This symposium was organized by
The Netherlands Society for Grassland and Fodder Crops
in cooperation with
The Department of Field Crops and Grassland Science, Agricultural University, Wageningen

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Proceedings of an International Symposium of the European Grassland Federation on

THE ROLE OF NITROGEN IN INTENSIVE GRASSLAND PRODUCTION

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PROFESSOR MAARTEN LEENDERT 't HART
Honorary life President of the European Grassland Federation
Maarten Leendert 't Hart was born on the 5th July 1915, on a farm in the village of Anna Paulowna in the province of North Holland. After passing through the secondary school, he enrolled in the Agricultural University in Wageningen in 1932. Even before completing his studies in 1938, he already worked at the Institute of Plant Breeding. In 1939 he became a scientific officer at the newly founded Central Institute of Agricultural Research (CILO). In 1946, 't Hart was appointed Head of the Division of Grassland and Forage Crops, and in 1948 Deputy Director of the CILO. His appointment as a part-time reader in grassland husbandry at the Agricultural University took place in 1949, and six years later he was appointed to the new chair of professor in grassland husbandry.

't Hart's research activities testify to his wide interest in the various grassland problems. Although he carried out research in many sectors of grassland husbandry - ranging from pasture establishment to herbage utilization - there was a number of aspects which received his special attention. Widely known is his research into the ecological factors which determine the yield of grassland. For this purpose, experimental fields - with or without fertilizer treatments - were established on different types of grasslands distributed over the most important pasture regions of the Netherlands. These experimental fields were used for many years, and in this way insight was gained into the yield fluctuations within seasons as well as between years. In 1947, such experimental fields could be found on 200 grassland sites.

The yield response to nitrogen, phosphorus and potassium fertilization was also studied during this research period. But, since increased use of fertilizers also changed the mineral composition of the grass, this led to mineral disorders in dairy cattle. In this respect, 't Hart performed pioneer research, especially regarding the occurrence and prevention of grass tetany.

In later years, he gave special attention to grazing systems. Initially, he investigated the effect of herbage allowance and of preceding treatment of the pasture on dry-matter intake by beef cattle. Thereafter, he investigated the productivity of dairy cattle under different grazing systems.

In view of his broad research experience, it is understandable that 't Hart has frequently been asked to participate in advisory committees, often in the capacity of chairman. In this way he had the opportunity to stimulate and co-ordinate grassland research in the Netherlands. For several years he was a member of the National Council for Agricultural Research (NALO).

At the Agricultural University 't Hart started activities concerning the education and training of students in 1949, which task gradually increased in the course of years. For more than 30 years he taught grassland husbandry, as far as the grassland botany was concerned assisted by the late professor D.M. de Vries (until 1965). Several years 't Hart also lectured on arable crops and had full responsibility for the Field Crops and Grassland Husbandry Curriculum. Many students served their apprenticeships with him, and under his guidance 15 Ph.D. theses on quite different themes have been written. It can truthfully be said that nearly all present grassland specialists of the Netherlands are his former pupils.

't Hart is not only a teacher, but an able administrator as well. Within the organization of the Agricultural University he has fulfilled a variety of functions, from member of the Executive Board and member of the Committee of Deans to chairman or member of numerous other organizing and advisory committees. Besides professor, he was also Head of the Department of Field Crops and Grassland Science of the Agricultural University.

A farmer's son, 't Hart received a thorough training in practical farming and animal husbandry at young age. Needless to say that later on, in his professional career, he showed a deep interest in all agricultural problems of the country. He became especially interested in grassland production in north-western Europe, and, as a member of an OECD team, he visited various member-countries in order to advise about grassland research and extension. He was a member of, and presented papers at several International Grassland Congresses. In later years, he also travelled to the tropics on advisory missions and he was deeply involved in the planning of Dutch research projects in developing countries.

In 1960, the Netherlands Society for Grassland and Fodder Crops (NVWV) was founded and...
a few years later it became an independent section of the Royal Netherlands Society of Agricultural Science. It was a matter of course that 't Hart, the man who took the initiative for the foundation of NVWV and who was known by every grassland expert in the country, became its first president.

In 1963, the European Grassland Federation (EGF) was formed at a Symposium of the British Grassland Society at Hurley. According to the Constitution, the President of the Executive Committee of the EGF is elected from the member-organization which organizes the next General Meeting. At the Hurley Symposium, the NVWV proposed to hold the First General Meeting in Wageningen in 1965 and to discuss the theme 'Nitrogen and Grassland'. This proposal was accepted and consequently 't Hart became the first President of the European Grassland Federation. In the years 1963-1967 he devoted himself to raising the young seedling to a vigorous, persistent perennial.

This is the portrait of a much respected and remarkable scientist. This year, 1980, he celebrates his 65th birthday and it is anticipated that he will resign his office in the near future. For this reason his pupils and colleagues have seized the opportunity to dedicate this Symposium to their teacher and friend: Professor Maarten Leendert 't Hart.

J.G.P. Dirven
Chairman Organizing Committee

J.W. Minderhoud
President Netherlands Society for Grassland and Fodder Crops (NVWV)
At the request of the European Grassland Federation (EGF), the Netherlands Society for Grassland and Fodder Crops (NVWV) agreed to organize an international Symposium on a subject typical of the Netherlands. Since the NVWV was planning to celebrate the 65th birthday of Professor M.L. 't Hart, the first chairman of the Executive Committee of the EGF, it was decided to combine both events.

In consultation and cooperation with the Department of Field Crops and Grass Science of the Agricultural University in Wageningen, the NVWV chose as subject of the Symposium: 'The Role of Nitrogen in Intensive Grassland Production'. This may be considered as a follow-up of the First General Meeting of the EGF in Wageningen in 1965 on 'Nitrogen and Grassland'.

The extent of the progress made in many aspects of this theme is clearly reflected in the contents of the invited papers and the offered posters. In these Proceedings the subject of the Symposium has been divided into three groups of topics: Gross Production, Utilization, and Nitrogen Cycle. We hope that the survey of these topics will provide ample reference material to the specialists in these subjects and also to others engaged in related aspects of plant nutrition, efficient fertilizer use, animal husbandry, and environment.

As publication form of the papers, the organizing committee of the Symposium decided to have the Proceedings prepared by photo-offset printing of camera-ready copy. This meant that the senior authors had to submit their papers ready for immediate processing. To standardize the manuscripts as much as possible, they were provided with instructions on letter type, lay-out etc. and with typing sheets in standard form. There would be no opportunity for major corrections after submission and the responsibility for the whole paper would rest with the authors. However, this system is less easy than was thought and in a number of cases, after ample consultations with the senior authors, the definite version had to be partly or wholly re-typed. We realize that our requirements have meant an extra burden to the senior authors who were already pressed to get their manuscript to the Editors well in advance of the Symposium.

We would like to thank the senior authors for their co-operation in conforming to our critical remarks. This acknowledgement certainly also applies to their secretaries who did the actual typing and lay-out and with whom 'the Editors were becoming very unpopular'. We hope that authors and readers will ultimately enjoy the result of our common efforts.

In a number of cases the organizing committee invited several authors - either from one country or from different countries - to present a joint paper. We have followed with great interest how these groups worked together. We would like to congratulate the authors of these groups with their contributions.

Unfortunately one of the contributors fell ill in early 1980 so that he could not have his paper ready for insertion in the Proceedings.

For review and grammatical correction of papers and summaries of posters we acknowledge with thanks the help of Messrs E.L. Leafe, J. Morrison and R.J. Wilkins (Hurley), S.B. Heath (Reading), D. Wilman (Aberystwyth), M.L. 't Hart (Wageningen), K. Dilz, T.A. van Dijk, L.C.N. de la Lande Cremer, P.A.C. Raats and C.H.E. Werkhoven (Haren).

We sincerely thank Miss Rea J. Bruggema of the Institute for Soil Fertility in Haren who typed some papers as well as the summaries of the posters and helped with the final correction of the papers.

Finally, we thank the Staff of PUDOC, Centre for Agricultural Publications and Documentation, for their co-operation in publishing the Proceedings.

Haren (Gr.), August 1980

W.H. Prins & G.H. Arnold
NITROGEN AND GRASSLAND - PAST AND PRESENT SITUATION IN THE NETHERLANDS

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Summary

A review of dairy farming in the Netherlands since 1965 is presented. First, general characteristics are described, namely the structure of dairy farming, conservation, grazing systems, concentrate feeding at pasture and nutrient aspects of animal manure. The second part deals with nitrogen fertilization, including subjects such as types of nitrogen fertilizers, nitrogen response studies, grassland management and utilization, timing the nitrogen application in spring. Finally, secondary effects of intensification are discussed, the main topics being fouling and grass utilization, sward quality, animal health, and environment.

A list of 160 references completes the review.

General characteristics of dairy farming in the Netherlands

At the first Meeting of the European Grassland Federation in 1965 De Groot (27) delivered the plenary paper on the history of nitrogen fertilization in the Netherlands. The purpose of this paper is to examine the lines along which grassland intensification has since developed.

The structure of dairy farming

Between 65 and 70 per cent of the agricultural area in the Netherlands is used for some form of forage production. Grass is the main crop and milk is the most important single product of farming. With a total milk production in 1979 of over 11 million tonnes the Netherlands dairy industry is, even by world standards, a substantial one.

The last 15 years cover a period in which tremendous developments occurred in this country. We saw drastic changes in the price ratios of the various cost factors (Figure 1) and consequently in the structure of dairy farming (Table 1).

- Farmers have been confronted with an explosion of labour costs, which already started in the late fifties and early sixties. To keep up their incomes in relation to the rest of the community, they had to intensify and increase labour productivity. In 1965 10 kg milk payed for 1 hour's labour while at present one requires 30 kg milk.

Figure 1. Relative prices of selected farm inputs and milk, 1965-1978 or 1979.
Table 1. Changes in the structure of dairy farming in the Netherlands since 1965.

<table>
<thead>
<tr>
<th>Item</th>
<th>1965</th>
<th>1979</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of dairy farms</td>
<td>161,950</td>
<td>71,550</td>
</tr>
<tr>
<td>Number of dairy cows</td>
<td>1,723,000</td>
<td>2,326,000</td>
</tr>
<tr>
<td>Average herd size</td>
<td>10.4</td>
<td>32.5</td>
</tr>
<tr>
<td>% Cows in herds &lt; 20 cows</td>
<td>66</td>
<td>10</td>
</tr>
<tr>
<td>% Cows in herds &gt; 50 cows</td>
<td>1.4</td>
<td>48</td>
</tr>
<tr>
<td>Number of cubicle houses</td>
<td>25</td>
<td>15,580</td>
</tr>
<tr>
<td>Agricultural area, ha</td>
<td>2,256,000</td>
<td>2,033,000</td>
</tr>
<tr>
<td>Grassland</td>
<td>1,307,000</td>
<td>1,213,000</td>
</tr>
<tr>
<td>Arable land</td>
<td>808,000</td>
<td>704,000</td>
</tr>
<tr>
<td>Forage maize</td>
<td>3,200</td>
<td>128,000</td>
</tr>
<tr>
<td>Fodder beet</td>
<td>19,900</td>
<td>1,700</td>
</tr>
<tr>
<td>Stubble forage crops</td>
<td>70,000</td>
<td>&lt; 10,000</td>
</tr>
</tbody>
</table>

1) 1 January 1980 : 17,943

- Nitrogen and feeding stuffs - two important means of production on a dairy farm - are, compared with milk, relatively still less expensive than 15 years ago. The price of nitrogen declined from 1965 to 1970 and increased thereafter gradually, almost parallel with the increase in milk price. At present 2.3 kg milk pay for 1 kg N as against 2.7 kg in 1965.
- The predominant position of grassland is clear.
- The area of forage crops has increased, mainly as a result of the dramatic increase of forage maize. The development of new varieties better adapted to our climate and improved production and harvesting methods and last but not least the greater demand for roughage have stimulated this expansion. Sharp increases in the price of protein in the early seventies together with the rapid expansion of the maize area raised interest in the use of NPN (Non Protein Nitrogen). However, since in the Netherlands rations are based mainly on relatively protein-rich grass and grassland products, there is not much scope for the use of NPN in ruminant feeding (23, 71).

Conservation

Despite the increase in stocking rate the percentage of grassland mown for conservation and other purposes (zero-grazing etc.) went up from 85 to 120. There has been a dramatic shift from hay to silage (Table 2).
- The number of dairy farms declined markedly, while the number of dairy cows increased by one third. As a result the average size of dairy herd trebled.
- The percentage of holdings with fewer than 20 dairy cows declined and these herds now account for only 10 per cent of the national herd. On the other hand the percentage of herds with over 50 cows rose markedly and these herds currently account for 48 per cent of all cows.
- The introduction of cubicle houses in the mid-sixties stimulated the rapid expansion in herd size. In the cubicle house/milking parlour combination one man can manage far more cows than was hitherto possible. At present over 25 per cent of the dairy farms have a cubicle house with an average herd size of 70 and these herds account for almost 55 per cent of the national herd.
- Because of a change in land use from agriculture to urban purposes the agricultural area declined steadily with an average of approximately 12,000 ha per annum shared equally between grassland and arable land.
- The area of forage crops has increased, mainly as a result of the dramatic increase of forage maize. The development of new varieties better adapted to our climate and improved production and harvesting methods and last but not least the greater demand for roughage have stimulated this expansion. Sharp increases in the price of protein in the early seventies together with the rapid expansion of the maize area raised interest in the use of NPN (Non Protein Nitrogen). However, since in the Netherlands rations are based mainly on relatively protein-rich grass and grassland products, there is not much scope for the use of NPN in ruminant feeding (23, 71).

Conservation

Despite the increase in stocking rate the percentage of grassland mown for conservation and other purposes (zero-grazing etc.) went up from 85 to 120. There has been a dramatic shift from hay to silage (Table 2).
- The main reasons for preferring silage to hay are: greater flexibility, less risk from weather, lower investment for storage, easier to leave the work to contractors, and finally the development of the high dry matter silage system that is currently standard practice (128). In 1978 high dry matter silage accounted for 87 per cent of all silage, as compared to 34 per cent only in 1965.
- In the Dutch system of grassland management, conservation receives much attention. In order to obtain a high feeding value in the conserved product, the grass is cut at a young stage. And being liberally fertilized with nitrogen, it is rich in protein and low in sugars. A
direct-cut silage of this material will give a sticky product without much texture, which animals do not like. The most important reasons for the development towards high dry matter silage are more palatable forage, higher feed intake, less feed wastage, simple mechanization with the self-loading forage wagon, higher rate of work and cheapness compared with the direct-cut or precision-chop systems. The entire development in grass conservation has to be seen against the background of the structure of dairy farming in this country. The more characteristic points in this respect are an integration between grazing and mowing for hay or silage in the utilization of grassland, a high level of nitrogen fertilization and a rather low level of mechanization.

One of the disadvantages of wilting is its adverse effect on regrowth. With wilting periods of up to six days, the next grazing will be retarded by 0.8 to 1 day per day wilting. This is a combined effect (93, 94, 104, 120) of light interception by the wilting material, damage by machinery and delayed application of nitrogen (approximately 20 per cent of the total effect).

The contribution made by silage to animal production depends to a large extent on its quality. A cow given early cut, high quality silage not only eats more of that silage but its feeding value is also higher. This means a higher milk potential from forage and less dependence on additional feeding stuffs. An often heard criticism abroad against early cut, high quality silage is that it will lead to lower forage production per ha and would thus require more forage hectares. However, too often it is forgotten (4, 18) that an increase in rate of nitrogen and consequently in the number of cuts, can more than compensate for the lower yield per cut (Table 3). More frequent cutting resulted in herbage with a higher ME-value and in a higher ME-yield. The extra nitrogen required at the higher frequencies produced approximately 50 MJ per kg.

### Table 2. Areas ($10^3$ ha) mown for hay, silage and other purposes (mainly zero-grazing) and, between parentheses the percentage distribution.

<table>
<thead>
<tr>
<th>Item</th>
<th>1965</th>
<th>1978</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grassland</td>
<td>1,337</td>
<td>1,221</td>
</tr>
<tr>
<td>Mown total</td>
<td>1,136 (85)</td>
<td>1,472 (120)</td>
</tr>
<tr>
<td>Mown for hay</td>
<td>784 (69)</td>
<td>331 (22)</td>
</tr>
<tr>
<td>Mown for silage</td>
<td>284 (25)</td>
<td>998 (68)</td>
</tr>
<tr>
<td>Mown for other purposes</td>
<td>68 (6)</td>
<td>143 (10)</td>
</tr>
</tbody>
</table>

### Table 3. Effect of cutting frequency on the amount of nitrogen required to obtain a dry matter yield of either 13.1 or 16.2 t ha$^{-1}$ and on ME-value and ME-yield (106).

<table>
<thead>
<tr>
<th>Number of cuts</th>
<th>N (kg ha$^{-1}$)</th>
<th>DM (t ha$^{-1}$)</th>
<th>ME (MJ kg$^{-1}$DM)</th>
<th>ME (MJ ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>160</td>
<td>13.1</td>
<td>9.7</td>
<td>127,250</td>
</tr>
<tr>
<td>8</td>
<td>400</td>
<td>13.1</td>
<td>10.7</td>
<td>140,700</td>
</tr>
<tr>
<td>4</td>
<td>320</td>
<td>16.2</td>
<td>9.6</td>
<td>155,850</td>
</tr>
<tr>
<td>8</td>
<td>640</td>
<td>16.2</td>
<td>10.6</td>
<td>171,750</td>
</tr>
</tbody>
</table>

**Grazing systems**

**Rotational paddock grazing**

Rotational paddock grazing was and still is the most common system with paddocks providing 2 to 5 days grazing. Paddock grazing is an efficient system for highly stocked farms. In 1965 it was mainly a system of day and night grazing with only some supplementary feeding in spring and autumn. At present, however, supplementary feeding with concentrates at pasture is common. It is estimated that as a result of the introduction of cubicle housing and of the higher stocking rate, in 1979 on 20 to 25 per cent of the dairy farms, mainly the larger ones, a modified paddock grazing system is in operation, i.e. day grazing and housed at night. To make up for the shorter grazing time fresh grass, silage or extra concentrates are fed at night. This modified system reduces particularly on highly stocked farms the problem of fouling and thus enables a better utilization of grass. In wet periods this system can be used to reduce poaching.

**Zero-grazing**

Zero-grazing is only practised on a very limited scale. Compared with rotational grazing, zero-grazing can increase herbage output by up to 20 per cent, which may correspond with an increase in stocking rate of 0.4 to 0.5 livestock unit per ha. This profit, however, is in normal situations counterbalanced by the disadvantages of a higher labour input and increased costs for machinery and concentrates.

For fragmented farms where efficient grassland management is rather difficult, zero-grazing offers a solution. It is also an effective method for increasing the stocking rate on farms with limited land, where the limit of the carrying capacity has been reached under very intensive grazing conditions. Furthermore zero-grazing might have advantages for very large herds.
Continuous grazing

Currently there is a growing interest in the modern intensive continuous grazing system with high stocking rates and high dressings of nitrogen. The system is rather popular in Belgium, Germany and the UK, where numerous experiments have been conducted comparing paddock and continuous grazing. Although the results are variable, there is sufficient evidence to suggest that yield levels of animal output are only marginally higher on rotational than on continuous grazing systems (43). In the Netherlands, continuous grazing is practised on only a small number of farms and experiments comparing the merits of continuous grazing with those of paddock grazing are also only of recent origin. Continuous grazing has the advantage of being a system with relatively low cost and labour input. It deserves more attention in this country.

Concentrate feeding at pasture

The feeding of concentrates to cows at pasture is widespread on modern dairy farms and there is no subject within dairy farming which provokes so much argument. This is an alarming development as herbage can provide enough energy to produce 20-25 kg milk in May-June dropping to approximately 16 kg in September-October. Results of many experiments have shown that when plenty of good quality grass is available, a poor response must be expected from supplementing concentrates and the feeding of 1 kg of cake will not automatically give 2 kg of milk (11, 13, 15, 28, 141). Feeding too much concentrate may have an adverse effect on percentage of butter fat. Supplementary feeding decreases the intake of herbage dry matter and the result is that total energy intake is not increased to the extent which is expected (15, 16, 46, 90).

As is shown in Table 4, drawn up after De Jong (33), the total consumption of concentrates and the consumption per cow almost trebled since 1965. The figures also show that at present 850 kg concentrates, or almost 50 per cent of the annual intake, is offered when the cows are at pasture (May-October). Total milk production per cow increased with 850 kg: 540 kg for the winter period and only 310 kg for the grazing period. These results indicate that 1 kg of concentrates fed at pasture produced only 0.4 kg milk. This agrees well with the figure of 0.3 kg quoted by Castle and Watkins (19).

