proefschrift van W.H. Prins
Limits to nitrogen fertilizer on grassland
Wageningen, 11 maart 1983

Aan mijn Moeder

Aan Josje,

Peter, Menno, Duke en Wendy

Woord vooraf

Aan de totstandkoming van dit proefschrift hebben velen met woord en daad bijgedragen. Hiervoor spreek ik graag mijn dank uit. Met name wil ik noemen:
Professor M.L. 't Hart voor zijn bereidheid om als promotor op te treden, ook al werd het onderzoek "op afstand" uitgevoerd, en voor zijn opbouwende kritiek en suggesties bij het samenstellen van het proefschrift.
P.F.J. van Burg, mijn co-referent en directeur, voor zijn grote belangstelling bij het verrichten van het onderzoek, dat indertijd zijn eigen werkterrein was, en bij het op schrift stellen van de resultaten.
Het Bestuur van de Stichting Landbouwkundig Bureau van de Nederlandse Meststoffenindustrie (LBNM) voor de geboden gelegenheid de resultaten van het onderzoek te bewerken tot een proefschrift.
C.M.J. Sluijsmans voor de gastvrijheid op het Instituut voor Bodemvruchtbaarheid (IB) te Haren.
De gebroeders Nijhof en de leden van de voormalige maatschap Landbouwcombinatie Finsterwolde, in het bijzonder H.E. Waalkens, voor het beschikbaar stellen van land voor de proefvelden in respectievelijk Ten Boer en Finsterwolde.
Het personeel van de Veldproevendienst van het IB voor de verzorging van de proefvelden.
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De medewerkers van de "Afdeling LBNM" aan het IB voor hun toewijding, in het bijzonder J. Postmus en G.J.G. Rauw voor hun hulp bij het gedetailleerde proefveldwerk en de verwerking van de resultaten, G.H. Arnold voor zijn taalkundige inbreng, en R.J. Bruggema, R.D. Kroon en C.H. Verboon-van den Berg voor het rekenen, typen en tekenen.
K.W. Smilde en de redactiecommissie van het IB, alsmede de collega's D.J. den Boer, A. Darwinkel, B. Deinum, J.G.P. Dirven, G.C. Ennik, A. Kemp, H.G. van der Meer, L. Sibma, L.A.H. de Smet, H. Thomas en H. Wieling voor hun bijdragen aan facetten van het onderzoek en commentaar op delen van het manuscript.
G.D. van Brakel en V.A. Kuipers-Betke voor de hulp bij het op korte termijn persklaar maken en laten drukken van het proefschrift.

Preface

The investigations reported in this doctoral thesis were carried out under the auspices of the Institute for Soil Fertility at Haren, the Netherlands, to which the author has been seconded by the Agricultural Bureau of the Netherlands Nitrogen Fertilizer Industry (LBNM). The opportunity given by the Board of LBNM to prepare this thesis is greatly appreciated.

Thanks are due to Professor M.L. 't Hart for his helpful criticisms and to P.F.J. van Burg for his interest and encouragement. The help of D.M.B. Chestnutt, A.E.M. Hood, J. Morrison, R.J. Wilkins and D. Wilman who critically read parts of the manuscript and of P.A. Gething who corrected parts of the English text, is gratefully acknowledged.

Curriculum vitae

Willem Hendrick Prins werd geboren op 13 november 1939 te Batavia. Direct na de oorlog repatrieerde hij naar Nederland. In 1958 behaalde hij het diploma Gymnasium-β aan het Openbaar Lyceum te Heerenveen en begon hij zijn studie aan de Landbouwhogeschool te Wageningen. In september 1966 slaagde hij voor het doctoraal examen in de richting tropische landbouwplantenteelt.

Van februari 1967 tot februari 1974 was hij in dienst van de Voedsel- en Landbouworganisatie van de Verenigde Naties (FAO) werkzaam in Afrika. De eerste drie jaren was hij Pasture Research Officer op het Southern Highlands Sheep Raising Project nabij Mbeya in Tanzania. De daaropvolgende vier jaren was hij toegevoegd aan de overheid van Zambia als Pasture Research and Extension Officer met als standplaats het Mount Makulu Central Research Station nabij Lusaka.

Sinds oktober 1974 is hij als wetenschappelijk medewerker van de Stichting Landbouwkundig Bureau van de Nederlandse Meststoffenindustrie (LBNM) gedetacheerd bij het Instituut voor Bodemvruchtbaarheid te Haren (Gr). Hij houdt zich daar bezig met bemestingsonderzoek, voornamelijk gericht op grasland.

Contents

This doctoral thesis is based on a series of published papers in chapters 2 to 8. Reference to the contents of these chapters should be made by citing the original publications

Chapter 1

General introduction

The history of grassland farming in the Netherlands shows that from time to time the rate of nitrogen fertilizer applied by farmers has been limited by one factor or another. These historical aspects will be dealt with briefly by drawing on the review papers by De Groot (1965) for the period 1900-1965, by 't Hart (1976) for the period 1930-1975 and by Van Burg et al. (1980) for the period 1965-1980.

Trials at the beginning of this century demonstrated that grassland yields could be increased by applying nitrogen but, before 1915, nitrogen fertilizer was so expensive that its use was not considered remunerative. During the 1920s the price of nitrogen fell but the price of agricultural produce also declined. It was only in the mid-thirties that the nitrogen/milk price ratio reached a level at which it became an incentive to use more nitrogen (Figure 1b).

Nevertheless, in the pre-war years there was opposition to the use of nitrogen on grassland. Questions posed were: Does nitrogen destroy the sward, kill the white clover and poison the cattle? Research showed that adaptation of the grazing system and cutting the grass at a younger stage of growth largely answered the first question. Clover was not killed but depressed by nitrogen through the competition of the accompanying grasses in the sward, resulting in less symbiotic nitrogen fixation. Finally, there were no indications that cattle diseases were promoted by nitrogen fertilizer. Hypomagnaesemia was ascribed to fertilizer nitrogen, but this disease, also occurring on farms without fertilizer, seemed to have far more complex causes.

The purpose of using nitrogen fertilizer was to produce more herbage for efficient and profitable milk production. The effect of nitrogen fertilizer in actual farm practice has been studied since 1935 on the so-called Nitrogen Pilot Farms. From the beginning these farms turned out to be ahead of the average farm in the Netherlands (Figure 1a).

After World War II the lack of foreign currency considerably restricted the import of feeding stuffs. Farmers were encouraged to produce as much fodder on the farm as possible. The nitrogen/milk price ratio remained fairly constant (Figure 1b) and more and more farmers increased their rates of nitrogen application. The Nitrogen Pilot Farms were set a target in 1949 to

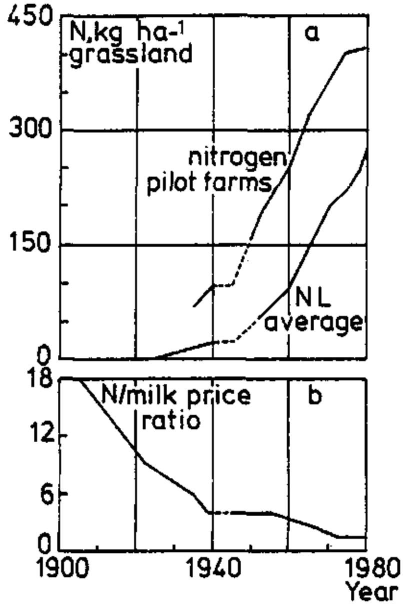

Figure 1. The use of fertilizer nitrogen on grassland in the Netherlands and on Nitrogen Pilot Farms (a) and the nitrogen/milk price ratio (b) since 1900

intensify to a level of 200 kg N per ha per year. Up to this rate the rule was: The more nitrogen the better the sward under a proper cutting and grazing regime ('t Hart, 1954). Nitrogen usage continued to increase and some farms were already applying 300-400 kg per ha N or more in the sixties. However, on many farms labour productivity and available housing for stock limited the nitrogen dressings. The removal of these limits through increased mechanization and improved housing (cubicle houses), both reducing labour requirements, led to higher stocking rates, greater demand for forage and higher rates of nitrogen application.

The effect of dressings higher than 200 kg N per ha has been the subject of study since the forties. Cutting trials on sand and clay soils showed that maximum dry-matter yields were often not reached with applications of 450-500 kg N per ha, while the greatest response was in the range 0 to 300 kg N (Boxem, 1973; Van Steenbergen, 1977). Animal health was not adversely affected per se by total applications up to 600 kg N per ha (De Groot et al. 1973). Results of research in cutting trials and in farming systems indicated optimum annual dressings of 400 kg N per ha on sand, clay and wet peat soils, and of 250 kg N on well-drained peat soils. The nitrogen must be applied in several dressings suited to grazing and mowing, the rate decreasing from beginning to end of the season.

Increasing the rate of nitrogen fertilizer results in higher productivity of grassland and allows stocking rates to be increased. However, this intensification of dairy farming was accompanied by reports of sward deterioration. The deterioration was not caused directly by the nitrogen fertilizer but was related to faults in management like too heavy conservation cuts, badly adjusted mowing machines, too long field periods and the use of slurry. These risks of intensive farming, on razor's edge, increased the proportion of unwanted plant species in the sward. Because suppression of these species through special grassland management is generally very difficult, this often meant re-seeding.

The profitability of the higher nitrogen dressings remained favourable; the fertilizer costs fluctuated around 5% of total production costs (Sluiman, 1981). Wieling's (1981) model of the optimum dairy farm showed how a number of factors interacted to affect profitability. Nitrogen appeared to have a positive effect on labour income at current prices. The optimum nitrogen application on sand and clay soils was always more than 400 kg N per ha per year and often labour income was highest at 500 kg N. Doubling of the price of nitrogen at current milk price or including extra costs of re-seeding in the calculations gave an optimum outcome near 400 kg N per ha per year.

Around 1970 dressings of 500, 600 or more kg N per ha were sometimes applied annually on dairy farms (Thomas, 1972). The question arose as to what might be the effect of such dressings on factors like seasonal response of grassland to nitrogen, productivity, sward quality, grass quality, grass intake, soil mineral nitrogen status, surface and ground water composition, and NO_x-emission. This could not be answered satisfactorily from the results of trials already conducted in the Netherlands. Either the nitrogen applications were not high enough (e.g. Oostendorp, 1964; Boxem, 1973; Van Steenbergen, 1977) or the applications were high but the trials were too short-lived (Van Burg, 1962) or were not concerned with these factors (Mulder, 1949; Alberda,1969). Therefore a new series of field trials was commenced in the early seventies by the Research and Advisory Institute for Cattle Husbandry (Wieling, till 1975) and the Institute for Soil Fertility (Van Burg, till 1974, and Prins, from 1974 onwards).

In the following chapters some of the above-mentioned factors will be examined on the basis of results of short-term (up to one year) and long-term (up to six years) trials on all-grass swards on sand and clay soils, in which nitrogen was applied at rates varying from low to very high. Our short-term trials were conducted in the period 1970-1974 on old permanent grassland (chapters 2 to 4). The long-term trials were carried out in the period 1974-1980 on old permanent grassland as wel as on more recently sown grassland (chapters 4 to 8).[1)]

Chapter 2 treats the nitrogen response of permanent grassland within one season under nitrogen regimes varying from 240 to 1080 kg N per ha per year. Among other things attention is paid to cutting at a set stage or at a set date and to the optimum rate of nitrogen application on the basis of dry-matter production per kg N applied. Thereafter chapter 3 outlines the residual effect of different intensities of nitrogen fertilization within one season.

Chapter 4 monitors the course of the changes in mineral nitrogen in the soil at different levels of nitrogen fertilizer within one season as well as from one season to the next over several years. This is expanded in chapter 5 which discusses season to season residual effects as indicated by dry-matter yield, N uptake and soil mineral N content. Chapter 6 is an extension of chapter 5, showing in detail the residual effects on heavy clay soil over two years.

Chapter 7 deals with the effect of nitrogen fertilizer on the nitrate content of the grass as quality limit.

Chapter 8 treats the effect of continuous very high nitrogen dressings on grassland productivity and sward quality as far as they may impose limits on nitrogen fertilizer usage. This includes aspects of grassland management and sward characteristics such as percentage cover and number of tillers. Finally, the topics dealt with in previous chapters are brought together in a general discussion in chapter 9.

1) Data on materials and methods are presented in the articles in chapters 2 to 8. Additional information on e.g. trial code numbers, soils, trial history and annual yields may be found in Annexes 1-6

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Chapter 2

THE SEASONAL RESPONSE OF GRASSLAND TO NITROGEN AT DIFFERENT INTENSITIES OF NITROGEN FERTILIZATION, WITH SPECIAL REFERENCE TO METHODS OF RESPONSE MEASUREMENTS

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Summary

Data are presented to demonstrate the response of grassland to nitrogen during the growing season in relation to different levels and frequencies (intensities) of nitrogen fertilization. The data have been derived from the results of seven field experiments in the years 1972-1975. The different intensities resulted in total applications of about 300 to over 1000 kg N per ha per annum.

Apart from these intensities of nitrogen fertilization, the experimental treatments included different times of nitrogen application during the season, increasing rates of nitrogen at each time of application, and a series of successive harvests after each time of nitrogen application in order to establish growth curves.

The response was first studied in terms of DM increase determined at a specific date, using two different methods, and secondly in terms of days time gain to reach a specific stage of growth.

Some general conclusions are:

- The response to nitrogen is highest in the first half of the season, decreasing with increasing rates of nitrogen application.
- The response is considerably lower with increasing intensity of nitrogen fertilization. This may be caused by a residual effect of the higher nitrogen pretreatment.
- At the end of the season the response at high rates of application can become negative in a high-nitrogen intensity system.

The intensity of nitrogen fertilization affects the optimum rate of nitrogen application for each cut, as is shown at an assumed marginal profitability of 7.5 kg DM per kg N applied.

Finally, an appraisal of cutting at a fixed frequency or at defined stages (e.g. grazing, silage stage) is presented.

Introduction

For the farmer fertilizer nitrogen is generally the most effective management input for manipulating grassland yield within the limitations imposed by the environmental factors like soil type, radiation, temperature and moisture (Morrison et al., 1974). In addition to these environmental factors variations in yield and response to nitrogen can be related to factors such as grass species and varieties, presence of a legume, frequency of defoliation, age of sward, season, and supply of other nutrients (Whitehead, 1970). Amongst these factors knowledge of the seasonal response is important as a tool for farm planning operations (Wieling, 1971).

The influence of nitrogen fertilization on the growth of grass during the season can be studied considering the following factors:

- 1. time of nitrogen application
  The season consists of a sequence of growth periods divided by the dates of nitrogen application and cutting. Each time of nitrogen application provides information on a particular part of the season.
- 2. response to nitrogen at each time of application
  This factor can be assessed by applying different rates of nitrogen at each date and measuring the herbage yield.
- 3. response to nitrogen during the course of growth
  With successive harvests the rate of growth can be determined, thus giving information on the response during each growth period.
- 4. *intensity of nitrogen fertilization*
  Different levels of nitrogen supply, from the soil or from previous nitrogen applications, can either directly give differences in response to nitrogen, or indirectly via a change in the productivity of the sward. With present-day high rates of nitrogen

* Seconded by the Agricultural Bureau of the Netherlands Fertilizer Industry (LBNM).
** Previously seconded to the Institute for Soil Fertility (IB), Haren (Gr.).

fertilizer in intensive grassland farming it is necessary to know a possible decrease in response at a higher intensity of nitrogen fertilization. 'Intensity' is meant here as a combination of a particular level and number of nitrogen applications throughout the season whereas 'rate' is meant as the amount applied at a specific date.

Over the period 1970-1975 the seasonal response of grassland to nitrogen was studied in field experiments by the Research and Advisory Institute for Grassland Husbandry (PR) and the Institute for Soil Fertility (IB). This article summarizes the results of the seven experiments based on cutting at a 'grazing' stage of growth viz. four PR-trials, all at one intensity of nitrogen fertilization, two IB-trials at two intensities and one IB-trial at four intensities of nitrogen fertilization. The experiments were located in various parts of the Netherlands (Figure 1). Some of the results have already been reported elsewhere (Minderhoud et al., 1976; Van Burg, 1977; Prins & Van Burg, 1977; Prins & Van Burg, 1979).

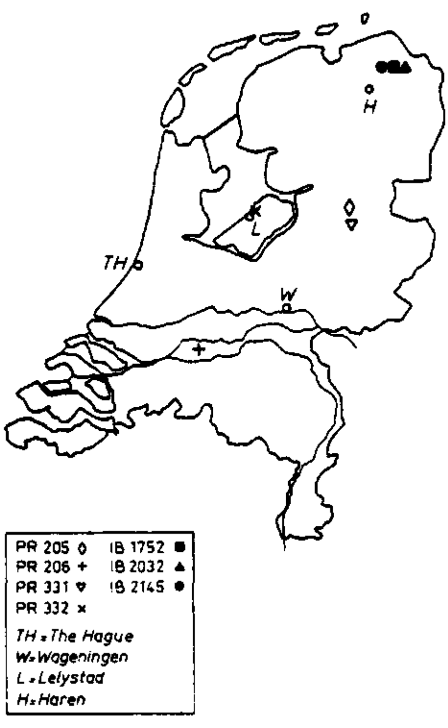


Figure 1. Location of the PR- and IB-trials in the Netherlands.

<u>Choice of experimental methods and analysis of results</u>

When studying the seasonal response to nitrogen the management can be based on either a fixed cutting frequency ('set date') or cutting at defined stages ('set stage' : grazing, silage or hay stage, or a combination of these stages). Advantages and disadvantages of both systems will be discussed later on in this article.

In order to simulate practical farming circumstances it is preferable to cut at defined stages of growth. In our experiments plots were cut at a yield of about 2 t DM per ha, the 'standard' grazing-stage of growth. Only with the IB-trial 1752 the first and fourth cuts were taken at a later stage (over 3 t DM per ha, see Appendix I).

Since an increase in the rate of nitrogen application generally accelerates grass growth, the grazing stage of growth is attained sooner with increasing intensity of nitrogen fertilization. Consequently, the higher intensity (higher nitrogen pretreatment) results in more 'standard' cuts and thus in more times of nitrogen application during the season than the lower intensity.

Time-of-nitrogen application blocks were allocated at random and numbered S1, S2 etc. in order of starting time. In order to study the response to nitrogen properly one requires growth curves for each rate of N. The time-of-application blocks were therefore subdivided into plots for the different rates of nitrogen and for successive harvests.

The response to nitrogen at each time of application was determined at rates of 0, 40, 80 and 120 kg N per ha. Only with IB 1752 also the rate of 200 kg N per ha was included. Herbage was harvested successively at intervals of about 6 to 12 days to establish the growth curves. The number of successive harvests varied from about 5 to 7 early in the season to 2 to 6 at the end of the season.

In all experiments the common intensity of nitrogen fertilization was 80 kg N per ha per standard cut. This corresponds with an <u>intensive</u> (I) system of nitrogen fertilization. In the IB-trials also an <u>extensive</u> (E) system of nitrogen usage was investigated by applying 40 kg N per ha at each standard cut. Finally, in IB-trial 2145 also rates of 60 and 120 kg N per ha at each standard cut were included, corresponding to an <u>intermediate</u> (P) and a very <u>intensive</u> (Z) system of nitrogen usage (Table 1).

To clarify these complicated experiments, the schemes and growth curves of some selected systems of the IB-trial 2145 are given in Table 2 and Figure 2, respectively. This type of experiment has been described in more detail by Prins & Van Burg (1979). Data on nitrogen application and measured DM yields per cut and per season are shown in Appendix I.

Table 1. General data of trial sites and intensities of pretreatment nitrogen fertilization.

Expt no.	Year	Location	Soil	0-5 cm		Rate of nitrogen application per standard cut, kg ha^{-1}; in parentheses number of cuts			
				pH-KCl	org. matter g kg^{-1}	E	P	I	Z
PR 205	1973	Nieuwleusen	sand	5.0	5.5			80 (6)	
PR 206	1973	Bruchem	clay	6.7	3.1			80 (6)	
PR 331	1974	Heino	sand	4.7	3.6			80 (6)	
PR 332	1975	Lelystad	clay	7.1	6.1			80 (6)	
IB 1752	1972	Ten Boer	clay	6.3	13.8	40* (7)		80* (8)	
IB 2032	1973	Ten Boer	clay	6.2	15.0	40 (7)		80 (8)	
IB 2145	1974	Ten Boer	clay	5.8	14.4	40 (6)	60 (7)	80 (8)	120 (9)

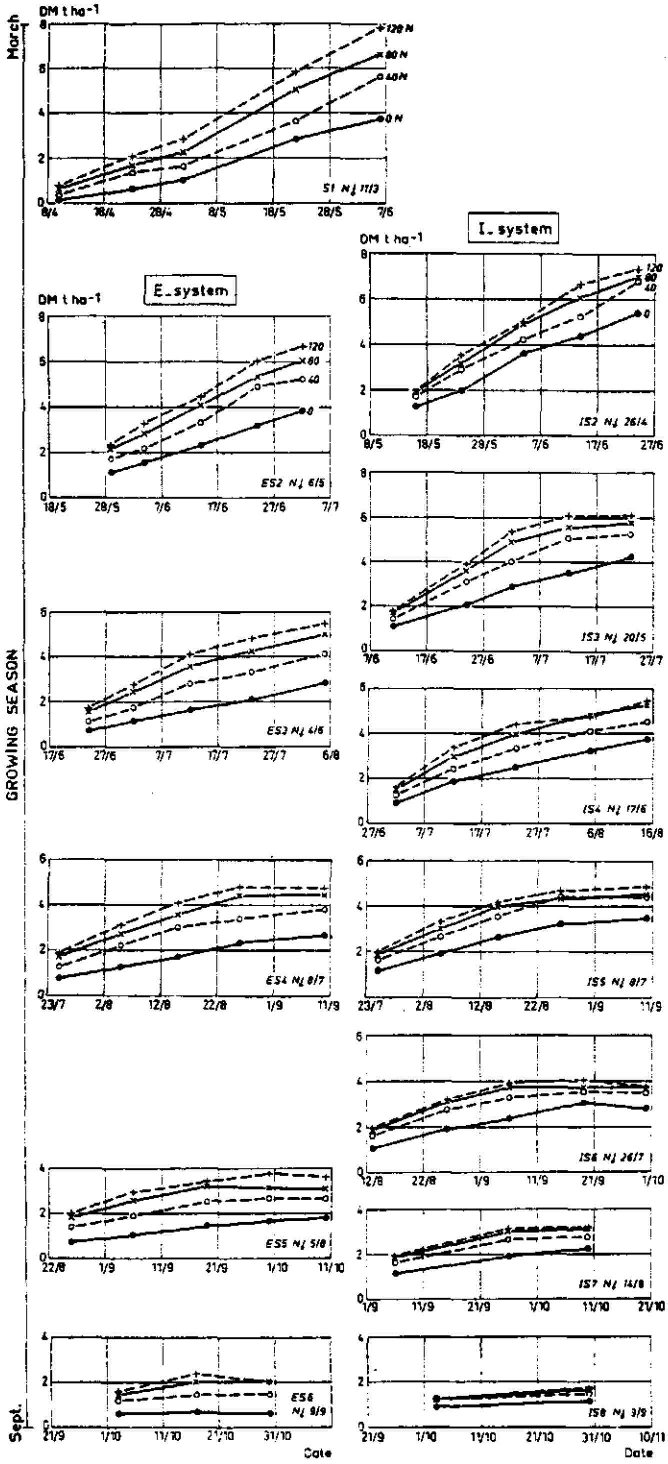
* The spring applications for the E- and I-systems of IB 1752 were 80 and 120 kg N per ha, respectively.

Table 2. Scheme of the extensive (E) and intensive (I) nitrogen fertilization systems of IB 2145 during 1974.

Date of N-appl.	Time-of-application blocks of E- and I-systems					*
	S1	ES2	ES3	ES4	ES5	ES6
11/3	0,40,80,120 M1-M5	40	40	40	40	40
6/5		0,40,80,120 M1-M5	40	40	40	40
4/6			0,40,80,120 M1-M5	40	40	40
8/7				0,40,80,120 M1-M5	40	40
5/8					0,40,80,120 M1-M5	40
9/9						0,40,80,120 M1-M3

	S1	IS2	IS3	IS4	IS5	IS6	IS7	IS8 *
11/3	0,40,80,120 M1-M5	80	80	80	80	80	80	80
26/4		0,40,80,120 M1-M5	80	80	80	80	80	80
20/5			0,40,80,120 M1-M5	80	80	80	80	80
17/6				0,40,80,120 M1-M5	80	80	80	80
8/7					0,40,80,120 M1-M5	80	80	80
26/7						0,40,80,120 M1-M3	80	80
14/8							0,40,80,120 M1-M3	80
9/9								0,40,80,120 M1-M2

* Area of time-of-nitrogen application blocks decreasing with decreasing number of successive harvests (M1, etc.).



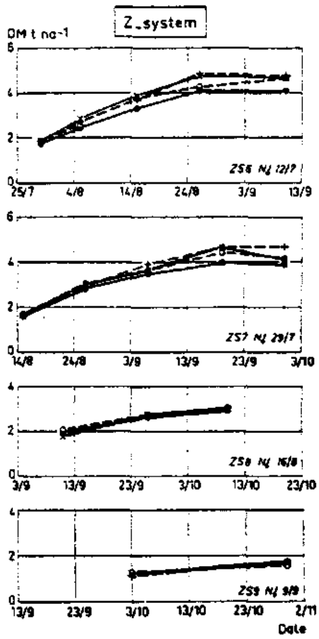


Figure 2. Effect of different rates of nitrogen (0, 40, 80 and 120 kg N per ha) on herbage yield at each time of nitrogen application (S1, S2, etc.) with the extensive (E = 40 kg N per ha at each standard cut), intensive (I = 80 kg N per ha at each standard cut) and very intensive system (Z = 120 kg N per ha at each standard cut) in Experiment IB 2145 of 1974. Of the Z-system growth curves of the last four times of nitrogen only have been determined. The available growth curves of the intermediate system (P = 60 kg N per ha at each standard cut) have not been included.
N↓ = date of nitrogen application.

The field experiments were carried out on permanent grassland on clay and sandy soils (Table 1). Lolium perenne was the dominant grass species of the swards which were either free from weeds and clover (IB-trials) or had nil to 1 % clover (PR-trials).

Nitrogen was applied as calcium ammonium nitrate (23 % N in 1972 and 26 % N thereafter). The first application was in spring in mid or late March, subsequent applications took place immediately after each cut. Phosphorus and potassium were applied for each standard cut in adequate amounts. The rates used for the second and following cuts in PR-trials 205, 206 and 331 were, however, slightly below the recommended rates as indicated by soil analysis.

Cuts were made at about 4 cm above ground level with a motor mower.

The effect of different rates of nitrogen may be determined 1) as 'vertical' and 2) as 'horizontal' N-effects.

1) at a specific date, measuring the DM production of the different treatments at one point in time (vertical N-effect).

This kind of determination of DM production is used in most experiments. In our trials it was possible to use two ways of analysis of the vertical N-effect:

A. by determining the DM yields at a fixed number of days after each time of application of the different rates of nitrogen. Arbitrarily the N-effect at 30 days after nitrogen application has been chosen as this fitted all seven trials at the I-system of nitrogen intensity as well as the IB-trials at the E-system. See the diagrammatic presentation in Figure 3a.

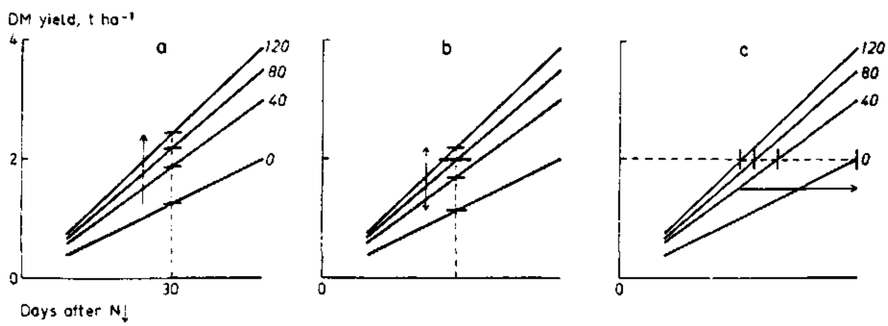
B. by taking a particular yield level at one rate of nitrogen application as reference for the other rates. For this kind of analysis the yield of 2 t DM per ha obtained with 80 kg N per ha has been chosen for the E- and I-systems of nitrogen intensity of the three IB-trials.
See for explanation Figure 3b.

2) at a particular yield level, measuring the number of growing days to reach a particular production stage like the grazing, silage or hay stage (horizontal N-effect). Such a measurement may provide the basis for the planning of a grazing/cutting scheme for the farmer. For this way of analysis the number of growing days to reach the standard grazing stage (2 t DM per ha) has been arbitrarily chosen for the I-system of all seven trials and for the E-system of the three IB-trials. See for explanation Figure 3c.

The vertical and horizontal N-effects can be read from the growth curves. For example, Figure 2 shows the growth curves after each time of application with the E- and I-systems as well as the last four times of application with the Z-system of IB-trial 2145. Of this trial the response to nitrogen at the end of the season will also be discussed in detail later in this paper.

The data for the vertical and horizontal N-effects have been calculated after establishing the best line of fit for each growth curve, generally a quadratic equation.

Figure 3. Schematic presentation of growth curves after application of 0, 40, 80 or 120 kg N per ha
(a) vertical N-effect measured as DM yields at 30 days after nitrogen application,
(b) vertical N-effect measured as DM yields against the reference yield of 2 t DM per ha with the 80 kg N rate of application, and
(c) horizontal N-effect in number of days required to attain 2 t DM per ha, the standard grazing stage.



2.6

Results

1. Vertical N-effect

A. DM yields at 30 days after nitrogen application

From the growth curves the increases in DM yields in the ranges 0 to 40, 40 to 80 and 80 to 120 kg N at 30 days of growth have been determined for the I-system (Figure 4). The initial application (S1) has not been included as it was not possible to use the date '30 days after the spring application of nitrogen' because of the low rate of growth early in the season. Figure 4 shows that
- the largest response to nitrogen occurred in the first half of the season
- the responses decreased with increasing rates of nitrogen application
- a negative response occurred towards the end of the season with the 80 to 120 kg N increment
- the variation in nitrogen response was considerable. The variation in response not only occurred in the PR-trials at different locations but also in the IB-trials at neighbouring fields in the same location but in different years. This variation occurred apart from the variation in DM yield at 0 N after 30 days of growth.

When we examine the three IB-trials separately and also determine the increase in DM yield with the E-system it is possible to assess the effect of the intensities of nitrogen fertilization on the response to nitrogen at 30 days after application.
For this purpose the average response of three IB-trials has been calculated at specific application dates throughout the season (Table 3).
It is evident that
- throughout the season DM yields at the 0 N rate were higher with the I-system
- the response to nitrogen was lower with a high (I-system) than low (E-system) nitrogen pretreatment. In the range 0 to 120 kg N the DM increase was about 1.4 t per ha from May to July with the I-system and about 1.8 t per ha from May to August with the E-system
- the response to nitrogen decreased towards the end of the season. With applications of 80 and 120 kg N per ha on 20 September the response in the I-system was even negative (see also Figure 4)
- the variation in response to nitrogen, as mentioned above, was largely compensated by the level of DM production at 0 N. This can be shown, for example, by adding the DM yield at 0 N and the DM increment 0 to 120 N at different times of application for both the E- and I-system.

The lower response to nitrogen, reported here, may be caused by the residual effect of the higher nitrogen pretreatment of the I-system. In this connection it should be kept in mind that in August the nitrogen pretreat-

Figure 4. Response to nitrogen expressed as yield increase for the 0→40, 40→80 and 80→120 kg N increments at 30 days after application. I-system of all PR- and IB-trials.

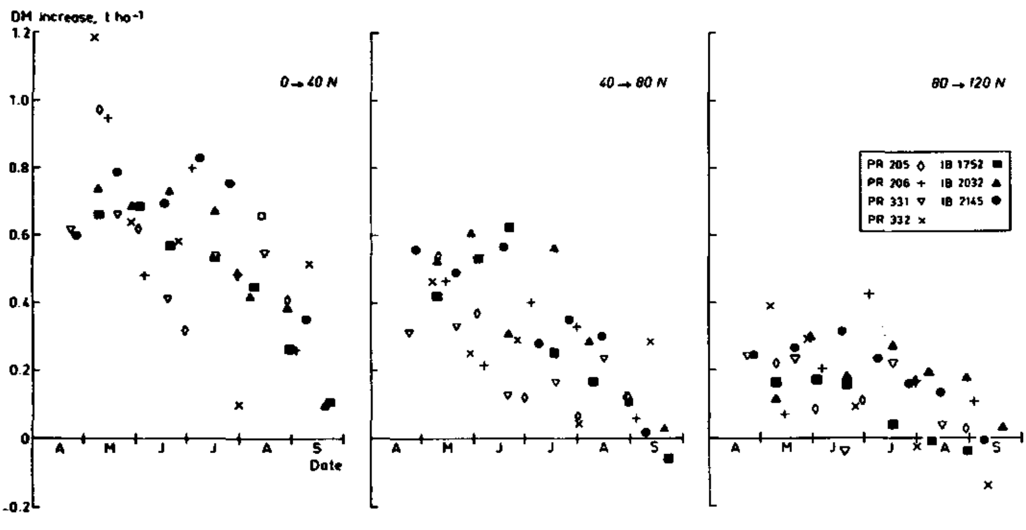


Table 3. Effect of time of nitrogen application and intensity of nitrogen fertilization on yield at 0 N and on yield increase between rates of nitrogen (kg DM per ha), measured 30 days after nitrogen application. Vertical N-effect, method A (see text). Average of three IB-trials.

Date of N-application	Intensity of nitrogen fertilization	Yield level at 0 N	0→40 N	40→80 N	80→120 N	0→120 N
10/5	E	1800	725	575	300	1600
	I	2250	675	525	200	1400
1/6	E	1700	825	650	350	1825
	I	2300	725	500	225	1450
1/7	E	1500	875	650	375	1900
	I	2200	700	450	200	1350
1/8	E	1200	850	575	325	1750
	I	1900	575	325	150	1050
1/9	E	750	700	400	200	1300
	I	1350	350	125	50	525
20/9	E	500	375	250	100	725
	I	850	150	-25	-25	100

ment with the I-system was already near 500 kg N per ha against near 200 kg N with the E-system.

We have arbitrarily determined the response to nitrogen at 30 days after application. From the course of the growth curves at the different rates of nitrogen application with the E- and I-systems it can generally be derived that with shorter growing periods this response is smaller and with longer growing periods larger than the values quoted above.

B. DM yields measured against the 2 t DM reference yield with the 80 kg N rate of application

With the previous method it was not possible to include the first time of application (S1). By using a constant yield as reference, however, the effect of the spring application of nitrogen can also be measured.

Table 4 shows the yield differences calculated from the three IB-trials at the E- and I-systems of nitrogen fertilization.

Table 4. Effect of intensity of nitrogen fertilization on yield increase (kg DM per ha) in the ranges 0→40, 40→80 and 80→120 kg N per ha, measured throughout the season against the reference yield of 2 t DM per ha at the 80 kg N rate of application. Vertical N-effect, method B (see text). Average of three IB-trials.