All the evidence suggests that feeding extra concentrates at pasture leads to a less efficient utilization of grass. Often on highly-stocked farms, extra concentrates are fed to save grass for conservation. However, there seems to be no point in taking a product capable of maintaining a cow and producing 25 kg milk and converting it into silage that will give maintenance plus 10 kg (95). Until grassland is producing up to its potential and until the grass is utilized efficiently, the substitution of expensive concentrate energy for cheaper herbage energy should not be considered.

Animal manure

The increase in intensity of dairy farming (Table 1) and the changes in herd management - at present, on 20-25 per cent of all farms cows graze during the day only and are housed at night - have resulted in an increase in manure production from 26 million tonnes in 1965 to approximately 40 million tonnes in 1979 (calculated as slurry). Moreover, there is a large intensive animal production (meat, eggs) industry in the Netherlands. In particular regions, problems are created by manure surplusses.

It is estimated that currently approximately 70 per cent of cattle manure is handled as slurry. The rapid change over from the farm yard manure (FYM) plus liquid manure system to slurry was brought about by the introduction of cubicle houses and the need to save labour. Formerly, manure was valued mainly for its nutrients; currently, the problems of storage and safe disposal (sward and herbage quality and environment) are the centre of interest. The disposal of slurry is difficult to incor-

Table 4. Data on number of stock, consumption of concentrates and milk production.

<table>
<thead>
<tr>
<th>Item</th>
<th>1965-66</th>
<th>1978-79</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of dairy cows</td>
<td>1,723,000</td>
<td>2,247,000</td>
</tr>
<tr>
<td>Number of additional stock, l.s.u.</td>
<td>861,000</td>
<td>1,020,000</td>
</tr>
<tr>
<td>Concentrates, t</td>
<td>1,595,000</td>
<td>4,684,000</td>
</tr>
<tr>
<td>Concentrates, kg (dairy cow + add. stock)⁻¹</td>
<td>925</td>
<td>2,085</td>
</tr>
<tr>
<td>Concentrates, kg dairy cow⁻¹</td>
<td>650</td>
<td>1,780</td>
</tr>
<tr>
<td>Concentrates May-October, kg dairy cow⁻¹</td>
<td>100</td>
<td>850</td>
</tr>
<tr>
<td>Milk, kg dairy cow⁻¹</td>
<td>4,200</td>
<td>5,050</td>
</tr>
<tr>
<td>Butter fat, %</td>
<td>3.86</td>
<td>3.99</td>
</tr>
<tr>
<td>Milk May-October, %</td>
<td>58.8</td>
<td>55.0</td>
</tr>
<tr>
<td>Milk May-October, kg dairy cow⁻¹</td>
<td>2,470</td>
<td>2,780</td>
</tr>
</tbody>
</table>
porate into intensive grassland systems. Consequently, slurry is being spread at times which fit in best with the management and on which the least damage is done to the sward, i.e. in autumn and winter. However, from the point of view of nutrient utilization and of the environment, these are the least satisfactory periods.

The real value of the nutrients in animal manure depends on a number of factors such as soil type, soil fertility status, time of application, rainfall after application and stocking rate (82). The nutrients originate partly from herbage and partly from animal feeding stuffs. As can be seen from Table 4, the consumption of concentrates has increased almost three-fold since 1965 and consequently the amounts of nutrients brought on to dairy farms have risen considerably (Table 5).

Table 5. Average composition of concentrates (% in DM) and farm imports of nutrients (tonnes) by concentrates. The composition in 1965 was assumed to be the same as in 1973 (61, 145, 146).

<table>
<thead>
<tr>
<th>Element</th>
<th>1965</th>
<th>1978</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2.8%</td>
<td>2.8%</td>
</tr>
<tr>
<td>P</td>
<td>0.7%</td>
<td>0.6%</td>
</tr>
<tr>
<td>K</td>
<td>1.25%</td>
<td>1.55%</td>
</tr>
</tbody>
</table>

Nitrogen

In manure, nitrogen is present in various forms (123, 140):
- inorganic mineral nitrogen \( \left( N_m \right) \) which is readily available
- organic nitrogen \( \left( N_o \right) \) which is easily decomposed and becomes available in the year of application and
- organic nitrogen \( \left( N_r \right) \) which is less easily decomposed and becomes available only in subsequent years.

The percentage distribution of these three compounds in cattle manures is given in Table 6. FYM shows the lowest percentage direct available nitrogen, while in liquid manure almost all nitrogen is readily available.

The nitrogen effect of manure is usually much lower than the effect of fertilizer nitrogen (103) because of: losses of ammonia by volatilization, losses by leaching when after application in autumn or winter and the presence of organic compounds which become available only after mineralization.

Phosphorus and potassium

Assuming a retention percentage of 30 and 8 for phosphorus and potassium, respectively, the amounts of P and K which came available per ha grassland and forage crops from concentrates were 13 kg P and 44 kg K in 1978 as against only 5 kg P and 12 kg K in 1965. Using the data of Henkens (50, 51), an overall average nutrient balance per ha grassland plus forage crops for all dairy farms was calculated. The results show the following changes:

- P: in 1965 the export and the import were almost in balance, while in 1978 the import was nearly twice the export.
- K: in 1965 the import covered only 40 per cent of the export, while in 1978 the import exceeded the export by some 10 per cent.

It is, therefore, not surprising that on dairy farms, particularly the intensive ones, very little phosphorus and potassium fertilizers have to be used (80, 81). In order to assess the situation on their farms, farmers should calculate the nutrient balance and fertilize accordingly. Soil nutrient levels have to be monitored occasionally by soil analysis. Over-application of manure can cause trouble because of an excessive build-up of nutrients in the soil which may have an adverse effect on herbage quality. On grassland the rate-limiting factor for manure is the amount of potassium because excess potassium can significantly reduce herbage magnesium, calcium and sodium.

Nitrogen fertilization

As demonstrated in Figure 2 the average annual rate of fertilizer nitrogen on grassland has increased considerably. Figure 2 also provides some background data on stocking rate and milk production per cow. It is evident that there has been a notable increase in the number of dairy cows per ha grassland plus forage crops and in the milk production per dairy cow as well. At present 250 kg N is used per ha, approximately 100 kg more than at the time of the First General Meeting of the European Grassland Society in 1965. Figure 2 also shows a marked similarity between the curves for the national average and for the group of Nitrogen pilot farms which currently use on average slightly more than 400 kg N per ha (variation between 280 and 520 kg). It looks as if there is still some room for a further increase in the national rate of nitrogen application. On many other commercial farms too, 400 to 450 kg nitrogen per ha is used.

It is well-known that the greater responses occur in the range from 0 to 300 kg nitrogen,
The use of nitrogen (kg ha\(^{-1}\) yr\(^{-1}\)) on grassland in the Netherlands and on Nitrogen pilot farms during 1965-1979. The figures within the graph refer to the average number of dairy cows per ha grassland plus fodder crops (upper figures) and the average milk production (kg yr\(^{-1}\)) per dairy cow (lower figures).

Nitrogen fertilizers

The most common nitrogen fertilizer is calcium ammonium nitrate (CAN), a mixture of calcium carbonate and ammonium nitrate. In the sixties Magnesamon, a magnesium containing nitrogen fertilizer (AN + kieserite + dolomite mixture), was introduced. This fertilizer was to be used to increase herbage magnesium content and so reduce the incidence of hypomagnesaemia. In 1972 the composition of CAN was changed by increasing the percentage of nitrogen from 23 to 26, consequently decreasing the calcium carbonate content. CAN-23 had sufficient calcium carbonate so as not to affect soil pH. However, CAN-26 has an acidifying effect on the soil, equivalent to 0.56 kg CaCO\(_3\) per kg nitrogen.

The optimum pH-KCl on grassland lies between 4.8 and 5.6. Where the pH drops significantly below the lower value the yield potential and/or the nitrogen response of the sward might be affected (83, 109). Under acid conditions the better grasses may be replaced by poorer species, the calcium and the magnesium content of the herbage can be reduced and acidity interferes with the activity of the soil micro-organisms. Particularly at higher rates of fertilization - 350 to 400 kg nitrogen per ha per year is common on intensive farms - the pH declines rather rapidly. The grassland farmer should be concerned about the dangers of letting the pH drop too low and he should apply the correct measures to counteract not only the acidifying effect of CAN-26 but also the natural losses of calcium by leaching. This can be done either by liming every 4 to 5 years or by (partly) changing over to the recently introduced improved Magnesamon (AN + dolomite mixture) with 22 per cent nitrogen and 4.2 per cent magnesium (Mg). At a rate of 300 kg nitrogen per ha, new Magnesamon compensates not only the acidifying effect of the nitrogen component but also the average natural calcium losses (39). In addition it has a positive effect on herbage magnesium content (6).

Many experiments have investigated the effectiveness of other nitrogen fertilizers in comparison with the standard CAN.

Anhydrous ammonia

Anhydrous ammonia injected into the soil as a mixture of liquid and gas was far less efficient than CAN. The inferior performance was mainly due to damage of the sward by the injection knives. Single large injections in early spring have in general not maintained growth throughout the season, while large losses from leaching have occurred following applications in autumn (135, 136, 137).

Urea

When urea is surface applied, significant quantities of nitrogen may be lost by volatilization because of its rapid hydrolysis to ammonium carbonate. The extent of the ammonia volatilization losses depended on the amount of rain in the first few days after fertilizer application (138). On sand and clay soils the efficiency of urea was only 50 per cent of that of CAN.

Nitrogen solutions

Experiments with nitrogen solutions, based on ammonium nitrate and urea, have shown this
method to be only 90 per cent as efficient as CAN (131, 139).

Sulphur coated urea

Single applications of sulphur coated urea - a delayed release fertilizer - was found to be inferior to multiple applications of CAN (K. Dilz, personal communication).

Nitrate fertilizers

On soils containing free CaCO$_3$ nitrate fertilizers are generally superior to ammonium and ammonium nitrate fertilizers due to gaseous losses of NH$_3$ from the latter fertilizers. However, when these soils are under grass NO$_3^-$ and NH$_4^+$-forms perform equally well (130, 159). This can be attributed to the high organic matter layer on the soil surface of grassland.

Nitrogen response studies

Nitrogen plays a key role in grass production. However, grassland management and grass growth form a very complex system and it is difficult to assess the value of nitrogen. Level of applied nitrogen and interval between defoliations are two of the major factors determining yield and quality of herbage. These factors should always be studied in combination.

On commercial farms, yield on offer is the criterion rather than a fixed number of grazings or cuttings. Nitrogen accelerates the growth of herbage and a given yield (stage) will be reached more rapidly. This suggests that with an increase in nitrogen the harvesting interval could be shortened. A shortcoming of many studies on nitrogen response is that they include only one frequency of defoliation. Consequently the results do not reflect the practical situation.

Data of Prins and Van Burg (107) plotted in Figure 3 illustrate the above. The response to nitrogen shows a different pattern at the different harvesting systems: a fixed system with three defoliation intervals of eight weeks and a flexible system with defoliation frequencies based on yield on offer (2 t DM ha$^{-1}$). At equal nitrogen rates, cutting less frequently increased the yield of dry matter, but reduced the energy content of the herbage markedly. With regard to quality, both harvesting systems produced completely opposite results.

Grassland management and utilization

Much effort has been put in developing for advisory purposes a grassland management and utilization programme (8, 110, 147, 149, 150, 152). Such a programme is based on the seasonal growth model for grass, the feeding value of the herbage, the utilization of the pasture either for grazing (different variants) or for conservation and the feed requirement of the cattle. The various standard values to set up such a programme have been published by Wieling and others (153). In a management programme the feed supply (herbage produced) is adjusted as much as possible in order to meet the feed requirement of the livestock better.

To optimize farm profitability, a grassland management programme is an indispensable tool. Management programmes can be used for various purposes:
- Short-term planning (one year) to specify optimum pasture utilization and to project the requirement for additional feeding stuffs.
- Long-term planning for development: to provide the farmer with information to use in deciding whether he should expand his farm operation by stepping up nitrogen fertilization, by increasing the number of cows, by investing in irrigation equipment, etc.
- Analysis of the present situation on a farm. By comparing the actual situation with the 'standard' optimum, an adviser is able to
pinpoint problem areas, such as poor performance from herbage due to weaknesses in the grazing system, unsatisfactory sward quality or over-feeding with concentrates at pastures.

In planning grassland utilization systems, information is needed on the grassland production system. The response to nitrogen is dependent on a complex of interacting factors in which soil, site, weather, part of the growing season, time of application, and stage of defoliation are important elements. During the last 15 years considerable attention has been given to the following aspects.

Timing the nitrogen application in spring

The dilemma in early spring is when to put on the first dressing. Timing is critical. If the dressing goes on too early this will on sandy soils almost inevitably lead to leaching of nitrogen. This happens particularly with fertilizers containing part of their nitrogen as the readily leachable nitrate. By applying an all-ammonium fertilizer like sulphate of ammonia, there is no risk of losing early applied nitrogen. However, the use of sulphate ammonia has many drawbacks, such as a sharp decrease in pH, an adverse effect on the mineral composition of the herbage and occasionally the occurrence of serious leaf scorch (10, 133). If nitrogen is applied too late, valuable growing days will be lost, in either case production is lost. According to Jagtenberg (56, 57) a. nitrogen ought to be applied at the beginning of grass growth and b. whatever the physiological mechanisms involved, in this country in most years, grass starts to grow when the sum of the average daily air temperatures above 0°C, recorded from 1 January, reaches 200°C (minus zero figures are not subtracted).

Many experiments carried out since have established that this T-sum method is a valuable aid in optimizing the timing of nitrogen in spring (96, 97, 98, 99, 100, 133). As an example, the results of six experiments from 1979 are shown in Figure 4. This figure demonstrates that a high degree of prediction can be brought to the spring fertilization system.

Since 1977 each spring from February onwards, the Proefstation voor de Rundveehouderij publishes the T-sums for the various weather stations in the country. The T-sum method is becoming rather popular, it features regularly in the farming press. However, many activities are still needed with the aim to utilize better the full growing season because there is considerable scope for improvement. This is illustrated in Figure 5, in which we have plotted for the period 1960-1980 inclusive mean dates at which the Nitrogen pilot farmers applied their first nitrogen, against the mean 'T-sum 200' dates. Figure 5 shows clearly that, particularly in (very) early years, nitrogen was applied (much) too late, while there is a tendency in late years to apply rather too early.

Seasonal growth pattern and the within-seasonal response to nitrogen

Alberda and others (1, 3) who studied the seasonal variations in grass growth at ample nutrient and water supply, reported the growth rate in August-September to be appreciably lower than between April and June. Similar results were obtained in other studies (31, 106, 134). The growth rate from May to the middle of September is very much influenced by light intensity (1, 31).

The response to nitrogen during the growing
season depends largely on the intensity of nitrogen fertilization. With annual rates of up to 300 kg N per ha the responses to nitrogen (after 4 to 5 weeks growth) are almost unaffected between April and early to mid-August.

With late August-early September applications, the response is reduced (106). This is in agreement with Deinum (31) who reported a decrease in nitrogen response at reduced light intensities. At higher annual intensities (400 kg N per ha and over), the responses to nitrogen during the season are not only significantly lower but decline already from May-June onwards (108). It is evident that in the latter situation this may be attributed to a build-up of residual nitrogen in the soil-plant system (105).

Residual nitrogen

Investigations have indeed shown that nitrogen applied earlier during the season might have a notable residual effect. This effect depends on the amount applied previously (58, 105, 106, 150). A sound fertilization policy should take this residual effect into account.

Stage of defoliation

It has been established that the pattern of regrowth is affected by the quantity of herbage harvested at the preceding cut. Delaying a defoliation results in a higher yield of dry matter, but in a poorer regrowth potential (1, 59, 93, 106, 148, 151). Data from Wieling (personal communication) in Table 7 illustrate clearly that the delay in regrowth increases exponentially with the increase in yield of the preceding cut.

Table 7. Effect of yield level of the first cut on the delay in regrowth (in days) with regard to regrowth after a yield of 2 t DM to attain a grazing stage yield. Regrowth fertilized with 80 kg N ha⁻¹.

<table>
<thead>
<tr>
<th>Yield first cut t DM ha⁻¹</th>
<th>Delay regrowth days</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>0.8</td>
</tr>
<tr>
<td>3</td>
<td>1.7</td>
</tr>
<tr>
<td>3.5</td>
<td>2.8</td>
</tr>
<tr>
<td>4</td>
<td>4.1</td>
</tr>
<tr>
<td>4.5</td>
<td>5.6</td>
</tr>
<tr>
<td>5</td>
<td>7.3</td>
</tr>
<tr>
<td>5.5</td>
<td>10.2</td>
</tr>
<tr>
<td>6</td>
<td>12.7</td>
</tr>
</tbody>
</table>

Soil type

The results of two long-term studies (12, 91, 144) have shown that on all soils and sites (wet and dry) and in all years there was a significant effect of nitrogen. However, on well-drained peat and clay on peat soils, nitrogen uptake by non-fertilized herbage was considerably higher than on normal clay and sandy soils, resulting in a correspondingly smaller response to nitrogen on the former soils. Hence the differences in the recommended rates of nitrogen application: peat soils 250-300 kg N per ha and clay and sandy soils 400-450 kg N per ha.

Drainage

Peat and clay on peat grassland cover some 375,000 ha or about one third of the total acreage. These low lying grasslands have a high water table, -25 to -30 cm being not uncommon. They are difficult to manage, the bearing capacity is low and poaching can be serious. Intensification presents many problems. Between 1965 and 1970 numerous experiments were started with the objective to determine whether deeper drainage by lowering the water level in the drainage ditches could raise the performance of these pastures. The studies have shown that substantial improvements can be achieved by lowering the water table from 30-50 cm to 70-90 cm below surface level (14, 17, 118): the bearing capacity increases, the grass starts to grow earlier, the grazing losses are lower, the botanical composition improves. It was also found that mineralization of the soil organic matter is greatly enhanced and consequently the response to nitrogen declines (14, 17, 118, 119) markedly. This agrees with the results of another study, reported by Van Steenbergen (144) that wet peat soils require more nitrogen than drier peat soils.

Irrigation

During the late sixties - early seventies, irrigation of grassland has increased in popularity due to various reasons such as increase in stocking rate, greater demand for roughage, and conversion of arable land into grassland on the drier soils. Water and nitrogen are the main factors affecting grass growth and in dry weather there is a positive nitrogen-water interaction (42, 119). Wieling (42) calculated a response to irrigation of 22.5 and 29.5 kg DM ha⁻¹ yr⁻¹ per mm moisture deficit at nitrogen rates of 200 and 400 kg N ha⁻¹ yr⁻¹, respectively. According to Garwood et al. (45) it is essential that there is sufficient water in the surface soil at the time of nitrogen application.

The two dry years 1975 and 1976 and the introduction of improved, labour saving, irrigation equipment (hose reel) have been a great stimulus for the expansion of irrigation (36, 37, 143). It is estimated that currently farmers have equipment available to irrigate (either by over-head or surface irrigation) approximately 180,000 ha grassland, as
compared with only 15,000 ha in 1965.

Irrigation of drought sensitive grassland (moisture deficit 150 mm and over) is without doubt profitable. On better, less drought-sensitive soils (approximately 100 mm moisture deficit) the profitability of irrigation is questionable (41, 42). However, the future will most probably see a further expansion of irrigation even on these soils. It appears that on many highly stocked farms irrigation is regarded as a valuable insurance to get over even short dry periods.

Nitrogen advisory scheme

The results of the studies noted above have led to the following general recommendations for nitrogen on sand, clay and wet peat soils (Table 8). On well-drained peat soils the rates are about 20 kg nitrogen lower from the second 'cut' onwards.

Table 8. Recommended rates (kg N ha⁻¹) for sand, clay and wet peat soils.

<table>
<thead>
<tr>
<th>Use</th>
<th>'Cut'</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1*</td>
</tr>
<tr>
<td></td>
<td>2 and 3</td>
</tr>
<tr>
<td></td>
<td>4 and 5</td>
</tr>
<tr>
<td></td>
<td>later</td>
</tr>
<tr>
<td>Grazing</td>
<td>80-40</td>
</tr>
<tr>
<td>Silage or hay</td>
<td>120-80</td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>80</td>
</tr>
</tbody>
</table>

* The higher rates refer to the first fields which will be grazed or mown.

Nitrogen pilot farms

Plot experiments can help us to understand the intricate relationships between soil, grass, animals and nitrogen. Since herbage ultimately is consumed by livestock, yield, quality and other improvements from fertilization have to be measured in terms of saleable animal products. Therefore the effect of nitrogen on farm economy in relation to the interacting forces and processes involved in the production and utilization of grass, can only be studied on a farm scale (129). In 1934, the above was the basic idea behind the proposal of Frankena and Boudewijn to set up a so-called Nitrogen pilot farm project (44). The project started in 1935 and has been in existence ever since, except for the interruption during World War II. When the scheme was revived after the war the prime object was to intensify to a level of approximately 200 kg N per ha (27).

Various institutions 1) co-operate in the scheme and are represented on the Nitrogen pilot farm Advisory Committee. There are presently 15 farms located throughout the country, operating the scheme. They are true commercial holdings which are fully costed and administered.

Soils, grass, silage etc. are analysed regularly and all data are published annually. By 1965 the pilot farms had already reached a high level of nitrogen fertilization and the average nitrogen rate of 315 kg N per ha exceeded the original target considerably. The economic conditions since then have encouraged an even more intensive use of nitrogen and over the last two years an average of 420 kg N per ha was realized. In the past the emphasis has been on increasing grass production. Currently, however, there is more need to improve on the efficiency with which the increased herbage production is utilized. To this end a 'Production and planning control and quarterly budget system' was introduced on the pilot farms. The objective is to provide the farmer with the data and tools which will enable him to optimize grassland management and utilization and consequently maximize his profits.

Just like their colleagues 45 years ago, the present-day Nitrogen pilot farmers can be regarded as pioneers in this field. Their farms serve both in a research and advisory capacity. They are still as necessary and important as they were in the early years.

Secondary effects of intensification

Fouling and grass utilization

As already stated above, slurry does not fit in with intensive grassland management. Applications to grazed grass should be avoided as the intake of grass will be reduced. Therefore farmers often apply slurry in autumn and winter which is nutritionally and environmentally the least favourable period. This has prompted investigations to examine ways in which slurry could be applied during the growing season to obtain more benefit from the slurry while at the same time maintaining good pasture utilization. These studies considered slurry irrigation (142) and slurry injection (158, 160). Applying diluted slurry (1 part slurry to 10 parts water) by sprinkler irrigation has given promising results as regards grass utilization. However, the large water consumption is a clear disadvantage for this method. At present experiments are being conducted to obtain information on the effects

1) Ministry of Agriculture Advisory Services; Research and Advisory Institute for Cattle Husbandry; Agricultural Economics Institute; Agricultural University, County Animal Health Services; Institute for Animal Nutrition and Agricultural Bureau of the Netherlands Fertilizer Industry.
of the mixing ratio. The results of injection experiments have indicated that this method offers possibilities especially on sandy soils, provided soil moisture is not too low. With a specially devised applicator (117) further trials are in progress to test the merits of injected slurry.

Pasture utilization is impeded by the faecal deposits of animals. When grassland is predominantly grazed, a greater part of the area will be affected by excreta. Cows often reject herbage growing around dung spots or herbage contaminated with dung. Experiments have shown that with a system of day and night grazing herbage intake and milk production were considerably higher on clean pasture than on fouled pasture (72, 92). These adverse effects can be overcome by better management (52): frequent topping increases the acceptability of the herbage and the number of defaecations and urinations at grass can be halved by changing from day and night grazing to day grazing. However, in the latter case the reduced grazing time must be compensated for by feeding extra concentrates. The problem of rejection can be overcome by increasing the stocking rate.

Heavy rates of slurry or manure and particularly uneven distribution may lead to deterioration of the sward (25) or may reduce herbage production due to a smothering or coating effect (7, 116). These negative effects of animal manures should receive more attention in practice.

Over the last few years, a number of studies have been conducted to measure the effect of dung and urine patches on herbage growth. Dung and urine are important means for the recycling of plant nutrients. However, both may have adverse side-effects on the sward (59, 69, 70). The droppings cause very uneven pasture growth. Dung and urine patches can significantly increase herbage production in the surrounding sward. However, the regrowth of these areas is considerably less than of the non-affected sward. On the other hand, grass underlying a dung patch, or on a urine spot, may die. In particular, the problem of urine scorch has received much attention lately. Not only do these dead spots result in a loss of pasture production but they also provide an opportunity for weeds and weed grasses to establish themselves. There are a number of factors which influence the effect of a urination. Particularly important are the prevailing weather and soil conditions (116).

Sward quality

In the fifties it was found that increases in nitrogen use and stocking rate led to a better sward quality (24, 35), with a noticeable increase of good grasses and a decrease of herbas, clover and grasses such as Festuca rubra, Agrostis sp. and Holcus lanatus. Later studies too showed that high rates of nitrogen need not have an adverse effect on sward quality (84, 85). On the other hand, however, Prins (110) noted a strong reduction in the number of tillers of Lolium perenne and other species at very high rates of nitrogen combined with frequent cutting, while Altena and Hijink (5) found a decrease in bearing capacity of the sward by increasing the rate of nitrogen fertilization.

By the developments in the sixties and seventies, i.e. more intensive stocking, more frequent cutting, more mechanization etc., the demands on soils and swards were increased (53). According to reports by De Goor (25, 26), there was a noticeable decline in sward composition with an increase of undesirable species like Poa annua, Elytrichia repens, Stellaria media and Rumex sp. particularly on farms in the sandy areas. It was established (84, 85) that sward deterioration is closely connected with the periods when grass is mown for conservation (58, 113). The main causes are heavy silage or hay cuts, faulty calibration of mowing machines, and excessively long wilting periods. Besides, sward deterioration can arise from too great application of slurry and especially uneven slurry distribution as well as from urine scorch, dung spots and poaching (40).

It is estimated that nowadays approximately 120,000 ha or 10 per cent of our permanent grassland are reseeded as against an estimated 25,000 ha only in 1965. The rise in reseeding activities can be attributed to:

- Increased intensification (higher stocking rate) which is attended by the need for better quality grassland.
- The introduction of new methods of seeding. In the past years various methods of reseeding and non-tillage sod-seeding with or without chemically killing the old sward, have been studied extensively (54, 84, 111, 112, 114). On peat soils and heavy clay soils where reseeding is difficult and may give disappointing results (55, 88, 89), sod-seeding is a reasonable alternative (86, 115).
- The increased mechanization requires larger and more workable fields: filling up ditches and field levelling is followed by reseeding. Reseeding is costly and there is always the risk of failure. An additional disadvantage is the inescapable loss of yield during the period that the new grasses are being established (78, 89, 114). Therefore reseeding and renovation have to be regarded as a sometimes necessary evil. The emphasis in grassland management should be on maintaining the sward in good condition. It is fortunate that all measures to achieve optimum production and utilization, favour the good grasses. In this respect it is notable that currently simple seed mixtures (BG 3, containing only hay and grazing type Lolium perenne) are popular, whereas around 1965, complex mixtures (BG 5) were commonly used. The reason is that, with a high rate of nitrogen fertilization and an
intensive use of grassland, within one or two years the sward will be composed of 80 per cent or more Lolium perenne.

Animal health

The purpose of fertilization is to correct soil nutrient deficiencies and to increase crop yields without adversely affecting crop quality. In animals nutritional disorders are associated with the nutrient requirement of the animal (for maintenance and production), the nutrient intake with the feed and the nutrient availability (the ability of animals to absorb nutrients from the intestinal tract).

During the pre-1965 period many studies were primarily concerned with the effect of increasing rates of nitrogen on the mineral composition of herbage. Nitrogen may affect herbage composition indirectly (change in botanical composition) or directly. The latter effects are rather inconsistent and depend to a large extent on the amount of available minerals in the soil. Apart from studies on the effect of intensive fertilization on the availability of nutrients for livestock (magnesium, copper), the interest in the mineral composition per se has declined since 1965. The increased use of concentrates is one of the reasons for this decline. Keuning summarized research on the composition of grazing-stage herbage on the highly intensive Nitrogen pilot farms and concluded that the average mineral composition could meet the requirements of animal nutrition (67).

Magnesium

In the late fifties and early sixties grass tetany presented a serious problem. At the 1965 meeting De Groot (27) reported on the early investigations. Results of extensive studies by Kemp and others (60, 62, 63) have clearly indicated:
- that grass tetany is associated with a deficiency of Mg due to a low Mg-intake and/or a reduced Mg-availability and
- that Mg-availability was regulated by the potassium and nitrogen content of the diet. The higher the product K x N, the higher the Mg-content has to be (29). According to Kemp and Geurink (63) the aim of measures to control grass tetany should be to increase herbage Mg-content rather than to improve the Mg-availability. The latter method is not effective enough because intensive grassland utilization (high nitrogen fertilization and grazing young herbage) is associated with low availability. The following means of increasing the magnesium concentration of the diet can be considered:
  - Applying magnesium or magnesium containing nitrogen fertilizers (6, 38, 39, 62, 121)
  - Dusting the pasture with magnesium oxide prior to turning the cows out (62) and
  - Feeding magnesium-enriched concentrates (62).

Over the past fifteen years, the prevention of grass tetany or hypomagnesaemia has received much attention. As a result, almost no difficulties are experienced at present anymore.

Copper

Copper deficiency can also be directly related to the intensive use of grassland. According to De Groot and others (30) cows grazing on high protein pastures showed a lower copper status than those grazing on low protein pastures. This agrees with reports that a decrease in the energy to protein ratio in the herbage has an adverse effect on the availability of dietary copper (9, 47). Copper deficiency can easily be corrected by feeding copper-enriched concentrates.

Nitrate

High rates of applied nitrogen (as fertilizer or manure) and growth-restricting conditions (shortage of other nutrients, light or water) are associated with increased nitrate nitrogen concentrations in plants: the accumulation of nitrate indicates the presence of unassimilated nitrogen. Deinum and Sibma (32) presented evidence to show that nitrate accumulation seldom occurs with nitrogen rates up to 400 kg per ha per year. It is significant to note that to obtain maximum herbage yields the nitrate nitrogen content in the dry matter ought to be in the region of 0.15 per cent (132). Plants are capable of accumulating considerably higher amounts without apparent ill effects. However, from an animal nutrition standpoint the occurrence of high levels of nitrate nitrogen in herbage and forage crops, has been of some concern the last 10 to 15 years.

In the autumn of 1966 the first nitrate trouble was experienced. Livestock deaths were reported after feeding turnips containing 0.8 per cent or more nitrate nitrogen in the dry matter. As at that time turnips with some 60,000 ha were still an important forage cash crop, there was need for more detailed information. It was found that late sowing, high rates of nitrogen fertilizer, and late top-dressing with nitrogen combined with heavy applications of animal manures, greatly increased the nitrate content of tops and roots (124, 125, 126). The problem was serious in autumns when light was growth limiting.

In the winter of 1968-1969, the first cases were reported of nitrate poisoning after feeding hay containing between 0.6 and 1.1 per cent nitrate nitrogen (127, 155). From surveys in the succeeding years it became apparent that difficulties could be expected when feeding conserved grass (hay or wilted silage) with a high nitrate content (20, 127,
It is notable that the herbage which caused the difficulties came from newly sown or reseeded pastures. These pastures generally receive liberal dressings of manure before cultivation and sowing. However, farmers do not take enough account of the amount of nitrogen which becomes available by mineralization of the organic nitrogen in the manure as well as the organic matter of the old sward. Later work has shown that the high herbage nitrate content of reseeded pastures is also associated with essential differences between grasses in a newly established pasture and those in the original sward: the former usually take up more nitrogen, produce less leaves but transfer relatively more nitrogen to those leaves (21, 22).

Extensive animal-feeding studies by Kemp and others (64, 65, 66) have shown a close relationship between the formation of methaemoglobin and level of nitrate intake, rate of nitrate intake and rate of nitrate release in the rumen. The rate of intake is lower at pasture than feeding grass indoors, while conservation of grass (into hay or wilted silage) is accompanied by an increase in the rate of release.

It is therefore not surprising that nitrate poisoning has been experienced when feeding high-nitrate silage or hay while no adverse effects of high nitrate herbage on health and production have been observed under grazing conditions (30, 67) not even when cows grazed on herbage with an excessively high nitrate nitrogen (0.8-1.0 per cent) content (34).

However, it should be noted that nitrate nitrogen content in excess of 0.15 to 0.20 per cent in the dry matter indicates a wasteful usage of nitrogen.

Physical nature of the herbage

A quality aspect which in recent years is attracting more attention, is the fibre content of the herbage. High rates of nitrogen and intensive pasture utilization (grazing or cutting herbage in a young stage) tend to decrease fibre content (Table 9). Likewise Keuning (67 and personal communication for 1977-1978 data) reported in his study on the herbage composition on Nitrogen pilot farms that approximately 40 per cent of the samples had a crude fibre content below 20 per cent. In herbage a low fibre content is usually associated with a low structural value of that herbage. In combination with the present high rates of concentrate feeding at pasture (see Table 4), herbage with low fibre may pose a problem. A total ration which has too little structural value depresses the production of acetates in the rumen and consequently lowers the percentage of butter fat (15, 30, 33).

Environment

Organic manure

The average stocking rate has increased from 2.0 livestock units per ha in 1965 to 2.7 in 1978. However, the area mown for winter-feed has not changed and still amounts to 0.4 ha per livestock unit. It has been established that on dairy farms all the animal manure can be applied safely to grassland provided the stocking rate does not exceed 3.4 livestock units per ha (48, 49, 51, 79, 140). Problems can arise, when, as so often happens, slurry is applied in autumn and winter. Leaching (nitrogen) and runoff (phosphorus) might then constitute potential dangers for either groundwater or surface water (77, 122).

Nitrogen fertilizer

At the 1965 meeting, Woldendorp and others (157) reported that provided nitrogen is applied on grassland during the growing season, losses by leaching are negligible. Since then the nitrogen balance has been the subject of many investigations.

Evidently nitrogen applied too early in spring or too late in autumn is liable to leaching (73, 133). According to Kolenbrander (74, 75, 76) leaching losses from grassland are far less than from arable land. With up to 200-225 kg fertilizer nitrogen per ha grassland, he found leaching losses of approximately 1 per cent only. The results of further investigations (122) suggest that at higher rates the losses increase exponentially to 6, 14 and 23 per cent at 300, 400 and 500 kg nitrogen per ha per year, respectively. However, other investigators (2, 144) have shown that up to 425-500 kg N per ha per year there is no fear for leaching because up to that rate the uptake of nitrogen by the herbage at least equalled the nitrogen input. In a long-term study, Prins (102) determined mineral nitrogen accumulation in various grassland soils. He demonstrated clearly that on old permanent grassland accumulation started above 400 kg nitrogen per ha but on younger grassland marked accumulation was not found until above 480 kg nitrogen per ha per annum.

The farmer's fertilizer policy should take the above into account in order to economize on fertilizer costs and minimize the risk of nitrogen losses and of pollution of ground water.


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...
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).

Choice of experimental methods and analysis of results

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 1).

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 intensive (I) system of nitrogen fertilization. In the IB-trials also an extensive (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 intermediate (P) and a very intensive (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.

![Figure 1. Location of the PR- and IB-trials in the Netherlands.](image-url)
Table 1. General data of trial sites and intensities of pretreatment nitrogen fertilization.

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

* 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.

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

* 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 treatment 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.

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**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.
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 (SI) 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.

<table>
<thead>
<tr>
<th>Date of N-application</th>
<th>Intensity of nitrogen fertilization</th>
<th>Yield level at 0 N</th>
<th>0 + 40 N</th>
<th>40 + 80 N</th>
<th>80 + 120 N</th>
<th>0 + 120 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/5</td>
<td>E</td>
<td>1800</td>
<td>725</td>
<td>575</td>
<td>300</td>
<td>1600</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>2250</td>
<td>675</td>
<td>525</td>
<td>200</td>
<td>1400</td>
</tr>
<tr>
<td>1/6</td>
<td>E</td>
<td>1700</td>
<td>825</td>
<td>650</td>
<td>350</td>
<td>1825</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>2300</td>
<td>725</td>
<td>500</td>
<td>225</td>
<td>1450</td>
</tr>
<tr>
<td>1/7</td>
<td>E</td>
<td>1500</td>
<td>875</td>
<td>650</td>
<td>375</td>
<td>1900</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>2200</td>
<td>700</td>
<td>450</td>
<td>200</td>
<td>1350</td>
</tr>
<tr>
<td>1/8</td>
<td>E</td>
<td>1200</td>
<td>850</td>
<td>575</td>
<td>325</td>
<td>1760</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>1900</td>
<td>575</td>
<td>325</td>
<td>150</td>
<td>1050</td>
</tr>
<tr>
<td>1/9</td>
<td>E</td>
<td>750</td>
<td>700</td>
<td>400</td>
<td>200</td>
<td>1300</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>1350</td>
<td>350</td>
<td>125</td>
<td>50</td>
<td>525</td>
</tr>
<tr>
<td>20/9</td>
<td>E</td>
<td>500</td>
<td>375</td>
<td>250</td>
<td>100</td>
<td>725</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>850</td>
<td>150</td>
<td>-25</td>
<td>-25</td>
<td>100</td>
</tr>
</tbody>
</table>

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.

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.

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

* Differences between E and I because of curve fitting.
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 to 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.

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</table>

* 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 re­s­
sults of this and previous research (Alberda &
Sibma, 1968; Behaeghe, 1968; Corral!, 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 conse­
quently yield at a certain date is larger
than at lower rates. Large yields may, espe­
cially in early season, considerably affect
the production of following cuts (Ennik,
1980; Garwood, 1980).

When choosing the cutting management in
grassland experiments one has to take advan­
tages and disadvantages into consideration.
Cutting according to a fixed series of dates
is, of course, easier as regards the organi­
zation of the work. An apparent advantage
with set dates is also that cutting and fer­
tilizing 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 nitro­
gen. 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 treat­
ments 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.

2. Optimum rate of nitrogen application

The purpose of the study of the seasonal
response to nitrogen is to establish guide­
lines for the optimum rate of nitrogen appli­
cation per cut depending on the usage of the
herbage. This means integrating vertical and
horizontal effects and taking possible resid­
ual 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.), Holstländner & 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 growing season.

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.

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<th>System</th>
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<th>Date of N-application</th>
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<th>DM yield level, t ha⁻¹</th>
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<td>200</td>
<td>40  80 120 160 200</td>
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* 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).

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.

References


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.

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<tr>
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<td></td>
<td>1.72</td>
<td>2.45</td>
<td>2.32</td>
<td>2.20</td>
</tr>
<tr>
<td>IB 2145</td>
<td>Z</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>S1</td>
<td>11/3</td>
<td>22/4</td>
<td>15/5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.94</td>
<td>2.36</td>
<td>2.20</td>
<td>2.34</td>
</tr>
</tbody>
</table>

*The spring applications were 80 and 120 kg N per ha in the E- and I-system, respectively.
THE INFLUENCE OF CLIMATE AND SOIL ON THE YIELD OF GRASS AND ITS RESPONSE TO FERTILIZER NITROGEN

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Grassland Research Institute, Hurley, Maidenhead, Berkshire, United Kingdom

Summary

The response of perennial ryegrass to fertilizer N was examined under two cutting managements, monthly or conservation frequency, at 21 lowland sites in Britain over four years. Optimum yield, the yield at which the incremental response to fertilizer N fell to 10 kg DM kg\(^{-1}\) N, varied widely between sites, 5 to 15 t ha\(^{-1}\), and between years within sites. Differences in yield between sites were greater than between managements at sites. Annual yield was affected by the amount of rainfall from April to September plus the available water holding capacity of the soil. The amount of fertilizer N required to meet optimum yield and the response to this rate were correlated with yield. Annual yield was unaffected by the pattern of seasonal application of fertilizer N although there was a redistribution of seasonal yields.

Introduction

The broad effects of fertilizer N on the yield of grassland, at least in temperate conditions, are well understood. The literature has been thoroughly reviewed by Whitehead (1970). In practice the yield potential of grassland is controlled by the environmental factors of climate, weather and soil. The interactions between these factors and the response to grass to fertilizer N are unclear. If fertilizer N is to be used efficiently on grassland then an understanding of the interaction between fertilizer N and environmental factors is necessary. This is particularly important near the upper levels of input and response which are reached on many intensive farms in Northern Europe.

This paper considers the variation in yield of grass, fertilizer N requirement and response to this N as influenced by climate and soil. Some aspects of the recovery of fertilizer N are dealt with by Dowdell et al. (1980).

Experimental

A series of experiments has been conducted jointly by the Agricultural Development and Advisory Service (ADAS) and the Grassland Research Institute with the objective of examining the variation in yield of perennial ryegrass and its response to fertilizer nitrogen in relation to climate and soil. The design and management of these trials have been described by Jackson (1970). The observations in this paper have been drawn from two of these experiments GM.20 and 21. Both were carried out over four years between 1970 and 1974 on representative lowland sites in mainland Britain. Each experiment was at 21 sites of which 17 were common to the two experiments. The distribution of sites is shown in Figure 1.

Figure 1. Distribution of experimental sites O GM.20, □ GM.21 and ● GM.20 and 21.
A sward of perennial ryegrass, cv. S23, was sown at each site in the year prior to the application of treatments. At every site there was a history of alternate cropping with arable crops and leys with one exception which had been under permanent grassland. In GM.21 a "conservation" management was applied with four main cuts. The first cut was in early June at 50 per cent ear emergence, this date for each site being estimated from its latitude. Subsequent cuts were taken at 42 day intervals. In GM.20 there were six main cuts at 28 day intervals the first cut being 28 days before the first cut in the other experiment. A clearing cut was taken in November if there was sufficient herbage; these cuts were small but the yield has been included in the annual yields. To ensure uniformity of management the cuts were made at fixed dates at each site relative to the first cut in GM.21.