Date of harvesting	Intensity of nitrogen fertilization	0→40 N	40→80 N	80→120 N	0→120 N
1/5	E	525 *	535 *	320 *	1380 *
	I	560 *	465 *	275 *	1300 *
1/6	E	535	460	260	1255
	I	495	360	170	1025
1/7	E	555	420	220	1195
	I	450	285	100	835
1/8	E	600	420	205	1225
	I	410	225	60	695
1/9	E	660	425	215	1300
	I	390	190	55	635
1/10	E	735	500	245	1480
	I	380	170	90	640

* Differences between E and I because of curve fitting.

2.8

The E- and I-systems were contrasting in their response: with the E-system the response was fairly even throughout the season, even increasing towards the end of the season; with the I-system the response to nitrogen slowly decreased throughout the season. The latter is most likely caused by the residual effect of the higher level of nitrogen fertilization during the pretreatment period.

Method A, measuring the response after 30 days, showed a decrease in response to nitrogen from beginning to end of the season with both systems (Table 3). This decrease was related to the decrease in growth rate from beginning to end of the season, implying a decreasing production at 30 days of growth. Later in the season it took the 80 kg N rate of application more days than earlier in the season to reach the reference yield of 2 t DM per ha (method B). These longer growing periods did not change the response to nitrogen as was shown by the E-system (Table 4).

2. Horizontal N-effect or time gain

From the growth curves the time gain to attain the standard grazing stage (2 t DM per ha) has been determined for the increments 0 to 40, 40 to 80 and 80 to 120 kg N per ha with the I-system of all seven trials (Figure 5). The time gain
- was greatest at the lower nitrogen increment (0 to 40 kg N)
- was greater in spring than in summer, but was greatest towards the end of the season
- showed the greatest variation at the lower increment.

When also considering the time gain with the E-system it is possible to assess the effect of intensity of nitrogen fertilization. For this purpose the average time gain of the three IB-trials has been calculated after N application at certain dates throughout the season (Table 5). It is evident that, besides the factors mentioned above:
- throughout the season the number of days to reach 2 t DM per ha at 0 N was smaller with the I-system
- the time gain was greater at a generally low nitrogen level, as represented by the E-system.

These effects were presumably caused by the residual nitrogen in the plant-soil system of the intensively fertilized swards.

We have arbitrarily chosen the time gain at reaching the standard grazing stage of growth (2 t DM per ha). From the growth curves, as given in Figure 2, it generally follows that at lower yield levels the time gain is smaller and at higher yield levels larger than the ones quoted above because of a still continuing diverging of the response curves and/or decreasing rates of growth with time.

For planning and modelling purposes it is necessary to work with averages. It is notable that the variation in response to nitrogen between different locations and years was considerable, as was shown by the effect of the nitrogen increments in Figures 4 and 5.

Figure 5. Response to nitrogen expressed as time gain for the 0→40, 40→80 and 80→120 kg N increments to reach the standard grazing stage (2 t DM per ha). I-system of all PR- and IB-trials.

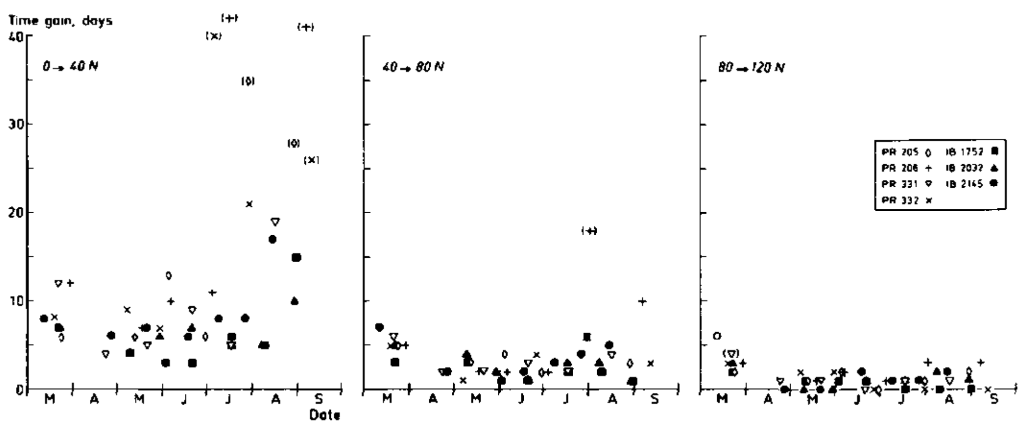


Table 5. Effect of time of nitrogen application and intensity of nitrogen fertilization on A. number of days to reach a production stage of 2 t DM per ha at 0 N and B. on days time gain in the ranges 0→40, 40→80, 80→120 and 0→120 kg N per ha to reach 2 t DM per ha. Horizontal N-effect (see text). Average of three IB-trials.

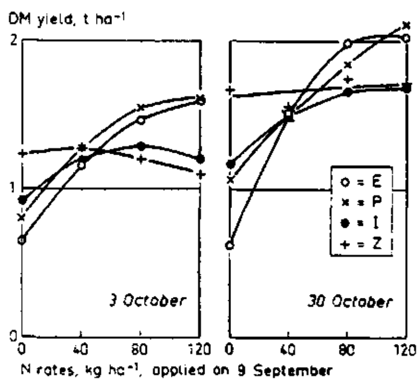
Date of N-application	Intensity of nitrogen fertilization	A	B			
		0 N	0→40 N	40→80 N	80→120 N	0→120 N
10/3	E	64*	8	7*	4	19*
	I	63*	8	5*	4	17*
1/4	E	51	7	4	3	14
	I	48	6	4	3	13
1/5	E	40	8	2	2	12
	I	34	5	3	1	9
1/6	E	36	10	3	2	15
	I	27	5	2	1	8
1/7	E	40	14	5	2	21
	I	27	6	2	0	8
1/8	E	51	20	10	2	32
	I	34	8	2	1	11
20/8	E	62	25	15	3	43
	I	42	11	3	1	15

* Slight differences between E and I because of curve fitting.

3. Response to nitrogen at the end of the season

Details on the residual effects of high nitrogen pretreatments have been given in this article and also previously (Prins & Van Burg, 1977). An extreme example can be found towards the end of the 1974 season with the four intensities of nitrogen fertilization of IB-trial 2145 when already 200, 360, 560 and 960 kg N per ha had been applied, respectively. For all systems the last time of application was 9 September. At that date the swards of the four intensities of nitrogen fertilization differed in appearance, becoming more open with increasing intensity. This was mainly because grass species like *Poa annua*, *Poa trivialis* and *Poa pratensis* nearly had disappeared, whereas the percentage of *Lolium perenne* had remained fairly constant. At both successive harvests DM yield at 0 N was highest with the highest nitrogen pretreatment: a positive effect of the residual nitrogen. Compared with the yield of the E-system, the residual effect was about 10-20 kg N with the P-system, 20-30 kg N with the I-system and about 50 kg N with the Z-system (Figure 6). Fresh applications of 80 or 120 kg N showed a small negative response on 3 October and nil or a small positive response on 30 October on the plots of the I- and Z-system. However, the grass of the E- and P-systems showed a considerable positive response, giving the highest yields. It is presumed that the fresh applications harmed the grass of the I- and Z-systems and did not harm the grass of the E- and P-systems. The negative effect of the fresh

Figure 6. Effect of intensity of nitrogen fertilization on response to nitrogen at two successive harvests towards the end of the season. Total nitrogen pretreatment rates of the E-, P-, I- and Z-systems till 9 September 1974 were 200, 360, 560 and 960 kg N per ha, respectively.



applications seems to have disappeared after 3 October. Namely between 3 and 30 October the growth rate of the grass of the I- and Z-systems was about the same as that of the E- and P-systems with sufficient nitrogen. The strong response of the E- and P-systems to nitrogen at the end of the season agrees well with the low levels of mineral nitrogen in the soil while in the I- and Z-systems mineral nitrogen had clearly accumulated in the soil (Prins, 1980).

General considerations

In the following we take first a closer look at the appraisal of the cutting system used in our experiments and secondly at the optimum rate of nitrogen application at each cut.

1. Appraisal of cutting at a set stage or a set date

It has been mentioned above that in order to simulate farming conditions as closely as possible, cutting according to a specific stage of utilization, whether for grazing, silage- or hay-making, is preferable. This necessitates cutting at a set stage as against a set date with a fixed cutting frequency. When aiming for a grazing or a silage stage it is not possible to work continuously with a fixed cutting frequency of, for example, four or six weeks. As has been shown by results of this and previous research (Alberda & Sibma, 1968; Behaeghe, 1968; Corrall, 1968) growth rate decreases from beginning to end of the season. This means a longer period of growth towards the end of the season before reaching the required stage. When working with different rates of nitrogen application, growth is faster at higher rates and consequently yield at a certain date is larger than at lower rates. Large yields may, especially in early season, considerably affect the production of following cuts (Ennik et al., 1980; Garwood et al., 1980).

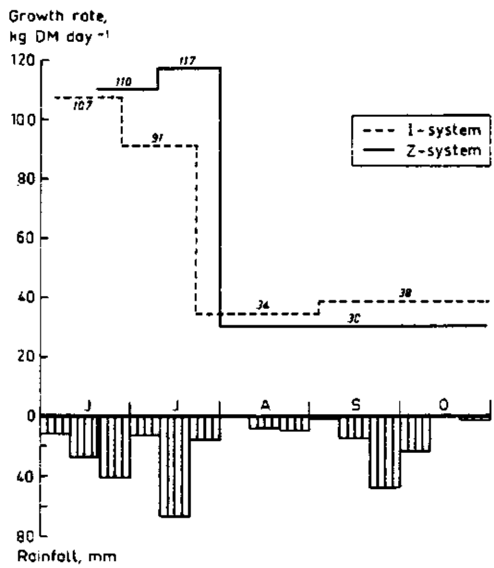
When choosing the cutting management in grassland experiments one has to take advantages and disadvantages into consideration. Cutting according to a fixed series of dates is, of course, easier as regards the organization of the work. An apparent advantage with set dates is also that cutting and fertilizing take place on the same day for all treatments. At set stage, however, treatments differ in dates of cutting and subsequent fertilizing, and weather conditions at these dates may influence the treatment results. An example of considerable influence of the weather is presented in Figure 7.

The effect of the weather was in this case larger than the effect of the applied nitrogen. Similar results have been reported by Garwood (1980).

It can be concluded that the system of cutting at a set stage is good as long as weather conditions for the different treatments are more or less equal. If not, it may be better to choose the system of set dates with the same weather conditions at cutting and fertilizing.

Whatever system for assessing the response to nitrogen is chosen one should in any case be aware of the disadvantages of that system and the results should be interpreted critically.

Figure 7. Example of an effect of weather conditions around the date of cutting and fertilizing on the subsequent response to nitrogen of the I- and Z-systems with 80 and 120 kg N per ha at each cut, respectively. The rainfall in mid-July promoted regrowth of the I-grass after cutting on 22 July 1975; the drought period from late July onwards hampered regrowth of the Z-grass after cutting on 31 July 1975. (Results of the long-term trial IB 2146, a follow-up of the annual trials mentioned in this paper.)



2. Optimum rate of nitrogen application

The purpose of the study of the seasonal response to nitrogen is to establish guidelines for the optimum rate of nitrogen application per cut depending on the usage of the herbage. This means integrating vertical and horizontal effects and taking possible residual effects into consideration. The optimum rate of nitrogen can be determined by the economics of the applications, keeping in mind factors like the maintenance of the sward productivity, the quality of the harvested grass or the amount of mineral nitrogen in the soil.

As regards the economics, the optimum rate of nitrogen can be read from the response curves at each time of application by assuming a marginal profitability at a yield whereby the response is still 7.5 kg DM per kg N applied. This is an average of the values 5.7, about 7, and 10 as used by Thomas (pers. comm.), Voigtländer & Voss (1977) and Morrison (1980), respectively. Of course, this value may be modified with changes in price of feed or fertilizer.

By connecting the points of marginal profitability at the different response curves it is possible to read at each time of nitrogen application the optimum rate of nitrogen required to obtain DM yields of, say, one up to five tonnes per ha. As an example of this method the response curves and the dotted line connecting the points of marginal profitability at the response curves of the first time of application (S1) of IB-trial 1752 are presented in Figure 8. In this way the optimum rates of nitrogen application have been determined for the E- and I-systems for all times of application (Table 6). So for the grazing stage of growth (2 t DM per ha) an application of 80-100 kg N per ha appeared throughout the season to be profitable in a 'continuous' low-N situation (E-system). In a high-N situation (I-system) for the grazing stage of growth the application had to decrease from 100 to 40 kg N during the

Figure 8. Example of the determination of the optimum rate of nitrogen application assuming a marginal profitability of 7.5 kg DM per kg N, in the spring of 1972, IB 1752, when rates up to 200 kg N per ha had been applied. By following the dotted lines connecting the intercepts, the optimum rates of nitrogen application can be read at different stages of growth.

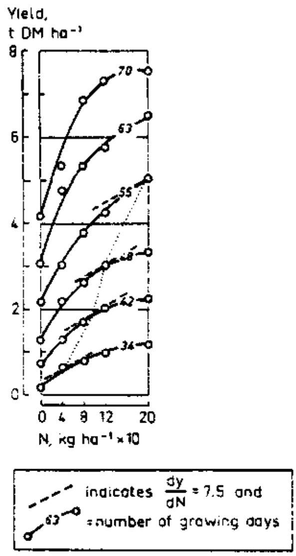


Table 6. Effect of intensity of nitrogen fertilization (E- and I-system) on the amount of fertilizer nitrogen required to meet the economic response of 7.5 kg DM per kg N at different yield levels, depending on the date of nitrogen application. IB 1752, 1972. Yields of pretreatment cuts are listed in Appendix I.

System	Time of N-application	Date of N-application	Nitrogen pretreatment kg ha^{-1}	DM yield level, t ha^{-1}				
				1	2	3	4	5
E	S1	21/3	0	60	100	120	160	200
	S2	12/5	80	40	80	100	120	140
	S3	7/6	120	40	80	100	100	120
	S4	1/7	160	40	100	120	120	140
	S5	4/8	200	40	80	120	160	200
	S6	30/8	240	40	80	100	-*	-
	S7	22/9	280	40	-	-	-	-
I	S1	21/3	0	60	100	120	160	200
	S2	9/5	120	40	60	80	100	120
	S3	2/6	200	20	40	80	100	100
	S4	20/6	280	20	40	80	100	120
	S5	17/7	360	0	40	60	80	100
	S6	9/8	440	0	40	60	80	-
	S7	30/8	520	0	40	80	-	-
	S8	22/9	600	0	-	-	-	-

* Yield not reached due to lateness in season.

season. For the silage and hay stages, rates were higher in both situations. Overall the difference in optimum rates between the E- and I-systems was about 20 kg N in May and June, and about 40 kg N per ha thereafter.

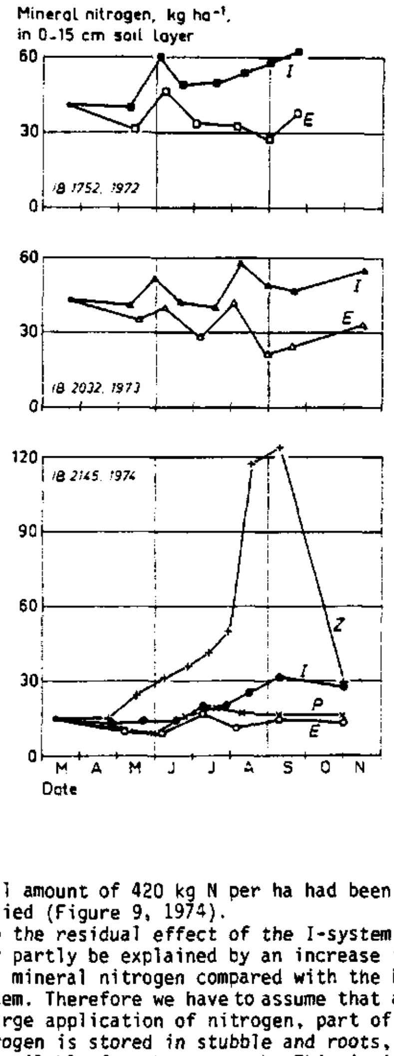
Table 6 can, however, not directly be used for advisory purposes. The difficulty is that, for example, once a rate of 120 kg N has been applied in a low-N situation to obtain a yield of 3 t DM per ha, the situation is no longer low-N and a possible residual effect has to be taken into account for the next application. Moreover, one has to take the cutting regime into account which in our example of IB 1752 included cutting at silage and grazing stage.

Still, Table 6 supports the general conclusion in the Netherlands that the first application of nitrogen should be the highest. Subsequent applications should be decreased in line with the decrease in the rate of grass growth.

As regards the difference between the E- and I-systems of 20 kg N in May and June, and of 40 kg N thereafter (see above), we can report that the latter value has been determined earlier in the IB-trials, following another way of calculation (Prins & Van Burg, 1977). It can be concluded from Figure 6 that with the intermediate P-system of nitrogen fertilization (60 kg N per ha at each cut) the residual effect is smaller than with the I-system. Likewise, the residual effect with the Z-system (very intensive, 120 kg N per ha at each cut) is considerably larger.

For different systems of grassland utilization it should be possible to construct a scheme with optimum rates of nitrogen application which take account of the nitrogen supply by the soil and the residual nitrogen over the season. However, at present it is not possible to predict the nitrogen supply by the soil through mineralization, nor is there a quick method to determine the nitrogen status of the sward. Knowledge of the nitrogen status of the sward seems essential to be able to predict the residual effect. In this article the experiments demonstrated this residual effect already after the first application (e.g. Table 2), while the difference between the quantity of mineral nitrogen in the upper 15 cm of soil of the E- and I-systems was minimal (less than 10 kg N per ha, Figure 9). From late July onwards the difference in the soil mineral nitrogen increased to 15-30 kg N per ha. Figure 9 clearly shows how in 1974 the applications of 120 kg N per ha at each cut (Z-system) increased the mineral nitrogen in the soil from the second cut onwards, up to a level of over 120 kg N per ha in the upper 15 cm in early September. Subsequent heavy rains reduced this large amount of mineral nitrogen to the level of the I-system in the same layer. It is notable that accumulation of mineral nitrogen in the soil was negligible with the P-system, even up to the end of the season when already a total amount of 420 kg N per ha had been applied (Figure 9, 1974).

Figure 9. Effect of intensity of nitrogen fertilization on changes in quantity of mineral nitrogen in the upper 15 cm of soil during the growing season. E, P, I and Z represent intensities of 40, 60, 80 and 120 kg N per ha at each cut, respectively. The higher the rate of nitrogen the more frequent the grass has been cut and fertilized as is shown by the number of symbols indicating the dates of cutting and fertilizing.



So the residual effect of the I-system can only partly be explained by an increase in soil mineral nitrogen compared with the E-system. Therefore we have to assume that after a large application of nitrogen, part of the nitrogen is stored in stubble and roots, and is available for the regrowth. This is in line with earlier findings by Dilz (1966). It may be a suggestion to obtain an increase in the rate of regrowth by establishing a reserve of nitrogen in the stubble-root-soil system at the beginning of the season and exploiting this reserve during the remainder of the season.

Maintaining the sward productivity is an important factor in the nitrogen response studies. In our experiments the yield potential per cut of the swards of the E- and I-systems was the same till the last time of application. This is illustrated nicely, for example, in Figure 2 when on 8 July 1974 the fourth and fifth times of application of the E- and I-systems coincided, respectively, and the same maximum yields were attained. However, the regrowth yields after the last time of application were not always as high with the I-system as with the E-system, as was, for example, shown in Figure 6.

All these results have been obtained in annual experiments. Recently it has been observed that very high rates of nitrogen application in one season may affect the productivity of the sward in the following season (Prins, 1978).

In practice farm management is geared towards an optimal grass production at the right time of the season, in accordance with the requirements of the livestock and the maintenance of the swards. Planning of the grassland production on the basis of our results and of those of, for instance, Boxem (1973) and Van Steenbergen (1977) may make management decisions for the utilization of the grassland easier. Here reference may be made to the concept of planning in grassland management based on certain production stages as described by Wieling (1977). These experiments have demonstrated variable responses to nitrogen imposed by differences in soil type, water supply, botanical composition, age of sward etc. These results have mainly been obtained in cutting experiments which may have a different response to nitrogen than grazing experiments (Boxem, 1973; Jackson & Williams, 1979).

It would seem that only by analyzing the results of many cutting and grazing experiments, conducted under different circumstances of climate, soil type and defoliation/fertilization regimes, it may be possible to establish more refined guidelines for the optimum rate of nitrogen application at different times of the season.

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Appendix I. Dates of nitrogen application and dates of mowing; DM yields (t ha^{-1}) of cuts preceding series S2, S3 etc. and of last successive cut of last series; intensities of nitrogen application: E-, P-, I- and Z-systems with rates of 40, 60, 80 and 120 kg N per ha at each cut, respectively.

Expt.	System	Series S1	S2	S3	S4	S5	S6	S7	S8	S9	Last cut	Total yield	Total N applied kg ha^{-1}
PR 205	-I												
		23/3	12/5	4/6	29/6	30/7	29/8				24/10		480
			2.47	2.33	1.65	1.32	1.52				2.75	12.04	
PR 206	-I												
		29/3	18/5	6/6	4/7	1/8	6/9				31/10		480
			2.57	1.83	2.55	2.59	1.68				2.46	13.68	
PR 331	-I												
		21/3	23/4	21/5	20/6	17/7	16/8				30/10		480
			2.19	2.51	2.42	1.73	2.36				2.94	14.15	
PR 332	-I												
		19/3	7/5	30/5	26/6	30/7	11/9				30/10		480
			2.12	2.33	2.11	1.57	1.07				2.69	11.89	
IB 1752	-E												
		21/3	12/5	7/6	1/7	4/8	30/8	22/9			9/11		320*
			3.18	1.48	1.99	2.82	1.87	0.89			0.89	13.12	
IB 1752	-I												
		21/3	9/5	2/6	20/6	17/7	9/8	30/8	22/9		9/11		680*
			3.31	1.66	2.26	3.48	1.86	1.61	1.13		1.36	16.67	
IB 2032	-E												
		22/3	16/5	7/6	5/7	2/8	29/8	19/9			12/11		280
			2.52	2.09	1.76	2.36	1.66	1.08			1.25	12.72	
IB 2032	-I												
		22/3	9/5	29/5	20/6	17/7	7/8	29/8	19/9		12/11		640
			2.40	2.13	2.20	2.48	2.28	1.58	1.72		1.36	16.15	
IB 2145	-E												
		11/3	6/5	4/6	8/7	5/8	9/9				30/10		240
			2.13	2.22	2.11	1.97	1.95				1.48	11.86	
IB 2145	-P												
		11/3	2/5	29/5	24/6	18/7	9/8	9/9			30/10		420
			2.09	2.59	1.83	2.16	1.82	2.27			1.68	14.44	
IB 2145	-I												
		11/3	26/4	20/5	17/6	8/7	26/7	14/8	9/9		30/10		640
			1.72	2.45	2.32	2.20	1.88	1.84	1.99		1.67	16.07	
IB 2145	-Z												
		11/3	22/4	15/5	7/6	26/6	12/7	29/7	16/8	9/9	30/10		1080
			1.94	2.36	2.20	2.34	2.22	1.70	1.80	1.50	1.72	17.78	

* The spring applications were 80 and 120 kg N per ha in the E- and I-system, respectively.

Chapter 3

The residual effect of fertilizer nitrogen on grassland within one growing season

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Summary

In field experiments it has become clear that at a high level of N fertilization an N reserve can be built up in the soil-plant system which can have a residual effect on the regrowth of a grazed or mown pasture. This residual effect is most apparent when the regrowth is not fertilized with N. In the experiments on clay soil comparisons were made between the amounts of residual N of high- and low-N pretreatments. This was done by calculating the difference between N application and N uptake during the pretreatment period. In the high-N pretreatments this difference was about 80 to 110 kg N per ha higher than in the low-N pretreatments. In the absence of new fertilizer N the residual effect of that quantity of N was found to be equivalent to 25 to 70 kg N per ha at 5 weeks of regrowth. Assuming no losses by leaching or denitrification, this meant a recovery of about 55% in July/August, decreasing to about 25% in September. When fertilizing with N, the residual effect became smaller because it was obscured by the freshly applied N.

Introduction

Generally not more than 60 or 70 per cent of the applied fertilizer nitrogen is recovered in the harvested grass. The N which is not recovered may

- have been lost because of denitrification and/or leaching;
- have been immobilized in the soil organic matter;
- be present in stubble and roots; or
- have been left behind in the soil as mineral N.

The N which is not lost because of denitrification or leaching may be available for further growth during the same season. This applies especially to the residual N in the unharvested parts of the plants and in the soil. Previous research has shown that the chance of a residual effect is greater

(1) after a high than after a low N application; and
(2) after early than after late cutting [1, 2, 3, 4, 5, 6].

Especially in connection with the increasing N consumption in present-day grassland farming it is of interest to know how much of the previously applied N remains available and how far the fertilizer policy of the farmer has to take a residual effect of this N into account. In the Netherlands the average level of N fertilization on grassland is already 230 kg N per

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ha, with some farmers on sand and clay soils applying up to 600 or 700 kg N per ha.

During the period 1970—1974, four trials were conducted to study the response to different rates of N during the season. In these trials on clay soil it was possible to determine in certain cuts the residual effect of previously applied N.

Methods

For the study of the residual effect each trial can be divided into two parts:

(1) *The pretreatment period* at two rates of N application: low (L) and high (H). During the pretreatment period in 1970 sheep grazed the L and H blocks continuously, while in 1972, 1973 and 1974 the L and H blocks were mown whenever they reached a production stage of approximately 2000 kg DM per ha. This system implies that because of faster growth the grass on the H blocks was cut once or twice more than that on the L blocks.

(2) *The experimental period*, following the pretreatment period. When the latter was ended at a certain date, an experiment with different rates of N (0, 40, 80 and 120 kg N/ha) was laid out on the L and H blocks to determine the N response. The experiment was so designed that new plots could be harvested periodically in order to determine the production curves. The number of periodical harvests was not the same in each experiment: it varied from 7 in the experiment of July 1970 to 2 in the experiment of September 1973.

The experiments were conducted on permanent grassland with *Lolium perenne* as the dominant species. White clover had been eradicated by spraying with a herbicide. N was applied as ammonium nitrate limestone.

Table 1 supplies details of the trials as regards level of N fertilizer, DM production, and the N uptake by the herbage during the pretreatment periods, as well as the starting dates of the experimental periods.

The residual effect can be studied in three seasonal periods, namely July (1970, 1974), August (1970, 1972, 1973), and September (1972, 1973, 1974).

Table 1. Scheme of low-N (L) and high-N (H) pretreatment application, DM yields and N uptake. The experimental period (with different rates of N) always starts at the final date of the pretreatment period

Year (exp. No.)	Pretreatment period						Start of experimental period
	Period	Level	N (kg/ha)	Number of cuts	DM yield (100 kg/ha)	N uptake (kg/ha)	
1970	9/4—15/7	L	125	—*	—*		15/7
(IB 1647)		H	265	—	—		15/7
	9/4—26/8	L	165	—	—		26/8
		H	345	—	—		26/8
1972	21/3—30/8	L	240	5	113.4	320	30/8
(IB 1752)		H	520	6	141.8	521	30/8
	21/3—22/9	L	280	6	122.3	355	22/9
		H	600	7	153.1	577	22/9
1973	22/3—29/8	L	200	5	103.9	276	29/8
(IB 2032)		H	480	6	130.7	454	29/8
	22/3—19/9	L	240	6	114.7	313	19/9
		H	560	7	147.9	530	19/9
1974	11/3— 8/7	L	120	3	64.6	145	8/7
(IB 2145)		H	320	4	86.9	268	8/7
	11/3— 9/9	L	200	5	103.8	251	9/9
		H	560	7	144.0	500	9/9

* grazed continuously by sheep, no yield data available

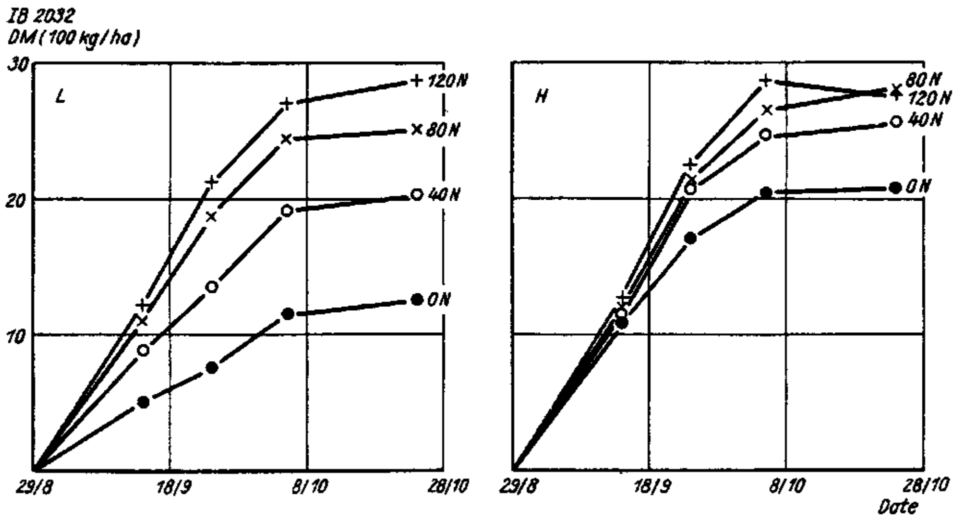

Fig. 1. Grass production curves at different rates of N application after a low-N (L) and a high-N (H) pretreatment. IB 2032, application on 29/8/1973

Results

The production curves of experiment IB 2032, presented in Fig. 1, are representative of all experiments. The different N rates were applied on 29 August, 1973. Figure 1 shows that there is some residual effect of the N level of the pretreatment period. This effect is largest with nil N, becoming smaller with higher rates of N application. Fig. 1 also shows that the rate of regrowth is faster after the high-N pretreatment. In the following the residual effect will be considered for different rates of N application.

Residual effect without added N

The residual effect is most apparent at the nil-N level. Figure 2 shows the production curves with nil N for all experimental periods (as given in Table 1, last column).

Without a fresh application of N fertilizer the DM yields are always largest following the high-N pretreatment. The differences between H and L increase with longer growing periods.

From the graphs in Figure 2 the difference in residual effect between L and H after a certain number of days can be calculated. Table 2 summarizes the results after 35 days of growth. This number of days was chosen since the regrowth period of experiment IB 1647 only lasted 35 days.

The differences in residual effect vary from 300 to over 1000 kg DM per ha. In September these differences are much smaller than in July and August, despite the greater difference in total N application during the pretreatment period.

Residual effect with increasing rates of N

It was already shown in Figure 1 that the residual effect of pretreatment on the DM yield decreases with increasing rates of N applied during the experimental period. To illustrate this in a simple way, the DM yields after 35 days of growth at different rates of N were read from the production curves and presented in Figure 3.

At the higher rates of N the differences in DM yield between the low-N and high-N pretreatment become less because the freshly applied N nullifies, or rather obscures the residual effect.

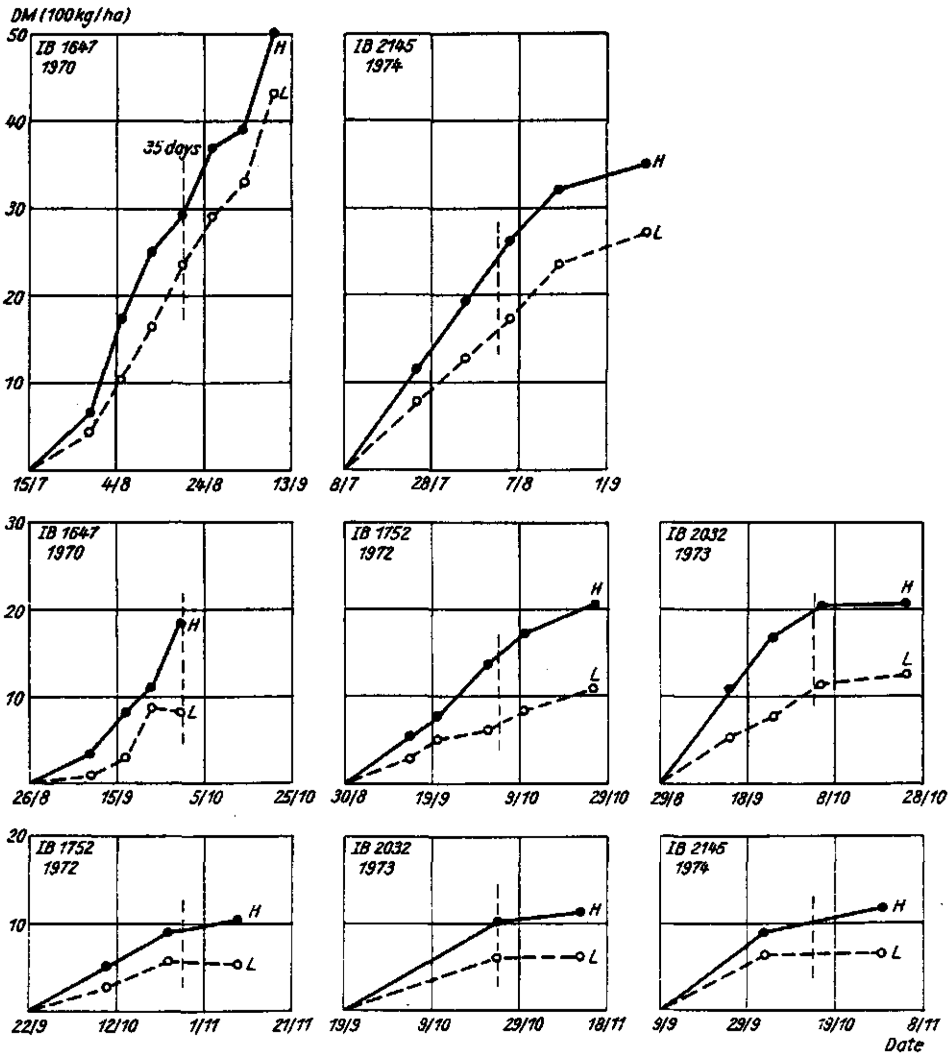

Fig. 2. Grass production curves for different parts of the growing season when no N was applied after low-N (L) and high-N (H) pretreatments

Figure 3 also shows that the N response decreases in the course of the season: in July the H and L curves rise steeply up to 80 kg N while the curves level off later in the season. This levelling off starts for H at a lower N level than for L.

Interpretation of results

The residual effect quantified

Figure 3, based on DM, gives an indication of the quantity of residual N by reading the dis-

Table 2. DM yield (expressed as 100 kg/ha) at 35 days of growth when no N was applied after low-N and high-N pretreatment

Start of regrowth	Level of N pretreatment		Difference H − L	Average difference
	Low (L)	High (H)		
15/7/70	23.5	29.2	5.7	7.1
8/7/74	15.8	24.3	8.5	
26/8/70	7.9	18.6	10.7	
30/8/72	6.5	14.7	8.2	9.5
29/8/73	10.5	19.5	9.5	
22/9/72	5.7	8.7	3.0	
19/9/73	6.0	10.0	4.0	3.5
9/9/74	6.5	9.9	3.4	

tance on the horizontal line from the nil N point on the H curve to the intersection with the L curve. On the basis of 35 days of growth the residual effect of H over L ranges from 20 to 70 kg N per ha. Similar curves as in Figure 3 have been constructed for the N uptake. These curves are not presented here.

Table 3 shows in columns a and b the quantities of residual N of H over L, estimated from the DM as well as the N uptake curves. Both ways gave almost the same results.