N was applied as ammonium nitrate at a range of rates up to 800 kg ha\(^{-1}\) year\(^{-1}\) in a series of patterns in which the first application was made in March followed by an application after each main cut excluding the last. The date of the initial application each year was that day in March on which the 10 cm soil temperature reached 5.5°C at 0900 GMT or 1st April if this temperature was not reached in March. Treatments were applied to the same plots each year. Lime was applied at the start of the experiments as necessary to raise the pH to 6.0. Potassium was applied as potassium chloride with the N at a rate of 0.75 kg K\(_2\)O kg\(^{-1}\) N and to the no N treatment at the same rate as to the lowest N rate. Phosphorus was applied as triple superphosphate in spring at a rate recommended on the P index of the soil based on standard ADAS advisory soil analyses each year.

The detailed results of GM.20 have been published (Morrison et al., 1980). The detailed results of GM.21 are being prepared for publication.

**Interpretation**

Each experiment produced 84 site-year combinations of results plus 21 site means. A response equation was fitted to annual dry matter yields for each site-year and the four-year site means. The form of curve which fitted the data best was an inverse polynomial

\[
Y = \frac{a + bN}{1 + cN + dN^2}
\]

where \(Y\) is the annual dry matter yield and \(N\) the annual amount of fertilizer N applied (Sparrow, 1979). The general form of the response is shown in Figure 2.

From the response equations the following variates were calculated:

- \(Y_{\text{max}}\) - maximum yield;
- \(\frac{dy}{dN} = 0\)
- \(Y_{10}\) - "optimum yield" being the yield at which the slope of the response to fertilizer N was 10 kg DM kg\(^{-1}\) N;
- \(\frac{dy}{dN} = 10\)
- \(N_{\text{max}}\) - fertilizer N required for maximum yield
- \(N_{10}\) - fertilizer N required to meet \(Y_{10}\)

It is assumed that N is non-limiting at \(Y_{\text{max}}\) which is, therefore, the potential yield under the management imposed for particular conditions of climate or weather and soil.

There was a wide spectrum of variation
between years at individual sites. However, at individual sites there was a consistency in the shape of the response curve for each year indicating that it was characterised by the particular combination of soil and climate.

**Variation in annual yield**

The striking feature of the results was the wide range of yields both between and within sites. Because there were only four years of experimentation and the range of environmental variation was less between years within sites than between sites, the variation between years within sites was difficult to interpret. Broadly, variation within sites was related to the same factors which influence between-site variation but was less closely correlated with them.

This paper is concerned primarily with between-site variation.

Within sites and overall, the difference in dry matter yield, \( Y_{\text{max}} \) or \( Y_{10} \), was relatively small between managements. The \( Y_{10} \) values of the two experiments were correlated (\( r = 0.76 \)). Yields for the conservation management were greater than those under the 28-day cutting frequency. This difference tended to become less as the swards aged. Under the 28-day cutting frequency there was a trend, which was not significant or consistent, for \( Y_{\text{max}} \) and \( Y_{10} \) to decline slightly with age. The trends of annual yield with age under the conservation management have not been fully analysed but at some of the lower rainfall sites there was an apparent decline in yield under this management which was not apparent at higher rainfalls.

The variation in the mean site values of \( Y_{\text{max}} \) and \( Y_{10} \) are shown in Table 1.

**Table 1. Ranges of mean-site values and overall means of \( Y_{\text{max}} \) and \( Y_{10} \) under two cutting frequencies, DM t ha\(^{-1}\).**

<table>
<thead>
<tr>
<th></th>
<th>Range</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6 cuts GM.20</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( Y_{\text{max}} )</td>
<td>6.51 - 15.04</td>
<td>11.92</td>
</tr>
<tr>
<td>( Y_{10} )</td>
<td>5.24 - 14.35</td>
<td>10.84</td>
</tr>
<tr>
<td><strong>4 cuts GM.21</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( Y_{\text{max}} )</td>
<td>8.66 - 16.40</td>
<td>12.48</td>
</tr>
<tr>
<td>( Y_{10} )</td>
<td>7.78 - 15.44</td>
<td>11.39</td>
</tr>
</tbody>
</table>

Under each management \( Y_{\text{max}} \) was closely correlated with \( Y_{10} \) (\( r = 0.98 \)) and mean \( Y_{10} \) was 0.92 of \( Y_{\text{max}} \). The correlation coefficients of \( Y_{\text{max}} \) and \( Y_{10} \) with variables such as rainfall and availability of water, which are examined later, were of the same order of magnitude. \( Y_{10} \), therefore, and the dry matter yields obtained from similar rates of fertilizer N, can be used as an index of yield for particular conditions of climate and soil.

\( Y_{\text{max}} \) and \( Y_{10} \) are computed values of annual yield indicating potential but they do not allow the calculation of seasonal yields. To do this the yields of actual treatments, for which the yields of individual cuts are known, have been used. The treatments used were 450 kg ha\(^{-1}\) N (6 x 75) for the 28-day cutting frequency and 400 kg ha\(^{-1}\) N (4 x 100) for the conservation management. In most cases these rates produce yields between \( Y_{\text{max}} \) and \( Y_{10} \) and the correlation coefficients with other variables are nearly identical.

**Main factors influencing yield at high fertilizer N rates**

The main factor determining yield at the higher rates of fertilizer N was the amount of water available to the crop over the growing season. Two factors contributed to water supply, first the rainfall over the growing season from April to the end of September (RGS) and secondly the available water holding capacity of the soil to rooting depth or 1 m (AWC), Table 2.

**Table 2. Between site correlation coefficients between yield and water supply GM.20 and 21.**

<table>
<thead>
<tr>
<th></th>
<th>GM.20</th>
<th>GM.21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall April-Sept (RGS)</td>
<td>0.62</td>
<td>0.58</td>
</tr>
<tr>
<td>Soil available water capacity (AWC)</td>
<td>0.36</td>
<td>0.26</td>
</tr>
<tr>
<td>Water available April-Sept (RGS + AWC)</td>
<td>0.76</td>
<td>0.67</td>
</tr>
<tr>
<td>Rainfall June-Sept</td>
<td>0.56</td>
<td>0.49</td>
</tr>
<tr>
<td>Water available June-Sept</td>
<td>0.74</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Mean RGS at individual sites ranged from 236 mm at Cambridge to 520 mm at Aberystwyth with a mean of 336 mm. AWC ranged from 46 mm on a sandy soil at Gleadthorpe EHF, to 161 mm on a clay-loam at Aylesbury with a mean of 110 mm. Under British conditions the soil is almost invariably at field capacity at the beginning of April and the water available to the crop is the amount of available soil-water plus rainfall which is more closely correlated with yield than either RGS or AWC. Water is rarely
Limiting in the early part of the season and annual yield was also closely correlated with the amount of water available from June onwards (calculated as AWC - actual deficit in early June plus the rainfall from June to the end of September). At the lower rainfall sites soil with a high AWC can supply over half the total water available over the season. In GM.20 the following relationship was established:

\[
Y_{10} \text{ (t ha}^{-1}) = -0.3186 + 0.02996 \text{ AWC (mm)} + 0.0392 \text{ RGS (mm)} - 0.00004379 \text{ RGS}^2
\]

\[R^2 = 0.35\]

Variation in annual yield resulted, to a large extent, from differences in production from June onwards under both managements. The range of variation in yields over the early part of the season and after June are shown in Table 3.

Table 3. Variation between sites in seasonal production with monthly cuts (GM.20) or conservation management (GM.21) 4-year means t ha\(^{-1}\) (calculated from 17 sites common with GM.21 which include the full range in GM.20).

<table>
<thead>
<tr>
<th></th>
<th>Range</th>
<th>Mean</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM.20 450 kg ha(^{-1})N (6 x 75)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April - June (cuts 1 - 2)</td>
<td>3.99 - 6.66</td>
<td>5.42</td>
<td>± 0.45</td>
</tr>
<tr>
<td>June onwards (cuts 3 - 7)</td>
<td>2.10 - 7.65</td>
<td>5.96</td>
<td>± 2.08</td>
</tr>
<tr>
<td>Total annual</td>
<td>6.09 - 14.26</td>
<td>11.38</td>
<td>± 3.93</td>
</tr>
<tr>
<td>GM.21 400 kg ha(^{-1})N (200, 100, 100, 0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April - June (cut 1)</td>
<td>6.05 - 8.94</td>
<td>7.13</td>
<td>± 0.91</td>
</tr>
<tr>
<td>June onwards (cuts 2 - 5)</td>
<td>1.88 - 7.43</td>
<td>4.82</td>
<td>± 1.97</td>
</tr>
<tr>
<td>Total annual</td>
<td>8.39 - 14.96</td>
<td>11.95</td>
<td>± 3.20</td>
</tr>
</tbody>
</table>

Yields over the early part of the season are less variable under both managements. Soil water deficits of varying severity occurred at every site at each cut in each year. Early production must have been limited to some extent by a shortage of water but less so than later production.

The relationships and correlations established between yield and availability of water have not taken account of the distribution of rainfall over growth periods. Garwood & Williams (1967) demonstrated that growth was not simply restricted by the total deficit but also by the amount of water in the upper horizon of soil which influenced the availability of N to the crop. Relationships were examined between the maximum yields observed at individual cuts and such variables as accumulated soil temperature, weekly rainfall, potential evapotranspiration and, calculated actual soil water deficits in the upper 10 cm and lower horizons of the soil but no significant single or multiple correlations were obtained.

Relationships between yield and requirement for and response to fertilizer N

The ranges of values of N\(_{10}\) and of response to this rate of fertilizer, \((Y_{10} - Y_{00})/N_{10}\), for the two experiments are shown in Table 4.

Table 4. Ranges of mean-site values, and overall means of N\(_{\text{max}}\), N\(_{10}\) and response to N\(_{10}\) under two cutting frequencies.

<table>
<thead>
<tr>
<th></th>
<th>Range</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 cuts (GM.20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N(_{\text{max}}) (kg ha(^{-1}))</td>
<td>540 - 678</td>
<td>624</td>
</tr>
<tr>
<td>N(_{10}) (kg ha(^{-1}))</td>
<td>260 - 530</td>
<td>386</td>
</tr>
<tr>
<td>Response to N(_{10}) (kg DM kg(^{-1})N)</td>
<td>15 - 26</td>
<td>21</td>
</tr>
<tr>
<td>4 cuts (GM.21)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N(_{\text{max}}) (kg ha(^{-1}))</td>
<td>390 - 668</td>
<td>561</td>
</tr>
<tr>
<td>N(_{10}) (kg ha(^{-1}))</td>
<td>111 - 445</td>
<td>281</td>
</tr>
<tr>
<td>Response to N(_{10}) (kg DM kg(^{-1})N)</td>
<td>21 - 37</td>
<td>27</td>
</tr>
</tbody>
</table>

Mean N\(_{10}\) values for the two experiments were 62 per cent with 28-day cutting and 50 per cent under conservation management of the appropriate N\(_{\text{max}}\) and supported yields of 92 per cent of maximum. At individual sites and overall the N\(_{10}\) values were lower for the conservation management than the other.

N\(_{10}\) and the response to this rate of fertilizer N were correlated with dry matter yield, Y\(_{10}\), Table 5.

Table 5. Between-site correlation coefficients of N\(_{10}\) and response to N with Y\(_{10}\), rainfall and available water, GM.20.

<table>
<thead>
<tr>
<th></th>
<th>N(_{10})</th>
<th>Response to N(_{10})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y(_{10})</td>
<td>0.60</td>
<td>0.64</td>
</tr>
<tr>
<td>Rainfall April-September</td>
<td>0.10</td>
<td>0.52</td>
</tr>
<tr>
<td>Available water April - September</td>
<td>0.22</td>
<td>0.52</td>
</tr>
</tbody>
</table>
No was not correlated with rainfall or available water as was the response to NJQ, although the correlation was less close than that between yield and available water (Table 2).

NJQ was influenced by the apparent N contribution from the soil ($N_s = \text{the yield of N in herbage without fertilizer N}$). In GM.20 the between-site correlation coefficient between $Y_{10}$ and $N_{10} + N_s$ was 0.82 compared with 0.60 with $N_{10}$. The effect of mineralised soil N and fertilizer N appeared to be additive as illustrated in Table 6.

Table 6. The influence of $N_s$ on $N_{10}$ at sites with similar yields but contrasting values of $N_s$, 4-year means GM.20.

<table>
<thead>
<tr>
<th>Site</th>
<th>$Y_{10}$ t ha$^{-1}$</th>
<th>$N_s$ kg ha$^{-1}$</th>
<th>$N_{10}$ kg ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pluckley Kent</td>
<td>12.6</td>
<td>16</td>
<td>475</td>
</tr>
<tr>
<td>Harewood Yorks</td>
<td>12.2</td>
<td>102</td>
<td>338</td>
</tr>
<tr>
<td>Wenvoe S.Wales</td>
<td>14.3</td>
<td>28</td>
<td>530</td>
</tr>
<tr>
<td>Bangor N.Wales</td>
<td>13.2</td>
<td>136</td>
<td>337</td>
</tr>
</tbody>
</table>

In broad terms, therefore, if potential yield could be predicted for particular conditions of climate and soil then an estimate could be made of a reasonable upper limit of fertilizer N input ($N_{10}$) and the likely response to this rate.

Seasonal distribution of yield

The seasonal distribution of dry matter yield may be as important in practice as the total yield obtained over the growing season. This is particularly important in systems of grazing management in which a surplus of grass in May is often succeeded by a shortage in June and July. Sites with either a high rainfall from April to September (RGS) or a soil with a high water holding capacity (AWC) or a combination of both show high yields in mid- and late-season. Table 7 shows the seasonal distribution of yield under the 28-day cutting frequency in some contrasting situations of climate and soil.

Three different patterns of applying annual rates of 300 and 600 kg ha$^{-1}$ fertilizer N were compared. These were (i) six equal applications (ii) half the total for the first two cuts with the remainder in four equal doses and (iii) half the total for cuts 3 and 4 in mid-season with the remainder in four equal doses for cuts 1 and 2 and 5 and 6. The pattern of application did not affect total annual yield at either rate of fertilizer N under any of the conditions encountered. The seasonal distribution of yield was markedly affected by the pattern of application of fertilizer N, Table 8.

At 300 kg ha$^{-1}$ N the pattern with a greater proportion of the fertilizer N in mid-season resulted in an improvement in mid-season production and a more even distribution of seasonal yield than the other patterns. Although the effect was most marked where either rainfall was high or on soils with a high water holding capacity it also occurred at those sites where production from June onwards was greatly restricted by a shortage of water. At 600 kg ha$^{-1}$ N the annual yield was higher than at 300 kg ha$^{-1}$ N as a result of a much higher yield in April and May but

Table 7. The influence of soil water holding capacity and rainfall on the seasonal distribution of yield at 450 kg N ha$^{-1}$ (3 x 75).

<table>
<thead>
<tr>
<th>Site</th>
<th>April - May</th>
<th>June - July</th>
<th>July - October</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hurley (RGS 317 mm AWC 84 mm)</td>
<td>5.36</td>
<td>2.50</td>
<td>1.93</td>
<td>10.23</td>
</tr>
<tr>
<td>Aylesbury (RGS 255 AWC 161)</td>
<td>5.16</td>
<td>3.35</td>
<td>3.07</td>
<td>12.24</td>
</tr>
<tr>
<td>Aberystwyth (RGS 520 AWC 60)</td>
<td>5.61</td>
<td>3.96</td>
<td>2.94</td>
<td>12.52</td>
</tr>
<tr>
<td>Wenvoe S. Wales (RGS 470 AWC 123)</td>
<td>5.93</td>
<td>4.36</td>
<td>2.91</td>
<td>13.58</td>
</tr>
</tbody>
</table>
Table 8. Mean effect of the pattern of application of 300 and 600 kg ha\(^{-1}\) N on the seasonal distribution of yield, DM t ha\(^{-1}\), GM.20.

<table>
<thead>
<tr>
<th>N kg ha(^{-1}) cut(^{-1})</th>
<th>cuts</th>
<th>April-May</th>
<th>June-July</th>
<th>August-October</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 kg ha(^{-1})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>4.40</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>75</td>
<td>38</td>
<td>37</td>
<td>5.24</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>37</td>
<td>75</td>
<td>38</td>
<td>3.90</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>75</td>
<td>75</td>
<td>38</td>
<td>2.79</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>38</td>
<td>75</td>
<td>75</td>
<td>2.47</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>37</td>
<td>37</td>
<td>38</td>
<td>2.05</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>75</td>
<td>75</td>
<td>38</td>
<td>3.41</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>38</td>
<td>75</td>
<td>75</td>
<td>2.38</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>37</td>
<td>37</td>
<td>38</td>
<td>2.75</td>
</tr>
<tr>
<td>4</td>
<td>38</td>
<td>75</td>
<td>75</td>
<td>38</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>38</td>
<td>75</td>
<td>38</td>
<td>2.75</td>
</tr>
<tr>
<td>5</td>
<td>38</td>
<td>75</td>
<td>75</td>
<td>38</td>
<td>2.75</td>
</tr>
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<td></td>
<td>75</td>
<td>38</td>
<td>75</td>
<td>75</td>
<td>2.75</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
<td>75</td>
<td>75</td>
<td>38</td>
<td>2.75</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>38</td>
<td>75</td>
<td>75</td>
<td>2.75</td>
</tr>
</tbody>
</table>

similar yield later and little difference in seasonal distribution of production between the patterns of application. These results support others which indicated that any management which allowed a full expression of growth in April and May restricted subsequent yields, Morrison (1977); at high rates of fertilizer N this effect was apparent with a 28-day cutting interval. The restriction of mid-season growth is most marked following a full conservation crop, Minderhoud et al. (1975).

The three patterns examined were formal experimental arrangements which were not designed for use in practice. The results show, however, that it is feasible to use fertilizer N to manipulate seasonal production. The more even distribution of seasonal yield resulting from the application of more fertilizer N in mid-season than in early-season could be of considerable value in grazing systems even under those conditions where a shortage of water limits mid-season production.

Conclusions

The results demonstrate the necessity of a multi-centre approach for the investigation of variation in the yield of grassland and its response to and requirement for fertilizer N. In all circumstances of climate and soil in lowland Britain temporary grassland will respond adequately to fertilizer N. Similar results have been obtained in the Netherlands on permanent grassland, Van Steenbergen (1977).

Under the two managements examined yield is broadly related to the amount of water available over the growing season. Rainfall is the primary source but the water holding capacity of the soil is also important. Response over the linear phase of the response curve is related to yield. The upper limit of fertilizer N input for practice, ca. N\(_{10}\), is dependent on the yield potential for particular conditions and the amount of N mineralised by the soil. The major difference between the response of temporary and permanent grassland is likely to be the amount of N mineralised by the soil. The average rate of fertilizer N applied to British grassland, ca. 120 kg ha\(^{-1}\), is well within the linear phase of response. On the most intensive dairy farms rates of over 400 kg ha\(^{-1}\) may be used; in these circumstances the sensible upper limit of fertilizer N input may be less than that currently used and account should be taken of climate and soil conditions planning fertilizer N rates.

The results provide a better basis for fertilizer N recommendations on grassland than hitherto. In a companion experiment GM.22 the response of grass to fertilizer N under cutting were compared; the amount of dry matter harvested by grazing was 60 to 80 per cent of that under cutting and the response between 200 and 400 kg ha\(^{-1}\) fertilizer N was only 4 kg DM kg\(^{-1}\) N, Jackson & Williams (1979). Evidence on response to fertilizer N under grazing is much scantier than that from cutting trials. There is, therefore, still a need to determine how the response obtained under cutting can be exploited under grazing and expressed in animal output.

References


THE INFLUENCE OF WATER SUPPLY TO GRASS ON THE RESPONSE TO FERTILIZER NITROGEN AND NITROGEN RECOVERY

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G. Lemaire
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Summary

Data are presented to demonstrate the effects of water supply on the utilisation of fertilizer N. These data show a significant correlation between soil water status and both DM yields and the recovery of N, particularly at high N levels. With continued application of N in dry periods, the lack of water to enable uptake of the N and subsequently the poor recovery in the herbage can result in substantial losses of N to drainage in winter. Supplementing rainfall by irrigation greatly increases the efficiency of use of N. However, utilisation of N in mid-season can be inefficient with some management practices, even with an adequate supply of water.

Introduction

Grassland is unique amongst agricultural crops in that, with the exception of crops cut late in the period of stem elongation in spring, the vegetative growth harvested repeatedly during the growing season is young and leafy. Because of this emphasis on the production of young leafy material the crop's requirements for water and nitrogen are high throughout the growing season.

In practice the response to fertilizer N is variable and this is due in part to factors such as management, species and the ability of the soil to supply N by mineralisation of organic matter. However, the effects of environment, weather and soil water status are of major importance in determining the response to applied N and N recovery. Thus Wolton et al. (1971) demonstrated how response to N varied between two sites of differing rainfall. More recently Morrison et al. (1980) have shown for a far wider range of conditions, a relationship between DM production, the response to N and the amount of water available to the crop over the growing season.

Experimental results and discussion

The data used in this paper to illustrate the effects of water supply on the utilisation of N fertilizer are drawn from two sites: Hurley (central southern England, Lat. 51.33N) and Lusignan (west central France, Lat. 46.26N). At both sites evapotranspiration exceeds rainfall during part of the growing season in all years, but potential evapotranspiration (PET) and soil water deficit (SWD) are normally greater at the more southerly site.

At neither site is there a water table sufficiently near the surface to affect the supply of water to the crop. Data from Hurley include material from a lysimeter experiment and several field experiments. A definition of some of the terms used, e.g. SWD and PET, are given in Appendix I at the end of this paper.
Table 1. Yields (t DM/ha) from perennial ryegrass cv. S23 swards receiving 250 kg (N\textsubscript{1}) or 500 kg N/ha (N\textsubscript{2}) under conditions of natural rainfall at Hurley, 1970 - 1979 inclusive.

<table>
<thead>
<tr>
<th>Approximate date of cut</th>
<th>21 May</th>
<th>2 July</th>
<th>18 Aug</th>
<th>28 Oct</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>N\textsubscript{1}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>4.09</td>
<td>2.17</td>
<td>1.56</td>
<td>1.78</td>
<td>9.62</td>
</tr>
<tr>
<td>Range</td>
<td>3.1-5.2</td>
<td>0.8-3.7</td>
<td>0.1-2.9</td>
<td>0.2-3.2</td>
<td>6.2-11.9</td>
</tr>
<tr>
<td>Coefficient of variation (%)</td>
<td>17.9</td>
<td>53.4</td>
<td>54.6</td>
<td>54.0</td>
<td>20.3</td>
</tr>
<tr>
<td>N\textsubscript{2}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>5.65</td>
<td>1.61</td>
<td>1.75</td>
<td>2.05</td>
<td>11.07</td>
</tr>
<tr>
<td>Range</td>
<td>4.7-7.5</td>
<td>0.3-3.0</td>
<td>0.2-3.7</td>
<td>0.5-3.1</td>
<td>9.1-14.2</td>
</tr>
<tr>
<td>Coefficient of variation (%)</td>
<td>15.2</td>
<td>62.3</td>
<td>68.2</td>
<td>62.3</td>
<td>21.0</td>
</tr>
</tbody>
</table>

Variation in DM yield and N uptake under natural rainfall

At Hurley the mean maximum potential SWD is 180 mm despite mean rainfall April to October of 397 mm. The average loss in annual yield from grassland due to this deficiency in water supply is between 20 and 25 per cent of the potential yield, i.e. that obtained with water non-limiting, but there is wide variation between years. Within-season variation in yield (April to October) due to variation in rainfall and to a lesser extent PET, is even greater. Uptake and utilisation of N are similarly affected. Thus Table 1 summarises DM yields (DM\textsubscript{y}) from two perennial ryegrass swards over a 10 year period. These swards received either 250 (N\textsubscript{1}) or 500 kg N/ha (N\textsubscript{2}), two-fifths in March and the remainder after cuts one to three. The soil profile was usually at or near field capacity (FC) when the N was first applied and rainfall and PET were broadly in balance in the early part of the season so that variation in DM\textsubscript{y} due to water was least in the first cut.

Response Table 2. Nitrogen (kg N/ha) recovered in herbage from perennial ryegrass swards receiving 250 kg (N\textsubscript{1}) or 500 kg N/ha (N\textsubscript{2}) under natural rainfall at Hurley, 1970 - 79 inclusive.

<table>
<thead>
<tr>
<th>Approximate date of cut</th>
<th>21 May</th>
<th>2 July</th>
<th>18 Aug</th>
<th>28 Oct</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>N\textsubscript{1}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>102</td>
<td>48</td>
<td>37</td>
<td>43</td>
<td>231</td>
</tr>
<tr>
<td>Range</td>
<td>83-121</td>
<td>19-70</td>
<td>4-63</td>
<td>9-56</td>
<td>167-279</td>
</tr>
<tr>
<td>Coefficient of variation (%)</td>
<td>13.1</td>
<td>41.1</td>
<td>50.0</td>
<td>41.3</td>
<td>18.3</td>
</tr>
<tr>
<td>N\textsubscript{2}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>173</td>
<td>51</td>
<td>64</td>
<td>74</td>
<td>362</td>
</tr>
<tr>
<td>Range</td>
<td>141-230</td>
<td>9-91</td>
<td>5-93</td>
<td>24-99</td>
<td>268-468</td>
</tr>
<tr>
<td>Coefficient of variation (%)</td>
<td>16.1</td>
<td>55.8</td>
<td>60.3</td>
<td>47.8</td>
<td>19.9</td>
</tr>
</tbody>
</table>
in DM to the additional N (N_2 - N_1) was also greatest in this period. In contrast to the additional N at the second cut was nil or negative in seven out of ten years. This was the result of taking a larger first cut from N_2 which resulted in an open sward with fewer tillers which was more susceptible to the dry conditions normally prevalent in this period. There was a significant negative correlation (N_1, P < 0.05; N_2, P < 0.001) between DM and the number of days when there was an actual deficit of 25 mm or more in the upper 30 cm soil (SW_30) during each growth period except the first.

Nitrogen recovered in the herbage (N_y) also varied considerably (Table 2) with a significant negative correlation between SW_30 and N_y at the two mid-season cuts with both N levels (Table 3). There was also evidence that N not fully utilised in one cut, due to a deficiency in water, could be utilised in a subsequent period. Under natural rainfall therefore both DM_y and N_y were considerably restricted by water supply and this would apply to many grassland situations.

**Table 3. Regression analysis of nitrogen yield (N_y) and the soil water deficit in the upper 30 cm of soil during each growth period, 1970-79 inclusive.**

<table>
<thead>
<tr>
<th>variates</th>
<th>r</th>
<th>significance of regression</th>
</tr>
</thead>
<tbody>
<tr>
<td>N_1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N_y cut 1 v SW_30</td>
<td>-0.414</td>
<td>NS</td>
</tr>
<tr>
<td>N_y cut 2 v SW_30</td>
<td>-0.749</td>
<td>*</td>
</tr>
<tr>
<td>N_y cut 3 v SW_30</td>
<td>-0.657</td>
<td>*</td>
</tr>
<tr>
<td>N_y cut 4 v SW_30</td>
<td>-0.610</td>
<td>NS</td>
</tr>
<tr>
<td>N_2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N_y cut 1 v SW_30</td>
<td>-0.424</td>
<td>NS</td>
</tr>
<tr>
<td>N_y cut 2 v SW_30</td>
<td>-0.877</td>
<td>***</td>
</tr>
<tr>
<td>N_y cut 3 v SW_30</td>
<td>-0.820</td>
<td>**</td>
</tr>
<tr>
<td>N_y cut 4 v SW_30</td>
<td>-0.844</td>
<td>**</td>
</tr>
</tbody>
</table>

The N balance shown in Table 4 indicates that the effect on apparent recovery of N was real, with a broad balance between the major inputs and N_y plus losses to drainage. This also demonstrates a further relationship between water and fertilizer applied to grassland. In a freely draining soil losses of N due to periods of excess rainfall and drainage during the growing season were low. In the 10 years such drainage varied between zero and 108 mm, but the maximum loss of N recorded in any one year was only 2 kg/ha on N_1 and 9 kg/ha on N_2. There is supporting data for the restricted movement of N in soils under grass during the growing season from D’Aoust (1965) and Sofield (1980) who reported little downward movement of N with excess irrigation in mid-season. However, N not utilised due to low rainfall during the growing season may be lost to drainage in the following winter (Table 4). As an extreme example, after two years of low rainfall (1975 and 1976) this amounted to 184 kg (N_1) and 590 kg N/ha (N_2) in winter 1976-77 (Garwood & Tyson, 1977). Thus injudicious and continued application of N to grass through a dry year not only results in inefficient utilisation but considerable loss of N with the possible contamination of water supplies with nitrate-N.

**Table 4. Mean annual N balance under natural rainfall (1970-79) of perennial ryegrass swards at Hurley receiving 250 kg (N_1) or 500 kg N/ha (N_2), excluding extremely dry years of 1975 and 1976, kg N/ha.**

<table>
<thead>
<tr>
<th></th>
<th>(a)</th>
<th>(b)</th>
<th>(c)</th>
<th>(d)</th>
<th>(c+d)-(a+b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N_1</td>
<td>250</td>
<td>11.5</td>
<td>244.2</td>
<td>7.9</td>
<td>-9.4</td>
</tr>
<tr>
<td>N_2</td>
<td>500</td>
<td>11.5</td>
<td>389.9</td>
<td>141.5</td>
<td>19.9</td>
</tr>
</tbody>
</table>

Effect of supplementing natural rainfall by irrigation

In a different environment and with another species (cocksfoot), the data from Lusignan illustrate very well that the response to irrigation is small in the absence of applied N and that response to irrigation is enhanced by increasing levels of N (Figure 1). Nitrogen uptake data over the 8-week period of regrowth show the same pattern as that of DM_y (Figure 2). These data clearly show the additive effects of water supplied as irrigation and fertilizer N.

Water use by the irrigated swards in this experiment was very similar to PET, but more water was used over the period by the irrigated swards receiving fertilizer N (N_1, N_2) than those without (N_0). This amounted to some 15 mm water (N_0) and 25 mm (N_1) by the end of the growth period. A similar increase in water consumption with increasing levels of N has been reported by Penman (1962) and Garwood & Tyson (1975).
Irrigation practice and N utilisation

Responses to N are uncertain and variable and so far we have shown the broad pattern of the relationship between water, fertilizer N and N uptake. The effect of irrigation in terms of DM produced per unit of water applied is extremely variable, both within and between years. It appears that this is related not only to the total amount of water applied and the relationship between this and the size of the SWD reached before irrigation (Stiles & Williams, 1966), but also to the distribution of water in relation to the time of defoliation and application of fertilizer N.

The amount of N available to the crop after defoliation depends on the extent of the water deficit in the upper layers of soil. By injecting N in concentrated solutions into those layers of the soil profile which were still near the FC value Garwood & Williams (1967) were able to obtain a markedly superior response to the N applied than when it was applied to the drier layers of soil. Therefore to ensure the immediate and effective use of fertilizer N, it is essential that there is sufficient water in the surface soil at the time of its application.

This is shown in Tables 5 and 6 where the effects of full irrigation (25 mm water at each 25 mm SWD) and partial irrigation (applying water only after defoliation and then in lesser amounts than required to return the whole soil profile to FC) on the

![Figure 1. Growth of cocksfoot between 5 July and 30 August 1979, Lusignan. No N (N0), 60 kg N (N1) or 120 kg N/ha (N2) applied on 5 July.](image1)

![Figure 2. Recovery of N by cocksfoot between 5 July and 30 August 1979, Lusignan. No N (N0), 60 kg N (N1) or 120 kg N/ha (N2) applied on 5 July.](image2)

<table>
<thead>
<tr>
<th>Cuts</th>
<th>5 June</th>
<th>16 July</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation</td>
<td>DMy</td>
<td>Ny</td>
<td>DMy</td>
</tr>
<tr>
<td>none</td>
<td>7.3</td>
<td>166</td>
<td>2.6</td>
</tr>
<tr>
<td>partial</td>
<td>8.1</td>
<td>184</td>
<td>5.6</td>
</tr>
<tr>
<td>full</td>
<td>7.3</td>
<td>175</td>
<td>5.9</td>
</tr>
</tbody>
</table>

160 kg N/ha applied in March, 80 kg N/ha applied for each of remaining three growth periods.

utilisation of N are examined in two contrasting years at Hurley. In both experiments the swards were cut at intervals of six weeks after the first cut (5 June 1973 and 27 May 1975). 1973 was a year of moderate deficit (maximum potential SWD of 140 mm) and the smaller amounts of water applied as partial irrigation, 88 mm compared with 175 mm for full irrigation, were sufficient to enable full utilisation of the 240 kg N/ha applied for growth periods two to four. There was no advantage to full irrigation in Ny or DMy. Efficiency of use per unit of water applied in increasing DMy and Ny (Table 7) was therefore markedly superior with partial irrigation. Also more
Table 6. Effect of three soil water regimes on DM yield (DMy, t/ha) and N yield (Ny, kg/ha) of perennial ryegrass swards after the first cut on 27 May, Hurley 1975.

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>DMy</th>
<th>Ny</th>
<th>DMy/Ny</th>
<th>Ny+</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>3.7</td>
<td>124</td>
<td>29</td>
<td>217</td>
</tr>
<tr>
<td>Partial</td>
<td>7.3</td>
<td>215</td>
<td>34</td>
<td>337</td>
</tr>
<tr>
<td>full</td>
<td>10.3</td>
<td>277</td>
<td>37</td>
<td>384</td>
</tr>
</tbody>
</table>

* 100 kg N/ha applied for each of 3 cuts in this period
** kg DM produced per kg N taken up in herbage
+ 400 kg N/ha applied in total for the year.

Table 7. Efficiency in use of water applied as irrigation in increasing DM yield (kg) and recovery of N (kg). Response per m³ of water applied, Hurley 1973 and 1975. Data refer to the yields in the remainder of the season after a first cut on 5 June 1973 and 27 May 1975, respectively.

<table>
<thead>
<tr>
<th></th>
<th>1973</th>
<th>1975</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>partial</td>
<td>3.4</td>
<td>0.118</td>
</tr>
<tr>
<td>full</td>
<td>1.9</td>
<td>0.062</td>
</tr>
</tbody>
</table>

Effect of sward management

When the wide variation in DM yield and response to N under natural rainfall were discussed earlier in this paper it was suggested that management had affected the response to high levels of N in mid-season. Data from another field experiment at Hurley and given in Figure 3 and Table 8 demonstrate the effect of a large yield at the first cut on yield and N recovery of perennial ryegrass in subsequent cuts. When a first cut of 7.8 t DM/ha was taken on 4 June from a perennial ryegrass sward which had received 160 kg N/ha in spring (n3), yield and N uptake were minimal in the second cut without irrigation. Even with irrigation, there was little response in yield to the higher level of N. With a lower yield at the first cut (taken two weeks earlier and with half the amount of N applied in spring) growth in the two sub-

![Figure 3. DM yields from perennial ryegrass swards at Hurley. First cut on either 4 June or 21 May (1) and then at intervals of 6 weeks (2 and 3). Nitrogen for first cut: n1, 40 kg; n2, 80 kg; n3, 160 kg/ha. Nitrogen for cuts 2 and 3: N1, 40 kg; N2 80 kg/ha.](image-url)
Table 8. Nitrogen recovered in herbage in mid-season (Ny, kg N/ha). Perennial ryegrass swards first cut on 4 June or 21 May and receiving either 40 kg (N1) or 80 kg N/ha (N2) for the second growth period of 6 weeks.

<table>
<thead>
<tr>
<th>Date of first cut</th>
<th>Natural rain Ny second cut</th>
<th>Irrigated Ny second cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N1</td>
<td>N2</td>
</tr>
<tr>
<td>4 June</td>
<td>38</td>
<td>12</td>
</tr>
<tr>
<td>21 May</td>
<td>57</td>
<td>70</td>
</tr>
</tbody>
</table>

sequent cuts was good (Figure 3) and recovery of N was high (Table 8). Where a large cut for conservation is the prime purpose, the low yield and lack of response to N in mid-season may be acceptable, but it should be noted that irrigation may do little to improve yield and utilisation of N in the aftermath. However, such management results in a very open sward and this can lead to an ingress of weed species and eventual deterioration of the sward.

Irrigation, in the dry conditions often prevalent at the time of the first cut, reduces the likelihood of this occurring.

Conclusions

The experimental data presented show the considerable effect that soil moisture conditions have on the response of grass to fertilizer N and that N recovery in the herbage is significantly correlated with the SWD in the upper layer of soil. Unless the N applied during periods when these surface layers of soil are dry is recovered by the sward later in the season, before growth ceases due to falling temperatures, the N is at risk to loss by leaching during the winter. Where rainfall is low during the growing season these losses can be large. There is, however, little evidence to suggest any substantial loss of N from free-draining soils under grass with excess rainfall during the growing season.

In areas where rainfall is low or unpredictable the full utilisation of high levels of fertilizer N can only be achieved if rainfall is supplemented by irrigation. In years or areas of moderate SWD during the growing season, small amounts of water applied as irrigation after cutting or grazing and applying the N will greatly increase the response to N and its recovery. However, in a system of management where regrowth is depressed after a large conservation cut, the response to N may be poor even with irrigation.

References


Appendix I

The soil water deficit (SWD) is the depth of water (in mm) required to return a partially dry soil profile to field capacity (see later). In the experiments described potential evapotranspiration (PET) was derived either from the corrected evaporation from a free water surface (Garwood & Tyson, 1973) or by calculation from meteorological data (Penman, 1949). The potential SWD was calculated as:

\[ \text{PET} - (\text{rainfall} + \text{any irrigation since the soil was last at field capacity}) \]

It should be noted that when the potential SWD exceeds some 25-30 mm the actual evapotranspiration falls below PET and the actual SWD is less than the potential SWD. At both sites the actual SWD was also measured using a soil moisture neutron probe.

Field capacity (FC) is defined as the amount of water held by a soil against gravitational forces. The concept is best applied to soils of high hydraulic conductivity with no water table near the surface. There is, however, no precise value for the FC of a soil profile under field conditions; slow drainage can continue over a long period of time. In the Hurley experiments FC was taken as the mean water content in the various layers of the soil profile in early spring after several days without rain and with negligible transpiration losses. For these free draining soils overlying chalk, the values so obtained approximate to the water content of intact cores of the soil when subjected to a water tension of 75 cm in the laboratory.
EFFECT OF HIGH NITROGEN SUPPLY ON SWARD DETERIORATION AND ROOT MASS

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L. Sibma
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Summary

During the establishment of a grass sward many plants die because they are crowded out by more vigorous plants. This competitive process is accelerated by high rates of nitrogen application, but it does not lead directly to an open sward.

In our trials sward deterioration became visible after the first cut or after a sequence of cuts with large, apparently dead, patches or with a more uniform thinning of the sward, both resulting in decreased grass production during regrowth. The larger the yield of the preceding cut, the greater the deterioration of the sward. The larger the rate of nitrogen application and the longer the period of application, the greater the effect.

The deleterious effect of high nitrogen application on regrowth is caused by a complex of factors. The following factors are discussed: elevation of growing point above defoliation level, exhaustion of carbohydrate reserves, and decrease of root mass. Chemical analysis failed to prove a close relation between the low persistence of a cultivar and its carbohydrate level, although this level was always low in case of deterioration and a negative relation was found between rate of nitrogen supply and carbohydrate level. A negative relation was also found between nitrogen supply and root mass. Only a short period without nitrogen application was required to increase the root mass considerably.

The deleterious effect of high rates of nitrogen application on regrowth may largely be overcome by harvesting the sward in a younger-stage. Persistence of grass can be markedly improved through breeding of new varieties.

1. Introduction

In intensive grassland production systems, proper management is required to keep the sward in good condition. Because of unpredictable factors (e.g., weather conditions) this is often difficult to achieve. Late cuts of heavy harvests can be followed by poor regrowth and deterioration of the sward (Gillet, 1972). Declining yields, ingress of weeds and thus the need for resowing make sward deterioration a serious problem.

In the Report of the British Grassland Society Working Party on Sward Deterioration (1978), different interpretations of the word "deterioration" are given. In the present paper the term is used to describe a sward which shows declining herbage yields (measured by dry weight or herbage quality). The word "persistence" is used either in a relative sense: the longevity of a variety relative to other varieties, or in an absolute sense: the longevity or survival of a plant or variety in a particular situation.

In this paper, we report a study of the lack of persistence of grass plants under high rates of nitrogen fertilization, and attempt to relate lack of persistence to the effect of nitrogen upon other characteristics of the grass plant, such as yield, soluble carbohydrate content, and root mass. Possible ways to counteract sward deterioration are discussed.

The trials were carried out in west central France (Lusignan) and in the Netherlands. Differences between the two sites in climate and management of the trials may have influenced the results. For instance, winter is milder in western France. As a consequence nitrogen fertilization before winter is efficient in this region but not in the Netherlands.

2. Description of sward deterioration under high nitrogen fertilization

Generally, two types of deterioration were observed after harvesting: occurrence of large dead patches or a more uniform thinning of the sward.