It is notable that residual N decreases in the September experiments. Figure 3 shows that in these cases the H curve crosses the L curve. This indicates a lower productivity with H which may have been caused by a deterioration of the sward after the high-N treatment (applications varying from 520—600 kg N per ha).

Differences in the quality of the sward have been observed despite the fact that with H as well as with L the grass of the pretreatment blocks was always cut at the grazing stage. Because of a faster rate of growth H was cut more often than L.

It is interesting to note that the H and L curves of 1970 do not show this crossing of the L and H curves. This may be because the pretreatment blocks were continuously grazed by sheep till the start of each experimental period. In this way the sward was kept in better condition. Moreover, the level of the high-N pretreatment of 1970 was lower than the level of the following years

The recovery of residual N

Table 3 also shows the possible quantity of residual N at the start of each experimental period. This quantity of N has been calculated from the N application and N uptake data in Table 1: it represents the pool of N which is additionally available in the high-N blocks as compared with the low-N blocks. It is assumed that the uptake of soil N is the same at the high (H) and at the low (L) fertilizer applications.

Column c shows the possible quantity of residual N of H over L, disregarding any losses.

Column e shows the residual N after subtractions of possible losses by denitrification. The losses by denitrification may be estimated on 15% of the total fertilizer application of the pretreatment period [7]. It is assumed then that these losses at a high N application are relatively the same as at a low N application.

Losses by leaching have been ruled out on the clay soil of these trials. The percentage recovery of the residual N has been calculated from the N uptake and the possible quantity of residual N of H over L.

If any losses by denitrification are disregarded, the recovery is 23—59% (Table 3, column d) with four experiments scoring higher than 50%. The last mentioned recovery figures are about the same as those found in trials with fresh applications of N [7].

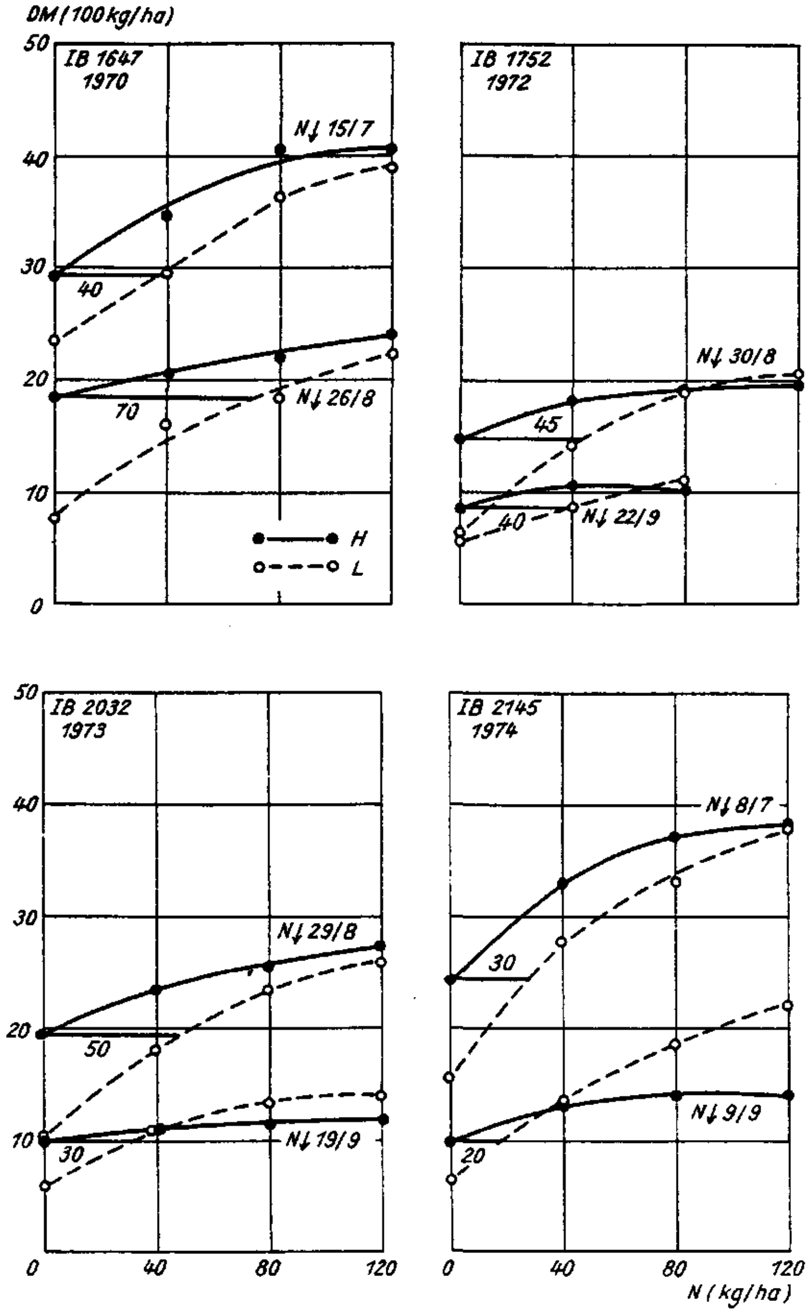

Fig. 3. Effect of rate of N application on DM yield after 35 days of growth following low-N (L) and high-N (H) pretreatment. N ↓ = date of N application

Table 3. Quantity of residual N of H over L, read in (a) DM curves of Fig. 3, and (b) N uptake curves,
(c) = difference in N between H and L at the end of the pretreatment periods, as calculated from Table 2 (*e.g.* 520—240 minus 521—320 = 79),

(d) = percentage of N recovered $\left(\frac{b}{c} \times 100\right)$ in regrowth,

(e) = as (c) buth with 15% losses by denitrification during the pretreatment period (*e.g.*
$\left(520 - \frac{15}{100} \times 520\right) - \left(240 - \frac{15}{100} \times 240\right)$ minus 521 — 320 = 37),

(f) = percentage of N recovered $\left(\frac{b}{e} \times 100\right)$

Date	Estimated residual N (kg/ha)		Possible available N and N recovery			
			No denitrification		15% denitrification	
	(a)	(b)	kg/ha (c)	% (d)	kg/ha (e)	% (f)
15/7/70	40	50	—*	—	—	—
26/8/70	70	70	—	—	—	—
30/8/72	45	45	79	57	37	122
22/9/72	40	55	98	56	50	110
29/8/73	50	60	102	59	60	100
19/9/73	30	35	103	34	55	64
8/7/74	30	40	77	52	47	85
9/9/74	20	25	111	23	57	44

* grazed continuously by sheep

Table 4. Quantity of mineral N in different soil layers, expressed as kg N per ha at the start of the experimental periods

Date	N pretreatment	Layer of soil profile		Difference H — L in layer	
		0—15	15—25	0—15	0—25
15/7/70	L	42	—*	10	—
	H	52	—		
26/8/70	L	33	—	23	—
	H	56	—		
30/8/72	L	28	—	30	—
	H	58	—		
22/9/72	L	38	—	25	—
	H	63	—		
29/8/73	L	21	7	28	31
	H	49	10		
19/9/73	L	24	7	23	33
	H	47	17		
8/7/74	L	17	7	3	5
	H	20	9		
9/9/74	L	14	5	17	20
	H	31	8		

— * = not determined

If losses by denitrification of 15 per cent during the pretreatment period are taken into account [7], the N recovery values will range from 44 to 122 per cent (Table 3, column f). This means that in at least three out of the six experiments the losses by denitrification are smaller than 15 per cent and that the pool of N additionally available in the high-N blocks has been used efficiently.

Mineral N in the soil

The question is whether the pool of N is present as mineral N in the soil profile. Table 4 shows the quantities of mineral N at the beginning of the experimental periods. Although we do not have figures of the whole soil profile, we can deduce from Table 4 that the difference in residual effect between H and L can only partly be explained by the larger quantity of mineral N in the soil with the high-N pretreatment. Whereas H contains about 5 to 30 kg mineral N per ha more than L to a depth of 25 cm, Table 3 shows the difference between H and L to be about 80 to 110 kg N without any losses by denitrification (column c) or about 40 to 60 kg N when assuming a loss of 15% by denitrification during the pretreatment period (column e). Most likely, the N content in stubble and roots is also higher in the plants of the high-N pretreatment which extra supply contributes to the subsequent regrowth.

No analyses have been carried out but this seems a logical explanation, in agreement with the conclusions by DILZ [8] who found a close relationship between regrowth and N reserve in the stubble and roots of grass plants.

Conclusions

The experiments show clearly that regrowth is better when grass of the previous cut or cuts has received more nitrogen. This means that at a high rate of N application there is a build-up of a certain N reserve in the soil-plant system which promotes regrowth after grazing or mowing. It may be an advantage to build up this N reserve with high applications of N in the first part of the growing season.

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Chapter 4

Changes in quantity of mineral nitrogen in three grassland soils as affected by intensity of nitrogen fertilization

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Key words: soil mineral nitrogen, grassland, nitrogen fertilization, nitrogen uptake

Abstract. Changes in quantity of soil mineral nitrogen down to a depth of 1 m in clover-free grassland were monitored within one growing season and over successive growing seasons. Accumulation of mineral nitrogen in the soil occurred on permanent grassland with split application of nitrogen totalling more than 400 kg N ha^{-1} yr^{-1} and on young grassland, sown after arable crops, with applications of more than 480 kg N ha^{-1} yr^{-1}. The relationship between the rate of nitrogen application minus nitrogen uptake, and accumulation of mineral nitrogen in the upper 50 cm of soil during each growing season is described.

When fertilizer nitrogen is applied to grassland, which is cut but not grazed, some of the nitrogen will be removed in the harvested grass, some will become incorporated in stubble and roots and a portion will remain in the soil as mineral nitrogen, i.e. ammonium + nitrate. The nitrogen may further be immobilized in the soil organic matter and some losses may occur through volatilization, denitrification and leaching.

Data on mineral nitrogen in the soil of grassland are rather scarce [7, 9, 11, 12, 13, 14]. Accumulation of mineral nitrogen in the soil indicates that the grass is not fully utilizing all of the nitrogen that is applied. The rate of nitrogen application should then be modified to suit the rate of uptake by the grass in order to minimize the risk of nitrogen losses and of polluting the drainage and ground water [15]. The present work was undertaken because it was thought that measurement of the amount of mineral nitrogen in the soil might provide information about the optimum amount of nitrogen to apply to grassland.

The present paper deals with changes in the amount of mineral nitrogen in the soil down to a depth of 1 m, as determined in field experiments during the period 1974–1978. Firstly, attention is paid to changes in mineral nitrogen in the soil within one growing season in one nitrogen fertilization experiment. Secondly, changes in mineral nitrogen are examined over a number of years in three long-term nitrogen fertilization experiments. Data

* Seconded by the Agricultural Bureau of the Netherlands Fertilizer Industry (LBNM)

are also presented on the quantity of nitrogen in the harvested grass (N-uptake) and on the apparent recovery of the applied nitrogen.

Materials and methods

Experimental sites

The experiments were located in the province of Groningen on old permanent grassland (experiments 1 and 4) and on sown grassland (experiments 2 and 3). *Lolium perenne* was the dominant grass species of the sward of experiments 1 and 4. All dicotyledonous plants, including clover, had been eradicated by spraying with a herbicide. Experiments 2 and 3 were conducted on fairly young grassland and on recently sown grassland, respectively, both established after a period of arable cropping. The sward of these two experiments were practically monocultures of *Lolium perenne*. General data of the experimental sites are provided in table 1.

Treatments

Rates of fertilizer nitrogen were applied, ranging from 0 to 120 or 160 kg N ha^{-1} at each cut. Herbage was mown to a stubble height of 3–4 cm when a dry matter yield of approximately 2–2.5 t ha^{-1} was reached. Because of faster growth with the higher rates of nitrogen, this technique necessitated more frequent cutting than when lower rates were used. Nitrogen was applied as ammonium nitrate limestone (26% N). The supply of nutrients other than nitrogen was adequate.

Chemical analysis

For chemical analysis of soil and herbage, samples of replicates were bulked. Soil samples were taken immediately before application of nitrogen fertilizer and, at the end of the season, as soon as possible after the last cut. Mineral nitrogen content of the soil (nitrate and ammonium) was determined after extraction with 1 *M* NaCl according to the method of Cotte and Kahane [5]. Total herbage nitrogen was determined according to a modified Kjeldahl method [6].

Results and discussion

Mineral nitrogen in the soil during the course of one growing season

Experiment 1. The treatments consisted of applications of 40, 60, 80 and 120 kg N ha^{-1} at each cut. Herbage was mown 6, 7, 8 and 9 times, respectively. This meant a total application of 240, 420, 640 and 1080 kg N ha^{-1}, respectively, for the different treatments.

Figure 1 traces the amount of mineral nitrogen in the soil layers 0–5, 5–15 and 15–25 cm at rates of 60, 80 and 120 kg N ha^{-1} per cut, from the first application of nitrogen on 11 March via the last application on 9

Table 1. General data of experimental sites

Experiment no.	1	2	3	4
Registration no.	2145	2146	2244	2259
Experimental year(s)	1974	1974–78	1975–78	1975–78
Location	Ten Boer	Finsterwolde	Finsterwolde	Ten Boer
Grassland	Old permanent	1971-sown	1974-sown	Old permanent
Soil	Clay	Sand	Clay	Clay
Soil layer 0–5 cm:				
fraction 0–0.016 mm, gkg^{-1}	410	140	730	480
fraction 0.016–2 mm, gkg^{-1}	450	830	150	370
org. matter, gkg^{-1}	144	32	48	142
$CaCO_3$, gkg^{-1}	2	2	72	7
pH-KCl	5.8	6.0	7.1	6.2

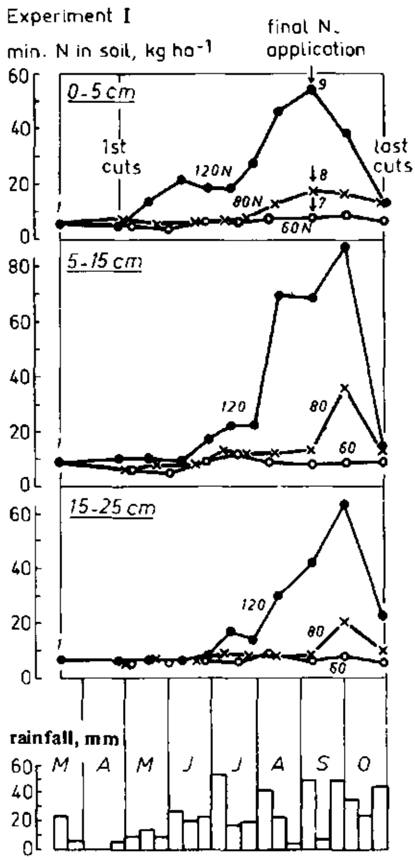

Figure 1. Top: changes in quantity of mineral nitrogen in the soil layers 0–5, 5–15 and 15–25 cm at rates of 60, 80 and 120 kg N ha^{-1} per cut throughout the growing season of experiment 1. Bottom: Rainfall from day 1–10, 11–20 and 21-end of each month during the growing season of 1974

September until the last cut on 30 October. The lowest application (40 kg N at each cut) has not been included in figure 1 as its effect was similar to that of 60 kg N ha^{-1} at each cut. This figure shows that:

(1) With successive applications of 60 kg N ha^{-1}, there was no change in the quantity of mineral N in the 0–5 cm soil layer. Although 7 x 60 = 420 kg N ha^{-1} had been applied, there was no accumulation of mineral N.

(2) Also with successive applications of 80 kg N ha^{-1}, there was at first no change in the quantity of mineral N in the upper 5 cm. It was not until 14 August that soil analysis demonstrated some accumulation of mineral nitrogen after fertilizer nitrogen application on 26 July. By that date 6 x 80 (= 480) kg N ha^{-1} had already been applied. After the last two applications (i.e. on 14 August and 9 September), there

was a further increase in accumulation, at first in the upper 5 cm and later on in the layers below 5 cm. With a total application of 640 kg N ha^{-1}, more N was evidently available than was taken up by the grass.

(3) After the first application of 120 kg N ha^{-1} there was no accumulation in the upper 5 cm of soil. After the second application the accumulation of N in the soil began: too much mineral nitrogen was available for the grass. With successive dressings the accumulation increased steadily.

(4) In the 5–15 and 15–25 cm soil layers the accumulation which occurred through vertical movement from the upper layer, appeared to be related to the amount of rainfall (bottom of figure 1). The steep decrease towards the end of the season clearly reflects the effect of the high rainfall combined with low evapotranspiration of the order of 1 mm per day.

The changes in the quantity of mineral N in the different layers of the soil profile down to 50–100 cm, are shown in figure 2. On 3 October

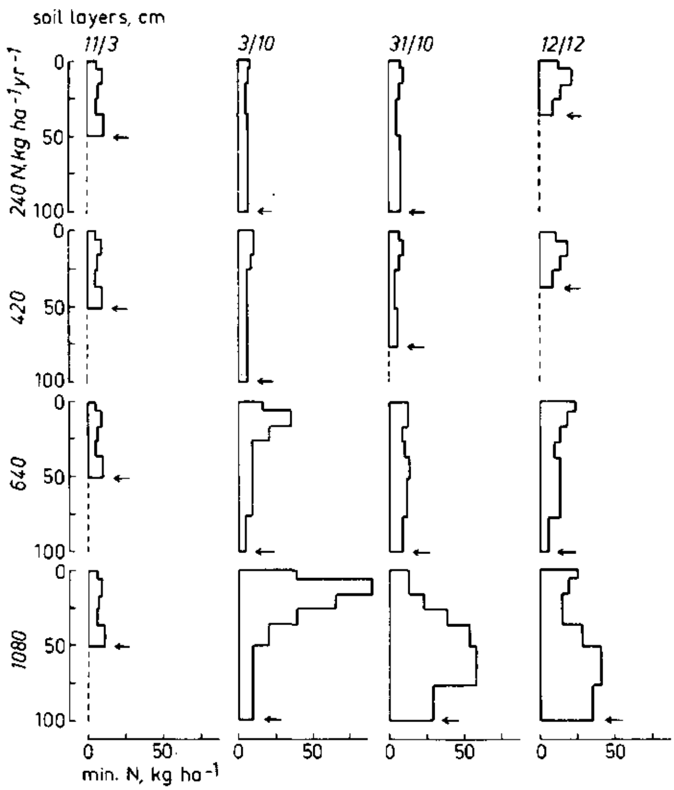

Figure 2. Experiment 1: effect of different rates of nitrogen application on changes in quantity of mineral nitrogen in the soil profile down to 100 cm at the beginning of the season (11 March), during the growth prior to the last cut (13 October), at the last cut (31 October) and in the following winter (12 December). ← denotes depth of sampling

accumulation is evident after applications of 640 and 1080 kg N ha^{-1}, but not after 240 and 420 kg N ha^{-1}.

The measurement on 31 October showed that the rains had washed down the accumulated nitrogen to a lower depth. This process of leaching continued so that on 12 December, the last date of sampling, the bulge of nitrogen had decreased, over 65 kg mineral nitrogen of the treatment with the highest rate of nitrogen application ha^{-1} having already disappeared below 100 cm. It is fairly safe to assume that the rainfall during the rest of that winter moved the nitrogen down to greater depths.

Mineral nitrogen in the soil over successive seasons

For the sake of clarity, out of the whole range of treatments of the three long-term nitrogen fertilizer experiments 2, 3 and 4, only the 0, 80 and 120 kg N ha^{-1} rates per cut are dealt with in detail. Figures 3 and 4 show the quantities of mineral N in the soil in the 0–50 and 0–100 cm layers, respectively, each year determined at the beginning and at the end of the growing season. The growing season usually began in March and ended in October. Precipitation data during the growing season (March to October) and in between growing seasons (October to March) are given in table 2.

Table 2. Precipitation (mm) during and in between growing seasons of experiments 2, 3 and 4

	1974		1975		1976		1977		1978
Experiment 2									
during	470		433		271		449		482
in between		389		274		311		294	
Experiment 3									
during			410		272		452		482
in between				268		308		294	
Experiment 4									
during			325		237		369		385
in between				279		272		311	

Experiment 2. With 80 kg N ha^{-1} at each cut, equal to an application of 400 to 480 kg N ha^{-1}, there was virtually no difference in the mineral N content of the upper 50 cm of soil compared with the control treatment (0 N) (figure 3a). Only in 1977 was there a slight accumulation of about 25 kg N ha^{-1}. Here, accumulation means the difference between the levels of soil mineral nitrogen for each treatment at the beginning and at the end of each growing season. With successive applications of 120 kg N ha^{-1}, totalling 600 to 840 kg N over the season, mineral nitrogen accumulated in the soil each year (figure 3a). The largest accumulation occurred in the exceptionally dry year of 1976 when at each cut the same rate of nitrogen (120 kg N ha^{-1}) was applied despite the fact that herbage was cut twice when the yield was only about 1 t dry matter ha^{-1}. The standard cutting system had been

modified in order to stimulate the regrowth of the sward. After this dry year not all nitrogen leached out of the upper 50 cm during winter as was the case the other winters (1974/75, 1975/76 and 1977/78). In fact, in the winters of 1975/76 and 1977/78 the accumulated nitrogen largely disappeared below a depth of 100 cm (figure 4a) despite the fact that the soil was more loamy from a depth of 30 to 40 cm onwards, on this site which had sandy topsoil.

Experiment 3. With total applications of 400–480 kg N ha^{-1} yr^{-1} the level of mineral nitrogen in the soil remained fairly uniform (figure 3b). During each growing season, except for 1978, the level of mineral nitrogen in the soil at the nitrogen rate went down. In the period between growing seasons the level rose again as nitrogen was mineralized. This was also true for the control, which, however, ultimately decreased to a low level of mineral nitrogen in the soil. With total annual applications of 600–840 kg N ha^{-1} during the growing season, excess nitrogen accumulated in the upper 50 cm of soil. In the 50–100 cm layer, however, there was a decrease in the amount of mineral nitrogen during each growing season. This decrease is not displayed here but may be read from the difference in the slope of the upper lines in the white zones of figures 3b and 4b. With the present observations it is not possible to say whether this decrease in soil mineral nitrogen in the 50–100 cm layer was because of upward movement with capillary water or because of losses.

Each winter nitrogen was leached to greater depths, only a part remaining in the upper 50 cm. At these very high rates of nitrogen application from the end of the first season onwards, a pool of 120 to over 160 kg N ha^{-1} was formed in the layer 0–100 cm of this heavy clay soil (figure 4b).

Experiment 4. In this other long-term experiment the results show that, at a rate of 80 kg N ha^{-1} at each cut, a slightly different picture emerged compared with those of experiments 2 and 3. With total applications of 400–480 kg N ha^{-1}, the level of nitrogen in the soil became higher at the beginning of each of the subsequent growing seasons than at the end of the immediately preceding season (figure 3c). This took place despite the fact that no accumulation of mineral nitrogen occurred during each of the four growing seasons with these applications of nitrogen fertilizer. It can be assumed therefore that the increase was the result of more mineralization taking place in the periods between growing seasons.

The level of mineral nitrogen in the soil of the control plots (0 N) slowly dropped, so that in 1978 the difference between 0 and 480 kg N ha^{-1} finally amounted to about 40–50 kg N ha^{-1}. At a rate of 300 kg N ha^{-1} (not presented in figure 3c) measurements in 1977 and 1978 indicated that there was neither a drop nor an increase in the level of mineral nitrogen in the soil.

With applications of 720 kg N ha^{-1} each season mineral nitrogen accumulated in the soil. It is notable that up to the end of the third season

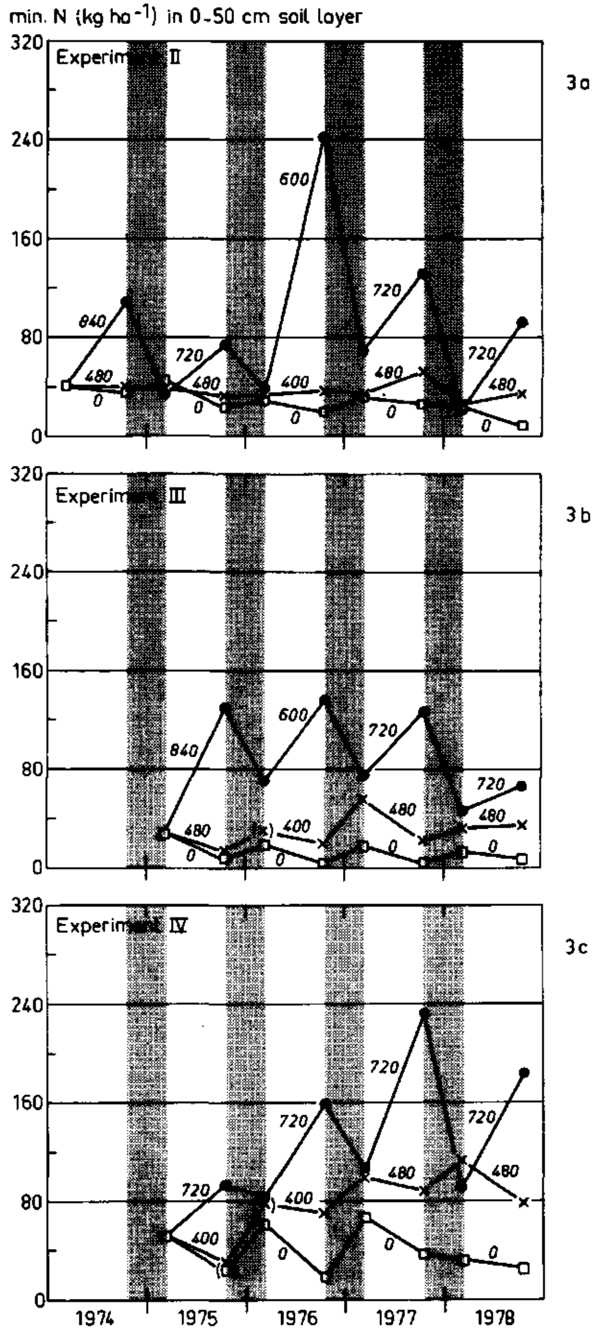

Figure 3. Experiments 2, 3 and 4: effect of rate of nitrogen application on change in mineral nitrogen in the 0–50 cm soil layers at beginning and end of successive growing seasons. Fertilizer rates were 0, 80 and 120 kg N ha^{-1} at each cut, indicated by the yearly applications of 0, 400–480, and 600–840 kg N ha^{-1}, respectively. Growing seasons and periods between successive growing seasons are indicated by white and grey zones, respectively.

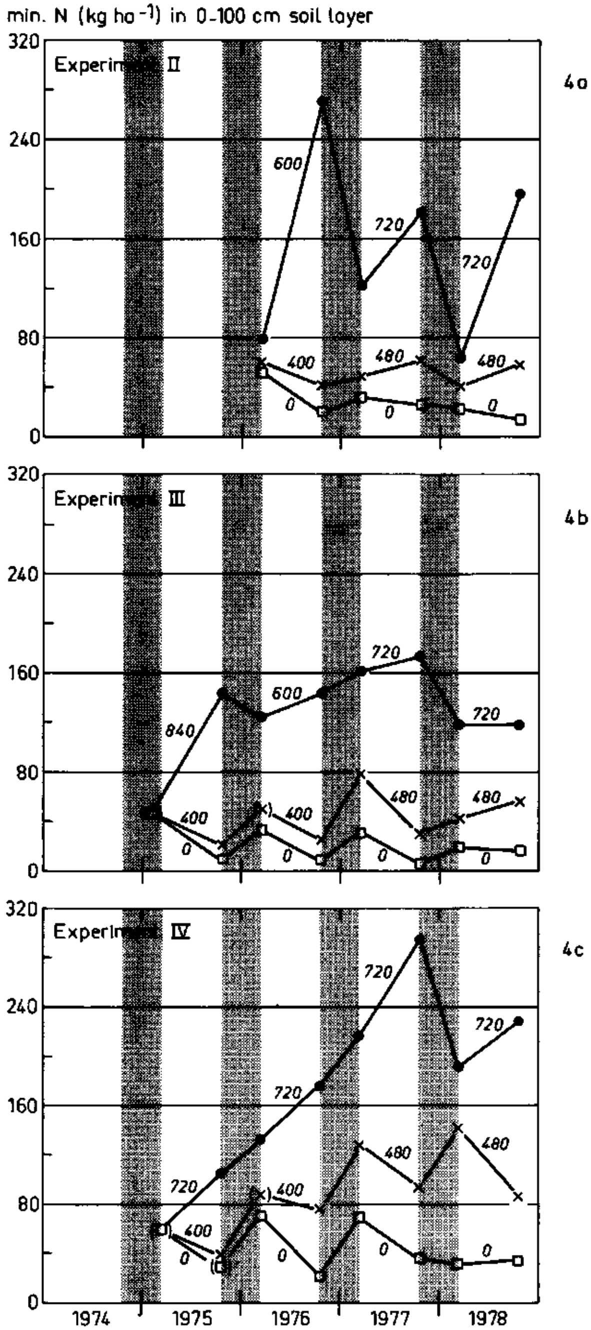

Figure 4. As figure 3, but for soil layer 0–100 cm. Not determined in the first two years of experiment 2

the amount of nitrogen in the 0–100 cm layer steadily increased up to nearly 300 kg N ha^{-1}. In the fourth year the pool of mineral nitrogen decreased to just below 240 kg N ha^{-1} (figure 4c).

This experiment showed, as did experiment 3, a decrease in the amount of mineral nitrogen in the 50–100 cm layer during the growing season.

Nitrogen uptake and apparent nitrogen recovery

In the annual experiment 1, the total amounts of nitrogen taken up in the harvested grass were 293, 410, 559 and 765 kg N ha^{-1} at rates of 240, 420, 640 and 1080 kg N, respectively. As calculated by the 'difference method' this meant, with a supply of 143 kg N by the soil at nil fertilizer N, an apparent N-recovery of 62, 64, 65 and 58%, respectively.

In the long-term experiments 2, 3 and 4, the average uptake at nil fertilizer nitrogen was 82, 64 and 104 kg N ha^{-1}, respectively. At rates of 400–480 kg N the apparent recovery of the applied nitrogen ranged from 64 to 91% (table 3). Especially in 1978 the recovery was high in all three experiments.

Table 3. Effect of rate of nitrogen application (kg ha^{-1} yr^{-1}) on nitrogen uptake in the harvested grass (kg ha^{-1} yr^{-1}) and apparent N-recovery (%) in experiments 2, 3 and 4. a = 80 kg N ha^{-1} cut^{-1}, b = 120 kg N ha^{-1} cut^{-1}

	1974		1975		1976		1977		1978		Average	
	a	b	a	b	a	b	a	b	a	b	a	b
Experiment 2												
N-upt. at 0 N	100		97		63		79		73		82	
N applied	480	840	480	720	400	600	480	720	480	720	464	720
N-uptake	424	607	431	608	324	341	441	535	469	539	418	526
N-recovery	68	60	70	71	65	46	75	63	82	65	72	61
Experiment 3												
N-upt. at 0 N			121		47		49		40		64	
N applied			480	840	400	600	480	720	480	720	460	720
N-uptake			448	661	328	429	408	564	448	619	408	568
N-recovery			68	64	70	64	75	72	85	80	74	70
Experiment 4												
N-upt. at 0 N			94		74		133		116		104	
N applied			400	720	400	720	480	720	480	720	440	720
N-uptake			352	524	329	522	465	531	554	631	425	552
N-recovery			64	60	64	62	69	55	91	72	72	62

At rates of 600–840 kg N ha^{-1}, the apparent N-recovery ranged from 46 to 80%. It is notable that in the dry year 1976, experiment 2 showed considerable accumulation of mineral nitrogen in the soil at the highest rate of nitrogen application (figure 3). In that same year, experiments 3 and 4, both on clay soil, showed no particular increase in accumulation compared with the other years. The difference between the experiments is reflected in the apparent recovery of the applied fertilizer nitrogen: 46% with experiment 2 and 64 and 62% with experiments 3 and 4, respectively (table 3).

In all cases except one, the recovery was lower with 600–840 kg N ha^{-1} compared with the 400–480 kg N rate. This means that with increasing nitrogen application a smaller proportion of the applied nitrogen is taken up by the grass and consequently a larger proportion may be found in the soil. In figure 5 the relationship between the annual nitrogen application minus the nitrogen uptake, and the accumulation of mineral nitrogen in the upper 50 cm at the end of each growing season is shown at rates of 0, 80, 120 and 160 kg N per ha at each cut, the total amounts applied ranging from nil to 1080 kg N ha^{-1} yr^{-1}. The upper 50 cm of soil was chosen, because (a) the accumulated nitrogen did not percolate below 50 cm before the end of the growing season (except for one year, see marked point in figure 5) and (b) the accumulated nitrogen more or less disappeared from the upper 50 cm of soil before the beginning of each following growing season in the longterm experiments.

Even though experiment 3 still showed some accumulated mineral nitrogen in the 0–50 cm layer at the beginning of the following season (figure

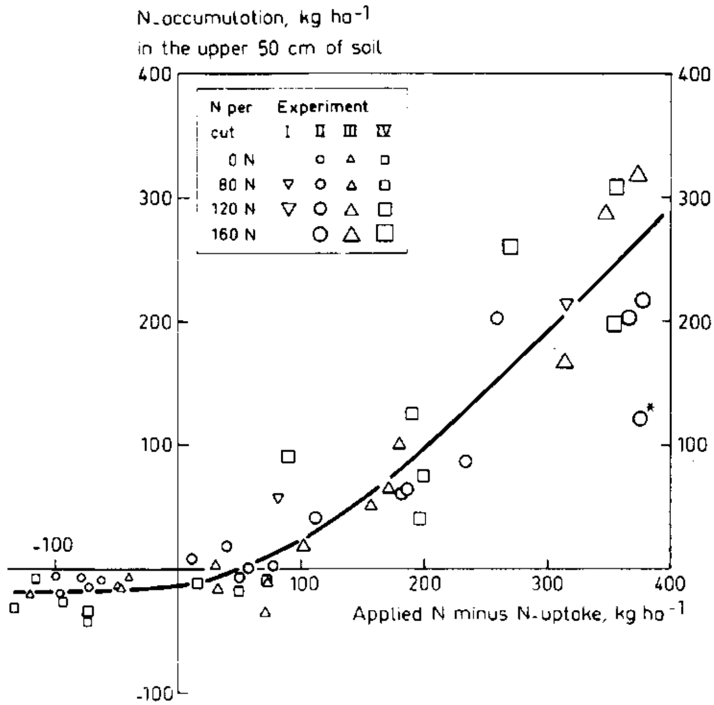

Figure 5. Experiments 1, 2, 3 and 4: relationship between the annual N-application minus N-uptake and the mineral N-accumulation in the upper 50 cm of soil from the beginning to the end of each growing season for each treatment. Fertilizer rates were 0, 80, 120 and 160 kg N ha^{-1} per cut throughout the growing season, total amounts applied ranging from nil to 1080 kg N ha^{-1}. The points fit a hyperbolic curve, described by $x - y - 115 + 1875/y + 30 = 0$. * = Exceptional point, not included in the calculation of the line.

3b), the agreement with the other experiments was good, as can be seen in figure 5. Although it is likely that there was some capillary rise of water during the growing season, the resulting upward movement of nitrogen from the deeper layers into the upper 50 cm has been neglected.

Within the range of nitrogen fertilizer rates tested in these experiments, the relationship shown in figure 5 leads to the following conclusions:

(1) Without nitrogen application (0 N) there is an apparent depletion of soil mineral nitrogen of about 20 kg N ha^{-1} per season.