In 12 trials in Lusignan the occurrence of dead patches, ranging in area from 0.25 to 3 m² or more, was the common type of sward deterioration. It always occurred immediately following a large cut and, in these trials this always was a spring cut, i.e., before July, but in other trials deterioration sometimes occurred at other times of the season. In most cases, deterioration followed a cut when the grass was in the reproductive stage,
but it occurred also in vegetative swards, either early in the season, or in June during regrowth. Adjacent to the dead patches regrowth was normal. Seemingly, grass simply failed to regrow on dead patches. However, it is known that when grass is in a reproductive stage, the early regrowth is hidden, starting from buds at soil level. On one occasion timothy (Phleum pratense L.) was defoliated in a vegetative state at the end of March; the regrowth started very uniformly for 2-3 days, but large patches died thereafter from the leaf tips downwards. This lag between defoliation and damage could, possibly, be general. Extremely slowly, a few green tillers may appear in the dead patches, so that the sward can recover to 'normal' after 1 month to 1 year, regardless of the extent of deterioration.

On a few occasions at Lusignan, but more often in the Dutch trials, deterioration was more uniformly spread over the area and consisted of a thinning of the sward. This was due to a reduction of the number of regrowing tillers after harvesting a heavy crop, independent of the date in the growing season or whether the grass was in a reproductive or vegetative state. Some tillers did not regrow at all, others started to regrow but died after a few days. Characteristically, in the regrowth of these heavily fertilized swards, small tussocks alternated with small open areas (1 dm$^2$ or less at ground level) throughout the sward. In the first few cuts or in the first season the canopy was closed again at harvesting. In the course of time the ratio between bare soil and grass cover increased, resulting in an open sward and lower yields.

3. Effect of N on shoot growth

3.1. Plant death due to competition during establishment

During establishment of a sward, plant numbers will steadily decrease, due to competition between the young grass plants. In a glasshouse trial 10 perennial ryegrass (Lolium perenne L.) plants per pot (content 1.2 l, surface area 109 cm$^2$) were grown on nutrient solution which was changed every 5-7 days. Nitrogen in the solution was in full supply for half the number of pots, in the other half nitrogen concentration was limited so that nitrogen was exhausted after a few days. The plants were cut at 4-week or 5-week intervals during the growing season (Ennik, 1973). Development of the individual plants was followed for three years. Plant numbers and yield per pot in the successive years are presented in Table 1. Intraspecific competition reduced the initial plant number of 10 per pot to 1-4 at the end of the third year. At the same time dry matter production was hardly affected, and certainly much less than the number of plants (cf. 2nd and 3rd year). So, the most competitive plant in a pot crowded out the others without loss of production. It appears from Table 1 that this process takes place faster with high N supply.

3.2. Relation between N application, yield and deterioration

Grass plants or tillers in a sward can also die because of lack of persistence. To study whether persistence is affected by N application and to what extent, a field trial was conducted with perennial ryegrass at two levels of N fertilization (85 or 120 kg N per ha per cut), with application of N starting before the 1st, 2nd, 3rd, 4th or 5th cut. Once started, N application was continued for the following cuts. All treatments were cut at 5-week intervals (Ennik, 1974). The results are shown in Figure 1.

Though the amount of N applied to the fifth cut was the same for all treatments at one fertilization level (either 85 or 120 kg/ha), yield of this cut was generally lower when more preceding cuts had been supplied with N. (An exception is the plots which received their first N application before the fifth cut; as is also shown by

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Table 1. Effect of rate of nitrogen application and cutting frequency on number of plants per pot and annual dry matter yield. Average of six pots. Perennial ryegrass cv. Barlenna and Hunsballe.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of plants at end of</th>
<th>Dry matter yield (g/pot)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st yr</td>
<td>2nd yr</td>
</tr>
<tr>
<td>Full N,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-wk</td>
<td>3.8</td>
<td>1.0</td>
</tr>
<tr>
<td>6-wk</td>
<td>5.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Limited N,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-wk</td>
<td>7.3</td>
<td>4.7</td>
</tr>
<tr>
<td>6-wk</td>
<td>7.8</td>
<td>5.5</td>
</tr>
</tbody>
</table>
the other treatments, the highest yield often being obtained in the second cut after starting N supply.) The effect was larger with a supply of 120 kg N per cut than with 85 kg per cut. The conclusion from this trial is that sward deterioration is more serious and the grass less persistent, the longer the period during which N is supplied and the higher the N application per cut.

In field trials in a perennial ryegrass sward in the Netherlands with different combinations of cutting frequency and N fertilization level, it appeared that with 1-week cutting intervals the sward remained fully closed, in spite of N dressings up to 800 kg/ha per year. With 7-week cutting intervals, however, the sward showed a mosaic-like appearance of grass clumps and open patches, which was worse with increasing N supply. Similar results were obtained by Bartholomew and Chestnutt (1977). This also corresponds with the findings of Morrison and Reeks (1978) that high input of N (up to 750 kg N per ha per year) reduced the contribution of perennial ryegrass under a 'conservation' management, but not when defoliation was frequent.

In several trials with high N supply in winter in Lusignan, it was found that for a given amount of N and a given date of spring defoliation, the earlier the application between August and February, the higher the yield and the lower the N and NO3 content at the first cut in the following spring, and the worse the deterioration thereafter. But, where the amount of applied N varied, in most trials damage was enhanced by N, especially above a level where yield was at its ceiling value, whereas N and NO3 contents still increased (Figure 2). The same relationship can be drawn from an accurate analysis of the results of Colby et al. (1974).

Nevertheless, in one of these French experiments, it was noted that damage increased from low to medium level of nitrogen application, when yield also increased. But at higher N levels, when there was no further increase in yield, there was no increase in

Figure 1. Relation between the yield of perennial ryegrass and the length of the period with high N supply. The plots receiving N before the 1st cut were topdressed on 20 March, following dressings are indicated by arrows. Left: N application 85 kg/ha per cut; right: N application 120 kg/ha per cut.

Figure 2. Effect of nitrogen, applied in 5 equal dressings from November to March, on yield, N and NO3-N content in the first cut at ear emergence, and on death after cutting (dead area as fraction of total area, estimated by eye) of tall fescue (Festuca arundinacea Schreb.) cv. Ludion.
dry matter (g/m²) vs. water-soluble carbohydrate (g/m²)

Figure 3. Effect of N supply on dry matter yield, and on yield and content of water-soluble carbohydrate of perennial ryegrass (shoot without stubble; 1st cut of field trial). Applied N:
- 0 kg/ha + 70 kg/ha
- 20 kg/ha x 120 kg/ha

4. Effect of N on root mass

If N does not limit growth, the shoot/root ratio of grass in a vegetative stage is constant under constant conditions, according to the functional equilibrium between shoot and root growth (Brouwer, 1967; Ennik, 1966). After disturbing the shoot/root ratio by defoliation, root growth stops until the original shoot/root ratio has been restored. Thereafter shoot and root continue to grow in this proportion. If the period between two defoliations is fully needed to restore the original shoot/root ratio, root mass will not further increase. Thus with full N supply root mass is determined by the frequency of defoliation: more frequent cutting will result in a smaller root mass (Ennik, 1966, 1976).

With suboptimal N supply the shoot/root ratio varies widely as was shown in a pot trial. Two cultivars of Italian ryegrass (Lolium multiflorum Lam.) were grown in pure culture on nutrient solution which was changed weekly (10 plants per 1.2 l pot). Nitrogen in the solution was in full supply for half the number of pots, in the other half nitrogen concentration was limited so that nitrogen was exhausted towards the middle of the week. To avoid root disturbance, root volume (which is proportional to root weight) was measured by immersing the roots in water and weighing the displaced water. The measured root volume included water that still adhered after five minutes draining. Figure 5 shows the results for a one-month-old crop (first harvest) and a four-month-old crop, which has been defoliated a few times. With full N supply shoot and root grow in proportion and the shoot/root ratio is the same for plants of the same age. With limiting N supply shoot growth is limited to the same level for all
Figure 5. Effect of N supply on shoot/root ratio and root mass of Italian ryegrass cultivars Sceempter and R.v.P., cut every 4 weeks; 5-6 replicates per treatment. a: 1 month old, b: 4 months old.

Figure 6. Effect of applied N and cutting frequency on the root mass of perennial ryegrass in October of the first year of treatment. Total N applied (March-September):
- 2-week cutting: 168, 336, 504 or 672 kg/ha,
- 4-week cutting: 162, 324, 486 or 648 kg/ha,
- 6-week cutting: 223, 446, 669 or 892 kg/ha.

Figure 7. Effect of applied N and cutting frequency on the root mass of perennial ryegrass in October of the first year of treatment. Total N applied (March-September):
- 2-week cutting: 168, 336, 504 or 672 kg/ha,
- 4-week cutting: 162, 324, 486 or 648 kg/ha,
- 6-week cutting: 223, 446, 669 or 892 kg/ha.

pots, but root growth varies widely. Consequently the shoot/root ratio also varies widely. It is obvious that with full N supply root mass is not only relatively but also absolutely smaller than with limiting N supply.

Similar results to those in the pot trial were obtained in a field trial on loam soil in the Netherlands in 1978. A perennial ryegrass sward cv. Pelo was cut at 2-, 4- or 6-week intervals. Superimposed were 4 levels of N application. All combinations were in triplicate. In October 1978 root mass was determined in one soil core (7-cm diameter, 15-cm deep) per plot (Figure 6).

Despite the small number of cores examined, there is a clear tendency for the root mass to decrease with increasing N supply, independent of cutting interval. The increase in cutting frequency did not result in a decrease of root mass. This is in contrast to the expectation for conditions of non-limiting N supply. However, N supply was suboptimal in this trial even with the highest N doses. This may be deduced from the relation between shoot and root mass for 2-week and 4-week cutting frequency, as shown in Figure 7. In agreement with Figure 5 shoot growth is limited to a certain level with limited N supply, whereas the corresponding root growth varies considerably. For the field trial, part of this variation, however, may be due to the small size of the examined root sample compared with the sampled area for herbage yield. Herbage yield increased and the average root mass decreased with increasing N supply for each cutting frequency. With the 6-week cutting interval the picture was irregular because of low yields due to sward deterioration on some of the higher fertilized plots.

That a short period of suboptimal N supply suffices to give a marked increase in root growth is shown in a pot trial by Ennik and Baan Hofman (Figure 8). Young perennial ryegrass plants were grown on a Hoagland nutrient solution in the glasshouse and from 9 April onwards harvested once a month. Until the first harvest on 9 April all pots had been treated the same. During the short periods 4-8 May, 5-8 June, and 2-5 July prior to the subsequent harvests on 8 May, 8 June and 5 July respectively, half the number of pots were kept on Hoagland solution
Figure 7. Effects of N rate and cutting frequency on the relation between herbage yield at the last cut (28 September 1978) and root mass (determined on 17 October 1978) of perennial ryegrass.

as before, but at a five degrees increase of temperature (°C) and with reduced light. The other half were placed on water without N supply during these periods, but at normal temperature and light supply at that time of the season. Outside these periods all pots were treated as before the first harvest.

At the first (= untreated) harvest root mass of the predestined 'no-N' pots was not higher than that of the other pots (Figure 8a). After two 4-day periods of withholding N, root mass had markedly increased (Figure 8b) and after three of these periods there was a striking difference in root mass between the pots from which N was withheld for 12 days in a 3-month period, and the pots with full N supply, combined with a slightly raised temperature and reduced light (Figure 8c).

5. Genetic variation

Table 2 shows the results that can be obtained by breeding. In a field trial (Ennik, 1979) two new selections of perennial ryegrass, bred by G.E. van Dijk (SWP, Wageningen), were exposed to the same N fertilization regime as in Figure 1 (except that only the highest rate of 120 kg N per cut was applied) and compared with the standard varieties Pelo and Splendor, known as varieties with a high persistence and a moderate to good persistence, respectively. Cutting regime was the same for all treatments. The fertilization regime was repeated in the second year.

In agreement with the results in Figure 1, yield of the fifth cut was lower, the earlier the application of N had been started in the season (Table 2). An exception was again the treatment with the first N before the fifth cut. In the first harvest year there was not much difference in yield between the four varieties (selections). In the second year the yield of the selections was considerably higher than the yield of the standard varieties, the more so when N had been supplied for a longer period. Ingress of unsown species was almost absent in the selections, but considerable in the standard varieties, particularly when N had been supplied for a longer period. If the yield of the sown species only is considered, the yield of the selections in the fifth cut of the second year was broadly twice that of the standard varieties, the sward of the latter having deteriorated seriously.

Examination of the sward in the autumn of the second year showed the occurrence of

![Figure 8. Relation between herbage yield and root volume of 4 cultivars of perennial ryegrass with full N supply (open symbols) or withholding of N for 4 days before harvesting (full symbols).](image)

- **b**: 3rd cut. Harvesting date: 8 June. Root volume determined: 12 June.
Table 2. Dry matter yield (t/ha) of the 5th cut of two new selections and two standard varieties of perennial ryegrass plus invading species in the first and second year of harvesting. The content of perennial ryegrass is shown in brackets. N application was started before 1st, 2nd, 3rd, 4th or 5th cut.

<table>
<thead>
<tr>
<th>Cut</th>
<th>Selection 1</th>
<th>Selection 10</th>
<th>Pelo</th>
<th>Splendor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5th cut</td>
<td>3.1</td>
<td>3.0</td>
<td>3.0</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>(100)</td>
<td>(97)</td>
<td>(74)</td>
<td>(59)</td>
</tr>
<tr>
<td>1978</td>
<td>2.8 (100)</td>
<td>2.8 (100)</td>
<td>2.1</td>
<td>2.0 (59)</td>
</tr>
<tr>
<td></td>
<td>(74)</td>
<td>(86)</td>
<td>(65)</td>
<td>(80)</td>
</tr>
</tbody>
</table>

some vegetative internode elongation, but this was at least as frequent with the more persistent selections as with the less persistent standard varieties.

6. Discussion

Soon after seeding or re-seeding of grassland many plants die because of interspecific or intraspecific competition. This is accelerated by high N application. Because during this process of active replacement, the role of the less competitive plants is taken over by the more competitive plants of the sown species or mixture, it does not result in a decrease in yield (unless the competitive plants are low yielders). Nor does the process lead directly to sward deterioration.

Sward deterioration may occur by crowding out of sown species by undesirable species with higher competitive ability, e.g. couch grass (Elytrigia repens (L.) Desv.). In our trials, however, deterioration was always caused by lack of persistence or, more generally, poor regrowth after defoliation. This manifested itself in two ways: the occurrence of rather large, apparently dead patches or by a more uniform thinning of the sward.

The first mentioned phenomenon bears much resemblance to the observations by Keuning and Entzinger (1978) on farms with high N supply. After mowing they observed a mosaic of patches with normal regrowth and patches with poor or no regrowth, the latter being attributed to patches of higher yields in the preceding cut. One month after cutting, yield on the patches with poor regrowth was considerably lower than on patches with normal regrowth; later yields were not determined.

Yields of successive cuts are often negatively related, mainly in spring (Ennik, 1974) or throughout the season (Prins & Van Burg, 1979). The same phenomenon occurs as a result of different cutting times in spring: if at a given rate of N application, the first cut is taken at a later date, and thus at a higher yield, regrowth and yield of the second cut (grown in equal time intervals) are diminished. Normally, this compensating effect between yields of successive cuts does not affect the annual yield (Sibma, 1966). It is not impossible, however, that under extreme conditions regrowth after the larger cut is reduced to such an extent that sward deterioration occurs.

High rates of application of fertilizer N will result in high yields and consequently enhance the chance of poor regrowth, especially when defoliation is infrequent. Continuation of high N application for a prolonged period will often result in sward deterioration and consequently in an invasion by undesirable species. The adverse effects of high N applications are even apparent in the following year. Prins (1978) found that the productivity of swards was often lower after a pretreatment in preceding years with 600-840 kg N per ha per year (5 to 7 cuts) than after a pretreatment with 160-200 kg N (4 to 5 cuts).

The mechanism of low persistence is still poorly understood. Some factors which may be involved are: 1. decapitation of growing points, 2. lack of carbohydrate reserves, 3. poor root development.

Decapitation of growing points has often been reported as a main cause of poor regrowth after harvesting a heavy cut, particularly with harvesting in the reproductive phase, when the development of the dormant buds left behind is strongly inhibited by apical dominance (Gillet et al., 1969; Groupe
are located close to the meristems. Either because they are less polymerised or carbohydrates, but only part of them are haps not all fructosans (the major soluble mental if followed by a rise in temperature. Involved in deterioration: for example those of sward deterioration and death in intensive production systems. According to Leafe et al. (1972), depletion of reserves in the stubble following a prolonged period in negative carbon balance appears to be the most likely cause of sward deterioration and death in intensive production systems. Dead patches never occurred where green stubble was left after harvesting, apparently because photosynthesis by the retained leaf blades and sheaths preserved the plant from lethal exhaustion. Death increased, the earlier regrowth started (Figure 4), suggesting a quicker exhaustion of reserves below a critical level. This seems to be in agreement with the observation of Gillet that defoliation was most detrimental if followed by a rise in temperature. A low content of carbohydrates may also be responsible for the worse regrowth with increasing N supply without a yield increase (Figure 3). However, chemical analysis failed to prove a relation between damage and carbohydrate level, though the latter was always low. Perhaps not all fructosans (the major soluble carbohydrates), but only part of them are involved in deterioration: for example those which are most rapidly available for regrowth, either because they are less polymerised or are located close to the meristems.

Colby et al. (1974) working with timothy, concluded that low levels of soluble carbohydrates were largely responsible for regeneration failure after harvesting. Plant death did not strongly parallel fructosan content of the stubble, however. Figure 9, drawn from these data, shows that for a given fructosan content damage was worse the higher the fertilization level.

Preliminary pot trials with perennial ryegrass growing in nutrient solution by Ennik and Baan Hofman did not indicate that differences in persistence between varieties were related to differences in carbohydrate content. As reported by Behaeghe (1979) there is evidence that carbohydrate is a growth limiting factor only below a critical level, which was probably not yet reached in our trials.

According to Vos (1973) differences in persistence between varieties are most marked in summer after the first or second cut, especially when the summer is dry and warm. This agrees with the findings of Lucanus et al. (1960) that high N supply reduced survival of periodically cut perennial ryegrass only under conditions of drought or high temperature. The effects were additive. But recent pot trials with perennial ryegrass on nutrient solution of different osmotic pressure by Van der Woude (RIVRO, Wageningen; pers. comm.) did not support the suggestion that differences in persistence between varieties were related to differences in drought resistance.

The negative relation between N supply and root mass of grass has been reported earlier by several authors (e.g. Troughton, 1957; Behaeghe, 1972). The relation holds above a
certain level of limiting N supply; below that level root mass increases with increasing N supply (Troughton, 1957; Dirven & Wind, 1980). In some field trials with ryegrasses grown for green manure on arable land in the autumn, Dilz et al. (1977) found an increase in root mass up to an N supply of 50 kg/ha. Root mass was negatively affected if the N supply was increased from 50 to 100 kg/ha, especially if the autumn was rather cool and cloudy. Brouwer (1962) showed that the nitrogen level at which there is a decline in root mass, depends on light intensity. A change-over of ryegrass plants from nutrient solution plus nitrogen to minus nitrogen resulted in an absolute faster root growth at a lower light intensity, but not at a higher light intensity. The enhanced root growth at lower light intensity after omission of nitrogen was attributed to an improved carbohydrate supply to the roots. Dirven and Wind (1980) found that, like root mass, the water-soluble-carbohydrate contents of shoot, stubble and roots increased at the lower rates of N, but decreased at higher rates. However, the N rate for maximum root mass did not quite coincide with the N rate for maximum carbohydrate content.

It is likely that the smaller root mass with high N supply makes the plants more susceptible to stress factors in the soil. According to Behaeghe (1972) it may worsen the water availability to the plant. In trials of Baan Hofman and Ennik (1980) a greater root mass ran parallel to a better competitive ability.

Grassland farming with high N supply requires harvesting in a rather young stage to ensure a good regrowth, but sometimes this is impossible because of circumstances beyond the farmer's control (e.g. weather conditions). Availability of more persistent varieties may be helpful, therefore, and it has been shown in this paper that persistence can be remarkably improved by the breeding method as described by Van Dijk and Winkelhorst (1978). In mixed swards, however, improved persistence of the grass may lead to less clover. Camlin (1978) reported that white clover content is in inverse proportion to ryegrass cultivar persistence.

According to Camlin (1978) and Aldrich (1978) relative differences in persistence between cultivars of one species are generally maintained over a wide range of managements, but in the trials in Lusignan, the ranking of the genotypes for deterioration after high N supply was somewhat different from one occasion to another.

7. References


POSITIVE AND NEGATIVE EFFECTS OF CATTLE MANURE ON GRASSLAND WITH SPECIAL REFERENCE TO HIGH RATES OF APPLICATION

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Summary

Nitrogen of cattle manure is generally inferior to fertilizer nitrogen owing to volatilization of ammonia and slow activity of faeces nitrogen. On intensively fertilized swards, in which legumes are widely suppressed by application of slurry and fertilizer nitrogen the following values for nitrogen efficiency of 1 : 0.5 diluted cattle slurry (1 part faeces + urine : 0.5 parts water) in comparison to fertilizer-N were ascertained: about 35% immediate (= direct) efficiency, 50% annual efficiency and 65% total efficiency (= long term efficiency, including accumulated residual efficiencies of slurry application in the preceding years). These figures are influenced by positive and negative secondary effects and they should therefore be regarded as "apparent" nitrogen efficiencies. If only slurry is applied (+ fertilizer PK, but without fertilizer-N) apparent efficiency (annual and total efficiency) of nitrogen of 1 : 0.5 diluted cattle slurry in comparison to fertilizer nitrogen can be considerably higher, because manure-N combines generally better with legume-N than fertilizer-N.

Efficiency of nitrogen is generally improved by further dilution of slurry but it is possible only to a limited extent to use this method when slurry is brought out by tanks. About 35% of total-N or two thirds of the ammonia-nitrogen of 1 : 0.5 diluted cattle slurry are lost, presumably by ammonia volatilization. There is urgent need for further research to reduce or eliminate the loss of ammonia from cattle manure on grassland.

Cattle manure may exert negative secondary effects on the growth of grass, thereby reducing the apparent nutrient efficiency of the manures and the yield potential of the sward. Especially the efficiency of large applications of manure may be disappointing, because together with the increased nutrient supply growth disturbing effects may become more and more significant. Therefore, combinations of manures and fertilizers are preferable to the exclusive application of relative high amounts of manures.

Experiments with dried FYM and with irrigation of slurry supplied on non-leguminous grassland proved that the negative effects of fresh cattle manure are mainly caused by coating or covering of the grass. However, the possibility of detrimental chemical ingredients is not yet to be excluded.

Urine scorching of pastures may arise to a problem, especially at high levels of nitrogen fertilization and with favourable weather conditions for the growth of grass.

Herbage intake and performance of grazing animals may be reduced by application of slurry. The liveweight gains of cattle may be reduced also by feeding silage from areas which where intensively dressed with cattle slurry. Cattle manure may contribute also to the spread of weeds and animal diseases.

Application of cattle manure on grassland is generally advantageous, but the danger of negative secondary effects should not be ignored, especially on intensively managed areas. Technology of application should be improved with the following aims: better nutrient utilization and minimization of the negative secondary effects.

Introduction

Manure was naturally recycled to grassland long before man adapted cattle for his needs. For centuries farmers used animal manures as the main source for maintaining soil fertility. It is only in the last decades with the advent of readily available cheap chemical fertilizers that in countries with intensive dairy farming manures are being viewed as a disposal problem rather than a valuable asset.

The increasing cost of scarce energy reserves and the limited world reserves of phosphorus may, however, require a new look at the importance of wastes in maintaining soil fertility.

* Seconded by the Agricultural Bureau of the Netherlands Fertilizer Industry (LBNM)
On a world scale the annual manure production from farm animals contains about 54, 12 and 52 million tonnes of nitrogen, phosphorus and potassium, respectively (Tunney, 1980). This compares with the 1976 estimated world chemical fertilizer production of 14, 11 and 20 million tonnes of nitrogen, phosphorus and potassium, respectively (F.A.O. 1977). It has been estimated that the potential fertilizer value of animal manures in the 9 EEC countries is worth about 3,000 million US dollars per annum.

Most of the land area of the EEC countries is under grass and most of the cattle manure is spread on grassland. Nowadays this occurs more and more in the form of slurry, and therefore this paper deals mainly with the value of slurry as grassland fertilizer.

We consider two main topics in this respect: 1) The potential value of cattle manure as a carrier of plant nutrients and 2) the secondary effects, which can be exerted by slurry and other manures on forage production and quality. Only with good information on these areas it is possible to make full profit from animal manures.

Prerequisite for a profitable utilization of manure nutrients is an accurate evaluation of their nutrient potential. Therefore, this paper deals firstly with manure production per cattle unit, nutrient content of manures and efficiency of manure nutrients. There exists a lot of data for evaluating these parameters, but they vary rather widely.

The phosphorus of cattle manure is slow acting on grassland and therefore unsuited to cover a phosphorus deficiency within a short time. But on the long term it responds as well as fertilizer phosphorus. Potassium of properly applied cattle manure is to be regarded as equivalent to fertilizer.

Most conflicting is the data regarding N-efficiency. One of the reasons is the fact that nitrogen efficiency, determined in the usual way, is only an "apparent" nitrogen efficiency; i.e. the eventual positive and negative secondary effects are combined in this term because of the difficulty to determine "true" nitrogen efficiency of manures or to divide apparent nitrogen efficiency into true nitrogen efficiency and secondary effects. This applies also for the figures in this paper and they should be considered therefore only as approximate values, with the reservation that extraordinary low values may have been influenced by damaging factors and very high values by favourable factors.

Damaging factors, which are supposed to be inherent in slurry, are often discussed, at least since the fundamental work of Truninger & Keller (1934) who showed, that some ingredients of slurry, like benzoic acid, can damage legumes. Further evidences for the existence of harmful substances in slurry were given by Gisiger (1961). He found, that ammonium carbonate can cause scorching under some circumstances. Many farmers hesitate to introduce the slurry system because of these harmful slurry effects.

Therefore, the aim of this paper is mainly to improve the information, which is necessary for making full use of the manure nutrients and to present some never results with regard to the mysterious question of harmful effects of cattle manure.

### The potential value of cattle manure as a carrier of plant nutrients

Data on the production of faeces and urine (= undiluted slurry) per cattle unit and the dry matter and nutrient contents of these products make it easier to plan fertilization and to make full use of the fertilizing value of slurry.

Since 1966 at Gumpenstein faeces and urine production under farm conditions have been measured. The animals studied consisted mainly of cows fed chiefly with hay in winter and nearly exclusively with mown fresh grass during summer. The results are summarized in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>kg per cattle unit per day</th>
<th>Dry matter content %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>fae- undil. fae- undil.</td>
<td>ces urin slurry ces urin slurry</td>
</tr>
<tr>
<td>Winter</td>
<td>25.1 10.3 35.9 14.8 5.2 12.1</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>25.4 18.7 44.1 12.3 4.3 8.9</td>
<td></td>
</tr>
<tr>
<td>Mean*</td>
<td>25.5 14.1 39.6 13.7 4.8 10.7</td>
<td></td>
</tr>
</tbody>
</table>

* Calculated with 200 winter- and 165 summer-feeding days

There are notable differences in slurry production between winter and summer (36 and 14 kg undiluted slurry per cattle unit per day), but still more striking are the differences in urine production: 10.3 and 18.7 kg. Also important are the differences in dry matter content of the undiluted slurries depending on the feeding period. Undiluted winter slurry on average contains about 12 % DM, summer slurry about 9 %. These figures are a suitable base for calculating the degree of dilution of slurries. For example: Cattle slurry with a DM-content of 6 % is diluted to a degree of 1 : 1 with winter slurry and to a degree of 1 : 0.5 with summer slurry. The rate of added water (= x) in relation to the amount of faeces + urine (= 1), may be calculated according to the formula:

\[
x = \frac{1}{\text{DM content} + 1}
\]
According to Table 2 great differences exist in nutrient content between faeces and urine and also, but smaller, differences between winter and summer. From these and other results of Gumpenstein it can be concluded that winter slurry generally contains more nitrogen and phosphorus than summer slurry. The situation regarding potassium is variable.

Table 2. Average nutrient content (%) of faeces, urine and undiluted slurry, collected on three Austrian farms between 1966 and 1979 (136 faeces- and 136 urine-samples).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faeces</td>
<td>Winter</td>
<td>0.36</td>
<td>0.26</td>
<td>0.18</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.32</td>
<td>0.24</td>
<td>0.21</td>
<td>0.38</td>
</tr>
<tr>
<td>Urine</td>
<td>Winter</td>
<td>0.66</td>
<td>0.02</td>
<td>1.75</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.47</td>
<td>0.02</td>
<td>1.49</td>
<td>0.02</td>
</tr>
<tr>
<td>Undil. slurry</td>
<td>Winter</td>
<td>0.45</td>
<td>0.19</td>
<td>0.63</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>0.38</td>
<td>0.14</td>
<td>0.75</td>
<td>0.23</td>
</tr>
<tr>
<td>Mean*</td>
<td></td>
<td>0.42</td>
<td>0.17</td>
<td>0.69</td>
<td>0.27</td>
</tr>
</tbody>
</table>

* Calculated with 200 winter- and 165 summer-feeding days.

The quantities of nutrients in slurry are calculated mostly by using average figures like those in Table 2. This procedure is not satisfactory because there exist even at a given DM-content of slurry considerable differences in nutrient content, depending on nutrients in the soil, intensity of fertilization, cutting time, feeding regime etc.

Table 3. Nutrient content of "undiluted" cattle slurry of 7 Austrian farms (annual means; slurries of farms G1 - G3 were really undiluted, the contents of the other slurries were converted to "undiluted" slurry according to DM-content).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>22</td>
<td>0.38</td>
<td>0.13</td>
<td>0.61</td>
<td>0.26</td>
</tr>
<tr>
<td>G2</td>
<td>23</td>
<td>0.44</td>
<td>0.16</td>
<td>0.60</td>
<td>0.30</td>
</tr>
<tr>
<td>G3</td>
<td>31</td>
<td>0.41</td>
<td>0.19</td>
<td>0.75</td>
<td>0.25</td>
</tr>
<tr>
<td>G4</td>
<td>71</td>
<td>0.54</td>
<td>0.25</td>
<td>0.72</td>
<td>0.29</td>
</tr>
<tr>
<td>P1</td>
<td>8</td>
<td>0.36</td>
<td>0.19</td>
<td>0.47</td>
<td>0.26</td>
</tr>
<tr>
<td>P2</td>
<td>22</td>
<td>0.34</td>
<td>0.10</td>
<td>0.61</td>
<td>0.33</td>
</tr>
<tr>
<td>P3</td>
<td>14</td>
<td>0.40</td>
<td>0.21</td>
<td>0.76</td>
<td>0.29</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>0.44</td>
<td>0.19</td>
<td>0.68</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Table 3 shows the average nutrient content of the slurries of the Austrian farms, of which slurries were used for the trials at Gumpenstein. Notable are the average values of farm "G1", that is an experimental farm at Gumpenstein. Fertilization is relatively high on this farm (since 1966 on an average 323 kg N, 156 kg P₂O₅ and 264 kg K₂O per ha per year have been applied with slurry and fertilizers), grass is cut early and conserved well, a lot of concentrates are fed, and accordingly the slurry contains much more nutrients than the slurries of the farms G1 - G3, which lie in the vicinity of Gumpenstein. Ideally, slurry should not be evaluated by average figures, but individually.

Ammonia-N, probably the more valuable part of slurry nitrogen, amounted to 53 % of total N in winter slurry and 57 % in summer slurry (average of all the samples in Table 3).

Of course, the variability in nutrient content of slurry is much greater when slurry with different degrees of dilution are compared. The results in Table 4 indicate that the variation in manure dry matter is the major factor contributing to the variation in nitrogen content.

Table 4. The nitrogen and dry matter content of cattle manures from different farms in Ireland (Tunney, 1977).

<table>
<thead>
<tr>
<th></th>
<th>N kg/t</th>
<th>N % in DM</th>
<th>% in fresh manure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>fresh</td>
<td>manure</td>
</tr>
<tr>
<td>Cattle slurry</td>
<td>Mean</td>
<td>8</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>1-14</td>
<td>0.8-5.6</td>
</tr>
<tr>
<td>Farmyard manure</td>
<td>Mean</td>
<td>20</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>13-26</td>
<td>3.2-6.5</td>
</tr>
</tbody>
</table>

This is further emphasized by the relationship between the dry matter and nitrogen content of the same cattle slurry samples, which is illustrated in Figure 1. Some of the samples, with as low as 1 % dry matter indicated several fold dilution with rain or wash water.

Efficiency of manure nitrogen on grassland

The phosphorus and potassium in cattle manure is generally presumed to be as effective as in chemical fertilizers (Schechtner, 1969; Collins, 1971). Equivalence of P and K in manures and fertilizers under long term application conditions is further proved by the long term slurry trials of Gumpenstein. P- and K-contents of herbage DM were nearly equal in the fertilizer and combined treatments (fertilizers or fertilizers + manures) of these trials.

The value of nitrogen in cattle manure is much more variable and complex. Efficiency levels of nitrogen compared with chemical
dry matter = 3.89 + 5.85(DM) - 0.17(DH)

\[ R^2 = 0.79 \quad (P = 0.001) \]

Figure 1. Relationship between dry matter and nitrogen in cattle slurry.

fertilizer from over 100 % to 0 % or even below 0 % have been reported by different research workers. It is difficult to decide under these circumstances which figures should be used in evaluating manures and planning fertilization.

Five long term Austrian slurry trials may contribute to a clarification of this problem. One of these experiments (No. 444) is being conducted on an old permanent meadow, the others mainly on sown permanent meadows.

Soils are sandy to loamy and Dactylis glomerata is the prevailing grass species. In order to imitate practical conditions, slurry dressings are principally related to the yield of the preceding year in these trials. Calculation basis: 100 kg herbage DM = about 35 kg slurry DM.

The time between slurry application and harvest of the forage was about 40 days on the average of all trials and years. Apparent nitrogen efficiency of these Austrian trials has throughout the paper been calculated via DM increase per kg N applied.

Table 5 shows the yields per cut which were used as the basis for calculation of the immediate and residual efficiency of manure and fertilizer nitrogen, that means the direct efficiency on the cut which received the manures or fertilizers and the residual efficiency on the following cut(s). Moreover the annual dry matter yields are included in Table 5 as the basis for calculation of the annual efficiency of manure- and fertilizer-N. On the base of these data-nitrogen efficiency was calculated absolutely (in kg dry matter/kg N) and relatively by using the absolute efficiency of comparable amounts of fertilizer-N as the base of comparison (= 100 %).

Table 5. Apparent nitrogen efficiency of faeces and urine slurry in comparison to fertilizers in exp. 484 of Gumpenstein. Dry matter yields in t/ha. Average of 13 years.

<table>
<thead>
<tr>
<th>Cut</th>
<th>PK(Control)</th>
<th>PK+120 N</th>
<th>Faeces sl.</th>
<th>Urine sl.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.00</td>
<td>2.73</td>
<td>2.25*</td>
<td>2.92*</td>
</tr>
<tr>
<td>2</td>
<td>2.39</td>
<td>2.31</td>
<td>2.61</td>
<td>3.04*</td>
</tr>
<tr>
<td>3</td>
<td>2.39</td>
<td>2.31</td>
<td>2.61</td>
<td>3.04*</td>
</tr>
</tbody>
</table>

* dressed with fertilizer-N (60 kg N/ha/cut) or similar amounts of faeces- and urine-N.

Residual efficiency of nitrogen - in absolute terms - was calculated basically in the same way as immediate efficiency, that means additional yield or yield loss divided by the applied amount of nitrogen, but in this case the nitrogen dressing to the preceding cut or one of the preceding cuts had to be used as divisor.

Annual efficiency of mineral N (120 kg per ha per year), serving as standard for evaluating the efficiency of slurry nitrogen, was not good in this experiment (5.9 kg DM/kg N), because white clover grew exceptionally well.

Immediate efficiency of fertilizer-N was fairly good, but residual efficiency was distinctly negative because of suppression of white clover (see e.g. Fig.2, cut 2: 23 % legumes in the plots with fertilizer-N applied to the first cut compared with 37 % at the control plots with PK only).

In spite of the 1 : 2 dilution immediate N-efficiency of the faeces slurry was rather poor (28 % in spring and 36 % in summer). However, residual efficiencies were relatively good, especially during summer, and thereby annual total efficiency reached the surprisingly high value of 86 %. Hence, faeces is a slow acting, but not insignificant source of nitrogen. In spite of the slow activity, legumes were suppressed rather strongly on
Figure 2. Apparent N-efficiency of faeces and urine slurry in exp. h89 of Gumpenstein. Same treatments and yields as in Table 5. Relative yields calculated from DM increases per kg N. Legumes were estimated visually as green matter percentage in the sward.

Leg. PK = legumes of the control plot receiving only P and K

the faeces plots, but not as much as on the fertilizer nitrogen plots.

Urine slurry proved on this mixed sward in every respect better than fertilizer-N (annual efficiency as calculated via the DM increase 12.6 kg DM/kg N = 214 %). This high relative efficiency may partly be ascribed to a potassium effect, because the supply of potassium was over-optimal in the urine slurry treatment and suboptimal in the last years in the NPK-fertilizer treatments. However, the 13 years average values are influenced only slightly by these differences. Although an extra 13 mm water (5 in spring and 8 in summer) was applied, a positive irrigation effect may probably be excluded (Stewart, 1968). It would seem that part of the high efficiency may also be ascribed to a positive effect of the diluted urine slurry on the legumes in the sward. Therefore, even at relatively high rates, fermented urine generally should not be detrimental to the sward, if sufficiently diluted and applied in spring or summer.

Apparent efficiency of slurry nitrogen

Efficiency of slurry-N was evaluated in the Austrian experiments at two intensity levels, namely without fertilizer-N ("PK-series") and with fertilizer-N ("NPK-series"); fertilizer-N given additionally to slurry or alternately with slurry. On average about 40 - 50 t slurry per ha per year was applied in the "PK-series" and 50 - 60 t/ha in the "NPK-series".

All treatments received sufficient P (about 1.2 kg P2O5/100 kg DM) and about 2.5 kg K2O/100 kg DM or more. Fertilizer and manure treatments were balanced in regard to the P and K supply.

Slurry was brought out by watering cans with battle plates and distributed thereby very well, probably more evenly as it is usually the case in farming practice.

Dried slurry films were generally crushed about 1 - 2 weeks after application by rakes, as it is usually done in practice by harrows or sledges.

In the experiments h44, h69, h90 and h90 slurry dressings are split and given partly in spring, partly in summer. In the split plot exp. h40 relatively high slurry dressings are given only in spring. Slurry application takes place in this experiment partly within a rotation (1 year potatoes and five years ley). The average degree of dilution of the slurry was about 1 : 0.5 (1 part faeces + urine : 0.5 parts water) in all trials and treatments, computed in Table 6 and 7.

In Table 6 the results of those experiments in which only slurry (+ fert. PK) and no fertilizer-N was applied. Under these circumstances clovers can contribute a good deal to the N-supply of the sward.

Annual efficiency of slurry-N was very variable on these mixed swards (3.5 - 11.0 kg DM/ kg N) and the average value of all five trials (7.1 kg DM/kg N) is approximately in the order which was expected from this type of manure. However, efficiency of fertilizer-N (120 kg N/ ha) was disappointing (8.8 kg DM/kg N), as is frequently the case when moderate dressings of fertilizer-N are given to grass/legume swards. Generally, small efficiencies of slurry-N corresponded with small efficiencies of fertilizer-N and vice versa. Since the efficiency of slurry-N was normal and efficiency
of fertilizer-N disappointing, the relative efficiency of slurry-N reached the surprisingly high value of 81%. It can be concluded from these results that slurry-N combines better with legume-N than fertilizer-N under usual conditions of application regarding to rate, dilution and time of application.

Independent time of application the immediate efficiency of slurry nitrogen was about 15% in these trials. Residual efficiency of slurry nitrogen, applied two times per year, was slightly negative in spring and clearly positive in summer. The single spring dressing in trial 480 had a negative residual effect. Observations showed that suppression of legumes was the main cause.

Table 7 contains data regarding the efficiency of slurry-N when applied in combination with fertilizer-N, i.e. additionally to fertilizer-N (30 kg/ha/cut) in exp. 444 or alternately with fertilizer-N (60 kg/ha/cut) in the other experiments. The legumes are widely suppressed by this fertilizing regime and it becomes possible thereby to recognize efficiency of slurry nitrogen more clearly.

Regarded absolutely, annual efficiency of slurry-N was very good in this "fertilizer-N-series" (11.2 kg DM/kg N on the average of all four trials). However, in comparison to fertilizer-N, efficiency of slurry-N was only 27%, because fertilizer-N, plotted against fertilizer-N, responded far better than fertilizer-N. The fertilizing value of slurry-N is characterized rather realistically by these figures, and even in the case of only moderate dilution, nitrogen efficiency of cattle slurry is to be judged as satisfactory according to these results. Indeed, the possibility of the existence of harmful slurry properties cannot be eliminated by these results, but these properties (even on medium high levels of fertilization) generally cannot be of great importance.

Immediate efficiency of slurry-N was similar in the "fertilizer-N-series" as in the "PK-series": about 45% in spring and summer. Residual efficiency was nearly always positive in the "fertilizer-N-series", and this means, that residual efficiency of slurry-N is principally positive, but this positive effect can be cancelled by suppression of legumes.
Table 7. Apparent immediate efficiency, residual efficiency and annual efficiency of the nitrogen of cattle slurry, applied combined with fertilizer-N (kg DM/kg N).