(2) When nitrogen application equals nitrogen uptake (at the intercept with the y axis) there is no accumulation of mineral nitrogen in the soil. There is even an apparent depletion of just over 10 kg N ha^{-1}.

(3) When nitrogen application exceeds nitrogen uptake by about 50 kg N ha^{-1} (at the intercept with the x axis), there is still no accumulation in the upper 50 cm of soil. Presumably a part of this excess nitrogen has been incorporated in stubble and roots.

(4) When nitrogen application becomes increasingly greater than nitrogen uptake, increasing amounts of mineral nitrogen are found in the soil. For example, it can be seen that with differences of 100, 200 and 300 kg N ha^{-1} the accumulation amounted to about 20, 100 and 195 kg N ha^{-1}, respectively (graph in figure 5).

General considerations

A study of accumulation of mineral nitrogen in the soil allows one to estimate the optimum rate of nitrogen fertilizer to apply to grassland. For example, the results of experiment 1, although based on equal rates of nitrogen application throughout the growing season, may indicate the following pattern of optimum nitrogen application: the first dressing in spring about 120 kg N ha^{-1}, the second and subsequent dressings about 80 kg N ha^{-1}, and the last dressing about 60 kg N ha^{-1}. This pattern of decreasing rates of nitrogen application on the basis of accumulation of mineral nitrogen in the soil agrees fairly well with the pattern based on grass growth [3, 16].

It is notable that after high applications of nitrogen at the beginning of a growing season the accumulated nitrogen may serve as a bank from which the grass can draw for its growth. This system is effective as long as losses through leaching or denitrification are small and as long as the grass depletes the reserve of soil mineral nitrogen towards the end of the growing season. When this does not occur, the mineral nitrogen will, during the winter period, wholly or partly disappear from the root zone. The nitrogen that does not disappear may be used by the grass in the following growing season. The residual effect of this remaining mineral nitrogen has been established [2].

With the suggested rates of nitrogen fertilizer at each cut the total application is in the range of 400–500 kg N ha^{-1} with five and six cuts per season, respectively. In the Netherlands, dressings of 400–500 kg N ha^{-1} on grassland for grazing and mowing are common practice on many farms [17]. At these rates, no accumulation occurred in experiments 2 and 3. The results relate to soils of young grassland, still in the process of building up organic matter [4]. In experiment 4, however, these rates slowly increased the level of mineral nitrogen in the soil. The results of the latter experiment were obtained on old grassland in which breakdown and buildup of soil organic matter had attained equilibrium [8, 10]. To minimize the risk of unjustifiable nitrogen losses and of environmental pollution the rate of application on old grassland should therefore not exceed 400 kg N ha^{-1}. This work indicates that estimates of the optimum rate of fertilizer nitrogen to apply to grassland, based on analysis of mineral nitrogen in the soil, agree well with those derived from earlier observations of the above ground material which dealt with nitrogen supply, nitrogen uptake and dry matter production [1].

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Chapter 5

Very high applications of nitrogen fertilizer on grassland and residual effects in the following season

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Key words: residual nitrogen, grassland, nitrogen fertilization, soil mineral nitrogen, yield, nitrogen uptake

Abstract. At very high nitrogen applications (480 and more kg N ha^{-1} yr^{-1}) in field trials on all-grass swards the amount of N applied exceeded the amount of N harvested. In the humid temperate climate of the Netherlands in the subsequent spring approximately 25, 40, and 50% of this excess nitrogen was recovered as accumulated mineral nitrogen in the 0–100 cm layer of sandy, clay and heavy clay soil, respectively. The effect of this excess nitrogen on growth during the subsequent season was measured through the increase in DM and N yield over a reference treatment. In this season all treatments received a uniform application (40 kg N ha^{-1} cut^{-1}). Residual effects were absent on sandy soil but distinct on the clay soils. On the clay soils each accumulated kg soil mineral nitrogen produced 15 kg DM. Assuming a relatively small contribution of residual nitrogen carried over in stubble, roots and organic matter, the accumulated soil mineral nitrogen would seem to be as effective as applied fertilizer nitrogen.

There are several reports on residual effects of nitrogen (N) fertilizers on grassland in low rainfall areas or after a dry year [e.g. 2, 6, 9, 10, 14, 15, 17]. In humid climates residual effects on grassland have seldom been observed [3, 20; Clement 1971, as cited by 21]. Leaching of N after the growing season in the wetter climates is the main cause of the lower residual effect. When leaching losses are negligible, as is the case in dry climates, or when the soil is covered with plastic [18] or when rainfall is partially intercepted with a glass cover [7], considerable residual effects of previous nitrogen applications are possible, even for more than 10 years [6].

In the humid temperate climate of the Netherlands, precipitation from November up to and including February is about 250 mm. In this winter period nitrogen uptake has almost completely stopped and this increases the risk of leaching of soil mineral nitrogen. In the Netherlands results of a study of the residual effects with arable cropping have been published [8] but as yet no results of grassland have been recorded.

During the period 1974–1980 we conducted trials on several aspects of the N fertilization of grassland. Nitrogen applications ranged from 0 up to 1120 kg N per ha per year. These trials showed that at rates over 400 or 480 kg N per ha per year the amount of nitrogen applied exceeded the amount of nitrogen removed with the harvested herbage, the excess nitrogen

*Seconded by the Agricultural Bureau of the Netherlands Fertilizer Industry (LBNM) accumulating largely as mineral nitrogen (NO_3-N + NH_4-N) in the soil. In the subsequent spring part of this excess mineral nitrogen was still present in the soil, particularly on clay [12]. Moreover, grass on these plots was often greening up earlier in spring than grass fertilized at lower rates of nitrogen application in the preceding year. These trials offered the opportunity to study residual effects of very high fertilizer nitrogen applications.

Materials and methods

Four trials were carried out (Table 1A). Trials 1 and 2 were located on sown grassland on sand and heavy clay soil, respectively, and trials 3 and 4 on old permanent grassland on clay soil. In the all-grass swards perennial ryegrass (*Lolium perenne* L.) was practically a monoculture in trials 1 and 2 and the dominant grass species in trials 3 and 4. Trials 1, 2 and 4 were long-term, lasting 4 to 6 years; trial 3 was short-term. The long-term trials had series of so-called variable-N treatments with plots receiving:

– every year 0, 40, 60, 80, 120 or 160 kg N per ha per cut throughout the growing season, totalling 0 to 1120 kg N per ha per year;

– every year total applications ranging from 400 to 620 kg N per ha but with decreasing amounts of N per cut from beginning to end of the growing season;

– one or more years total applications of approximately 200 to 300 kg N per ha followed by one or more years with total applications of 720 and more kg N per ha.

Within these trials it was possible to allocate spare plots which received variable high amounts of N in a 'pretreatment' year to study the effects of these applications in a subsequent 'experimental' year. The spare plots were already available from the start of the trial since for several variable-N treatments extra plots had been laid out, or came available by splitting plots into two halves, one half continuing as variable-N treatment, the other half to be used for the study of the residual effects in the so-called residual-N treatments.

Plot sizes ranged from 12.5 to 30 m^2. Nitrogen was applied as calcium ammonium nitrate (26% N). Phosphate and potash were applied in adequate amounts ranging from 20 to 45 kg P_2O_5 and from 40 to 90 kg K_2O per ha per cut.

The study of the residual effects included two periods, the 'pretreatment' year with variable-N treatments and the 'experimental' year with residual-N treatments:

– Pretreatment year with variable-N applications ranging from 160 to 1120 kg N per ha per year (Table 1B). At the lowest rates (40 kg N per ha per cut), underlined in Table 1B, no residual effect was expected and these were used as reference treatments. Herbage of the variable-N treatments

Table 1. General data of trials and details of N application and herbage N-uptake per pretreatment year and of N application per subsequent experimental year. Underlined are the reference treatments

Trial no.	1	2	3	4
A Registration no.	IB 2146	IB 2244	IB 2258	IB 2259
Location	Finsterwolde (Gr)	Finsterwolde (Gr)	Ten Boer (Gr)	Ten Boer (Gr)
Grassland	1971-sown	1974-sown	old permanent	old permanent
Soil	sand	heavy clay	clay	clay
Soil layer 0–5 cm:				
fraction 0-0.016 mm, $g kg^{-1}$	140	730	480	480
fraction 0.016–2 mm, $g kg^{-1}$	830	150	370	370
organic matter, $g kg^{-1}$	32	48	142	142
Duration of trial	1974–1979	1975–1980	1975–1976	1975–1978
B N application ($kg ha^{-1} yr^{-1}$) in pretreatment year				
1975			240, 480, 960	
1976	160, 600			160, 480, 800
1977	200, 720	200, 720, 960[b]		200, 720
1978	200, 560, 720, 960[a]	200, 560, 720, 720, 870[c]		
1979		240, 840, 1120[d]		
C Herbage N-uptake ($kg ha^{-1} yr^{-1}$) in pretreatment year				
1975			209, 348, 475	
1976	142, 341			137, 418, 446
1977	217, 576	212, 539, 612		251, 553
1978	252, 521, 562, 585	187, 528, 559, 602, 639		
1979		218, 556, 573		
D N application ($kg ha^{-1} yr^{-1}$) in experimental year				
1976			200, 200, 200	
1977	160, 160			200, 200, 200
1978	200, 200	200, 200, 200		200, 200
1979	240, 240, 240, 240	240, 240, 240, 240, 240		
1980		200, 200, 200		

[a, b, c, d] relate to treatments which had already received substantial N applications, namely 800 and 960 (*a*); 884 and 800 (*b*); 870 (*c*); 840, 500, 600, 600 (*d*) $kg N ha^{-1} yr^{-1}$, for 2, 2, 1 and 4 years, respectively, before the pretreatment year mentioned in the table

5.3

was mown when a dry matter (DM) yield of approximately 2 to 2.5 t per ha was reached. Because of differences in growth rate this technique necessitated more frequent cutting at the higher than at the lower rates of nitrogen application. Figure 1 shows for all treatments the amounts of N

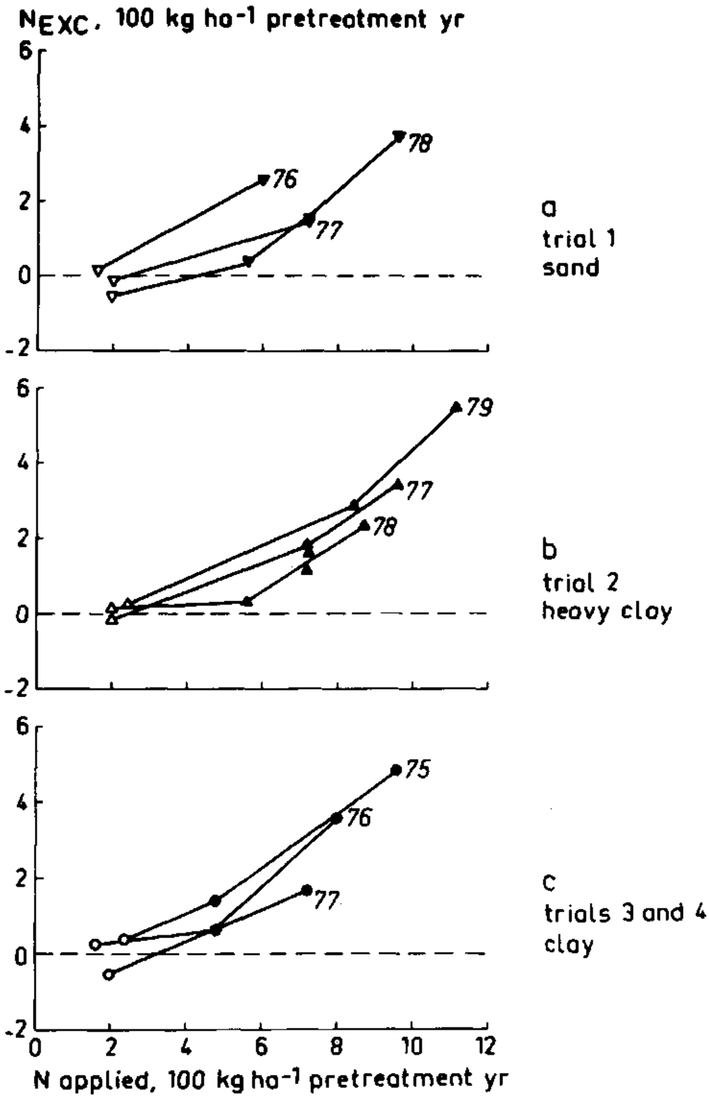

Figure 1. Pretreatment year: relationship between N applied and N applied exceeding N harvested (N_{EXC}). White symbols indicate reference treatments, black symbols indicate variable-N treatments for the study of the residual effect

applied in the respective pretreatment years in relation to N_{EXC} which is defined as the amount of N applied exceeding the amount of N harvested (B minus C in Table 1). It can be seen that N_{EXC} was approximately 0 at the reference applications of about 200 kg N per ha per year, and increased to about 400 to 500 kg N per ha at applications around 1000 kg N per ha. Thus after these very high nitrogen applications a residual effect might be expected in the following year, i.e. the experimental year.

– Experimental year with uniform N applications. All residual-N plots received 40 kg N per ha per cut. This rate was chosen to encourage reasonable grass growth on all plots. Herbage was mown at fixed dates, namely at the same date as the reference treatments. Depending on growing conditions the trials were cut 4 to 6 times, but usually 5 times, as can be deduced from the total application per experimental year (Table 1D).

The residual effect was measured by calculating the increase in dry matter yield and N yield* over the reference treatment. Moreover, the mineral (NaCl-extractable) N in the soil at the beginning of grass growth in each experimental year (N_S) was measured in the 0–100 cm layer. More details of locations, methods of measurements and analyses have been reported elsewhere [12].

Results

Soil mineral nitrogen

The relation between N_{EXC} and N_S is shown in Figure 2. It is clear that with increasing N_{EXC} in the pretreatment year the soil contained increasing amounts of mineral nitrogen at the onset of the subsequent experimental year. However, the soils showed distinct differences at the start of the experimental year:

– trial 1 on sandy soil had the smallest accumulation of mineral nitrogen in comparison with the reference treatments in the respective years (Figure 2a);

– trial 2 on heavy clay soil showed the largest accumulation, with a maximum of nearly 300 kg N_S per ha in the spring of 1978 (Figure 2b). This high amount of accumulated nitrogen was a result of more than one year of high application of fertilizer (see note to Table 1);

– in trials 3 and 4 (Figure 2c) the clay soil of the old permanent grassland, with its higher organic matter content, contained more mineral nitrogen (N_S) in the reference treatments than the soils in trials 1 and 2. The average amounts of N_S were 39, 27, and 73 kg per ha in the reference treatments of trials 1, 2, and 3 and 4, respectively;

– the dotted lines indicate the approximate relationship between N_S

*N yield = N harvested = total N-uptake in herbage and N_{EXC} assuming no effect at the reference N level. The differences in soil type are clearly reflected in the different percentages in Figures 2a, b, and c. The linear component of the relationship was significant and the

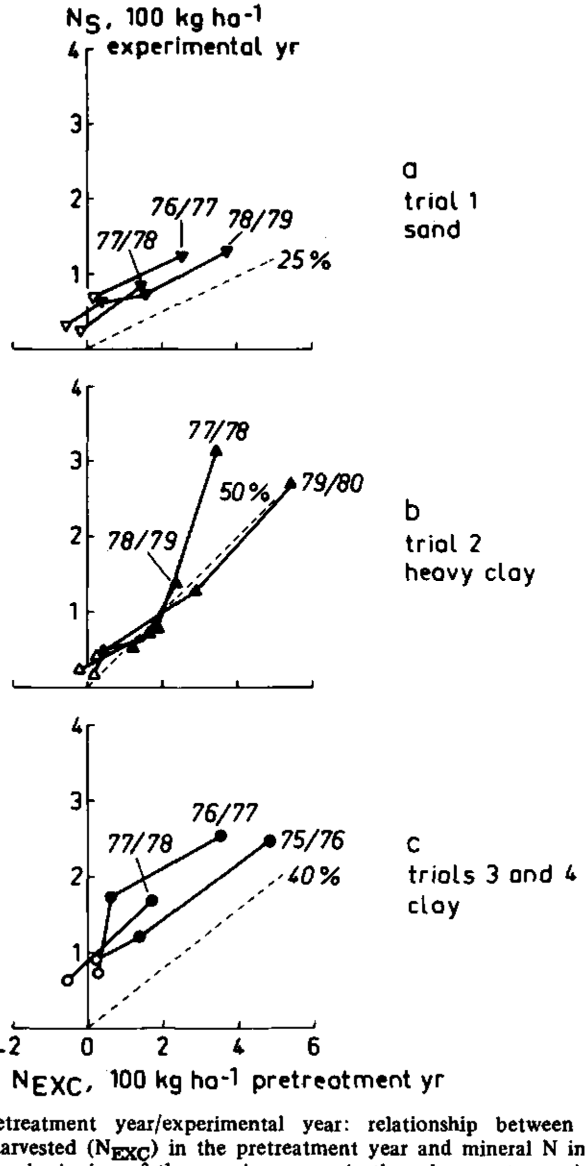

Figure 2. Pretreatment year/experimental year: relationship between N applied exceeding N harvested (N_{EXC}) in the pretreatment year and mineral N in 0–100 cm soil layer at the beginning of the growing season in the subsequent experimental year (N_S), e.g. 77/78 means pretreatment year 1977 and experimental year 1978. Dotted lines show soil mineral nitrogen as percentage of N_{EXC}. White symbols indicate reference treatments. Black symbols indicate variable-N treatments in the pretreatment year, becoming residual-N treatments in the subsequent experimental year

calculated percentages for sand (trial 1) and clay (trials 2, 3 and 4 combined) were 25 and 45%, respectively (see b in Table 3A).

Dry matter yield

Figure 3 shows the DM yields in the different experimental years plotted against N_S in spring:

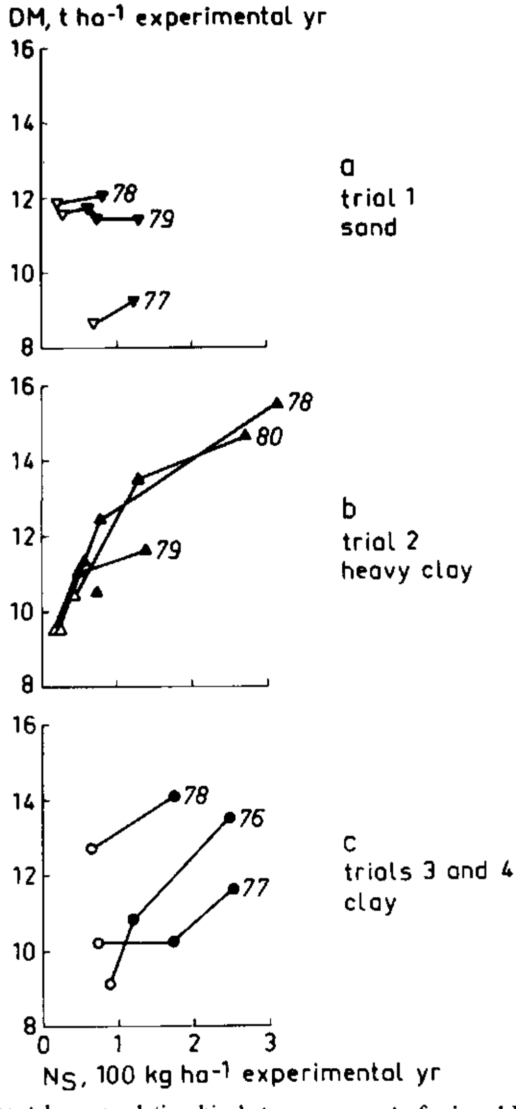

Figure 3. Experimental year: relationship between amount of mineral N in 0–100 cm soil layer at the beginning of the growing season (N_S) and DM yield. White symbols indicate reference treatments, black symbols indicate residual-N treatments

Table 2. Example of DM yield and N yield per cut in trials 1 (sand) and 2 (heavy clay) in the experimental year 1978 after two different rates of N application in 1977

Cut	DM yield, t ha^{-1}				N yield, kg ha^{-1}			
	Trial 1		Trial 2		Trial 1		Trial 2	
N pretreatment year, kg ha^{-1}	200	720	200	720	200	720	200	720
N experimental year, kg ha^{-1}	200	200	200	200	200	200	200	200
Cut 1	3.3	2.6	2.8	4.2	63	53	44	76
Cut 2	2.7	3.2	1.8	2.2	48	63	37	54
Cut 3	1.8	1.7	1.9	2.1	41	42	38	46
Cut 4	2.3	2.8	1.8	2.3	50	62	34	47
Cut 5	1.8	1.8	1.2	1.5	50	54	34	45
Total	11.9	12.1	9.5	12.3	252	274	187	268

– yield levels in the experimental year varied in each trial, partly because of the level of N applications (160, 200, or 240 kg N per ha, Table 1D) and partly because of different growing conditions. For instance, 1978 was a good year for grass growth;

– on the clay soils the increase in DM yield owing to residual nitrogen was distinct (Figures 3b and c). Yield increases were more or less of the same order of magnitude, as indicated by the slope of the response curves;

– on the sandy soil of trial 1 (Figure 3a) the effect of N_S on DM yield was practically nil. In contrast to the clay soils the response at the first cut on sandy soil was always clearly negative. An example of the differences between sand and clay soils is given in Table 2.

The relationship between N_{EXC} in the pretreatment year and the DM yield in the experimental year was approximately linear. Figure 4a and Table 3B show that the correlation was nil on sand.

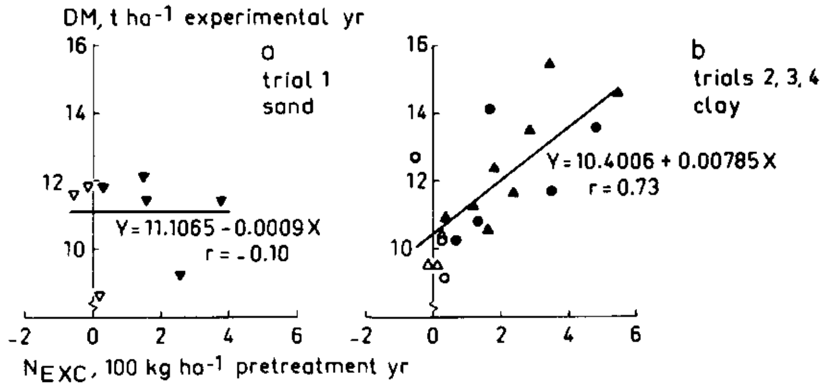

Figure 4. Pretreatment year/experimental year: relationship between N applied exceeding N harvested (N_{EXC}) in the pretreatment year and DM yield in the subsequent experimental year in a. trial 1 (sand) and b. trials 2, 3 and 4 (clay)

On the clay soils of the trials 2, 3 and 4 combined, however, the correlation was clear and each kg N_{EXC} produced nearly 8 kg DM in the experimental year (Figure 4b). Table 3B shows that the correlation on the clay soils was significant. The correlation between N_S and total DM yield has also been calculated. Table 4 shows that on the clay soils the correlation was significant, each accumulated kg N_S producing 15 kg DM.

Nitrogen uptake

The linear correlation between N_{EXC} in the pretreatment year and N yield in the experimental year is shown in Table 3C. On sand there was no significant correlation; on clay the linear effect was significant, indicating that the N yield increased at a constant rate with increasing N_{EXC}. On the clay soils approximately 30% of N_{EXC} was recovered in the herbage in the experimental year (Table 3C). It should be noted in Tables 3 and 4 that the

Table 3. Linear relationship between the amount of N applied exceeding the amount of N harvested in the pretreatment year (N_{EXC}, kg ha^{-1}) and A. soil mineral N in the 0–100 cm layer at the start of growth (N_S, kg ha^{-1}), B. DM yield (t ha^{-1}) and C. N yield (kg ha^{-1}), in the experimental year, on sand (trial 1) and clay soils (trials 2, 3, and 4) as expressed by the regression equation Y = a + b X

	a	b	r	n	sign.[a]
A. $X = N_{EXC}$ in pretr. yr and $Y = N_S$ at start of exp. yr					
Sand	44.9215	0.2485	0.94	8	*
Clay	51.5486	0.4458	0.85	19	*
B. $X = N_{EXC}$ in pretr. yr and Y = DM yield in exp. yr					
Sand	11.1065	−0.0009	−0.10	8	ns
Clay	10.4006	0.00785	0.73	19	*
C. $X = N_{EXC}$ in pretr. yr and Y = N yield in exp. yr					
Sand	250.6650	0.0061	0.02	8	ns
Clay	239.8029	0.2956	0.77	19	*

[a] * = significant at $P \leqslant 0.05$; ns = not significant

Table 4. Linear relationship between soil mineral N in the 0–100 cm layer (N_S, kg ha^{-1}) and DM yield (t ha^{-1}), both in the experimental year, on sand (trial 1) and clay soils (trials 2, 3, and 4) as expressed by the regression equation Y = a + b X

	a	b	r	n	sign.[a]
$X = N_S$ at start of exp. yr and Y = DM yield in exp. yr					
Sand	11.8352	−0.0113	−0.33	8	ns
Clay	9.8054	0.0151	0.73	19	*

[a] * = significant at $P \leqslant 0.05$; ns = not significant

calculated values of 'a' (in Y = a + b X) relate to a level of nitrogen application of about 200 kg N per ha in the experimental year.

In a few instances the nitrogen content of the stubble was determined at the last cut in the pretreatment year as well as at the beginning of growth in the experimental year (Table 5). The increase in N content with increasing nitrogen applications was clear. No analysis of N content in the roots or soil organic matter was available in the trials.

Soil mineral N and applied N

To get an idea of the effectiveness of soil mineral N we analyzed how far the sum of N_S and freshly applied fertilizer N (N_F) of the residual-N treatments could be compared with $N_S + N_F$ of the variable-N treatments in each experimental year. This applies to continuing variable-N treatments with similar levels of N application in each year. The comparison was made according to the quadrant method as described by De Wit (1953): from the $N_S + N_F$ versus uptake curves and the uptake versus yield curves, the $N_S + N_F$ versus yield curves were constructed.

Table 5. Example of stubble N-content (g per 100 g DM) at end of pretreatment year 1977 in trial 1 and at start of experimental year 1978 in trials 1 and 2

N application pretreatment year, kg ha^{-1}	Trial 1, sand		Trial 2, clay
	18 October 1977	6 March 1978[a]	15 March 1978[a]
200	2.27	3.56	3.20
360		3.78	
480		3.78	3.96
720		4.02	4.09
960	3.54	4.09	4.39

[a]The N-contents refer to stubble + some regrowth since November 1977

Figures 5, 6, and 7 illustrate the relationship for trials 1, 2, and 4, respectively. Trial 3 was excluded because there were no variable-N treatments in experimental year 1976.

– The $N_S + N_F$ versus uptake curves show that in the $N_S + N_F$ range of approximately 200 to 500 kg N per ha the percentage of N harvested from varying amounts of N_S and small uniform amounts of N_F was similar to the percentage uptake from small amounts of N_S and varying amounts of N_F. N-uptake was less with residual-N treatments than with variable-N treatments in trial 1 in 1979 (Figure 5c) and trial 4 in 1977 (Figure 7a).

– The uptake versus yield curves show that the efficiency of N taken up in the residual-N treatments was generally equal to that of the variable-N treatments. Only in trial 4 in 1977 (Figure 7a) was the efficiency lower and in trial 2 in 1978 and 1980 (Figure 6a and 6c) was the efficiency higher in the residual-N treatments.

– The $N_S + N_F$ versus yield curves are the outcome of the curves of the other quadrants: yields were lower with the residual-N treatments in trial 1 in 1977. However, in trial 2 in 1978 and 1980 these yields were clearly higher. Possible explanations follow in the discussion.

Discussion

Sources of residual nitrogen

With increasing nitrogen applications, increasing amounts of nitrogen are removed with the harvested herbage. The relationship between nitrogen applied and nitrogen harvested is generally linear up to applications of about 500 kg N per ha [16]. At higher applications a smaller proportion is removed with the herbage and consequently a larger proportion can be left in the soil-plant ecosystem. This has recently been demonstrated by the accumulation of mineral N in the soil [12].

In spite of partial losses through leaching, a certain amount of the excess nitrogen, in organic or inorganic form, can be carried over in the soil-grass

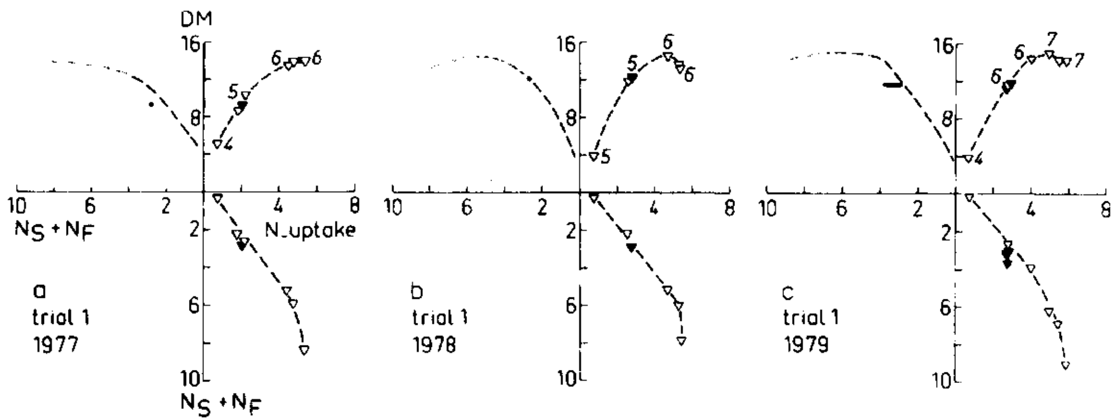

Figure 5. Experimental years 1977, 1978 and 1979 in trial 1 (sandy soil): relationship between soil mineral nitrogen at start of growing season in 0–100 cm layer plus fertilizer nitrogen ($N_S + N_F$, 100 kg ha^{-1}) and herbage N-uptake (100 kg ha^{-1}); herbage N-uptake and DM yield (t ha^{-1}), and $N_S + N_F$ and DM yield. The $N_S + N_F$ versus DM yield curves in the quadrant above left have been constructed from the curves in the quadrants on the right. White symbols and broken lines indicate continuing variable-N treatments, inclusive of the reference treatments. Extreme fertilizer applications of 1000 kg N and more per ha per year have not been included. Black symbols and thick black lines indicate residual-N treatments. Figures on the herbage N-uptake versus DM yield curves indicate number of cuts

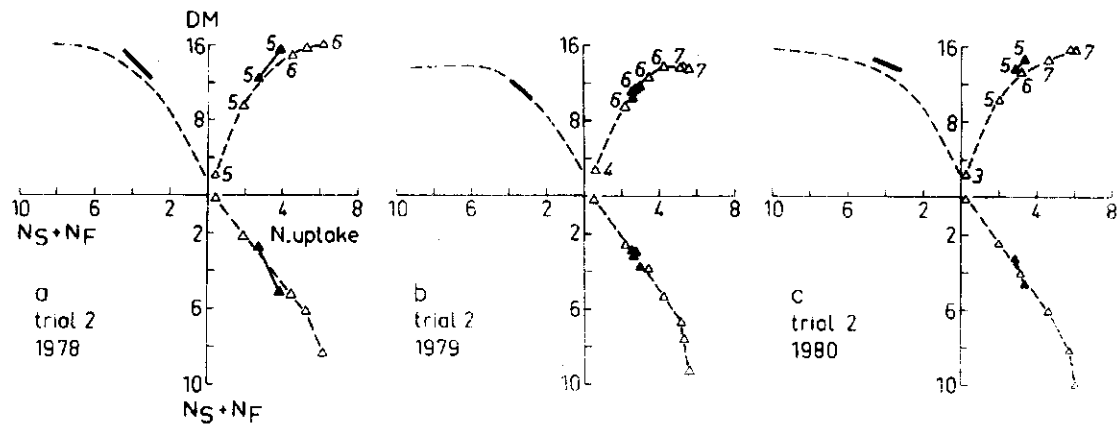

Figure 6. As Figure 5, but now for experimental years 1978, 1979 and 1980 in trial 2 (heavy clay soil)

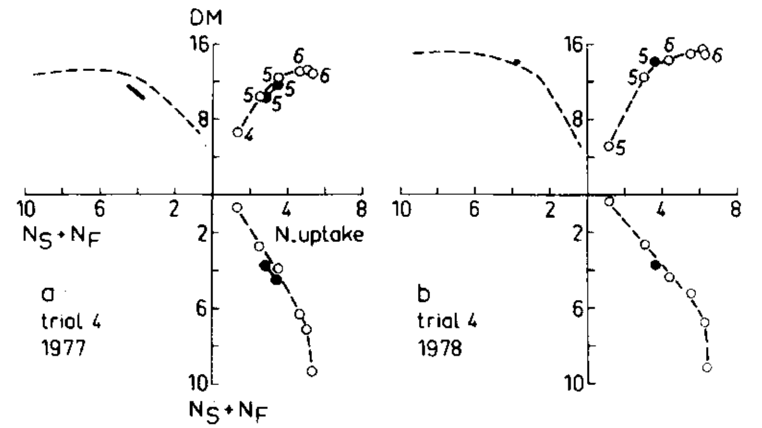

Figure 7. As Figure 5, but now for experimental years 1977 and 1978 in trial 4 (clay soil)

ecosystem to the following season. In organic form N may be carried over in stubble, roots and soil organic matter. In our trials this was clear from the few instances of stubble-N determinations (Table 5). No root-N analyses were carried out, but other data [1, 4] support the suggestion of higher N contents in the roots with increasing nitrogen applications.

If we assume that the contribution from stubble, roots and soil organic matter is small in comparison with that from accumulated soil mineral nitrogen, the residual N may be characterized by the increased amount of N_S. This is in agreement with White et al. [19] who showed that the effects of residual nitrogen on DM yield were largely due to increased quantities of soil mineral nitrogen originating from the preceding fertilizer applications.

Soil mineral N and applied N

Figures 5 to 7 illustrate the relationship between nitrogen supply (soil mineral N + fertilizer N: $N_S + N_F$), uptake and yield. Uptake and efficiency were generally about equal in the variable-N treatments and the residual-N treatments, despite differences in quantities of soil mineral N or fertilizer N. Assuming a negligible contribution from residual N in the organic form it would seem that the mineral N in the 0–100 cm soil layer at the start of the growing season has about the same effect on uptake and efficiency as the fertilizer N, applied throughout the season. However, there are some instances of less or higher uptake and/or efficiency:

1. Uptake was distinctly less in the residual-N treatments than in the variable-N treatments in trial 1 in 1979 (Figure 5c) and trial 4 in 1977 (Figure 7a). As regards trial 1, the spring of 1979 was very wet, rainfall amounting to 276 mm during April-June against 177 and 115 mm in the same period of 1977 and 1978, respectively. We suppose that the accumu-

lated mineral N stayed out of reach of the grass roots during 1979. As regards trial 4-1977, a possible explanation lies in the decreased productivity of the sward. It is a well-known fact that high nitrogen applications may exert stress on grass plants, especially with mowing, causing thinning of stand and reduction of root mass. Prins (1978) has described how in 1977 productivity was affected by the very high N application in 1976. This decrease in productivity was expressed in a lower DM yield at the first cut in comparison with the reference treatment. The same applies to trial 1 in 1977 (Figure 5a), although only one residual-N treatment was used. The lower yield in comparison with the variable-N treatments is thus caused by a combination of less uptake and slightly less efficiency.

2. In trial 2 in 1978 and 1980 (Figures 6a and 6c) the efficiency of the residual-N treatments was higher than that of the variable-N treatments. This can be explained by the difference in cutting frequency, being 5 times in the residual-N treatments and 6 times in the nearby variable-N treatments. In 1979 (Figure 6b) there was no difference in cutting frequency and no difference in efficiency.

Estimation of residual effect

In our trials the residual effect was not measured on unfertilized plots, as is usually the technique, but it was measured by calculating the increase in yield over the reference treatment at one rate of nitrogen application. This application was necessary to ensure reasonable grass growth especially on the sandy soil of trial 1. We have assumed that the grass on the reference plots and on the plots with the preceding very high nitrogen applications used the 'natural' contribution of soil nitrogen with equal effectiveness.

The residual effect was considerable on the clay soils where each kg N_{EXC} and each extra kg N_S produced approximately 8 and 15 kg DM, respectively (b in Tables 3B and 4), in comparison with the reference treatment. Also, on the clay soils approximately 45% of the N_{EXC} from the pretreatment year was found as accumulated mineral nitrogen in the soil (b in Table 3A) and approximately 30% was recovered in the harvested grass in the experimental year (b in Table 3C). Thus two-thirds of the accumulated soil mineral N was recovered in the harvested grass. This is about the usual recovery of freshly applied fertilizer nitrogen in the herbage [23] and shows once again that the effect of soil mineral N is similar to that of fertilizer N.

It should be realized that our results are only estimates of residual effects. The results are influenced by the condition of the sward itself, as has been described above. However, we may add that the swards have not been damaged by winter kill. In addition, after the year with high N application the sward recovers to a large extent at the lower rate of nitrogen in the experimental year as is shown by an increase in tiller density (Table 6) and root mass (J. Floris, personal communication). It is likely that part of the residual nitrogen is used for the restoration of the sward. We must therefore

Table 6. Example of changes in tiller density per dm^2 with rather low (L = 40 kg N ha^{-1} per cut) and very high (H = 120 or 160 kg N ha^{-1} per cut) rates of nitrogen application in pretreatment year 1977–experimental year 1978

1977–1978	End pretr. year	Start exp. year	End exp. year
Trial 2, heavy clay			
L-L	67	57	96
H-L	47[a]	51[a]	92
H-H	47[a]	51[a]	66
Trial 3, clay			
L-L	229	171	166
H-L	99	112	129
H-H	92	131	51

[a]Adjoining plots, treated equally from 1975 to start of experimental year 1978

realize that the amount of residual nitrogen cannot be fully estimated by our way of measuring increases in DM and N yield.

Regardless of the sward-effects, the residual response on the sandy soil was smaller because the accumulated amount of mineral nitrogen in the sandy soil at the onset of the experimental year was smaller than in the clay soils, although the amounts of accumulated nitrogen were about equal in the previous autumn [12]. This indicates greater losses from the sand due to winter rainfall (Table 7). Similarly, losses from the lighter clay soil of trials 3 and 4 during winter were greater than from the heavier clay soil of trial 2 as can be read from Figure 2.

When to expect a residual effect

The question arises from which rate of nitrogen application a residual effect can be expected, especially on clay soils. Donohue et al. [5] took as the lower limit the rate of N at which N removal equals N application. In our case this point was reached at applications between 300 and 400 kg N per ha per year. However, because of the nitrogen carried over in stubble and roots, a residual effect might be expected at a slightly lower nitrogen application. When a residual effect is expected, the rate of N application should be adjusted accordingly. By reducing the rate of N application the residual N can then be used properly. Of this we have a spectacular example in Table 8 where on the heavy clay soil of trial 2 applications of 80 kg N per ha per cut over four years gave about the same total DM yields as a succession of years with an alternating system of very high → low → very high → low rates of N application. Generally, the latter system is not advisable for farming practice because of the risk of leaching and other losses, and because of the possible deterioration of the sward in the years with very high nitrogen applications.

Table 7. Precipitation during March–October, roughly coinciding with the growing season, and November–February in relevant pretreatment and experimental years. Normal rainfall in these periods is about 500 and 250 mm, respectively. The actual evapotranspiration of grassland in the Netherlands is about 575 mm per annum, leaving a precipitation surplus of about 175 mm

Location	Period	Years 1975	1976	1977	1978	1979	1980
Finsterwolde	March–October		278	459	506	531	557
(trials 1 and 2)	November–February		302	268	181	290	
Ten Boer	March–October	354	242	369	410		
(trials 3 and 4)	November–February[a]	274	291	276			

[a]The winter data are from Eelde Airport, 15 km from the trial site

Table 8. Trial 2 (heavy clay): four years' DM yields ($t\,ha^{-1}$) of a treatment with regular applications of $80\,kg\,N\,ha^{-1}$ per cut and a treatment with alternating years of very high ($120\,kg\,N\,ha^{-1}$ per cut) and rather low ($40\,kg\,N\,ha^{-1}$ per cut) rates of N application

Treatment	1977		1978		1979		1980		1977–1980	
	N	DM	N	DM	N	DM	N	DM	N	DM
Regular	480	14.7	480	14.8	480	13.7	560	14.5	2000	57.7
Alternating	720	15.3	200	12.4	840	14.4	200	13.5	1960	55.5

Differences between years

Despite fairly large differences in winter rainfall and in growing conditions in the experimental years, as expressed by rainfall March–October (Table 7), on the clay soils there was a reasonable relationship between N applied minus N harvested in the pretreatment years and the DM yield and N yield in the experimental years (Tables 3B and 3C).

It was mentioned in the footnote of Table 1 that some treatments had already received substantial nitrogen applications for more than one year. Nevertheless, the increase in DM and N yield of these treatments were comparable with those receiving a very high nitrogen application for one year. Only one treatment showed a considerable residual effect which lasted at least two years. This particular case has been described in full elsewhere [13].

Implications

It has been shown that very high nitrogen applications can produce residual effects in a following year. It should be noted that these applications were well above those advised in practice. Overdosing may occur when nitrogen is applied in excess of crop requirements, be it through fertilization or through application of large amounts of animal manure, spread by the farmer or dropped by the grazing animals. From the environmental point of view the results imply that in cases of overdosing more harm may be done on sandy soil than on clay soils.

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Chapter 6

Residual effects of two years of very high nitrogen applications on clay soil under grass in a temperate climate

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Key words: grassland, nitrogen fertilization, residual nitrogen, soil mineral nitrogen, yield, nitrogen uptake

SUMMARY

In recent field trials on all-grass swards on clay soils fertilizer rates of 480 kg N per ha and over showed distinct residual effects in the following year. This paper analyses the considerable residual effects of one treatment on heavy clay soil over two experimental years, after very high rates of N had been applied during three pretreatment years (totalling 800 kg N or more per ha per year). The residual effect was measured through the increase in yield over a reference treatment, at one rate of N application (40 kg N per ha for each cut, totalling 200 and 240 kg N per ha in the first and second experimental year, respectively).

Over the three pretreatment years the amount of N applied exceeded the amount of N harvested by 941 kg N per ha. The excess N was reflected in accumulation of mineral N in the soil.

At the beginning of the first experimental year the soil contained 314 kg mineral N per ha against the reference treatment 21 kg N. The accumulated mineral N was nearly depleted by the end of the first season. A residual effect was evident at every cut, and over the whole growing season the increase in yield was 6 t DM and 199 kg N per ha.

In the second experimental year there was no difference in soil mineral N status of the treatments. Still, a residual effect was observed through an increase in yield of 1.1 t DM and 21 kg N per ha.

The study showed that on heavy clay soils - despite N losses from the soil, especially through leaching in winter - part of the applied N may remain in the soil-plant ecosystem and will be available for grass growth in the following season(s).

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INTRODUCTION

It has recently been shown in field trials on all-grass swards of mainly perennial ryegrass (*Lolium perenne* L.) that at rates of 480 kg N per ha and more in one season, residual effects occurred in the following season (Prins *et al.* 1981). These residual effects were small or absent on sandy soil but considerable on clay soil. One treatment showed a particularly high residual effect following very high N applications during the pretreatment years 1975 to 1977. As visual observations indicated that residual effects possibly lasted longer than one season, it was decided to extend the study over two successive seasons, referred to as experimental years 1978 and 1979.

EXPERIMENTAL

In 1975 a long-term fertilizer trial (IB 2244) with different rates of N application was laid out on a heavy clay soil (in the upper 20 cm 57% of the mineral fraction was smaller than 0.002 mm), in Finsterwolde, in the north-eastern part of the Netherlands. The site had been sown to grassland in 1974 after arable cropping. Three treatments (A, B, and C) were selected to study the residual effect, see Table 1.

The residual effect of treatments B and C was determined through the increase in herbage DM and N yields over the 'reference' treatment A. For this purpose all treatments received one rate of N during the experimental years, namely 40 kg N per ha for each cut (Table 1).

Full experimental details have been reported by Prins *et al.* (1981).

RESULTS AND DISCUSSION

Pretreatment years

The very high rates of N of treatments B (1977 only) and C (1975-1977) gave much higher DM and N yields than the N-rate of reference treatment A (Table 1). It is notable that in 1976 yields were much lower, mainly due to drought.

In treatment C, N applied exceeded N harvested[1)] in all three pretreatment

1) N harvested = N yield = herbage N uptake

Table 1. Annual N application, herbage DM yield and herbage N yield, and soil mineral N in the layer 0-100 cm in pretreatment years 1975-1977 and experimental years 1978 and 1979

Treatment	N-appl. kg/ha	DM yield t/ha	N yield kg/ha	Soil mineral N, kg/ha start of season	Soil mineral N, kg/ha end of season
Pretreatment years					
1975					
A=B*	200(5)**	12.6	248	28***	14
C	884(7)	17.4	664	28***	136
1976					
A=B	160(4)	8.2	143	NR	11
C	800(5)	12.0	427	NR	388
1977					
A	200(5)	11.6	212	39	8
B	720(6)	15.3	539	44	52
C	960(6)	15.3	612	263	518
Experimental years					
1978					
A	200(5)	9.5	187	21	20
B	200(5)	12.4	268	77	30
C	200(5)	15.5	386	314	37
*1979*****					
A	240(6)	9.5	218	19	14
C	240(6)	10.6	239	23	11

* Treatments A and B were identical in 1975 and 1976
** In parentheses number of cuts
*** 28 kg N per ha in layer 0-50 cm. No data of 50-100 cm available
**** In the second experimental year treatment B was not any longer included

years. This was reflected in accumulation of mineral N in the soil (Table 1). Although part of the accumulated N disappeared from the upper 1 m of soil in between growing seasons, at the beginning of the first experimental year (1978) the soil contained over 300 kg mineral N (Table 1).

Treatment B received a very high rate of N in one season only, so the amount of accumulated N was less.

No accumulation occurred in reference treatment A (Table 1).

Experimental year 1978

At one rate of N application treatments B and C showed considerably higher DM and N yields than treatment A (Table 1). As has been reported elsewhere (Prins *et al.* 1981), part of the residual effect may be explained through the accumulated soil mineral N from preceding very high rates of N application. During the first experimental year soil mineral N was determined in spring and at the start of regrowth following each cut. Figure 1a shows the relationship between the amounts of mineral N in the upper 1 m of soil and the DM yield of each of the five cuts. Throughout the season the effect was clear: the larger the amount of mineral N in the soil, the larger the DM yield. A similar relationship existed between soil mineral N and herbage N content, as can be deduced from the trends of DM yield and N yield in Figures 1a and 1b, respectively.

Figure 2 shows changes in the amount of mineral N in various layers of the upper 1 m in the course of the growing season. The largest change occurred during spring growth when more than half of the soil mineral N disappeared. Herbage N uptake was large (Figure 1b) and possibly some leaching losses occurred because rainfall was higher than normal during March. Figure 2 shows how the amount of soil N decreased during the season, particularly with treatment C. The last cut was on 25 October, and on 7 November the soils of treatments B and C still contained slightly more mineral N than the soil of reference treatment A (Figure 2).

Compared with treatment A the increase in N yield over the season was 81 and 199 kg for treatment B and C, respectively (Table 1). The increase for treatment B (81 kg N) was higher than the amount of accumulated mineral N in the soil in spring (56 kg N, see Table 1). Other sources of residual N in the soil-plant ecosystem, like N in roots and stubble, have been discussed in full elsewhere (Prins *et al.* 1981).

Experimental year 1979

At the beginning of the second experimental season the soil mineral N status was about the same for treatments A and C (Table 1). (Treatment B was no longer included in the study of residual N). Nevertheless, during the season treatment C showed a DM increase of 1.1 t per ha compared with reference

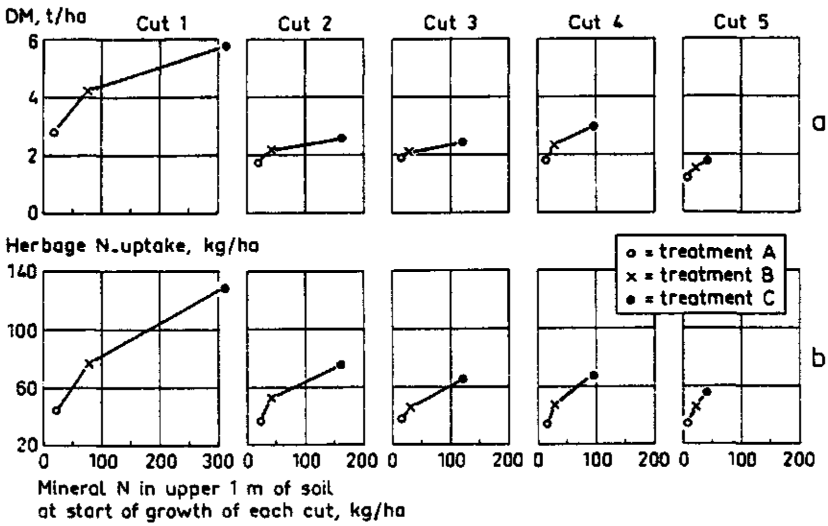

Figure 1. Relationship between quantity of mineral N in the 0-100 cm layer of the soil at the start of grass growth for each of five cuts and a) DM yield and b) herbage N uptake in the experimental year 1978

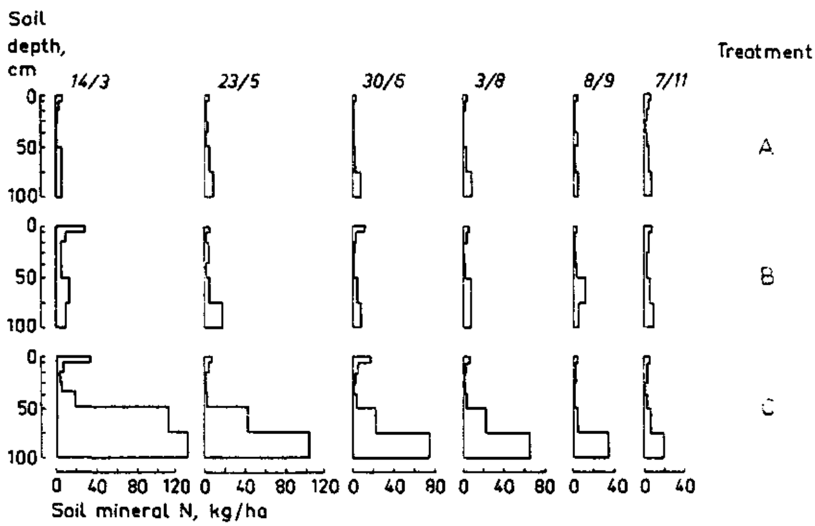

Figure 2. Changes in the quantity of mineral N in the soil profile down to 100 cm, in the course of the growing season in experimental year 1973

treatment A (Table 1). At every cut, except the last one, DM yields of treatment C were higher. Only in the first cut, however, was there a clear indication of a specific residual N effect of treatment C since herbage N content was also higher than for treatment A (Table 2). Although N uptake in the following cuts was higher, herbage N contents were lower (Table 2). Together with the higher DM yields this suggests also an improved sward condition and a better N utilization by treatment C. Due to the average lower N content in treatment C, the increase in the total N yield was only 21 kg N per ha compared with treatment A (Table 1).

Table 2. Herbage DM yield and herbage N content of each of six cuts of treatments A and C in the second experimental year

Treatment	DM yield, t/ha		N-content, %	
	A	C	A	C
Cut 1	2.2	2.4	1.8	1.9
2	1.3	1.8	2.6	2.4
3	2.0	2.3	2.1	2.0
4	1.8	2.0	2.3	2.2
5	1.4	1.4	2.5	2.5
6	0.8	0.7	3.3	3.4
	9.5	10.6		

With a total excess of 941 kg N applied over N harvested in treatment C during the pretreatment years 1975-1977, the total yield increase for the two following years was 7.1 t DM and 220 kg N per ha in comparison with reference treatment A (Table 1). This residual effect is remarkable considering the possibility of N being lost during these years, especially during the winter periods (Table 3), as has also been indicated by Van der Paauw (1963) in his study of the residual effect with arable cropping in the Netherlands. For treatment C these losses of N are reflected in the differences in quantity of mineral N in the soil between the end of 1976 and the beginning of 1977, and also those between the end of 1977 and the beginning of 1978 (Table 1).

Table 3. Precipitation (mm) at Finsterwolde during the periods 1 March - 31 October (roughly coinciding with the growing season) and 1 November - 28 February

	Pretreatment years						Experimental years		
	1975		1976		1977		1978		1979
March - October*	453		278		459		506		531
November - February*		321		302		268		181	

* Mean precipitation is about 500 and 250 mm, respectively, in these periods

CONCLUSION

The results clearly show that on heavy clay soil under grass not all N applied in excess of N taken up is lost under the climatic conditions of the Netherlands. Part of the N remains in the soil-plant ecosystem and is available for grass growth in the following season. Even in a second season there can be a residual effect through a combination of residual N and improved sward condition.

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Chapter 7

Effect of a wide range of nitrogen applications on herbage nitrate content in long-term fertilizer trials on all-grass swards

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Key words: nitrogen fertilization, grassland, nitrate content

Abstract. In three long-term nitrogen fertilization experiments with total applications of up to 1120 kg N per ha per year and cutting at a DM yield of 2 to 2.5 t per ha, the herbage nitrate content of all-grass swards was studied for each cut. At applications of 60 kg N per ha per cut, with a maximum of 360 kg N per ha per year, there was little or no increase in nitrate content. At applications of 80 kg N per ha per cut, totalling 400–560 kg N per ha per year, 3% of the samples had nitrate contents higher than 0.75% NO_3. At applications of 120 and 160 kg N per ha per cut, totalling 600–1120 kg N per ha per year, 61 and 67% of the samples exceeded 0.75% NO_3, respectively. The excess nitrate did not occur in the spring cuts, but for the most part in the summer cuts and seldom in the autumn cuts. This may explained by a positive relationship between temperature and herbage nitrate content, under favourable moisture conditions. In warm but dry periods there was no relationship and nitrate contents were low.

For maximum dry-matter (DM) yields sufficient nitrogen (N) is necessary. Maximum grass yields generally occur at nitrate (NO_3) contents of about 0.3–0.6% of dry matter [5, 6, 18, 21]. Higher nitrate contents do not impede grass growth but may affect cattle health when they exceed certain values. Recent research in the Netherlands has shown that there is a range of critical values, viz. 0.75% NO_3 for conserved grass such as pre-wilted silage and hay when fed twice daily, 1.50% for freshly mown grass when fed twice daily indoors and 2% or somewhat more for grazed pasture [19]. The higher critical value for grazed pasture results from the extended period of time during which the cattle consume their forage and from the slower rate of nitrate release from fresh grass in comparison with silage or hay. However, the critical value for grazed grass has not yet been firmly established and there is evidence that higher nitrate levels are tolerated by grazing cattle [eg 4, 8].

The amount of nitrate accumulated in plants is the difference between the amount taken up and the amount converted to organic nitrogen. Uptake strongly depends upon the supply of nitrogen, whereas conversion depends

*Research Officer with the Stichting Landbouwkundig Bureau van de Nederlandse Meststoffenindustrie, LBNM (Agricultural Bureau of the Netherlands Fertilizer Industry), seconded to the Institute for Soil Fertility upon production and distribution of dry matter [9]. Nitrate content will be low (a) when nitrate uptake is low due to low nitrogen availability (low nitrogen supply or drought) and (b) when nitrogen supply and uptake are adequate but conversion is efficient. Nitrate content will be high when nitrate uptake is high and nitrate conversion is low.

There is considerable evidence showing that the amount of nitrogen applied is positively correlated with the herbage nitrate content [e.g. 2, 9, 13]. As yet little is known about the effect of repeated very high nitrogen applications on herbage nitrate accumulation.

This paper presents the effects of a wide range of nitrogen fertilizer applications on herbage nitrate in three long-term trials during 1974–1980. The study constitutes part of the research undertaken to define limits to nitrogen application on grassland as regards productivity [29], herbage quality and accumulation of mineral nitrogen in the soil [26].

Materials and methods

Experimental sites

The trials were located in the province of Groningen on sown grassland on sandy soil (trial 1) and heavy clay soil (trial 2), and on old permanent grassland on clay soil (trial 3). The all-grass swards were virtually perennial ryegrass (*Lolium perenne* L) in trials 1 and 2, and this was also the dominant component in trial 3. General data on the trials are presented in Table 1A.

Treatments

The trials included series of plots receiving 0, 40, 60, 80, 100 (100 in trials 2 and 3 only), 120 and 160 kg N per ha for each cut. The 160 kg N rate was not introduced until 1976. Table 1B presents the lowest and highest nitrogen applications in each year. The first nitrogen dressing of the season was applied near temperature sum 200°C; subsequent dressing were applied immediately after herbage was cut.

General information

Nitrogen was applied as calcium ammonium nitrate (CAN, 26% N). Phosphate and potash were applied on the basis of the results of soil analysis. The rates ranged from 9 to 20 kg P and from 33 to 75 kg K per ha per cut, mostly as compound fertilizer 0–7–25. Plot sizes ranged from 12.5 to 30 m². Herbage was mown with a reciprocating mower to a stubble height of 3 to 4 cm when a dry-matter yield of approximately 2 to 2.5 t per ha had been reached. Because of faster growth at the higher rates, this technique meant more frequent cutting at the higher than at the lower rates of nitrogen application (Table 1C). Numbers of cuts were almost the same at the 80 to 160 kg N applications per ha per cut. The fresh herbage from each plot was weighed and sampled for dry-matter determination. Samples were dried at

Table 1. General data (A), range of nitrogen applications (B) and number of cuts per year (C)

	Trial 1 (IB 2146)	Trial 2 (IB 2244)	Trial 3 (IB 2259)
A General data			
Location	Finsterwolde (Gr)	Finsterwolde (Gr)	Ten Boer (Gr)
Grassland	1971-sown	1974-sown	old permanent
Soil	sandy	heavy clay	clay
Duration of trial	1974–1979	1975–1980	1975–1978
B Range of nitrogen applications, kg ha^{-1} $year^{-1}$			
1974	0–840		
1975	0–720	0–840	0–720
1976	0–800	0–800	0–800
1977	0–960	0–960	0–960
1978	0–960	0–960	0–960
1979	0–1120	0–1120	
1980		0–1120	
C Number of cuts corresponding with range of N (under B)			
1974	3–7		
1975	3–6	4–7	3–6
1976	4–5	4–5	3–5
1977	4–6	4–6	4–6
1978	5–6	5–6	5–6
1979	3–7	4–7	
1980		3–7	

105°C to constant weight. For chemical analysis herbage samples from three replicates (trial 1) or four replicates (trials 2 and 3) were bulked. Total nitrogen, including nitrate, was determined according to a modified Kjeldahl method [14]. The nitrate content was measured spectrophotometrically according to the xylenol method. In the soil the groundwater level and, in the top 15 cm, the moisture content were monitored at irregular intervals.

Results and discussion

There was little or no increase in herbage nitrate at applications of 0, 40 or 60 kg N per ha per cut, totalling 0 to 360 kg N per ha per year. The nitrate contents of the dry matter at the higher rates of nitrogen (excluding the 100 kg N rate per cut that gave NO_3-contents intermediate between the 80 and 120 kg N rates per ha per cut) are presented in Figure 1, which shows the following:

– In the first cut the content did not exceed 0.75% NO_3, even after an application of 160 kg N per ha, except in one case in trial 3 in 1977.

– In subsequent cuts nitrate contents were higher. However, the grass with 80 kg N per ha per cut never contained more than 0.75% NO_3, except in two cuts in 1978 in trial 3. With 120 kg N, and even more so with 160 kg N

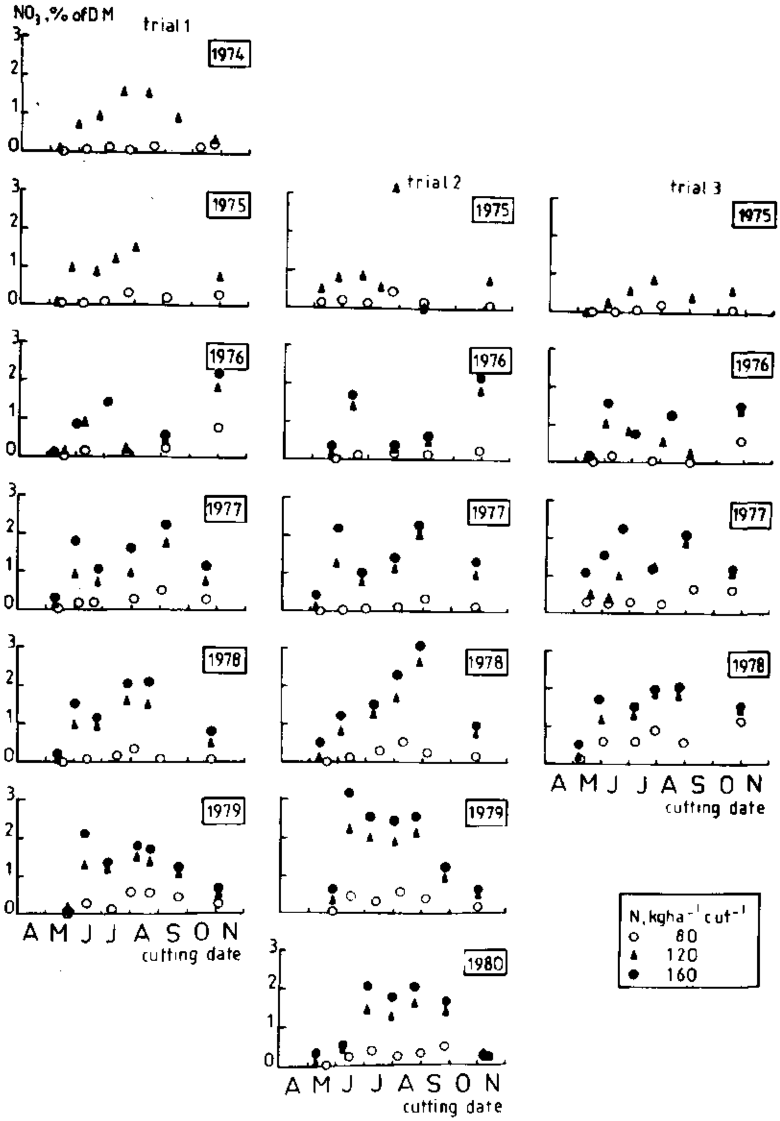

Figure 1. Effect of rate of nitrogen application on herbage nitrate content in each cut during successive growing seasons in trials 1, 2 and 3. In 1974 and 1975 the 160 kg N rate per cut had not yet been included

per ha per cut, all three trials showed an increase in nitrate contents from the second cut onwards rising to over 2 or 3% NO_3.

– Peak nitrate contents for each trial and year occurred mostly in summer, namely five times in June and eight times in July and/or August and only once in September and twice in October.

– In each growing season the three trials showed similar patterns of nitrate accumulation. There was a low content in late August/early September in 1975; a low in July/August and a peak in October in 1976; after a peak in May and a low at the end of June again a peak during late August/early September in 1977, etc. This similarity among trials in the same year seems to point to effects of weather conditions on the nitrate content.

In his review, Darwinkel [9] mentioned that the nitrate content is influenced not only by nutrition, weather and time in season, but also by plant species, sward age, type of plant organs and age of leaves. In discussing the results of our trials, we concentrate especially on the first three factors as the remaining factors in our type of trial are probably of minor importance or are impossible to discern in our data, because:
– The plant species was virtually only (trials 1 and 2) or mainly (trial 3) *Lolium perenne*.
– The swards were always older than one year, except in trial 2 in 1975, so no effect of sward age [10] is to be expected.
– The plant organs (stems, leaves) were not analyzed separately, but because of the system used in our trials, namely cutting at a yield of 2 to 2.5 t DM per ha, differences in plant organs are to be expected between the slow growing grass, at low applications of nitrogen, and faster growing grass. However, within the group of the faster growing grass, at applications of 80, 120 and 160 kg N per ha per cut, there was little difference in growth rate and hence little difference in leaf/stem ratio or in age of leaves would be expected. The grass of these treatments never reached the flowering stage, except during a very long, dry period, e.g. in 1976.

Rate of nitrogen application

The range of nitrate contents, deduced from the data in Figure 1, is expressed in Figure 2 which shows the range from lowest to highest NO_3-contents at different rates of nitrogen application. It is clear that in the first cut (Figure 2a) the range was smaller than in the second and following cuts (Figure 2b). The nitrate content increased with increasing nitrogen applications. However, the bottom line in Figure 2b indicates that in a number of cases grass with a low nitrate content was harvested even at the highest rates of nitrogen application. At rates over 400 and over 500 kg N per ha some peak nitrate contents from the second cut onwards exceeded the above mentioned critical values of 0.75 and 1.50% NO_3 for conserved and zero-grazing grass, respectively (Figure 2b).

Bartholomew and Chestnutt [2] reported that herbage nitrate increased, on average, from 0.40% NO_3 at an application rate of 300 kg N per year to 1.15% at 600 kg N. They concluded that, in general, nitrate contents of herbage do not reach dangerous levels until nitrogen applications exceed those at which maximum dry-matter yields are obtained. The same

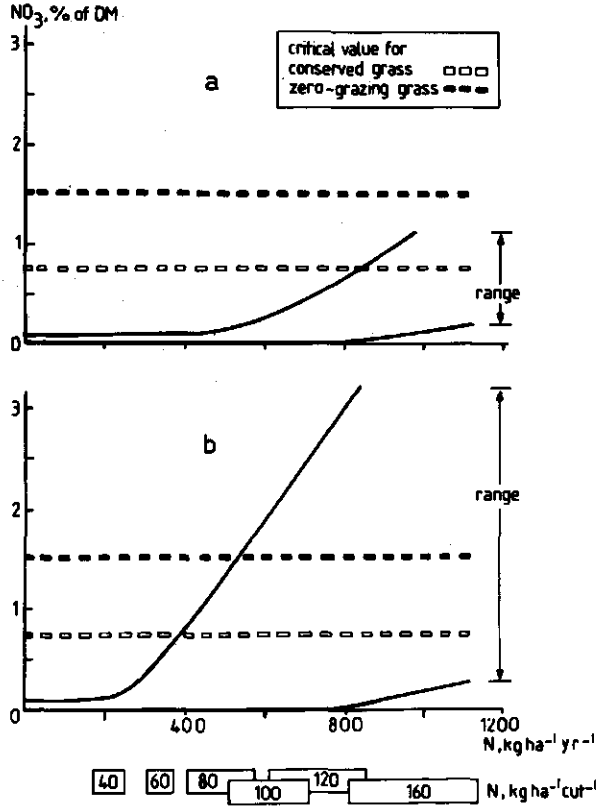

Figure 2. Effect of rate of nitrogen application on range of lowest and highest herbage nitrate contents in (a) the first cuts and (b) the second and following cuts of trials 1, 2 and 3

conclusion can be deduced from a study by Wieringa et al. [34] in the Netherlands. In their trials, herbage with risky nitrate accumulation occurred more often than in our trials, at comparable total rates of nitrogen application. This greater frequency may be due to differences in fertilization and cutting regime, and to the inclusion of nitrogen-rich peat soils. That the supply of nitrogen from sources other than fertilizer may influence herbage nitrate was also shown in recent trials with cattle slurry injected into grassland. With a total fertilizer application of 426 kg N per ha and no slurry 19% of the herbage samples exceeded the critical value of 0.75% NO_3, whereas with a total fertilizer application of 213 kg N per ha and 90t slurry per ha this occurred in 39% of the samples [23].

The frequency distribution in Table 2, deduced from the data in Figure 1, gives an idea of the occurrence of risky nitrate accumulation in the grass in our trials. At a rate of 80 kg N per ha per cut, only 3% of the herbage samples

Table 2. Percentage of grass samples in three ranges of nitrate contents at three rates of nitrogen application

N, $kg\,ha^{-1}\,cut^{-1}$	N, $kg\,ha^{-1}\,year^{-1}$	Number of samples	NO_3-range		
			0–0.75	0.76–1.50	≥ 1.50
80	400–560	92	97	3	0
120	600–840	98	39	42	19
160	800–1120	72	24	29	47

exceeded the critical value of 0.75% NO_3, against 61 and 67% of the samples from grass fertilized with 120 and 160 kg N per ha per cut, respectively.

Time in season: spring

Despite the very high spring nitrogen applications of 160 kg N per ha, the herbage nitrate contents of the first cut remained below the critical value of 0.75% NO_3 in all cases but one. This is the more notable in view of the extra supply of N from residual nitrogen present in soils after very high nitrogen applications in the preceding year [30]. Low nitrate contents in spring grass have been found also in many other studies [e.g. 2, 3, 15, 32]. The low nitrate contents may be due to efficient conversion in spring grass leaves [22]. This is in agreement with Van Burg [7], who found that nitrate accumulation in spring took place at a higher total nitrogen content than in summer and autumn. A low nitrate content has also been connected with the high light intensity in spring [12]. However, herbage grown on our trials at similar or higher light intensities had higher nitrate contents, e.g. in the second and third cuts.

It should be noted that at rates exceeding 160 kg N per ha excessive nitrate accumulation in spring grass becomes more likely. This was shown after an application of 320 kg N per ha [5], and also in our trials with 'winter' N applications which have been reported elsewhere [29].

Time in season: summer and autumn

Peak nitrate contents occurred in most cases in summer grass. This is in contrast with the general notion that an increase in nitrate levels especially occurs in late summer grass [24] or in autumn grass [3, 11, 32]. In previous one-year trials [27, 28] and in an ongoing long-term grazing trial (D.J. den Boer, private communication) peak contents of about 3–4% NO_3 also occurred in summer compared with about 1–2% in autumn. The latter was not expected as the very high nitrogen applications of over 1000 kg N per ha per year resulted in accumulation of mineral nitrogen in the soil-plant system during the growing season.

It should be mentioned here that the low nitrate contents in spring grass in comparison with summer and autumn grass were not caused by 'dilution' due to increased dry-matter yield [as noted by Deinum, 12] because in our trials the grass was harvested at a fixed yield level.

7.8

Weather

The variation in nitrate contents within and between seasons shows a similar picture at each high rate of nitrogen application in all three trials (Figure 1). The peak nitrate contents in summer indicate a possible correlation with temperature. There appeared to be a positive relationship between herbage nitrate and temperature, be it with certain exceptions as will be discussed below. The effect of temperature is shown in Figure 3a, where the 120 kg N rate of application per cut of trial 2 has been taken as an example. In spring average daily temperatures, calculated as from 1st April, are lowest, coinciding with the lowest nitrate contents. With increasing temperatures in each

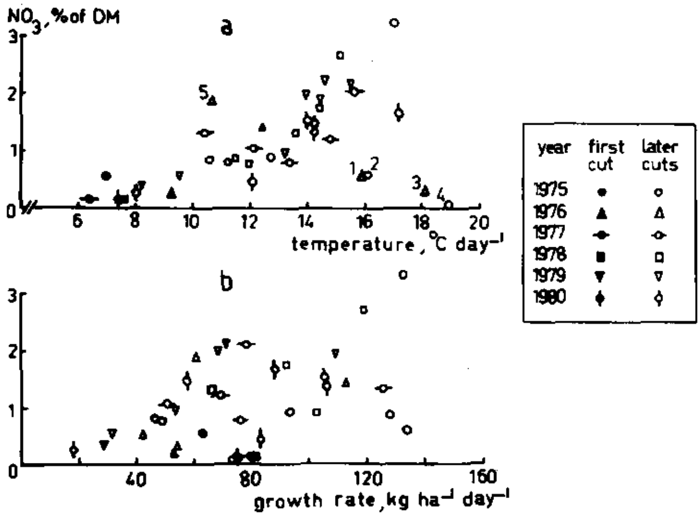

Figure 3. Effect of (a) average daily temperature (mean of daily maximum and minimum) and (b) average daily growth rate in each growth period of 1st cut (measured as from 1st April) and following cuts on herbage nitrate content at a fertilizer regime of 120 kg N per ha per cut in trial 2. See text for explanation of symbols marked 1–5 in (a)

growing period the herbage nitrate contents increase, at least if soil moisture conditions are favourable for nitrogen uptake. Figure 3a suggests that the critical values of 0.75 and 1.50% NO_3 are exceeded at average daily temperatures of 11 and 14°C, respectively. An increase in nitrate with increasing temperatures has been reported before [1, 12, 13, 15, 33].

The low nitrate contents in warm periods in August/September 1975 and in July/August 1976, indicated by the symbols marked 1–4 in Figure 3a, were almost certainly connected with the low nitrogen uptake due to drought in these periods. This is illustrated in Table 3, where the dry year 1976 and the fairly wet year 1979 have been taken as an example of different soil moisture conditions in trials 1 and 2.

Table 3. Groundwater level (gwl, cm below soil surface) and soil moisture content (mc, % by weight) in trials 1 and 2 in the contrasting years 1976 and 1979

Item	June		July			August			September			October	
	Trial 1, 1976												
gwl	110	120	123	132	140		150	153		>157	>157		>157
mc, 0–5 cm		6	7	5		12	17	5					
mc, 5–15 cm		6	7	5		6	13	6					
	Trial 1, 1979												
gwl	80	75				65			95		110	105	
mc, 0–5 cm	31	33				32			27		39	30	
mc, 5–15 cm	20	20				21			17		29	19	
	Trial 2, 1976												
gwl		120	123	129	140		165	>165		>165	>165		>165
mc, 0–5 cm		16	17	15		28	32	16		27	27		39
mc, 5–15 cm		23	22	20		23	30	21		18	21		32
	Trial 2, 1979												
gwl	90	70				80			100		113	120	
mc, 0–5 cm	39	40				41			34		39	41	
mc, 5–15 cm	32	33				33			30		39	33	

Drought-induced nitrogen deficiency has been reported before [5, 17]. Van Burg found that even after one application of 240 kg N per ha during drought there was no appreciable nitrate accumulation and total nitrogen uptake was low. However, with irrigation nitrate accumulation was evident.

It should be mentioned here that during mid-season in the very dry year 1976 as well as in the years with sufficient moisture supply (1978 and 1979) soil mineral N was already ample at the 120 and 160 kg N rates of application per cut (Table 4).

Table 4. Trial 2.Quantity of mineral N (NO_3-N + NH_4-N) in the soil during late July/early August at three rates of nitrogen application in three selected years

Year	Soil layer, cm	N, kg ha^{-1} cut^{-1}		
		80	120	160
1976	0–25	10	141	300
	25–50	3	9	21
1978	0–25	25	55	186
	25–50	4	7	27
1979	0–25	28	70	210
	25–50	11	17	88

Nitrate content is related to age of herbage: the older the herbage the lower, in general, the nitrate content [13, 20, 27, 28]. With more favourable weather (which includes a temperature effect) growth is faster and herbage reaches earlier the stage 2 to 2.5 t DM per ha. The relationship between nitrate content and growth rate is shown in Figure 3b for the same NO_3-data as in Figure 3a. It appears that this relationship is similar to that of nitrate content and temperature but less close when the symbols marked 1–4 in Figure 3a are left out of the comparison.

It is notable that herbage nitrate was much higher in the autumn of 1976 (see Figure 1 and symbols marked 5 in Figure 3a) than in the other autumns. This may be connected with the preceding long, dry and hot summer of 1976 but is not well understood as the average air and soil temperatures of the autumn of 1976 were not different from those of 1975, 1977 and 1978. Only the growth rate was slightly higher, 61 kg DM per ha per day in the autumn of 1976 in comparison with 46–50 kg DM in the other years.

Unfortunately, the data of our trials do not permit definite answers as to the causes of the variation in herbage nitrate content within the different treatments. This variation is most likely caused by differences of morphological or physiological nature.

Concluding remarks

Our study has shown that considerable accumulation of herbage nitrate may occur at applications of nitrogen exceeding 400–560 kg N per ha per year, especially during growing periods with fairly high daily temperatures together with favourable soil moisture conditions. When applying the results to farm practice it is necessary to be aware of the differences – e.g. soil, sward age, animal manure – between cutting trials like ours and the farm situation. Because of the lower yield at cutting (2 to 2.5 t DM per ha) the nitrate contents of the grass from our trials cannot be compared directly with those of silage and hay, produced under normal farming conditions. Also slow drying in the field, with pre-wilted silage and hay, results in a general decrease in nitrate content [25]. Moreover during fermentation of low-dry-matter silage (containing less than 40% DM), the decrease in nitrate may be considerable [31]. Grass harvested from our plots is best compared with zero-grazing grass on the farm. In that case the critical value of 1.50% NO_3 [19] should be used. In our trials this critical value was not exceeded at applications of 80 kg N per ha per cut. However, at applications of 120 and 160 kg N per ha per cut, totalling 600–1120 kg N per ha per year, 19 and 47% of the samples exceeded 1.50% NO_3.

It may be worthwhile to examine in more detail the relationship between temperature and herbage nitrate content under conditions of ample nitrogen supply so as to be able to predict on the basis of weather recording whether risky nitrate accumulation can be expected.

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Chapter 8

Grassland productivity as affected by intensity of nitrogen fertilization in preceding years

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Summary

In three long-term nitrogen fertilization experiments with total applications of up to 1120 kg N per ha per year and cutting at a set stage of growth the productivity of all-grass swards was studied. The productivity was found to decrease with increasing rates of nitrogen application in the pre-treatment year(s). This decrease in productivity was associated with a deterioration of the sward as evidenced by a more open sward and a lower number of tillers. Annual applications of 400 to 480 kg N per ha were found to be a good compromise between yield and sward condition. The study showed that one-year experiments with very high nitrogen applications do not allow general conclusions as to long-term effects, because one-year experiments may give too optimistic a picture of the response to nitrogen.

Introduction

In one-year grassland experiments with very high nitrogen applications (over 500 kg N per ha per year) in combination with close and frequent cutting (every three to four weeks), dry-matter yields of about 18 tonnes per ha have been obtained in the humid temperate climate of Western Europe (Sibma & Alberda, 1980; Morrison et al., 1980; Prins et al., 1981b). However, under such a nitrogen and cutting regime the sward often becomes more open towards the end of the season (e.g. Prins et al., 1981b). There is evidence that with increasing rates of nitrogen application herbage mass increases, while depletion of plant reserves is stimulated and root mass is reduced. Eventually plant vigour may be affected and tiller numbers be reduced (Whitehead, 1970). Ennik et al., (1980) have re-

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viewed the direct and indirect effects of high nitrogen supply on sward deterioration. They found that thinning of the sward is caused to a large extent by poor regrowth following heavy cut(s) or by adverse weather conditions. This effect increases with increasing applications of nitrogen. The question arises whether the alteration in the sward may have a deleterious effect on future productivity. This would be in agreement with Sibma (1974), who suggested that the significant drop in yield in the second and third year of his trials was related to sward deterioration. The question is then to what extent the rate of nitrogen application can be increased without adversely affecting sward productivity.

During the periode 1974-1980 three long-term field trials were conducted to study several aspects of nitrogen fertilization of grassland. These trials offered the opportunity to study the effect of different intensities of nitrogen and cutting regimes in preceding years on the productivity of the sward in the following year.

This paper reports on the productivity studies in the years 1977 to 1980 after one or more pre-treatment years. Preliminary results of the year 1977 have already been published (Prins, 1978).

Materials and methods

Three long-term nitrogen fertilization trials were carried out (Table 1). Trials 1 and 2 were located on sown grassland on sandy and heavy clay soil, and trial 3 on old permanent grassland on clay soil. In the all-grass swards perennial ryegrass (*Lolium perenne* L.) was virtually the only grass species in trials 1 and 2, and the dominant component in trial 3.

The study of sward productivity included two periods: the so-called 'pretreatment year(s)' with different rates of nitrogen application, and the 'experimental year' with one rate of nitrogen application.

Pre-treatment year(s)

The trials comprised treatments with 40, 60, 80, 120 or 160 kg N per ha per cut during the pre-treatment year(s). Herbage was mown at a set stage of growth, namely when a dry-matter (DM) yield of 2 to 2.5 tonnes per ha was reached. Because of a faster grass growth at the higher rates of nitrogen, this technique meant that the frequency of cutting increased with higher rates of nitrogen ap-

Table 1. General data on trials.

	Trial 1	Trial 2	Trial 3
Registration number	IB 2146	IB 2244	IB 2259
Location	Finsterwolde (Gr)	Finsterwolde (Gr)	Ten Boer (Gr)
Grassland	1971-sown	1974-sown	old permanent
Soil	sandy	heavy clay	clay
Duration of trial	1974-1979	1975-1980	1975-1978

plication. The number of annual nitrogen applications ranged from 4 or 5 at the 40N (40 kg N per ha) rate per cut to 5, 6 or 7 at the 120N and 160N rates of application. The number of pre-treatment years varied from one to five (see also Table 2).

Experimental year
The treatments contained extra plots which could per experimental year be allocated for the productivity study. The extra plots were either available from the start of the trial, or were created by splitting plots into two halves, one half continuing to receive the treatment application, the other half to be used for the productivity study. Moreover, in a few cases plots which had been used for the study of residual effects (Prins et al., 1981a) were subsequently used for the productivity study. To determine productivity, these extra plots received in the experimental year a liberal amount of nitrogen, namely 120 kg N per ha per cut. The continuous 120N rate per cut, in pre-treatment and experimental years, served as a reference.

Productivity was determined by the difference in dry-matter yield between the 'productivity' treatments and the reference treatment. In the experimental year, herbage of the productivity treatments was mown at the same dates as the reference treatment in each trial.

A complicating factor might be the residual nitrogen, carried over from very high applications of nitrogen in the pretreatment period (especially on the clay soil; Prins et al., 1981a). To recognize possible interference from residual nitrogen, a number of extra plots with an extra dressing of 150 kg N per ha during winter, i.e. some weeks before the start of spring growth, were included in this study to provide a starter amount of mineral nitrogen in the soil to compensate for possible residual nitrogen.

Sward characteristics
Usually at the beginning and the end of the growing season, the botanical composition, the number of tillers and the stubble[1] weight were determined in approximately 25-cm^2 cores (De Vries, 1940). Per plot 25 cores were taken; with three replications in trial 1 and four replications in trials 2 and 3, this means a total of 75 and 100 cores per treatment, respectively.

General information
Nitrogen was applied as calcium ammonium nitrate (CAN, 26 % N), except in the cases of an extra dressing during winter which was applied as calcium nitrate (15.5 % N). Phosphate and potash were applied in adequate amounts ranging from 20 to 45 kg P_2O_5 and from 40 to 90 kg K_2O per ha per cut, mostly as compound fertilizer 0-15-30. The rate depended on the results of soil analysis. Plot sizes ranged from 12.5 to 30 m^2. Plots were harvested with a reciprocating mow-

[1] Stubble = residual herbage to 3 or 4 cm, except at the beginning of spring growth when some regrowth since the previous autumn was included.

er, which cut the herbage at about 3 to 4 cm above ground level. The fresh herbage from each plot was weighed and sampled for dry-matter determination.

Results

Productivity in Trials 1, 2 and 3 (1977-1980)

For a general picture it is best to compare the productivity of two extreme pre-treatments: 'low N' swards with an application of 40 kg N per ha per cut and 'high N' swards with an excessive application of 120 kg N per ha per cut. The application of 120 kg N was chosen as the reference because there were more productivity studies with this pre-treatment rate than with 160 kg N per ha per cut. The total nitrogen applications of the selected pre-treatments amounted to 160-200 and 600-840 kg N per ha per year, respectively, and were chosen as being representative of a dense and of a more open sward.

Comparison of A and B in Table 2 shows that the 'low N' pre-treated swards in Trial 1 produced distinctly more DM than the 'high N' swards and about the same in Trial 2. The difference in productivity between Trial 1 (sandy soil) and Trial 2 (heavy clay soil) may largely be due to differences in quantity of residual nitrogen in the soil (Prins et al., 1981a). As a result the negative effect on productivity of the more open sward of the 'high N' pre-treatment in Trial 2 might have been compensated by a positive effect of the residual nitrogen. This hypothesis is supported by the results in C and D in Table 2. 'Low N' as well as 'high N' swards received an extra 150 kg N per ha during winter to compensate for possible residual nitrogen. Without interference from residual nitrogen the productivity of the 'low N' swards was found to be higher than of the 'high N' swards on both sandy and clay soils.

Results of Trial 3 were generally in between those of the other trials. The negative effect of sward deterioration on clay soil would seem to be larger in Trial 3 on old permanent grassland than in Trial 2 with the selected grass cultivars.

It is notable that the 'winter' N application on the 'low N' sward increased yield by an average of 5 %, amounting to about 5 kg DM per kg 'winter N' applied (columns B and D in Table 2). Apparently the very early application of 150 kg N per ha before the first liberal dressing of 120 kg N per ha at the beginning of spring growth had a clear starter effect.

Productivity and sward characteristics, Trial 1 (1978)

For details as regards productivity per cut and sward changes during the experimental year we take a closer look at Trial 1 in 1978, considering all pre-treatment application rates. This trial gives the clearest picture because there was almost no interference from residual nitrogen and because the sward was virtually a monoculture of perennial ryegrass. The remaining grasses (up to about 10 % of the total number of tillers) consisted mostly of *Poa* species. The pre-treatments were 40, 60, 80 and 120 kg N per ha per cut since 1974 and 160 kg N per ha per

Table 2. Comparison of the productivity of 'high N' pre-treated swards (A, C) and 'low N' pre-treated swards (B, D). A, B without and C, D with an extra winter application of 150 kg N per ha before the start of grass growth in the experimental year. Yields expressed relative to reference treatment A (= 100).

					A	B	C	D	
Pre-treatment year(s)									
N ($kg\ ha^{-1}\ cut^{-1}$)					120	40	120	40	
Experimental year									
N ($kg\ ha^{-1}\ cut^{-1}$)					120	120	120	120	
Trial No	'Low N' pre-treatment year(s)	Experimental year	Number of cuts	DM yield of reference treatment A ($t\ ha^{-1}$)					
1	1976	1977	6	13.8	100	109	–*	117	
	1974-1977	1978	6	13.2	100	111	108	116	
	1978	1979	7	14.3	100	110	97	106**	
		Av.			*100*	*110*	*103*	*113*	*(111)****
2	1975-1976	1977	6	15.2	100	101	–	108	
	1975-1977	1978	6	16.0	100	97	99	104	
	1978	1979	7	13.5	100	108	98	110**	
	1979	1980	7	15.6	100	99	104	105	
		Av.			*100*	*101*	*100*	*107*	*(106)****
3	1975-1976	1977	6	12.8	100	117	–	122	
	1975-1977	1978	6	14.9	100	97	102	105	
		Av.			*100*	*107*	*102*	*114*	*(105)****
		Overall average			*100*	*106*	*102*	*111*	*(107)****

* No results because of absence of pre-treatment year with winter N application. The results presented in column C have been obtained after only one pre-treatment year with an extra winter N application.
** In these cases there were no 'low N' swards with 40 kg N per ha per cut present in the pre-treatment years. Therefore, 'low N' swards pre-treated with 60 kg N per ha per cut have been used (with pre-treatment years 1974-1978 in Trial 1 and 1976-1978 in Trial 2, respectively).
*** In parenthesis average of D excluding 1977, for better comparison with C.

cut since 1976. In 1977 the total pre-treatment applications amounted to 200, 360, 480, 720 and 960 kg N per ha, respectively. In the experimental year 1978 all treatments received $6 \times 120 = 720$ kg N per ha.

Fig. 1 shows the summation of DM yields per cut. The trend is clear: the lower the nitrogen application in the pre-treatment year, the higher the productivity as measured in the experimental year. The differences in total annual yield were in most cases due to the significant differences ($P < 0.01$) in yield of the first cut. In the other trials the yield of the first cut was also the most important in creating the differences in yield over the whole season. Generally, in 1978 the yield level in Trial 1 was below normal, mainly because of a severe dry, hot spell immedi-

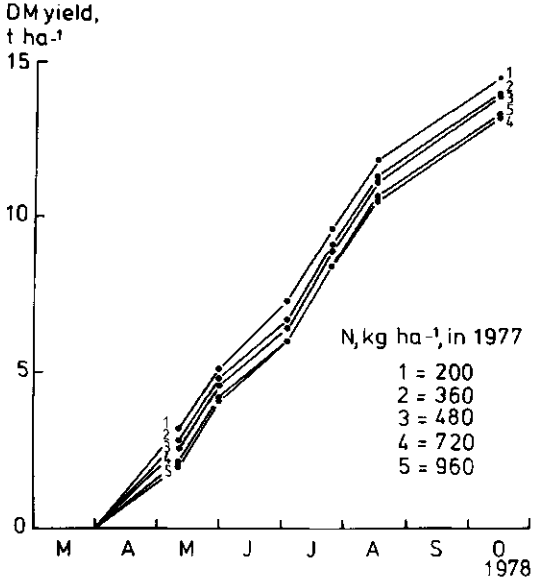

Fig. 1. Trial 1. Effect of intensity of nitrogen and cutting regime (5 times 40, 6 times 60, 80, 120 and 160 kg N per ha per cut) in 1977 on productivity in 1978, expressed as cumulative DM yields per cut at one rate of nitrogen application (120 kg N per ha per cut).

ately after cutting on 31 May. Reduction in grass regrowth in this period is reflected in the bend in the summation curves of Fig. 1.

The difference in productivity between the swards with different pre-treatment applications of nitrogen was associated with differences in sward characteristics.

Stubble weight per dm². The stubble weights were determined before the start of spring growth and immediately after the 1st, 3rd, 5th and final cut. At all times there was no significant difference in stubble weight per unit of area between swards with different nitrogen pretreatments, at least partly due to the large variation (Fig. 2).

Number of tillers. The number of tillers was determined before the start of spring growth (March) and immediately after the 1st, 3rd, 5th and final cut. Throughout the season, except after the final cut, the number of tillers in the swards with the lower pre-treatment nitrogen applications tended to be higher. Only in March, however, swards showed highly significant ($P < 0.01$) differences. From the number of tillers it would appear that under a very high nitrogen regime an initially 'low N' sward starts to resemble a 'high N' sward in the course of the season (Fig. 3). This statement is supported by the frequency distribution of the number of tillers per dm^2, which was very different in the 'low N' and 'high N' swards at the start of the season but became similar towards the end of the season (Fig. 4). The openness of the 'high N' sward is shown by the fact that up to 40 % of the samples contained between 0 and 40 tillers per dm^2.

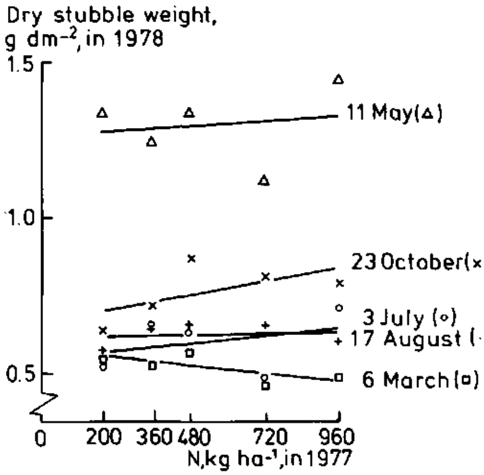

Fig. 2. Trial 1. Effect of intensity of nitrogen and cutting regime (5 times 40, 6 times 60, 80, 120 and 160 kg N per ha per cut) in 1977 on stubble DM weight per unit of area at the start of spring growth (March), the 1st, 3rd, 5th and last cut in 1978, at one rate of nitrogen application (120 kg N per ha per cut).

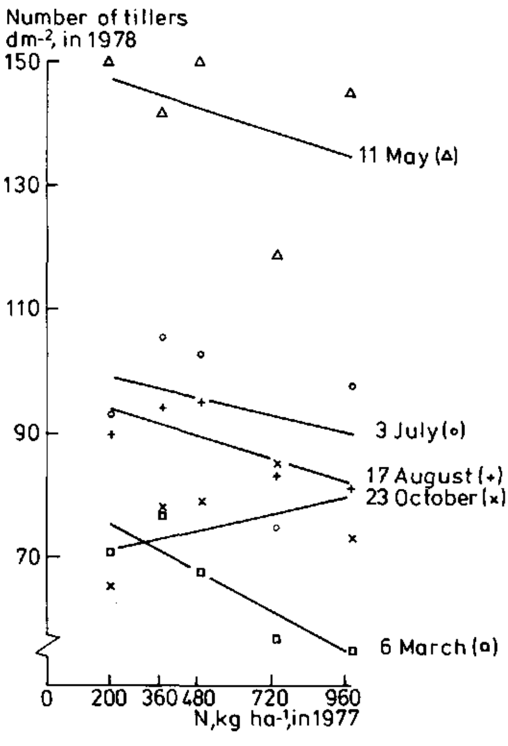

Fig. 3. Trial 1. As in Fig. 2 but now for the number of tillers.

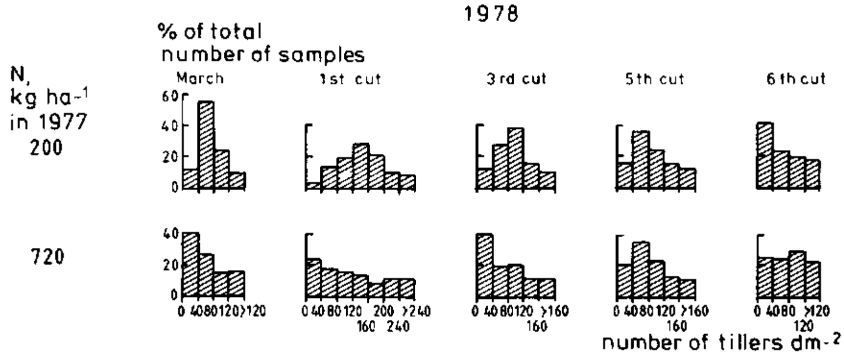

Fig. 4. Trial 1. Effect of pretreatment nitrogen application on 'low N' and 'high N' swards with 5 times 40 and 6 times 120 kg N per ha per cut in 1977, respectively, on the frequency distribution of the number of tillers in 1978 at one rate of nitrogen application (120 kg N per ha per cut).

Weight per tiller in the stubble. From the number of tillers and the stubble weight per dm² the weight per tiller in the stubble can be deduced (Fig. 5). Throughout the season, except after the last cut, the weight per tiller in the stubble increased significantly ($P < 0.05$) with increasing pre-treatment nitrogen applications.

The results of Trial 1 in 1978 show that the denser 'low N' swards produced more DM than the more open 'high N' swards, with the 'near-optimum N' swards taking a middle position. Moreover, the results show that a 'low N' sward subjected to a 'high N' regime will resemble a 'high N' sward already within one season.

Sward characteristics, Trial 3 (1978)

Results of percentage cover and number of tillers in the productivity study of 1977 on old permanent grassland have been presented earlier (Prins, 1978). At

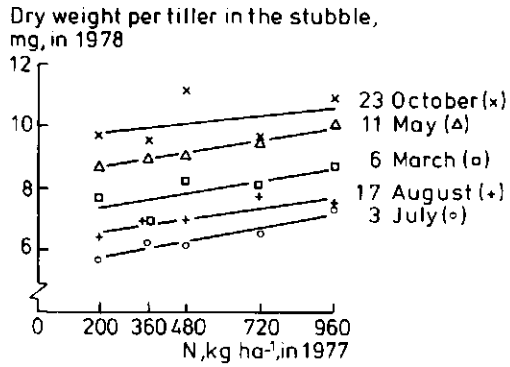

Fig. 5. Trial 1. As in Fig. 2 but now for the DM weight per tiller in the stubble.

Table 3. Trial 3. Changes in the number of tillers of *Lolium perenne* L. plus other species – mainly *Poa trivialis* L., *Poa pratensis* L., *Dactylis glomerata* L. and *Elytrigia repens* L. – and in parenthesis *Lolium perenne* L. only, under (a) a continuous regime of 40, 60, 80 or 120 kg N per ha per cut, and (b) a one-year regime of 120 kg N per ha per cut in experimental year 1978. The number of cuts per season was five (40 N rate in 1977 and 1978, and 60 N rate in 1977) or six (60 N rate in 1978, and 80 and 120 N rates in 1977 and 1978).

	a	b	a	b	a	b	a = b
Pre-treatment year 1977							
N (kg ha^{-1} cut^{-1})	40	40	60	60	80	80	120
Number of tillers dm^{-2}							
start of season	156 (58)	156 (58)	124 (63)	124 (63)	85 (65)	85 (65)	46 (34)
end of season	229 (77)	229 (77)	113 (62)	113 (62)	161 (107)	161 (107)	92 (57)
Experimental year 1978							
N (kg ha^{-1} cut^{-1})	40	120	60	120	80	120	120
Number of tillers dm^{-2}							
start of season	171 (63)	171 (63)	162 (89)	162 (89)	142 (94)	142 (94)	131 (51)
end of season	166 (50)	56 (34)	114 (54)	45 (23)	76 (40)	64 (34)	51 (20)

the end of 1977 there was no difference anymore in percentage cover and total number of tillers between the initially dense 'low N' sward and the reference 'high N' sward. It is interesting to complete the picture with the data on number of tillers in 1978 (Table 3). Under a continuous 'low N' regime of 40 kg N per ha per cut the number of tillers remained high. Under a continuous regime of 60 or 80 kg N per ha per cut the total number of tillers clearly remained higher than under the 'high N' regime of 120 kg N per ha per cut. However, when subjected to a 'high N' regime in 1978, the number of tillers in the different types of sward decreased, arriving at about the same number at the end of the year as in the 'high N' reference treatment. The decrease was due in particular to a decrease in number of tillers of species other than *Lolium perenne* (Table 3). These results agree with those of 1977 (Prins, 1978).

Discussion

Productivity

The results of the three long-term trials show that the productivity of moderately fertilized swards, with a history of 40 kg N per ha per cut and 4 to 5 cuts per season, is higher than that of swards, which have been fertilized excessively, i.e. with 600 kg N and more per ha per year. To our knowledge similar results have not been reported in the literature, presumably because productivities after different nitrogen regimes have never been compared directly.

Examples of European long-term experiments of at least three or four years duration to measure the response to fertilizer nitrogen up to very high nitrogen applications, each year on the same plots, are: Behaeghe et al. (1974, 1978), Garstang (1981), Hiivola et al. (1974), Huokuna & Hiivola (1974), Hnatyszyn

Table 4. Comparison of response to nitrogen, expressed as kg DM per kg N applied, in the first year and later years in Trial 1 (1974-1979), Trial 2 (1975-1980) and Trial 3 (1975-1978). In parenthesis comparable ranges of kg N per ha.

Trial 1	Year 1	19.0	(0-480)	2.2	(480-840)
	Year 2 + 4 + 5 + 6*	19.0	(0-500)	−0.2	(500-750)
Trial 2	Year 1	17.5	(0-480)	5.8	(480-840)
	Year 3 + 4 + 5 + 6*	23.6	(0-500)	2.3	(500-780)
Trial 3	Year 1	14.0	(0-400)	6.7	(400-720)
	Year 3 + 4*	15.4	(0-480)	2.5	(480-720)

* The year 1976 (year 3 in Trial 1 and year 2 in Trials 2 and 3) has been left out of the comparison because of exceptional drought.

(1975), Kreil et al. (1965), Morrison et al. (1980), Paris (1980), Reid (1970, 1972, 1978), Smith (1979). These experiments showed that, generally (Behaeghe et al., 1978; Hiivola et al., 1974; Hnatyszyn, 1975; Smith, 1979) or in many cases, the greatest response to nitrogen occurred in the first production year. Also in our long-term trials the first year gave generally the highest DM yields at the highest nitrogen applications.

The difference between the response to nitrogen in the first year and that in the following years (excluding the exceptionally dry year 1976) is illustrated in Table 4. It is notable that in the high nitrogen range the response to nitrogen, in comparison with that of the first year, was small or even negative in the following years.

In this paper we report on productivity from one season to the next. It has also been shown that a change in productivity may occur within one season (L. Sibma, personal communication; Prins et al., 1981b; Ennik et al., 1980). The latter demonstrated that 'sward deterioration was more serious and the grass less persistent the longer the period of nitrogen application and the higher the nitrogen application per cut'.

Sward characteristics

Herbage yield is the product of number of tillers and mass per tiller. It would appear that the larger number of tillers of the moderately fertilized swards, especially at the start of the season, was the main contributing factor to the increase in productivity over the excessively fertilized swards (Fig. 3, Table 3). Although the weight per tiller in the stubble was higher in the 'high N' sward, this does not seem to have had an important effect on productivity.

The mechanism of loss of tillers, meaning loss of persistence and productivity, is still poorly understood. Ennik et al. (1980) mentioned as factors which may be involved: (a) elevation of growing points above the cutting level; (b) exhaustion of carbohydrate reserves; and (c) decrease of root mass. Our results showed that the 'high N' swards are characterized by fewer tillers in comparison with the 'low N' swards (e.g. Table 3). Moreover, occasional pinboard determinations in our trials showed less root mass and shallower root depth in 'high N' swards than in 'low N' swards (J. Floris, personal communication). That changes in swards may take place rapidly was clearly demonstrated in 1974 in a one-year trial where under a 'high N' regime a substantial decrease in number of tillers and root mass already occurred in one season (Prins et al., 1981b).

Although we did not determine the carbohydrate content in the plants, we may deduce from the results of others (e.g. Deinum, 1966) that our 'high N' swards contained less carbohydrate reserves. The decrease in tiller numbers, root mass, root depth and carbohydrate reserves most likely led to the lower productivity of the 'high N' swards.

The results of our trials on clay soils suggest that the modern species in the sown sward of Trial 2 could withstand a 'high N' regime better than the species in the old permanent grassland of Trial 3. The latter had evolved in a period of over at least thirty years in an extensive farming system with low inputs. At certain times during the trial period we thought that the 'high N' sward of Trial 3 would not recover from the stress caused by the intensive nitrogen fertilization. It did so, however, be it that the botanical composition deteriorated through invasion of *Elytrigia repens* L. On the 'high N' plots of Trials 1 and 2 the swards became more open and less productive but these swards with modern cultivars never deteriorated to a similar extent as the old grassland of Trial 3. It would appear that for more intensive grassland management, inclusive of nitrogen fertilization, plant breeders have selected more persistent varieties than those present in the old permanent sward. The breeding of still more persistent varieties is one way of coping with the deterioration of the sward due to intensification. Ennik et al. (1980) described promising results in this field.

Effect of cutting and grazing management

Our results have been obtained in a specific system in the pre-treatment years, namely with cutting whenever a yield of 2 to 2.5 tonnes DM per ha had been reached. This meant cutting every 3 to 4 weeks in the case of the 'high N' regime with 120 or 160 kg N per ha per cut. In line with the findings of Ennik et al. (1980) it is expected that with fewer cuts per season, corresponding with higher yields per cut, deterioration of the sward would be greater than in our cutting regime. On the other hand, the results of our system may also differ from more frequent cutting, for instance every week, i.e. 28 times per season, as was done by Sibma & Alberda (1980). This regime kept the sward closed and green like a lawn even at applications of 800 kg N per ha (Ennik et al., 1980). Similar results were obtained by Bartholomew & Chestnutt (1977).

The continuous presence of an assimilating leaf area seems to be a prerequisite for keeping a dense sward with living tillers under a 'high N' regime such as is produced in practice in an intensive, continuous grazing system (Ernst et al., 1980). Our results are based on a cutting system which is quite different from systems with only grazing (especially continous grazing) or with grazing and cutting combined. This means that our findings cannot be translated directly into these other systems, although it has been reported that in a grazing trial 600 kg N per ha per year produced a more open sward than 150 kg N (Anon., 1974). The same was true in the case of 1000 kg N per ha per year in comparison with 150 or 300 kg N in a trial with a combined grazing-and-cutting system (D. J. den Boer, personal communication).

'Winter' N application
To determine whether the positive effect of the residual nitrogen on 'high N' plots on clay soil obscured the negative effect of sward deterioration, we applied an extra 150 kg N per ha to a number of 'low N' plots some weeks before the start of spring growth. Although we could not exactly duplicate the amount of residual nitrogen, it was remarkable how close we came to attaining the same level of mineral nitrogen in the soil profile with this 'winter' nitrogen. It would seem that part of this amount of nitrogen was taken up before the start of spring growth which is around the temperature sum of 200 °C (Jagtenberg, 1966). This could be deduced from the greening of the grass and from the grass growth, which was earlier on the 'winter N' plots than on the normal productivity plots.

'Winter N' application is not advisable in the Netherlands because of the risk of nitrogen losses before the temperature sum of 200 °C is reached (Postmus, 1976).

Conclusions

1. Our research has shown that in a system involving cutting every 3 or 4 weeks the sward increasingly deteriorates with increasing rates of nitrogen application, resulting in loss of productivity. At moderate nitrogen input (about 200 kg N per ha per year) the sward stays in good condition but yields are much lower than at higher rates of nitrogen application. In practice a compromise between dry-matter yield and sward condition has to be found. It would seem that, in a management system as used in the experiments, a total application of about 400 to 480 kg N per ha would give a good yield without serious deterioration of the sward. This has been achieved with the continuous treatment of 80 kg N per ha per cut in our three long-term trials.

2. One-year experiments may give too optimistic a picture of the response to nitrogen. In the first year of our long-term trials the DM yields continued to increase with increasing applications up to at least 720 kg N per ha per year. In subsequent years the response to nitrogen was less and the yield level lower. Therefore one-year experiments with very high fertilizer nitrogen applications do not allow general conclusions for long-term effects.

3. When the sward of a permanent grassland has become more open as the consequence of an intensive nitrogen regime the sward may be improved again by changing to a less intensive regime. This improvement may take place in one year (Prins et al., 1981a). The problem of a more open sward is to keep aggressive weed species out. When weeds invade a sward, costly reseeding is usually

necessary. However, this may give the opportunity to choose modern cultivars. Under a very intensive nitrogen and cutting regime the best policy may be to adopt a ley system of grassland farming instead of a system based on permanent grassland.

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Chapter 9

General discussion

To provide answers to questions regarding the effect of nitrogen fertilizer applications of 500, 600 or more kg N per ha, as applied on some dairy farms in the Netherlands around 1970, we have conducted short-term and long-term cutting trials. The research was geared towards seasonal response of grassland to nitrogen, productivity, sward quality, grass quality (nitrate) and soil mineral nitrogen status. These factors have been separately discussed in detail in the previous chapters; in this chapter all the factors will be considered together.

SHORT TERM: SEASONAL RESPONSE

The response to nitrogen appeared to be strongest in the first half of the season, gradually decreasing from July onwards (chapter 2). This agrees with Alberda and Sibma (1968) who found that the growth rate of grass only gradually decreases from beginning to end of the season. In many other experiments a strong response was found in the first cut whereas in the second cut the response appeared to be much less strong (e.g. Mulder, 1949; Garstang, 1981). The differences in response to nitrogen can partly be explained by differences in cutting regime. In our short-term trials, plots were harvested whenever a DM yield of about 2 t per ha had been reached, while with the other workers plots were cut on fixed dates.
Regrowth is especially slow to start after a heavy first cut (e.g. Brockman, 1966; Ennik et al. 1980; Garwood et al. 1980; Dawson et al. 1982). In such a system the yield curve shows peaks and troughs over a season. Cutting at fixed dates generally does not correspond with grassland use in actual farm practice and it is better to cut at a set stage of growth or production (chapter 2).

Whether grass is cut at a set date or at a set stage also affects response to nitrogen in terms of the total seasonal yield. This can be illustrated with Figure 1 (Prins et al. 1981) where relations are shown in quadrants as used by Frankena and De Wit (1958). With less frequent cutting DM yield per nitrogen dressing is higher and response per kg nitrogen applied is higher (quadrant II). This has been found often (e.g. Mulder, 1949;

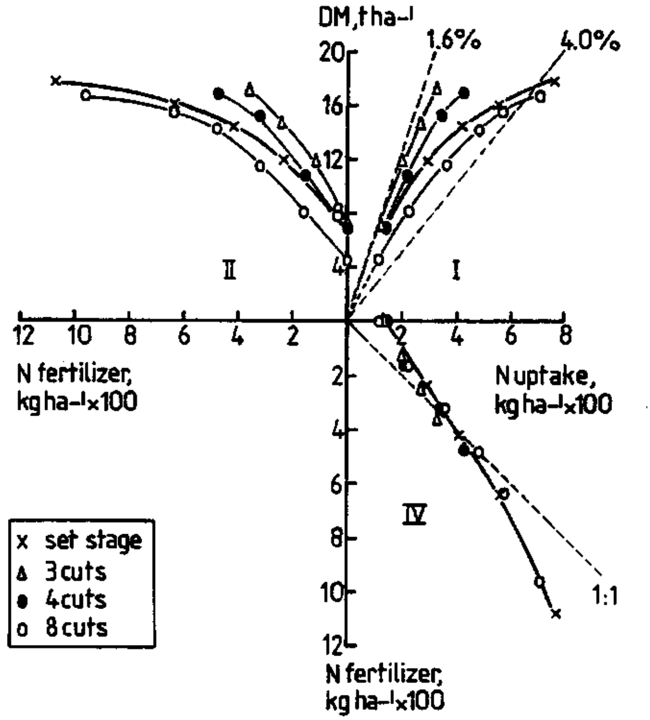

Figure 1. Relationship between nitrogen uptake and DM yield in quadrant I, nitrogen fertilizer and DM yield in quadrant II, and nitrogen fertilizer and nitrogen uptake in quadrant IV as affected by cutting at a set stage of 2 t DM per ha per cut and at three different fixed frequencies, viz. 3 cuts at 8-week interval, 4 cuts at 6-week interval and 8 cuts at 3-week interval. Thin dashed lines in quadrant I indicate the total N content of dry matter. Source: Short-term trial IB 2145, 1974 (Prins et al. 1981)

Cowling, 1966; Bartholomew and Chestnutt, 1977; Sibma and Alberda, 1980). Total herbage production increases with length of the growing period per cut and nitrogen is then used more efficiently (quadrant I). Cutting at a yield of 2 t DM per ha results in a response curve which is in agreement with the corresponding curves for the fixed frequencies, viz. beginning at the curve for four cuts and nearly touching the curve for eight cuts (quadrant II in Figure 1). It may be expected that the yield curve levels off at still higher rates of application than 1080 kg N per ha, but it is not known whether the yield would finally decrease. Sibma and Alberda (1980) and Bartholomew and Chestnutt (1977) found no yield decrease with nine and ten cuts at a cutting interval of three weeks and nitrogen applications totalling 1000 and 1500 kg N per ha, respectively.

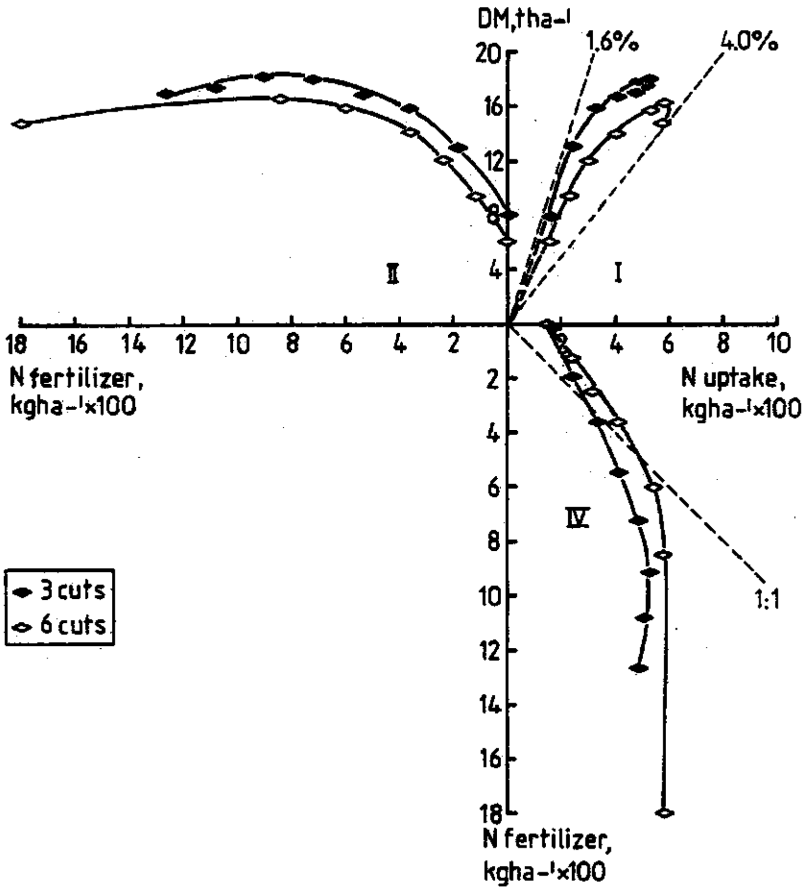

Figure 2. As Figure 1, but now for cutting at two fixed frequencies only.
Source: Short-term trial PR 641a, 1942 (Mulder, 1949)

With less frequent cutting generally a clear maximum yield is reached (Mulder, 1949; Kreil et al., 1968; Bartholomew and Chestnutt, 1977; Lee et al., 1977). This is illustrated in Figure 2 from Mulder's (1949) results with three and six cuts per season on a type of grassland comparable to that of Figure 1.

Results of cutting trials generally show that herbage production is roughly proportional to the input of fertilizer nitrogen up to rates of 300-400 kg N per ha per year and falls off only slightly at still higher rates up to 500-600 kg N per year (see examples in Van Burg et al. 1981). On good productive grasslands on mineral soils in the humid temperate climate of Western Europe maximum yields are reached from these rates up to 900 kg N (e.g. Mulder, 1949; Lee et al., 1977; Garstang, 1981) or even higher (e.g.

Le Clerc, 1976; Bartholomew and Chestnutt, 1977; Reid, 1978) rates per ha per year. Exceptions occur in dry years or with very infrequent cutting, as in the case of Bartholomew and Chestnutt (1977) who attained the maximum yield at 300 kg N per ha with only two cuts per season. It is noteworthy that Reid (1978) even with only three cuts did not reach a maximum yield in the first year as the response was maintained up to the highest application of 900 kg N per ha. A possible explanation is that within each frequency the cutting dates were decided on the basis of herbage growth stage and not exactly according to the calendar.

In contrast with cutting at set dates the number of cuts with cutting at a set stage of, say, 2 t DM per ha is determined by the rate of nitrogen application. At higher rates the number of cuts increases, to a large extent because a shorter period is needed to reach full cover at about 1.5 t DM per ha. This is illustrated in Table 1 which shows that with 80 kg N per ha for each cut it took six days less than with 40 kg N to reach full cover. After reaching full cover growth continued to be faster at 80 kg N: a further two days were gained in reaching 2 t DM per ha (Prins et al. 1981).

Table 1. Effect of rate of nitrogen application per cut on number of days to reach full cover (about 1.5 t DM per ha), as read from growth curves of trial IB 2145 of 1974 (chapter 2), excluding the last cut

40 kg N $ha^{-1}cut^{-1}$				80 kg N $ha^{-1}cut^{-1}$			
cut no.	period	no. of days		cut no.	period	no. of days	
1	10.3-27.4	47		1	10.3-21.4	41	
2	6.5-26.5	20		2	26.4-11.5	15	
3	4.6-29.6	25	22	3	20.5- 8.6	19	
4	8.7-28.7	20		4	17.6- 2.7	15	16
5	5.8-28.8	23		5	8.7-22.7	14	
				6	26.7- 9.8	14	
				7	14.8- 1.9	18	

SHORT TERM: SWARD QUALITY

It was found that the sward became more open during the season as nitrogen applications increased (chapters 2 and 3). This can be illustrated by trial IB 2145 where in early September the number of tillers with 240 kg N per ha after five cuts and with 1080 kg N after eight cuts at the beginning of regrowth for the last cut was 215 and 81 per dm^2, respectively. It was remarkable that the number of *Lolium perenne* tillers was about the same, viz. 66 and 56. The large difference originated from the disappearance of species other than *Lolium perenne* from the old permanent grassland. (Prins et al. 1981). It is notable that in other experiments the number of *Lolium perenne* tillers also decreased (chapter 8).

The sward also changed when cut at set dates: with less frequent cutting the sward became more open and this was aggravated by heavier cuts through higher nitrogen applications (Prins et al. 1981). Similar results were reported by Wilman et al. (1976), Bartholomew and Chestnutt (1977) and Alberda and Sibma (1982). The effect of nitrogen may be explained as follows: Nitrogen stimulates tillering (Whitehead, 1970) whereas a heavy crop reduces the number of tillers (Ennik et al. 1980). As nitrogen dressings are increased the growth rate increases and higher DM yields are reached within a specific growing period. The longer the growing period, the heavier the crop and the greater the reduction in tillers. Wilman et al. (1976) studied these effects in a trial in which up to 525 kg N per ha was applied. They found a negative interaction between level of nitrogen and interval between harvests on the number of tillers, the number of tillers being increased by nitrogen with short intervals and tending to be reduced with long intervals. Tiller death was associated with intense shading in a heavy crop, low residual leaf area in the stubble and depletion of carbohydrate reserves after harvesting, or by hot and dry conditions (Wilman et al. 1976), or by decapitation of growing points and poor root development (Ennik et al. 1980). Moreover, there would seem to be some specific negative effect related to nitrogen, as was noted in the response to nitrogen at the end of the season in chapter 2. The specific effect has also been mentioned by Ennik et al. (1980) and can be seen in Figure 3 where at similar total DM yields within one cutting frequency the sward became more open as the rate of nitrogen increased. However, very frequent cutting may counteract the adverse effect of very high

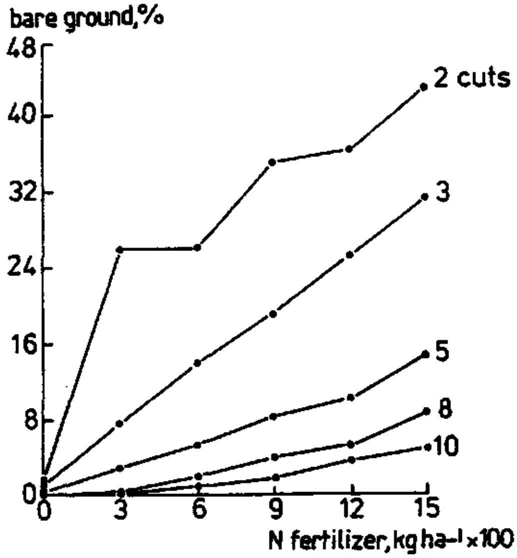

Figure 3. Effect of nitrogen fertilizer and cutting interval treatments on proportion of bare ground on plots (early November). Cutting intervals with decreasing number of cuts were: 22, 28, 45, 75 and 112 days, respectively. Copied from Bartholomew and Chestnutt (1977)

nitrogen applications by maintaining green leaf area. This was shown by Sibma and Alberda (1980) who kept a sward dense and green with weekly cutting, i.e. 28 times per season, and a total application of 1000 kg N per ha.

SHORT TERM: PRODUCTIVITY

Although there are results suggesting that with infrequent cutting a more open sward does not necessarily need to be less productive (Smith, 1982), there is evidence that denser swards have a higher productivity (Sibma, personal communication). The productivity was found to decrease towards the end of the season in our short-term trials after intensive nitrogen fertilization in spring and summer (chapters 2 and 3). This decrease in productivity was associated with a change in sward quality. This is in agreement with Gately et al. (1972) who found a negative response to nitrogen at the end of the season at the highest rate applied (672 kg N per ha per year), which they associated with bare patches in the plots.

In a short-term trial Alberda and Sibma (1982) manipulated sward density with different cutting frequencies in the first and second half of the season at different nitrogen applications. They were able to restore sward density within one season by a temporary increase in the cutting frequency from a six-weekly to a two-weekly scheme. They concluded that a sward can be kept in good condition either by a low nitrogen regime or by a high cutting frequency.

LONG TERM: SWARD QUALITY AND PRODUCTIVITY

The foregoing results were obtained in periods lasting at most one season. It is interesting to study the possible changes in sward quality and productivity over a period of years. Our long-term trials with cutting at 2 to 2.5 t DM per ha showed a decrease in annual productivity of about 1 to 1.5 t DM per ha after a pretreatment with 120 kg N compared with 40 kg N per ha per cut (chapter 8). This decrease was associated with a smaller number of tillers in the high-N pretreated sward. To our knowledge similar results of decreases in productivity have not been reported in the literature, presumably because productivities after different nitrogen regimes have never been directly compared.

In our long-term trials, the highest rate of nitrogen applied gave the highest yield in the first year but, in subsequent years, this was seldom the case and maximum yields were usually lower.
Productivity was often found to decrease after the first year in long-term trials with a fixed cutting frequency (see examples in chapter 8). Sibma (1974) has investigated the effects of an average application of 560 kg N per ha over four years on a newly sown trial on arable land. He related the decrease in DM production from 20.4 t DM per ha in the first year to 15.5, 14.7 and 18.4 t in the following years to some form of sward deterioration.

Few results of trials with different fixed cutting frequencies and nitrogen applications lasting more than one year have been reported. Wilman et al. (1976) found that the negative interaction between level of nitrogen (up to 525 kg N per ha per year) and interval between harvests (up to 10-week interval) became larger in the second and third years than in the first: the positive effect of nitrogen on number of tillers in the short intervals took some time to become fully established and the negative effect of nitrogen in the long intervals was to some extent a cumulative effect. Reid (1978) found a greater response to nitrogen and higher DM yields in the first year in comparison with the second and third years, which agrees with the results of our long-term trials. He noted that in the second and third year, just as in the first year, the DM yield and response to nitrogen decreased with more frequent cutting while the yield curve continued to climb as nitrogen applications increased. The decrease in response to nitrogen after the first year with three cuts per year was related to a reduction in the density of ryegrass plants at and above nitrogen rates of 300 kg per ha. With five cuts per year thinning of the sward was noted at the highest nitrogen rates only and no thinning was recorded with ten cuts per year. Increasing the number of cuts per year from five to ten decreased the total DM yield considerably and reduced the yield response to nitrogen (Reid, 1978).

In practice a compromise has to be found between dry-matter yield and sward quality. It would seem that, in a management system of cutting about every three or four weeks, a total application in the range of 400 to 500 kg N per ha would give a good yield with little deterioration of the sward. This has been achieved in our three long-term trials with continuous treatment at 80 kg N per ha per cut, but also with the treatment starting with 120 kg N and finishing with 60 kg N per ha (see Annexes 3-5).

A general picture of the differences between short-term and long-term trials with cutting at a set stage is given by Figure 4 which shows the average first year and average last two years of our three long-term trials [1]) The 'long-term curve' in quadrant II declines strongly at just over 400 kg N while the 'short-term curve' shows a comparatively slight decline in response above this rate. To establish a link with our previous short-term trials (chapter 2) the highest DM yield of Figure 1 has been included in Figure 4. Figure 4 shows that the limit to nitrogen fertilization as regards DM yield (quadrant II) and efficiency of utilisation of the nitrogen taken up (quadrant I) is clearly lower in long-term trials than in short-term trials. Our research has shown that one-year trials may give too optimistic a picture of the response to dressings higher than 500 kg N per ha and it has indicated once again that one-year trials do not allow general conclusions as to long-term effects.

[1]) The last two years have been chosen to exclude the exceptional dry year 1976 and in order to take an equal number of years from each trial

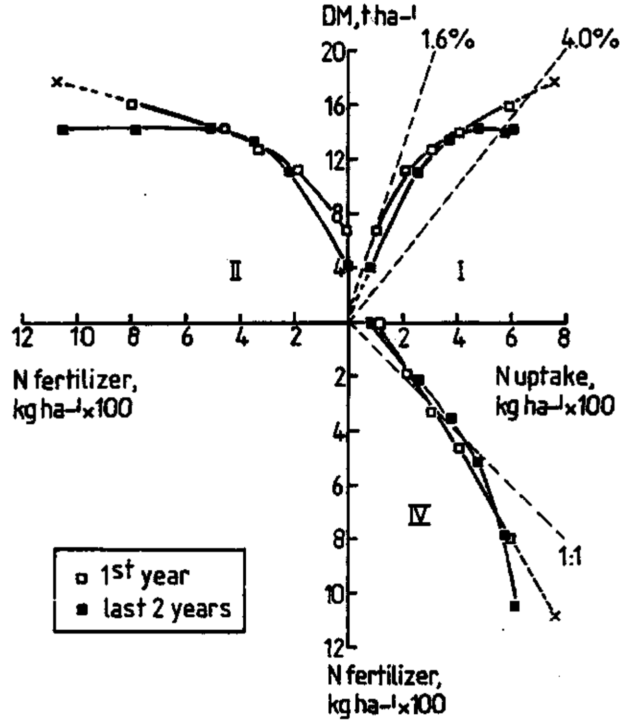

Figure 4. As figure 1, but now for cutting at a stage of 2 to 2.5 t DM per ha per cut in the first year and last two years of the long-term trials IB 2146: 1974 and 1978/79, IB 2244: 1975 and 1979/80 and IB 2259: 1975 and 1977/78, respectively. Point x corresponds with the extreme point x in Figure 1

EXCESS NITROGEN

Up to now we have discussed limits to nitrogen application as regards DM yields and sward quality. When looking at quadrant IV of Figures 1, 2 and 4 we see that at low applications of nitrogen the amount removed in the harvested herbage is higher than the amount applied. At higher rates of nitrogen the situation reverses and it is then that the nitrate content of the herbage may increase and mineral nitrogen may accumulate in the soil.

It is notable that the crossing of the 45^0-line in quadrant IV occurs earlier, i.e. N-recovery is lower, with fewer cuts per year (Figures 1 and 2). Evidently more frequent cutting encourages a greater uptake of applied nitrogen in the herbage than does less frequent cutting. This is in agreement with the findings of Dilz and Woldendorp in ^{15}N trials (Woldendorp, 1963). They have shown that with less frequent cutting, i.e. with longer growing periods, more of the applied nitrogen was retained in the roots and less in the herbage than with more frequent cutting.

Herbage nitrate

The general trend is that nitrate accumulates strongly in the herbage at rates of nitrogen application above a certain level. At the point where the yield response to nitrogen starts to level off (quadrant I in Figures 1, 2 and 4), nitrogen uptake continues to rise, total nitrogen content increases and more and more is accumulated in the herbage in the form of nitrate.

In our research we paid special attention to the effects of cutting frequency, but no general differences were noted (Figure 5). The literature is conflicting on this point: There are reports of both higher (Bartholomew and Chestnutt, 1977) and lower (Alberda and Sibma, 1980) nitrate contents with increasing cutting frequency. The conflicting results may be connected with effects of nutrients other than nitrogen, morphology of the crop, DM yield, weather conditions (Darwinkel, 1975).

When short-term and long-term trials, in which herbage is cut at a stage of 2 to 2.5 t DM per ha, are compared a difference in nitrate accumulation is apparent (Figure 6): The short-term trials and the first years of the long-term trials tend to show less accumulation at the same total N uptake, especially when over 500 kg total N per ha is taken up. This effect is most probably caused by the difference in DM yields and nitrogen efficiency in first years as compared with later years, see quadrant I in Figure 4. It should be noted that the first years of our trials were on swards older than one year, exept for one case (see chapter 7), so no effect of sward age, as found by Darwinkel (1976), is to be expected. It is interesting that in Figure 6 the group of points representing the very dry year 1976, where half the nitrate accumulation was caused by the increase in nitrate contents in the last cut, is well separated from the rest. The DM yield of the last cuts was about one quarter of the generally low total DM yield. Very high nitrate concontents in the autumn of 1976 have also been reported by Sibma and Alberda (1980).

The relationship between total N uptake and nitrate accumulation would seem to be curvilinear according to Figure 6. This conclusion can also be drawn from a figure presented by Kemp (1982) but it is not in line with Darwinkel

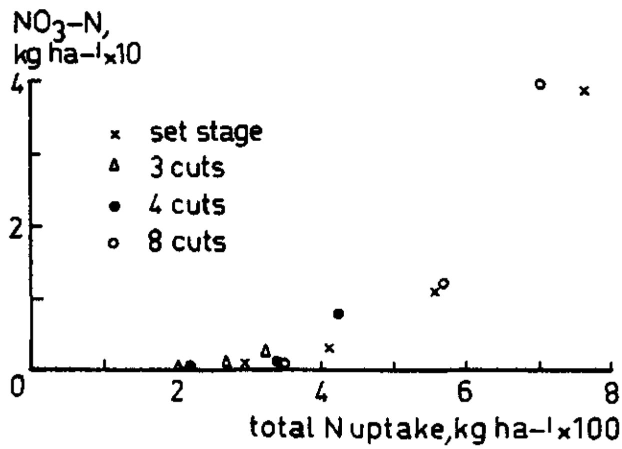

Figure 5. Relationship between total nitrogen uptake and NO_3-N yield for cutting at a stage of 2 t DM per ha per cut and at three different fixed frequencies, viz. 3 cuts at 8-week interval, 4 cuts at 6-week interval and 8 cuts at 3-week interval.
Source: Short-term trial IB 2145, 1974 (Prins et al. 1981)

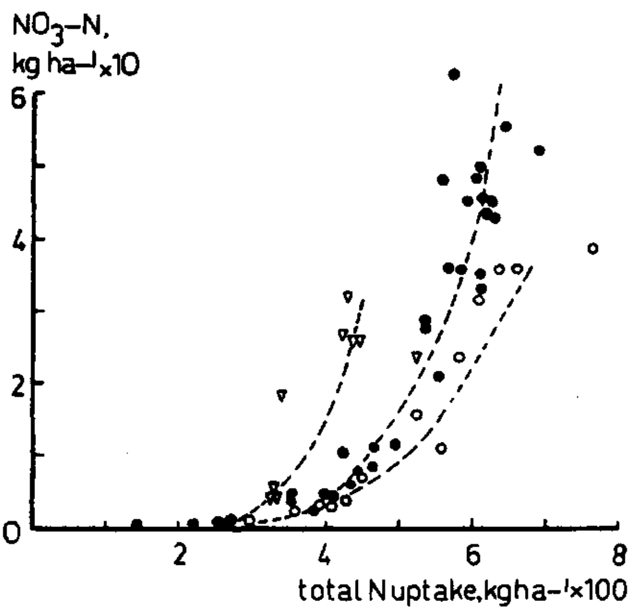

Figure 6. Relationship between total nitrogen uptake and NO_3-N yield for short-term and long-term cutting at a stage of 2 to 2.5 t DM per ha per cut.
o = short-term; ● = long-term, excluding 1st year and 1976; ∇ = long-term, 1976 only

(1975) who found the relationship to be almost linear. A comparison with Darwinkel is difficult because his results applied to the first cut of newly sown grass and his ratio of total nitrogen uptake to nitrate accumulation differed greatly from ours.

Soil mineral nitrogen

When more nitrogen is applied than removed the chance of accumulation of mineral nitrogen in the soil increases. In our short-term trial with cutting at 2 t DM per ha, there was no accumulation of mineral nitrogen in the soil with 60 kg N per ha per cut at a total application of 420 kg N per ha (chapter 4). However, in that same trial cutting at a fixed frequency would seem to result in accumulation at a slightly lower level of nitrogen application (Figure 7). This difference cannot be explained by the present data.

In the long-term trials the level of soil mineral nitrogen increased following total applications exceeding 400 kg N on old permanent grassland with about 14% organic matter and exceeding 480 kg N on young grassland, established after arable cropping, containing about 3 to 5% organic matter (chapter 4). These

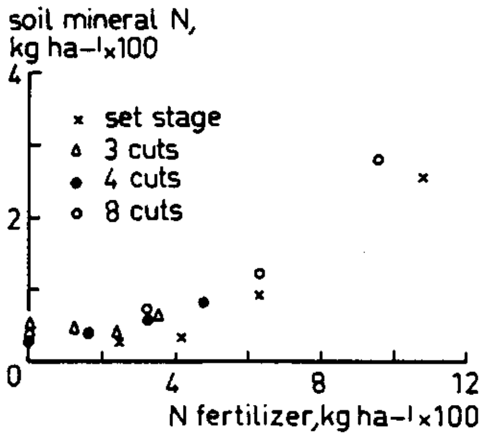

Figure 7. Relationship between nitrogen fertilizer application and soil mineral nitrogen status (0-50 cm layer) at the end of the season with cutting at a set stage of 2 t DM per ha per cut, (sampling date 3 October) and at three different fixed frequencies, viz. 3 cuts at 8-week interval, 4 cuts at 6-week interval and 8 cuts at 3-week interval (sampling date 30 September).
Source: Short-term trial IB 2145, 1974 (Prins et al. 1981)

levels were determined with equal rates of nitrogen per cut throughout the season. According to our data, such a system seems to lead to a slightly higher accumulation of soil mineral nitrogen than a system in which the same total amount of nitrogen is applied, but at rates that decrease in the course of the season.

Our results on permanent grassland may be compared with other results in the Netherlands. Little or no accumulation occurred in experiments on permanent grassland of intensive farms at a total dressing of 300 kg N per ha but accumulation was evident at the next higher total dressing of 500 kg N per ha per year (H.G. van der Meer, personal communication). Elsewhere on permanent grassland on well-drained peat soil accumulation was recorded at total dressings of 300 and 600 kg N per ha in most years whereas with dressings of 1000 kg N excessive accumulation occurred in all years since recording started in 1978 (D.J. den Boer, personal communication).

On young grassland in the first two years of a trial on clay soil in the Flevopolder mineral nitrogen did not accumulate in the soil towards the end of the season even at rates of 600 kg N per ha. However, in the third and fourth year accumulation occurred at this rate of application. This coincided with the lower level of DM yield and herbage nitrogen yield in these years (H.G. van der Meer and L. Sibma, personal communication). Our results on young grassland may also be compared with the results of Morrison et al. (1980) in the U.K. with young grassland. They could not detect an increase in mineral N in the soil profile in autumn over the control treatment at rates of 150 and 450 kg N per ha; it was only at 750 kg N per ha that increases in mineral N were apparent. Such differences were not evident at the time of their subsequent spring sampling.

In the Netherlands, after a winter with a precipitation surplus, the accumulated mineral nitrogen either disappeared on light sandy soils (Prins and Postmus, unpublished results) or partly remained in the profile but less so on slightly loamy sand than on heavy clay (chapter 5). The mineral nitrogen remaining partly explained the residual effects from one season to the next (chapters 5 and 6).

'OPTIMUM' NITROGEN APPLICATION

The discussion above relates to nitrogen fertilizer requirements for maximum

DM yield. It is more important to know the limit above which the yield increase does not pay for the nitrogen input. This is different for each farming system and it is difficult to provide a general recommendation. An estimate can be made by assuming a certain marginal profitability. Over all 16 trial-years of our long-term trial the 'optimum' nitrogen application at an assumed marginal profitability of 7.5 kg DM per kg applied N was 420 kg N per ha, ranging from 360 to 520 kg N (Annex 6). This 'optimum' is higher than the value near 300 kg N per ha found by Van Steenbergen (1977). The shape of his response curves may, however, be affected by the fairly fertile conditions in his trials, the unfertilized plots yielding on average 226 kg N per ha per year.

Morrison (1980) and Garstang (1981) arrived at 'optimum' applications of 386 and around 450 kg N per ha, respectively, at a higher marginal profitability of 10 kg DM per kg N applied. Reid (1972) came to higher 'optimum' applications, viz. 450-500 kg N per ha per year, but he reckoned with a marginal profitability of only 5 kg DM per kg N applied.

All these results were reached under a cutting management without field periods and without grazing. There are reports in the literature that the response to nitrogen under a cutting management is larger than under grazing (Boxem, 1973; Jackson and Williams, 1979). On the other hand, there is ample evidence that the response may be similar up to at least 400 kg N per ha on sand and clay soils (Boxem, 1973; Richards, 1977; Thompson and Baker, 1982). The problem with cutting trials is what corrections are necessary to translate the results to practical conditions which include grazing.

The over-all results of the study of the different factors in our long-term trials are summarized in Figure 8. It is remarkable how the above-calculated 'optimum' nitrogen application of 420 kg N per ha based on DM production is so near the limits for herbage nitrate and soil mineral nitrogen accumulation. The limit is also near the present General Recommendations in the Netherlands for grasslands on sand and clay soils, which are based on applications of up to 80 kg N per ha for each grazing cycle and up to 120 kg N for each mowing, totalling, on average, about 400 kg N per ha (Wieling, 1981).

'OPTIMUM' NITROGEN AND HERBAGE NITRATE RISKS

The 'optimum' N application on productive grassland on sand and clay soils as shown in Figure 8 carries little risk of nitrate poisoning to dairy cattle

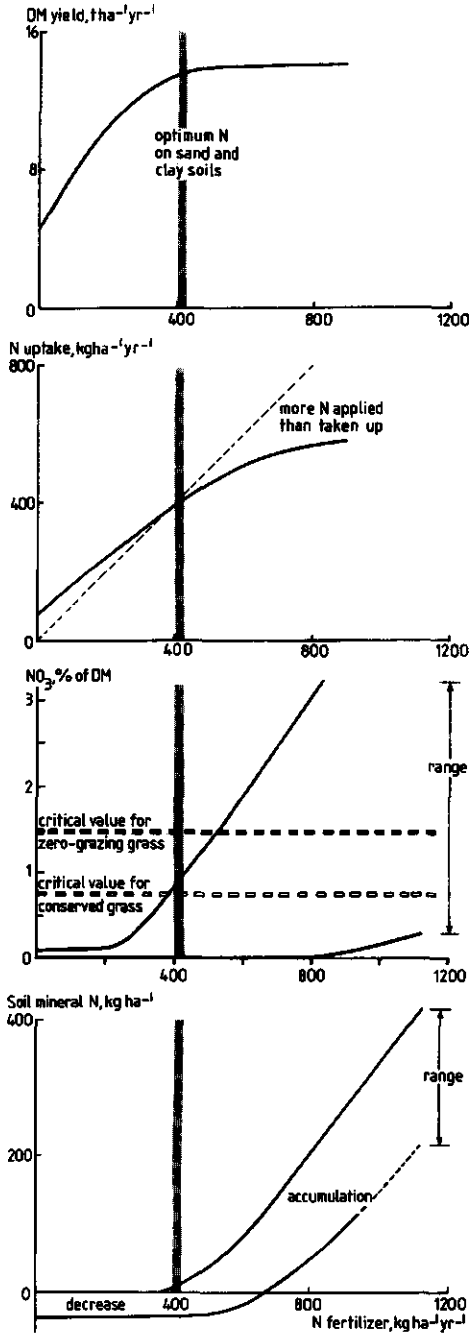

Figure 8. Limits to nitrogen fertilizer on grassland as shown by the relationship between fertilizer nitrogen application and DM yield, herbage nitrogen uptake, herbage nitrate content and soil mineral nitrogen accumulation from beginning to end of the season, respectively.
Source: Three long-term trials on sand and clay soils during 1974-1980

(chapter 7). It is notable that at nitrogen dressings similar to those applied to sand and clay soils, the risks will be greater on well-drained peat soils or on newly sown grassland where a considerable amount of animal manure has been added, because of the supply of nitrogen from the soil and the manure, respectively. Under these conditions the fertilizer nitrogen dressings must be adjusted to these nitrogen supplies.

In connection with Figure 8, the risk when nitrogen supply is supra-optimal is greatest with conserved grass, followed by fresh stall-fed grass (Kemp, 1982). When grass is expected to have a high nitrate content the best policy is to have it consumed at pasture, in view of the favourable experiences in grazing trials (Behaeghe and Carlier, 1973; Phipps, 1975; Coombe and Hood, 1980; Den Boer, 1980 and D.J. den Boer, personal communication). Aside from risks to the animal the risk of accumulated nitrate in the milk for human consumption should also be considered (Kemp, 1982).

'OPTIMUM' NITROGEN AND SOIL MINERAL NITROGEN LOSSES

As in the case of herbage nitrate the 'optimum' nitrogen application involves little risk of soil mineral N accumulation and thus of environmental pollution (Figure 8). When more N is applied than is taken up leaching losses may endanger the groundwater. Our results with residual nitrogen from one season to the next (chapter 5) imply that when nitrogen is applied in excess of crop requirements more environmental harm may be done on sandy soil than on clay soil.

In the case of over-use of nitrogen on heavy soil the residual nitrogen has to be taken into account in the following year. However, the problem at present is that the farmer is not aware of any available mineral nitrogen in his soil even though the amounts in spring may vary up to 25 - fold (Leusink, 1981; Van der Meer; 1982a). Even if he were, this knowledge would not affect his management because research has shown that this nitrogen can be used by the grass, though it cannot be predicted at what stage in the season (chapters 5 and 6; H.G. van der Meer, personal communication). On well-drained soils a good relationship has been found between the amount of soil mineral and soil mineralizable nitrogen in early spring plus the amount applied as fertilizer nitrogen and nitrogen uptake by the grass (Van der Meer, 1982b). Research should be directed towards the value of mineral and mineralizable nitrogen in the soil in relation to the response to applied nitrogen so as to be able to better define the nitrogen requirement per cut.

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Chapter 10

Summary

1. Around 1970, nitrogen fertilizer dressings higher than the recommended 350 to 400 kg N per ha per year were sometimes applied to grassland dairy farms on sand and clay soils in the Netherlands. The question arose as to what effect such high dressings would have on the seasonal response to nitrogen, on sward quality and productivity as determined by dry-matter yields per cut and per year, on herbage nitrate content and on soil mineral nitrogen status. The effects of extremely high dressings were studied in short-term and long-term cutting trials, harvested at a yield of approximately 2 to 2.5 t dry matter per ha per cut.

2. The seasonal response to nitrogen was studied in seven short-term trials at different levels of nitrogen pretreatment, ranging from 240 to 1080 kg N per ha per year. Attention was paid to methods of measuring the response, i.e. whether plots should be harvested according to a fixed cutting scheme or at a defined stage of production or growth. The first method gives information mainly about the effect on yield, whereas the second method gives an idea of the growth rate and thus of the days gained by applying nitrogen, which is more relevant to actual farm practice.

The response to nitrogen was strongest in the first half of the season and decreased with increasing level of nitrogen pretreatment. This decrease was associated with the residual effect of previously applied nitrogen. The variation in nitrogen response was considerable and was related to locations and years. At a fertilization level of 40 kg N per ha per cut there was at the end of the season a positive response to nitrogen up to a dressing of 120 kg N per ha. But at a much more intensive fertilization level there was little or no response and an application of 120 kg N could even give a negative response. At such a high level the sward had become more open.

Finally, the 'optimum' rate of nitrogen application for each cut was calculated, at an assumed marginal profitability of 7.5 kg dry matter per kg N applied. From the second cut onwards, this presented difficulty because the possible supply of nitrogen from residual nitrogen as well as the cutting regime had to be taken into account.

3. Residual nitrogen may be present in the plant in stubble and roots, and in the soil as mineral nitrogen or temporarily immobilized. The residual effect of previously applied nitrogen was studied in detail in short-term trials on clay soil at different levels of nitrogen fertilization. The residual effect was most apparent when the regrowth was not fertilized with nitrogen since a fresh application obscured the residual nitrogen. In this study the sward with a pretreatment of about 200 kg N per ha showed a higher productivity towards the end of the season than the swards pretreated with an application over 500 kg N. Moreover the level of soil mineral nitrogen appeared to be higher after the higher than after the lower pretreatment.

4. Soil mineral nitrogen under old permanent grassland was monitored throughout the season. Under the system in which cuts were taken at the stage of 2 t dry matter, soil mineral N remained constant when 60 kg N per ha was applied at each cut (420 kg N per ha per year). At higher rates of N application, the level rose: at 80 kg N per cut accumulation started in August after six applications, while at 120 kg per ha accumulation started as early as May after two applications. On the basis of accumulation of mineral nitrogen in the soil it was possible to estimate the right pattern of fertilization through the season. Over successive growing seasons accumulation occurred on old permanent grassland with split applications of nitrogen totalling more than 400 kg N per ha per year and on young grassland, sown after arable crops, with applications of more than 480 kg N per ha per year. The relationship between the annual nitrogen application minus nitrogen uptake (N_{EXC}) and the mineral nitrogen accumulation in the upper 50 cm of soil from beginning to end of the season could be described by an hyperbolic equation.

5. When N was applied at 480 or more kg per ha, approximately 25, 40 and 50% of N_{EXC} was recovered in the following spring as accumulated mineral nitrogen in the 0-100 cm layer of slightly loamy sand, clay and heavy clay soils, respectively. N_{EXC} had no effect on dry matter yield or nitrogen yield on the sandy soil but it had a distinct effect on the clay soils. On the clay soils 1 kg N_{EXC} from the previous year gave 8 kg dry matter as a residual effect, while each kg soil mineral nitrogen, still present in the subsequent spring, produced 15 kg dry matter. Assuming a relatively small contribution from residual nitrogen carried over in stubble, roots and organic matter, the accumulated soil mineral nitrogen would seem to be as effective as freshly applied fertilizer nitrogen.

6. Soil residual effects have been found to persist for two years on heavy clay soils. Over three pretreatment years N_{EXC} had increased to 941 kg N per ha. N_{EXC} was reflected in accumulation of mineral nitrogen in the soil. At the beginning of the first residual year the soil contained 314 kg mineral nitrogen against the reference treatment 21 kg N. The residual effect was evident at every cut, and over the whole growing season the increase in yield over the reference treatment was 6 t dry matter and 199 kg N per ha. By the end of that year the accumulated soil mineral nitrogen was nearly depleted. Although no difference in soil mineral nitrogen could be detected in the second year, there was still a residual effect on herbage yield of 1.1 t dry matter and 21 kg N per ha.

7. The nitrate content of the harvested herbage was determined at every cut. In the long-term trials at applications of 60 kg N per ha per cut, with a maximum of 360 kg N per ha per year, there was little or no increase in nitrate content. At applications of 80 kg N per cut, totalling 400-560 kg N per ha per year, 3% of the samples had nitrate contents higher than 0.75% NO_3. At applications of 120 and 160 kg N per cut, totalling 600-1120 kg N per ha per year, 61 and 67% of the samples exceeded 0.75% NO_3 while 19 and 47% of the samples even exceeded 1.50% NO_3. Of all 44 first-cut samples only one had a content higher than 0.75% NO_3. Nitrate accumulation mostly occurred in summer grass and seldom in autumn grass. Under favourable soil moisture conditions there was a positive relationship between herbage nitrate content and temperature. In warm but dry periods there was no relationship and nitrate contents were low.

8. With increasing rates of nitrogen application but especially after applications totalling about 500 kg N and more in preceding years, productivity was lower in the subsequent year. This decrease in productivity was associated with changes in sward characteristics such as a decrease in percentage cover and in number of tillers. As a consequence of the change in productivity the response to nitrogen in the first year of the long-term trials (up to at least 720 kg N per ha per year) differed from that in subsequent years. The study showed that short-term trials may give too optimistic a picture of the response to nitrogen.

9. Special attention is paid in the general discussion to the manner in which the results differed between cutting systems and between short- and long-term experiments. The response to nitrogen, both per cut and on the

basis of total yield per season, differed between cutting at set dates and cutting at a set stage of growth. When there were many cuts per season dry matter production increased up to the highest rate of nitrogen tested, while if there were only few cuts (up to about four per season) the response curve showed a definite maximum. There was a negative interaction between length of growing period and level of nitrogen fertilizer, increasing nitrogen rates increasing the number of tillers in short growing periods but reducing it in long growing periods. When the sward was cut at a set stage of 2 to 2.5 t dry matter per ha per cut it became more open as the rate of nitrogen increased as shown by a decrease in percentage cover and in the number of tillers. The more open sward was associated with lower sward quality and decreased productivity both within one season in short-term trials and from one season to the next in long-term trials. In actual farm practice a compromise has to be found between dry-matter yield and sward quality. With cutting every three or four weeks a total dressing in the range 400-500 kg N per ha per year would seem to give a good yield with little deterioration of the sward.

With cutting at a set stage our short-term trials showed a clear response to nitrogen at dressings over 500 kg N per ha per year, which generally was not the case in the long-term trials. This difference in productivity gave at these very high rates less herbage nitrate accumulation in the 'short-term' grass than in the 'long-term' grass. There was a curvilinear relationship between the total nitrogen uptake of the grass and nitrate accumulation, whereby the nitrate accumulation increased strongly in the nitrogen uptake range of 400-500 kg N per ha. Mineral nitrogen started to accumulate in the soil of young grassland at a higher level of nitrogen application than in the soil of old permanent grassland.

At an assumed marginal profitability of 7.5 kg dry matter per kg N applied the 'optimum' application in our long-term trials on sand and clay soils appeared to be 420 kg N per ha per year, with a range of 360-520 kg N. At this 'optimum' application the risks of herbage nitrate accumulation above 0.75% NO_3 and of soil mineral nitrogen accumulation were minimal. The 'optimum' application is close to the present recommendation of 400 kg N per ha per year on sand and clay soils in the Netherlands.

Chapter 11

Samenvatting

1. Rond 1970 werden hier en daar in Nederland op melkveebedrijven op zand- en kleigrasland hoeveelheden stikstof toegediend die hoger waren dan de adviesgift van 350 tot 400 kg N per ha per jaar. Dit was aanleiding onderzoek te doen naar het effect van dergelijke hoge giften. In het onderzoek werd de opbrengst aan droge stof bij sterk uiteenlopende stikstofgiften gemeten in eenjarige en veeljarige maaiproeven waarbij het gras steeds in het stadium van ongeveer 2 à 2,5 t droge stof per ha werd gemaaid. Daarnaast werd de invloed van stikstofbemesting op de zodekwaliteit, op het nitraatgehalte van het gras en op de hoeveelheid minerale stikstof in de grond nagegaan.

2. De reactie van het gras op de toegediende stikstof gedurende het seizoen werd in eenjarige proeven bepaald bij verschillende niveaus van bemesting. Deze niveaus liepen uiteen van 240 tot 1080 kg N per ha per jaar. Er werd ruim aandacht geschonken aan methoden om het effect van de stikstof te bepalen, zoals het oogsten volgens een vast maaischema of het oogsten in een bepaald groei- of opbrengststadium. De eerste methode geeft vooral informatie over verschillen in droge-stofopbrengst op een bepaalde datum. De tweede methode verschaft gegevens over verschillen in groeisnelheid en daarmee over het aantal dagen dat een bepaald stadium eerder wordt bereikt. Dit laatste is van belang voor de praktijk waar men wil weten hoeveel vroeger men met behulp van stikstof weidegras of kuilgras kan verkrijgen.

De reactie van het gras op stikstof liep sterk uiteen en hing samen met standplaats en jaar. De reactie was het sterkst in de eerste helft van het seizoen en nam daarna geleidelijk af. Naarmate in de voorafgaande periode meer stikstof was gegeven nam het effect van de later toegediende stikstof af. Dit kon in verband worden gebracht met de nawerking van de eerder gegeven stikstof. Tegen het einde van het seizoen reageerde het gras na een voorafgaande stikstofbemesting van 40 kg N per ha per snede nog positief op een bemesting met 120 kg N. Bij een niveau van voorafgaande stikstofbemesting van 80 of 120 kg N per snede was de reactie op stikstof echter gering of soms zelfs negatief. Bij een dergelijk hoog niveau van stikstofgebruik was de zode veelal opener geworden.

Tenslotte werd aandacht geschonken aan de "optimale" stikstofgift per snede, waarbij een marginale opbrengst van 7,5 kg drogestof per kg toegediende stikstof werd aangenomen. De bepaling van de "optimale" gift langs deze weg was moeilijk uitvoerbaar omdat vanaf de tweede snede rekening moest worden gehouden met het maairegime en met de nawerking van eerder gegeven stikstof.

3. De nawerking van eerder gegeven stikstof in de loop van het seizoen is op kleigrasland bij verschillende niveaus van stikstofbemesting nagegaan. Stikstof die tot nawerking komt, kan in de plant aanwezig zijn in stoppel en wortel, en in de grond als minerale stikstof en als tijdelijk vastgelegde, organische stikstof. In onze proeven werd alleen de minerale stikstof in de grond bepaald.

De nawerking kon het best binnen een seizoen worden aangetoond als het gras bij hergroei niet opnieuw met stikstof werd bemest. Bij vijf weken hergroei was de nawerking van een voorafgaande stikstofbemesting van in totaal ongeveer 500 kg N per ha ten opzichte van in totaal 200 kg N gelijk aan een kunstmestgift van ongeveer 40 kg N per ha.

De produktiviteit van de zode tegen het einde van het seizoen was bij het lagere niveau van stikstofbemesting hoger dan bij het hogere niveau.

4. Het niveau van de minerale stikstof in de grond van oud, blijvend kleigrasland is van het begin tot het einde van één seizoen gevolgd. Dit niveau veranderde niet als steeds 60 kg N per ha per snede, in totaal 420 kg N over het seizoen, werd gegeven. Het niveau steeg bij steeds 80 of steeds 120 kg N per snede: bij 80 kg N trad in augustus ophoping van minerale stikstof in de grond op na zes keer 80 kg N; bij 120 kg N was dat al in mei na twee keer 120 kg N het geval. Uit de ophoping van minerale stikstof in de grond kon het bemestingspatroon over het seizoen benaderd worden.

Gerekend over meerdere seizoenen trad bij oud, blijvend grasland ophoping van minerale stikstof in de grond op bij bemesting met meer dan 400 kg N per ha per jaar en bij jong grasland bij bemesting met meer dan 480 kg N. Het verband tussen de hoeveelheid stikstof die jaarlijks meer is toegediend dan is afgevoerd met het geoogste gras (N_{EXC}) en de ophoping van minerale stikstof in de laag 0-50 cm van het begin tot het einde van het seizoen kon met een hyperbolische functie worden beschreven.

5. Bij stikstofgiften van 480 kg N en meer per ha werd van N_{EXC} in het volgende voorjaar op zwak lemig zand, klei en zware klei respectievelijk

ongeveer 25, 40 en 50% als minerale stikstof in de laag 0-100 cm teruggevonden. In dat jaar was er geen effect van N_{EXC} op de opbrengst aan droge stof en aan stikstof in het gras op de zandgrond; op de klei was er wel een duidelijk effect. Daar leverde 1 kg N_{EXC} van het vorige seizoen 8 kg droge stof op als nawerking, terwijl 1 kg in het voorjaar in de grond teruggevonden minerale stikstof 15 kg droge stof produceerde. Als men uitgaat van een betrekkelijk geringe bijdrage van de stikstof die achtergebleven is in stoppel, wortel en organische stof van de grond, dan lijkt de conclusie gerechtvaardigd dat de overgebleven minerale stikstof in de grond even werkzaam was als vers toegediende kunstmeststikstof.

6. Op de zware kleigrond werd zelfs gedurende twee achtereenvolgende jaren een nawerking van eerder gegeven stikstof gevonden. Over de drie daaraan voorafgaande jaren was door zeer hoge stikstofbemesting N_{EXC} opgelopen tot in totaal 941 kg N per ha. Aan het begin van het eerste jaar van nawerking bevatte de grond 314 kg minerale stikstof terwijl het vergelijkingsobject 21 kg bevatte. De nawerking werd bepaald bij een niveau van 40 kg N per ha per snede voor zowel het nawerkings- als het vergelijkingsobject. De nawerking was duidelijk bij elke snede en bedroeg over het gehele seizoen 6 t droge stof en 199 kg in het gras opgenomen N per ha. Aan het eind van het eerste jaar van nawerking was bijna alle opgehoopte minerale stikstof in de grond uitgeput. Hoewel er in het tweede jaar geen verschil meer was in hoeveelheid minerale stikstof in de grond werd toch nog een effect van 1,1 t droge stof en 21 kg in het gras opgenomen N per ha gevonden.

7. In het geoogste gras werd per snede het nitraatgehalte bepaald. In de veeljarige proeven was er met 60 kg N per ha per snede, met een maximum van 360 kg N per jaar, geen of vrijwel geen toename van het nitraatgehalte. Met 80 kg N per snede, in totaal 400-560 kg N per jaar, overschreed 3% van de monsters het gehalte van 0,75% NO_3 van de droge stof. Dit gehalte wordt momenteel beschouwd als veilige grens bij de voedering van geconserveerd gras aan rundvee. Met 120 en 160 kg N per snede, in totaal 600-1120 kg N per jaar, lag het nitraatgehalte in 61 en 67% van de monsters boven 0,75% NO_3, terwijl in 19 en 47% van de monsters het gehalte hoger was dan 1,50%, de veilige bovengrens voor vers gras gevoerd op stal. In het gras van de 44 monsters van de eerste snede kwam het gehalte slechts één keer boven 0,75% NO_3. Nitraatophoping werd ook zelden gevonden in het herfstgras; het kwam vooral voor bij het zomergras. Bij gunstige vochttoestand van de grond

bleek het nitraatgehalte van het gras toe te nemen bij stijging van de temperatuur. In warme maar droge perioden was het nitraatgehalte echter laag.

8. De produktiviteit van het grasland nam af naarmate de stikstofbemesting in voorgaande jaren hoger was, vooral bij hoeveelheden van 500 kg N of meer per ha per jaar. Deze teruggang in produktiviteit hing samen met een achteruitgang van de kwaliteit van de zode, nl. een lagere bedekkingsgraad, een geringer aantal spruiten en een geringere wortelmassa en bewortelingsdiepte. Het verschil in produktiviteit tussen een zode met een voorgeschiedenis van lage stikstofbemesting en een met een hoge stikstofbemesting was vooral duidelijk in de eerste snede als beide zodetypen eenzelfde bemesting van 120 kg N per ha per snede kregen.

De reactie van het gras op hoge stikstofgiften week als gevolg van dit verschil in produktiviteit in het eerste jaar van de veeljarige proeven af van die in de volgende jaren. Het onderzoek toonde aan dat eenjarige proeven een te optimistisch beeld van de reactie van de grasgroei op stikstof kunnen geven.

9. In de algemene discussie is vooral aandacht besteed aan verschillen in resultaten als gevolg van verschil in maaifrequentie en in proefduur (eenjarig of veeljarig). Maaien op datum of maaien op groeistadium gaf verschil in reactie op stikstof, zowel per snede als over het gehele seizoen. Hoe vaker gemaaid werd, des te langer bleef de opbrengstcurve stijgen. Slechts bij weinig keren maaien per seizoen (tot ongeveer vier keer) vertoonde de opbrengstcurve een duidelijk maximum.

Er werd een negatieve interactie van het niveau van stikstofbemesting en de lengte van de groeiperiode op het aantal spruiten geconstateerd: met toenemende bemesting werd bij korte groeiperioden, dat wil zeggen bij veel sneden per seizoen, het aantal spruiten groter; bij langere groeiperioden nam het aantal spruiten steeds meer af en werd de zode opener. Ook bij maaien in een stadium van 2 à 2,5 t droge stof per ha per snede werd bij toenemende stikstofbemesting de zode meer open. Dit bleek samen te gaan met een vermindering van de produktiviteit, zowel binnen één seizoen als ook van het ene seizoen op het andere. In de praktijk moet een compromis tussen droge-stofopbrengst en zodekwaliteit worden gevonden. Bij eens in de drie à vier weken maaien lijkt op zand- en kleigrond een totale jaargift van 400-500 kg N per ha een goede opbrengst te geven, waarbij de zode slechts weinig in kwaliteit achteruitgaat.

Bij maaien in een stadium van 2 à 2,5 t droge stof per ha per snede lieten de proeven in het eerste jaar bij giften boven 500 kg N per ha per jaar nog een stijging van de opbrengst zien. In volgende jaren was dit veelal niet het geval. Het verschil in produktiviteit uitte zich bij giften boven 500 kg N per ha in een geringere nitraatophoping in "eerste-jaarsgras" dan in "latere-jaarsgras".

Wanneer we uitgaan van een marginale opbrengst van 7,5 kg droge stof per kg toegediende N is gemiddeld over onze veeljarige proeven op zand- en kleigrond de "optimale" stikstofgift 420 kg N per ha per jaar, met een variatie van 360-520 kg N. Bij deze "optimale" stikstofgift was er vrijwel geen gevaar voor overschrijding van de kritische grens van 0,75% NO_3 voor geconserveerd gras of voor ophoping van minerale stikstof in de grond. De "optimale" gift ligt dicht bij de huidige adviesgift van 400 kg N per ha per jaar voor het Nederlandse grasland op zand- en kleigrond.

Annex 1

General data of trials, including numbering of trials in chapters 2 - 8

Trial IB no	Trial year(s)	Location	Numbering in chapter						
			2	3	4	5	6	7	8
1647	1970	Ten Boer		1647					
1752	1972	Ten Boer	1752	1752					
2032	1973	Ten Boer	2032	2032					
2145	1974	Ten Boer	2145	2145	1				
2146	1974-1979	Finsterwolde			2	1		1	1
2244	1975-1980	Finsterwolde			3	2	2244	2	2
2258	1975-1976	Ten Boer				3			
2259	1975-1978	Ten Boer			4	4		3	3

Chapters 2 to 8 provide information as regards materials and methods of the trials. These trials were complex because of cutting at a specific stage of growth. This entailed regular measurement or estimation of the yield level of the different treatments. The treatments were mostly mown at different dates, depending on the growth rate at different levels of nitrogen application.

Details of the short-term trials of 1972, 1973 and 1974 have been reported elsewhere[1, 2]. The history of the long-term trials is described in Annexes 3 to 5, showing how the original treatments were expanded to study residual nitrogen, productivity etc. on spare plots reserved from the beginning or made available later by splitting plots into two halves.

1. Prins, W.H. & P.F.J. van Burg (1979) The seasonal response of grassland to nitrogen at different levels of nitrogen pretreatment. I. Experiments 1972 and 1973. Neth. Nitrogen Techn. Bull. no.11, pp 45
2. Prins, W.H., P.F.J. van Burg, G.J.G. Rauw & J. Postmus (1981) The seasonal response of grassland to nitrogen at different levels of nitrogen pretreatment. II. Experiment 1974. Neth. Nitrogen Techn. Bull. no.12, pp 40

Annex 2

Details of soils

A Soil data of 0-5 cm layer at start of trial

Trial IB no.	Location	Soil type	Contents of oven-dry soil, g kg^{-1}				pH-KCl
			Org. matter	$CaCO_3$	0-0.016 mm	0.016-2 mm	
1647	Ten Boer	clay	160	2	520	320	5.7
1752	Ten Boer	clay	138	3	450	410	6.3
2032	Ten Boer	clay	150	5	440	410	6.2
2145	Ten Boer	clay	144	2	410	450	5.8
2146	Finsterwolde	sandy	32	2	140	830	6.0
2244	Finsterwolde	heavy clay	48	72	730	150	7.1
2258	Ten Boer	clay	142	7	480	370	6.2
2259	Ten Boer	clay	142	7	480	370	6.2

B Particle-size analysis of soils of long-term trials

Trial IB no.	Location	Soil layer, cm	Mineral fraction, %				
			0-0.002 mm	0.002-0.016mm	0.016-0.05mm	0.05-0.15mm	0.15-2mm
2146	Finsterwolde	0-5	10.7	4.9	10.8	35.2	38.4
		5-15	11.5	5.1	11.0	33.5	39.0
		15-25	11.2	5.2	11.3	33.7	38.6
2244	Finsterwolde	0-5	56.2	24.0	16.3	2.3	1.2
		5-15	59.3	25.3	12.9	1.8	0.7
		15-25	52.6	23.5	21.1	2.1	0.7
2259	Ten Boer	0-5	36.2	22.9	35.4	4.8	0.7
		5-15	39.6	22.2	33.5	4.3	0.4
		15-25	40.3	22.3	33.1	3.9	0.4

C According to the system of soil classification for the Netherlands[1] the clay soils of the trials at Ten Boer and Finsterwolde, and the sandy soil at Finsterwolde are classified as "Polder" vague soils and "Goor" earth soil, respectively.

Annex 2 continued

The sandy soil is described as slightly loamy sand of 30 to 50 cm thickness, overlying a more or less loamy (boulder clay[2]) subsoil. Detailed investigation of the soil profile showed that four classes of loaminess could be discerned (De Smet, private communication), which were not divided equally over the treatments. For example, the treatment with continuous 60 kg N per ha per cut (treatment 7 in Annex 3) was on a more loamy subsoil than the treatments with continuous 80 and 120 kg N per ha per cut (treatments 11 and 14 in Annex 3, respectively). This may explain why the 60 kg N-treatment performed relatively better than expected. However, the Coefficient of Variation was of the same order of magnitude as in the other two long-term trials (see Annex 6).

1. Bakker, H. de & J. Schelling (1966) Systeem van bodemclassificatie voor Nederland. De hogere niveaus. Pudoc, Wageningen
2. Smet, L.A.H. de (1961) Het Dollardgebied. Bodemkundige en landbouwkundige onderzoekingen in het kader van de bodemkartering. Versl. landbouwk. onderz. 67.16. Pudoc, Wageningen

Annex 3

History of long-term trial IB 2146 on sandy soil at Finsterwolde.
Number of cuts x N rate per cut (kg ha^{-1}) = total N application (kg $ha^{-1} year^{-1}$). Plots measured 5x5 = 25 m^2

Treatment No.	1974	1975	1976	1977	*1978	*1979
1	7x0=0	1x120+ 4x80+1x60=500	4x40=160	*W+6x120=870(c)	W+6x120=870(c)	6x40=240
2	7x0=0	1x120+ 4x80+1x60=500	4x40=160	*6x120=720(b)	5x40=200(a)	7x120=840(b)
3	4x0=0	3x0=0	4x0=0	4x0=0	5x0=0	3x0=0
4	5x40=200	5x40=200	4x40=160	5x40=200	5x40=200	6x40=240
5	5x40=200	5x40=200	4x40=160	5x40=200	6x120=720(b)	7x120=840
6	5x40=200	5x40=200	4x40=160	1x0+ 4x40=160	W+6x120=870(c)	W+7x120=990(c)
7	6x60=360	5x60=300	5x60=300	6x60=360	6x60=360	6x60=360
8	6x60=360	5x60=300	5x60=300	6x60=360	6x60=360	7x120=840(b)
9	6x60=360	5x60=300	5x60=300	6x60=360	6x60=360	W+7x120=990(c)
10	6x60=360	5x60=300	5x60=300	6x60=360	6x120=720(b)	6x40=240(a)
11	6x80+ 1x0=480	6x80=480	5x80=400	6x80=480	6x80=480	7x80=560
12	6x80+ 1x0=480	6x80=480	5x80=400	6x80=480	6x80=480	7x120=840(b)
13	6x80+ 1x0=480	6x80=480	5x80=400	6x80=480	6x120=720(b)	7x120=840
14	7x120=840	6x120=720	5x120=600	6x120=720	6x120=720	7x120=840

Annex 3 continued

Treatment		1974	1975	1976	1977	*1978	*1979
No.	15	7x120=840	6x120=720	5x120=600	1x0+ 4x40=160(a)	6x120=720	7x120=840
	16	120+80+40 +80+60+40=420	1x120+ 4x80+1x60=500	5x160=800	6x160=960	6x160=960	7x160=1120
	17	120+80+40 +80+60+40=420	1x120+ 4x80+1x60=500	5x160=800	6x160=960	6x160=960	6x40=240(a)
	18	120+80+40 +80+60+40=420	1x120+ 4x80+1x60=500	5x160=800	6x160=960	6x160=960	7x120=840
	19	120+80+40 +80+60+40=420	1x120+ 4x80+1x60=500	5x160=800	6x160=960	6x120=720(b)	6x40=240
	20	3x80+ 3x60=420	1x160+ 2x80+3x60=500	2x120+ 2x80+1x60=460	2x120+ 3x80+1x60=540	2x120+ 4x80=560	2x120+ 4x80+1x60=620
	21	3x80+ 3x60=420	1x160+ 2x80+3x60=500	2x120+ 2x80+1x60=460	2x120+ 3x80+1x60=540	2x120+ 4x80=560	6x40=240(a)

* After splitting plots into two halves plot size became 2.50x5=12.50 m^2 for some treatments in 1977, and for all treatments in 1978 and 1979

(a)= residual N treatments, to be compared with treatment 4 (chapters 5 and 6)

(b)= productivity treatments, to be compared with treatment 14 (chapter 8)

(c)= productivity treatments with extra 'winter' (W) 150 kg N per ha in split applications some weeks before the start of spring growth (chapter 8)

Annex 4

History of long-term trial IB 2244 on heavy clay soil at Finsterwolde.

Number of cuts x N rate per cut (kg ha^{-1}) = total N application (kg $ha^{-1} year^{-1}$). Plots measured 5x5 = 25 m^2

Treatment No.	1975	1976	1977	1978	*1979	*1980
1	4x0=0	4x0=0	4x0=0	5x0=0	4x0=0	3x0=0
2	5x40=200	4x40=160	5x40=200	5x40=200	6x40=240	5x40=200
3	5x40=200	4x40=160	5x40=200	*6x120=720(b)	6x40=240(a)	5x40=200
4	5x40=200	4x40=160	5x40=200	W+6x120=870(c)	W+7x120=990(c)	7x120=840
5	5x40=200	4x40=160	*W+6x120=870(c)	*W+6x120=870(c)	6x40=240(a)	7x120=840(b)
6	5x40=200	4x40=160	*6x120=720(b)	*5x40=200(a)	7x120=840(b)	5x40=200(a)
7	6x80=480	5x60=300	6x60=360	6x60=360	6x60=360	6x60=360
8	6x80=480	5x60=300	6x60=360	6x60=360	W+7x120=990(c)	W+7x120=990(c)
9	6x80=480	5x80=400	6x80=480	6x80=480	6x80=480	7x80=560
10	6x80=480	5x80=400	6x80=480	*6x120=720(b)	6x40=240(a)	5x40=200
11	7x120=840	5x100=500	6x100=600	6x100=600	7x100=700	7x100=700
12	7x120=840	5x100=500	6x100=600	6x100=600	7x160=1120	5x40=200(a)
13	7x120=840	5x120=600	6x120=720	6x120=720	7x120=840	7x120=840
14	1x104+ 6x130=884	5x160=800	6x160=960	6x160=960	7x160=1120	7x160=1120
15	1x104+ 6x130=884	5x160=800	6x160=960	*5x40=200(a)	6x40=240(a)	5x40=200

Annex 4 continued

Treatment No.	1975	1976	1977	1978	*1979	*1980
16	1x104+ 6x130=884	2x120+ 2x80+1x60=460	2x120+ 3x80+1x60=540	2x120+ 4x80=560	2x120+ 4x80+1x60=620	2x120+ 4x80+1x60=620
17	1x104+ 6x130=884	2x120+ 2x80+1x60=460	2x120+ 3x80+1x60=540	2x120+ 4x80=560	6x40=240(a)	W+7x120=990(c)

* After splitting plots into two halves plot size became 2.50x5=12.50 m^2 for some treatments in 1977 and 1978, and for all treatments in 1979 and 1980

(a)= residual N treatments, to be compared with treatment 2 (chapters 5 and 6)
(b)= productivity treatments, to be compared with treatment 13 (chapter 8)
(c)= productivity treatments with extra 'winter' (W) 150 kg N per ha in split applications some weeks before the start of spring growth (chapter 8)

Annex 5

History of long-term trial IB 2259 on clay soil at Ten Boer.
Number of cuts x N rate per cut (kg ha^{-1}) = total N application (kg ha^{-1} $year^{-1}$). Plots measured 5x6 = $30m^2$

Treatment		1975	1976	1977	1978
No.	1	3x0=0	3x0=0	4x0=0	5x0=0
	2	4x40=160	4x40=160	5x40=200	5x40=200
	3	4x40=160	4x40=160	5x40=200	W+6x120=870(c)
	4	5x60=300	5x60=300	5x60=300	6x60=360
	5	5x60=300	5x60=300	5x60=300	6x120=720(b)
	6	1x120+ 2x80+2x60=400	1x120+ 3x80+1x60=420	1x120+ 3x80+2x60=480	1x120+ 3x80+2x60=480
	7	5x80=400	5x80=400	6x80=480	6x80=480
	8	5x80=400	5x80=400	6x80=480	6x120=720(b)
	9	1x120+ 4x80=440	2x120+ 3x80=480	2x120+ 3x80+1x60=540	2x120+ 4x80=560
	10	1x120+ 4x80=440	2x120+ 3x80=480	5x40=200(a)	5x40=200
	11	1x160+ 2x80+2x60=440	5x100=500	6x100=600	6x100=600
	12	6x120=720	6x120=720	6x120=720	6x120=720
	13	4x40=160	5x160=800	6x160=960	6x160=960
	14	4x40=160	5x160=800	5x40=200(a)	5x40=200
	15	4x40=160	4x40=160	5x40=200	6x120=720(b)
	16	4x40=160	4x40=160	*W+6x120=870(c)	*W+6x120=870(c)
	17	4x40=160	4x40=160	*6x120=720(b)	*5x40=200(a)

* After splitting plots into two halves plot size became 2.50x6=$15m^2$ for some treatments in 1977 and 1978

(a)= residual N treatments, to be compared with treatment 2 (chapters 5 and 6)
(b)= productivity treatments, to be compared with treatment 12 (chapter 8)
(c)= productivity treatments with extra 'winter' (W) 150 kg N per ha in split applications some weeks before the start of spring growth (chapter 8)

Annex 6

Annual DM yields (t ha^{-1}) of selected treatments of long-term[1] trials. Values with different letters following were significantly different ($P<0.05$). Coefficient of Variation (=C.V.).
'Optimum' DM yield (t ha^{-1}) at assumed marginal profitability of 7.5 kg DM per kg applied N (=$Y_{7.5}$).
Fertilizer N requirement (kg ha^{-1}) for 'optimum' yield (= $N_{7.5}$). 'Optimum' yield as percentage of maximum yield (= $\frac{Y_{7.5}}{Y_{max}}$ x 100)

Trial and Year	Treatment number[2]							C.V.	$Y_{7.5}$	$N_{7.5}$	$\frac{Y_{7.5}}{Y_{max}}$x100
IB 2146	3	4	7	11		14	16				
1974	6.06(a)	12.22(b)	14.71(c)	15.18(cd)		16.00(d)	14.75(c)[3]	2.54	14.8	380	93
1975	7.00(a)	11.66(b)	14.13(c)	14.66(c)		16.12(d)	15.04(c)[3]	2.18	14.6	420	91
1976	3.80(a)	6.73(b)	9.28(c)	9.82(d)		9.04(c)	10.35(d)	2.05	9.0	370	87
1977	4.99(a)	10.34(b)	13.12(c)	13.47(cd)		13.79(cd)	14.33(d)	2.90	13.1	360	92
1978	3.78(a)	11.84(b)	13.92(cd)	14.52(d)		13.18(c)	13.67(c)	1.93	14.4	450	99
1979	3.80(a)	11.62(b)	14.43(cd)	14.95(d)		14.27(c)	14.10(c)	1.51	14.4	370	96
IB 2244	1	2	7[3]	9	11[3]	13	14				
1975	6.88(a)	12.61(b)		15.31(c)		17.35(d)	17.36(d)	2.23	15.2	460	87
1976	3.16(a)	8.22(b)	10.39(c)	12.23(d)	12.06(d)	12.51(d)	11.99(d)	2.89	12.0	400	96
1977	3.10(a)	11.61(b)	13.86(c)	14.66(d)	14.83(de)	15.18(ef)	15.33(f)	1.22	13.8	380	90
1978	2.12(a)	9.50(b)	12.99(c)	14.78(d)	15.81(e)	16.02(e)	16.04(e)	0.81	14.9	500	93
1979	2.77(a)	9.50(b)	12.60(c)	13.74(d)	13.61(d)	13.46(d)	13.20(d)	1.60	13.6	470	99
1980	2.43(a)	10.42(b)	13.10(c)	14.51(d)	15.54(e)	15.62(e)	15.43(e)	1.29	14.0	460	90

Annex 6 continued

Trial and Year	Treatment number[2]							C.V.	$Y_{7.5}$	$N_{7.5}$	$\frac{Y_{7.5}}{Y_{max}}x100$
IB 2259	1	2	4	7	11[3]	12	13[3]				
1975	6.93(a)	8.82(b)	10.71(c)	12.54(d)		14.66(e)		1.56	13.2	520	90
1976	3.79(a)	6.62(b)	9.96(c)	10.72(c)	10.73(c)	12.65(d)	10.68(c)	3.56	1.0	420	92
1977	6.55(a)	10.23(b)	12.19(c)	13.12(cde)	13.32(de)	12.77(cd)	14.01(e)	2.65	12.8	370	91
1978	5.12(a)	12.73(b)	14.27(c)	15.00(cd)	15.21(d)	14.92(cd)	15.26(d)	2.13	14.6	390	96

1) Annual DM yields of short-term IB-trials in 1972, 1973 and 1974 can be found in Appendix of chapter 2
2) For total N applications per year corresponding with treatment numbers, see Annexes 3-5
3) It is to be noted that, in some treatments, N applied in the first year(s) differed considerably from the rates applied in later years

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