<table>
<thead>
<tr>
<th>Exp. trial no.</th>
<th>Nitrogen application and DM yield of the control &quot;N,PK&quot;</th>
<th>Application systems (SI = slurry)</th>
<th>1st year</th>
<th>2nd year</th>
<th>3rd year</th>
<th>4th year</th>
<th>5th year</th>
<th>Annual efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of years</td>
<td>kgN/ha/yr</td>
<td>t DM/ha/yr</td>
<td>cut 1 imm. eff.</td>
<td>cut 2 res. eff.</td>
<td>cut 3 res. eff.</td>
<td>cut 4 tot. res. eff.</td>
<td>slurry-N fert.-N efficiency</td>
</tr>
<tr>
<td>hhh</td>
<td>16</td>
<td>120</td>
<td>7.56</td>
<td>30N+SI 30N 30N+81 30N</td>
<td>7.7</td>
<td>+1.0</td>
<td>6.7</td>
<td>+5.3</td>
</tr>
<tr>
<td>469</td>
<td>12</td>
<td>120</td>
<td>8.32</td>
<td>21(8N) 60N 21(96N) 60N</td>
<td>9.3</td>
<td>+2.9</td>
<td>8.8</td>
<td>+2.3</td>
</tr>
<tr>
<td>450</td>
<td>11</td>
<td>120</td>
<td>8.96</td>
<td>21(59N) 60N 21(65N) 60N</td>
<td>8.7</td>
<td>+1.5</td>
<td>11.1</td>
<td>-0.3</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Relative Efficiency

<table>
<thead>
<tr>
<th>Nitrogen application and DM yield of the control treatment &quot;N,PK&quot;</th>
<th>Application systems (SI = slurry)</th>
<th>1st year</th>
<th>2nd year</th>
<th>3rd year</th>
<th>4th year</th>
<th>5th year</th>
<th>Annual efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-3 *</td>
<td>120</td>
<td>9.74</td>
<td>21(226N) 60N 60N</td>
<td>11.5</td>
<td>+2.6</td>
<td>+2.4</td>
<td></td>
</tr>
<tr>
<td>L-3 *</td>
<td>120</td>
<td>11.48</td>
<td>21(214N) 60N 60N</td>
<td>8.8</td>
<td>+1.3</td>
<td>+0.9</td>
<td></td>
</tr>
<tr>
<td>P-5 *</td>
<td>240</td>
<td>11.88</td>
<td>21(235N) 60N 60N 60N</td>
<td>7.6</td>
<td>-0.5</td>
<td>+0.5</td>
<td>+0.6</td>
</tr>
<tr>
<td>L-5 *</td>
<td>240</td>
<td>12.11</td>
<td>21(217N) 60N 60N 60N</td>
<td>7.5</td>
<td>-0.9</td>
<td>+0.3</td>
<td>+1.1</td>
</tr>
<tr>
<td>Mean (13 years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8.9</td>
</tr>
</tbody>
</table>

**P = Sown permanent meadow; L = Ley; 3 = 3 cuts, 5 = 5 cuts per year**

**Immediate efficiency of slurry-N in comparison to fertilizer-N was derived from the dry matter yields of the following fertilizer treatments:**

Exp. 444: PK+240 N = N₀ (60+60+60+60) plotted against PK+120 N = N₁ (30+30+30+30)

Exp. 469 and 490: PK+260 N (60+60+60+60)

**Annual efficiency of slurry-N in comparison to fertilizer-N was derived from the dry matter yields of the following fertilizer treatments:**

PK+240 N = N₀ (60+60+60+60) plotted against PK+120 N = N₁ (30+30+30+30)

---

Long-term efficiency of slurry-N

Figure 3 shows the development of annual efficiency of slurry nitrogen with increasing duration of application.

It can be seen, that efficiency of slurry-N is increasing with time. Thus, the quoted average values are valid only for application periods of about 10 - 15 years. In the first years of application efficiency of slurry-N may be considerably lower and after about 10 years considerably higher. Probably the reason for this lies mainly in an accumulation of residual efficiencies of faeces-N, because there is usually a residual effect from the nitrogen in the organic fraction of manure which is gradually released by mineralisation.

Work in California (Pratt et al., 1973) attempts to quantify the residual effect of manures. Decay series have been developed to show the proportion of nitrogen applied in manure that can become available in years subsequent to application. For example, for cattle manure with 0.35% nitrogen, the decay series is 0.75, 0.15, 0.10 and 0.05. They can be interpreted as 75% of nitrogen is effective in the first year, 15% in the second year, etc.
year and so on. This means that the apparent effectiveness of manure can be higher in the year of application on land that has received appreciable quantities of manure for a number of years.

The efficiency of manure nitrogen has recently been studied by Sluijsmans & Kolenbrander (1977). These workers have divided manure nitrogen into three fractions namely, a) readily available, b) easily decomposable and available in first year and c) relatively resistant to decomposition and becoming available in subsequent years. This work suggests that 50% of cattle slurry nitrogen is readily available and 25% is easily decomposable and can be available in the first year.

Dilution and apparent efficiency of slurry-N

In exp. 484 at Gumpenstein cattle slurry was examined with different rates of dilution under mixed sward conditions with good growth of white clover. No additional fertilizer-N has been used in this experiment. The results are summarized in Table 8. It can be seen, that efficiency of slurry nitrogen can be improved by dilution and, in the case of mixed swards, apparent nitrogen efficiency of diluted slurry can even be better than the efficiency of fertilizer-N.

Inexplicable, in the case of the single spring application, the annual efficiency of nitrogen of the 1:1 diluted slurry was not better than that of the undiluted slurry, because the undiluted slurry was distinctly superior in residual efficiency. This exceptional result may be explained by ammonia or other slurry ingredients reaching the roots of the legumes owing to the higher degree of dilution. This may be detrimental to rhizobium activity or to the legume root system (Kutschera-Mitter, 1974).

Table 9 summarizes the results of the effects of dilution where slurry was applied alternately with fertilizer-N. Dilution improved efficiency of slurry nitrogen in these experiments too, but the economic effect of this measure is questionable. Other positive effects of dilution, especially the reduction of the danger of fouling the herbage, should be taken into consideration.

The values for immediate efficiency of slurry-N are approximate in these two trials, because the values for the negative residual effects of the mineral nitrogen fertilization on the yields of the first and third cut, which are needed for calculation of the "real" efficiency of the alternately (with fertilizer-N) applied slurry-N (Schechtner, 1978), had to be estimated in these two trials.

### Table 8. Apparent efficiency of slurry-N as influenced by the degree of dilution. Exp. Gump. 484 (Average of 13 years). Slurry applied without fertilizer-N (kg DM/kg slurry-N and relative efficiency in comparison to fertilizer-N).

<table>
<thead>
<tr>
<th>Frequency of appl.</th>
<th>Immediate efficiency</th>
<th>Annual efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>spring</td>
<td>summer</td>
</tr>
<tr>
<td>Single application</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:0*</td>
<td>3.0</td>
<td>30%</td>
</tr>
<tr>
<td>1:1</td>
<td>5.2</td>
<td>52%</td>
</tr>
<tr>
<td>1:0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1:1</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* DM content 11.6% in spring and 8.7% in summer

### Table 9. Apparent efficiency of slurry-N as influenced by the degree of dilution. Mean of exp. 489 (Admont, 12 years) and 490 (Fiber, 11 years). Slurry application in alternation with fertilizer-N (kg DM/kg slurry-N and relative efficiency in comparison to fertilizer-N).

<table>
<thead>
<tr>
<th>Degree of dilution (ca.)</th>
<th>Immediate efficiency</th>
<th>Annual efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>spring</td>
<td>summer</td>
</tr>
<tr>
<td>1:0.1</td>
<td>9.0</td>
<td>97%</td>
</tr>
<tr>
<td>1:1</td>
<td>12.3</td>
<td>61%</td>
</tr>
</tbody>
</table>

* DM content 8.4% in spring and 6.5% in summer

Table 10 results from Gumpenstein on the influence of time of application on apparent efficiency of slurry-N are summarized. All these results are from slurry dressings without additional application of fertilizer-N, that means from mixed grass/legume swards. Dilution of slurry in exp. 484, situated at
 Gumpenstein, was 1:1. In exp. 489 and 490, situated at Admont and fiber, rates of dilution were about 1:0.4.

Table 10. Apparent efficiency of slurry-N as influenced by time of application; kg DM/kg N. Data refer to PK-treatments with slurry only.

<table>
<thead>
<tr>
<th>Time of applic.</th>
<th>Exp. trial</th>
<th>No. years</th>
<th>Total</th>
<th>#eff.</th>
<th>res.</th>
<th>ann.</th>
<th>eff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>late winter</td>
<td>484</td>
<td>13</td>
<td>4.4</td>
<td>+1.3</td>
<td>5.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>winter</td>
<td>489</td>
<td>12</td>
<td>4.7</td>
<td>-5.2</td>
<td>-0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>autumn</td>
<td>489</td>
<td>11</td>
<td>9.0</td>
<td>+4.1</td>
<td>13.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>5.9</td>
<td>-0.02</td>
<td>5.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>early spring</td>
<td>484</td>
<td>13</td>
<td>5.2</td>
<td>-0.2</td>
<td>5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>spring</td>
<td>489</td>
<td>12</td>
<td>4.1</td>
<td>-1.2</td>
<td>2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>summer</td>
<td>489</td>
<td>11</td>
<td>6.9</td>
<td>+4.7</td>
<td>11.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>autumn</td>
<td>489</td>
<td>11</td>
<td>9.3</td>
<td>+1.1</td>
<td>10.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>6.1</td>
<td>+0.5</td>
<td>6.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

On average late winter dressings responded similarly to the dressings at other times of the year, but there were large differences between the experimental sites. Under the rough climatic conditions of Admont the late winter dressings responded badly, under the warmer climatic conditions of fiber they did well. The reason for the disappointing results at Admont is the clear negative residual efficiency of the slurry-N. Apparently legumes can be damaged rather strongly by late winter dressings of slurry under rough climatic conditions, but the results at Gumpenstein (exp. 484) shows that early spring dressings can sometimes be disappointing too. It depends probably on the soil and weather conditions before, during and after slurry application, to what degree legumes are damaged by late winter and spring applications of cattle slurry. It seems to be disadvantageous for the growth of legumes when greater amounts of certain slurry components, like ammonia, get to the roots of legumes during cool soil and weather conditions in late winter or early spring. Very exceptionally even grasses can be damaged by slurry under these conditions.

Further it can be seen in Table 10, that the application of moderately diluted slurry on grass/clover swards during summer can also give a comparatively small response. In contrast to the results of other workers the autumn dressings of slurry responded relatively well.

Negative effects of cattle manure

Work in Ireland in the past decade shows variable, though generally poor, response of grass yields to cattle slurry. Better results have been obtained with pig slurry indicating a higher apparent efficiency of pig slurry nitrogen. Pig slurry contains a relative high proportion of urine (a 2:3 ratio of faeces and urine; Tietjen & Vetter, 1972) and its superiority to cattle slurry may also be explained by the relative low proportion of fibres in faeces. Moreover the covering effect on the sward is smaller than with cattle slurry.

To find out the reasons of the disappointing results with cattle slurry an experiment was laid down in 1976 to study the efficiency of manure nitrogen. It was a factorial experiment with incremental rates of slurry and fertilizer nitrogen. In 1976 and 1977 the cattle slurry rates were 0, 28, 42 and 64 tonnes per hectare applied in spring. In addition there was one pig slurry treatment at 42 tonnes per hectare. The fertilizer nitrogen treatments were 0, 30, 60 and 90 kg N per hectare. The rates for 1976 were somewhat higher. The results of this experiment for 1977 and 1978 are summarized in Figures 4 and 5, respectively. There was an additional treatment where the effects of washing the slurry off the grass immediately after spreading was studied. This work is more fully described elsewhere (Tunney et al., 1980). The results in Figures 4 and 5 show a positive yield response to slurry. There is very little difference in yield response to the three rates of cattle slurry. In other words the low rate of cattle slurry was as effective as the high rate, and the apparent efficiency of nitrogen at the low rate was much better than at the high rate. The effectiveness of the nitrogen at the low rate of cattle slurry, relative to fertilizer nitrogen, was about 48% in 1977 and 26% in 1978.

Figures 4 and 5 also show the good yield response obtained with pig slurry relative to cattle slurry. Washing the slurry off the grass surface after spreading gave increased yield, but the response was small. Perhaps the disappointing yield response of cattle slurry on grassland can be partly explained by volatilization of ammonia from slurry shortly after spreading.

Recent laboratory studies at Johnstown Castle Research Centre in Ireland have shown that over 95% of the ammonia in cattle slurry is lost on drying. Most of the ammonia in pig slurry is also lost on drying but the percentage loss is lower than with cattle slurry. Field studies with pig slurry (Sherwood, 1980) indicated that 50% to 80% of ammonia was lost by volatilization within one week of spreading.

However, the disappointing response of slurry-
ry in this experiment could still have other reasons. It may be, that the nitrogen, additionally applied by the higher slurry dressings, could not show an apparent efficiency, because the efficiency was cancelled by detrimental properties of cattle slurry. Chemical ingredients could have caused such a counteraction but also physical properties of cattle slurry. It is known, that cattle slurry tends to stick on the grass surface after application. The visual effect of the slurry on the surface may be evident for two weeks or more after spreading, particularly in dry weather. This coating effect, in addition to promoting ammonia loss and preventing nutrients getting to the plant roots, also probably reduces the rate of photosynthesis of the grass. Never results from the Netherlands have shown that grass growth, in fact, can be hampered by cattle manure and more likely by physical than by chemical properties.

Hampering of grass growth by coating effect

In 1974 the Institute for Soil Fertility in the Netherlands carried out a field experiment to assess the phosphate effect of farmyard manure on grassland. The knowledge on this point under Dutch conditions was very scarce. The experiment was carried out on a P-deficient soil with four levels of superphosphate, each at three levels of FYM: 0, 20 and 40 t per ha, applied in early winter (25 January). Since the FYM contained 0.37% P₂O₅, it was expected that 40 t should give about an equal grass yield as with 148 kg P₂O₅ as superphosphate. The results, however, showed a different picture (Figure 6). The phosphate effect of FYM seemed considerably less than expected. The most striking observation, however, was the course of the 40 t FYM curve at higher rates of superphosphate application, indicating lower yields than without FYM. The total annual yield (four cuts) showed a more or less similar picture. When the experiment was repeated in 1975 on different sites, again lower yields were obtained with increasing levels of FYM.

As it was presumed that the covering of the grass by the FYM might be the principal cause of the observed yield depressions an experiment was performed in 1976 similar to those in previous years but including dried and finely ground FYM equivalent to 40 t fresh FYM. This second type of experiment was repeated in 1977 with 20 and 40 t dried FYM. Table 11 shows the results of all the above-mentioned experiments.

In 1976 the 40 t fresh FYM showed a yield depression similar to that in the previous years. This negative effect was absent when dried and ground FYM was used. The negative effect appeared thus to be a physical and not a chemical one.

It is notable that high rates of fresh FYM application caused no yield depression in 1977. This was most probably due to the very wet period after FYM application (Table 11). It is presumed that the manure has been washed off the rains before growth started. A similar observation has been made by Tunney et al. (1978).

The above-described experiments were carried out with farmyard manure although nowadays in the Netherlands the most common form of animal manure is slurry. In 1978 a precision slurry applicator had been developed at the Institute of Soil Fertility and was available for field trials. In that year a field experi-
Figure 6. The effect of three rates of farmyard manure application on DM yield of grassland at four superphosphate levels on a phosphorus-deficient river clay soil. Exp. 2140, 1974. Farmyard manure application 25.1.1974. Basal dressings: K2O 240 kg/ha equally divided over 25.1, 15.11, 8.11, 29.11 and 19.IV; N 60 kg/ha on 15.11 and 100 kg/ha on 15.III. Pure grass sward with over 90% Lolium perenne.

Table 11. The effect of fresh or dried and ground farmyard manure on relative DM yield of grassland. Wt FYM=100. Actual DM yields in t per ha. The experiments were carried out at optimum N, P and K supply.

<table>
<thead>
<tr>
<th>Year</th>
<th>Expt. no.</th>
<th>Actual FYM</th>
<th>Fresh</th>
<th>Dried</th>
<th>Rain- fall</th>
<th>20</th>
<th>40</th>
<th>20*</th>
<th>40*</th>
<th>mm**</th>
</tr>
</thead>
<tbody>
<tr>
<td>First cut</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1974</td>
<td>2140</td>
<td>4.0=100</td>
<td>98</td>
<td>95</td>
<td>-</td>
<td>-</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td>2206</td>
<td>3.8=100</td>
<td>96</td>
<td>90</td>
<td>-</td>
<td>-</td>
<td>65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td>2319</td>
<td>4.3=100</td>
<td>88</td>
<td>90</td>
<td>-</td>
<td>-</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1977</td>
<td>2372</td>
<td>3.1=100</td>
<td>106</td>
<td>102</td>
<td>104</td>
<td>108</td>
<td>135</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total of 4 cuts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1974</td>
<td>2140</td>
<td>11.7=100</td>
<td>102</td>
<td>101</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td>2206</td>
<td>12.6=100</td>
<td>102</td>
<td>98</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td>2319***</td>
<td>8.3=100</td>
<td>108</td>
<td>98</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1977</td>
<td>2372</td>
<td>12.1=100</td>
<td>109</td>
<td>101</td>
<td>100</td>
<td>101</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Rates of dried FYM (DM content about 85%) equivalent to those of fresh FYM (about 25% DM).

** Rainfall between time of FYM application and start of grass growth

*** 3 cuts

A comprehension analysis of irrigation conducted with cattle slurry (about 10% DM). Measured DM yields of 0, 38 and 73 t per ha were applied. Immediately after the slurry application half of the plots were irrigated overhead with 4 mm water. This was done so vigorously that the slurry was washed off the grass.

The yield-depressing effect of slurry application without irrigation appeared to be similar to that of FYM application — not a chemical but a physical effect: When the slurry was washed-off there was only a small negative effect at the very high rate of slurry application. That grass growth was inhibited by slurry was evident from measurements of leaf area cover.

The effect of cattle slurry application with and without irrigation on grass growth and leaf area cover and the relation between growth and leaf area cover are shown in Fig. 7.

These experiments show, that at optimal N-P- and K-fertilizer supply, the application of animal manures may result in lower yields than without manure application. This result agrees with Boon & De Venter (1978), who compared slurry with equivalent NPK fertilizers and came to the conclusion, that with increasing app-
plication rates of slurry maximum yields could not be reached. Thus, depending on the amount of manure used and on the rate of sub-optimal N, P or K supply, the effect of an application of animal manure will result in a positive response, no response or a negative response in grass yield.

It has been proved by experimental work in Switzerland (Truninger & Keller, 1934; Gisiger, 1961) that chemical ingredients in the urine fraction of fermented slurry can be harmful to the sward. In the Netherlands recent results of research on urine scorches have indicated that even unfermented urine may be detrimental to the sward.

Damage in grassland by urine scorches

When a cow urinates on a pasture, either growing patches or patches where the sward is more or less damaged appear afterwards. In serious cases the sward on those patches dies completely. Then we talk about urine scorch. Damage, caused by urine scorches, especially yield reduction and deterioration of sward, can be so great that resowing is necessary.

The phenomenon of urine scorches in grassland has been known for several years. Yet, little research has been done on this subject. Some results are available, mainly derived from other investigations.

In New Zealand Doak (1952) investigated some chemical changes in the nitrogenous constituents of urine when voided on pasture. Doak (1954) continued his work and reported the possibility that urine contains substances with phytotoxic properties. In England Richard & Wolton (1975) made observations on urine scorch on pastures grazed by animals and found a relationship between extent of scorch and grass N content. Furthermore the same scientists collected urine samples and measured N, K and Na contents, pH, specific gravity and osmotic potential (Richard & Wolton, 1976).

In the Netherlands Luten (pers. comm.) collected the results of observations in practice and literature. His report showed that there are more urine scorch problems with increasingly intensive grassland production.

In 1977 the Research and Advisory Institute for Cattle Husbandry in cooperation with the Agricultural Bureau of the Netherlands Fertilizer Industry started an investigation on causes and consequences of urine scorches at the experimental farm "de Olde Weije" at Vaassen.

Causes of urine scorch

Factors, which can cause urine scorches are:

- weather conditions and moisture content of the soil
- nitrogen fertilization
- animal influences
- time of the day
- chemical composition of the urine

These factors will be discussed in short in the following.

Weather conditions and moisture content of the soil

The frequency of the burned patches during the season from May until November is sometimes high and sometimes low (Figure 8).

![Figure 8. Frequency of urine scorches in 1978.](image)

The investigation during 3 years showed that urine scorch occurs if the soil is moist and the average 24 hours day temperature is approximately between 15° - 20°C.

When the growing conditions for the grass are good the subsequent urine scorch is usually large. If the temperature is too low (e.g. in autumn) or too high (e.g. some hot days in summer) there is no urine scorch.

Nitrogen fertilization

Patches with urine scorches were counted and measured after each grazing time on plots where amounts of 0, 150, 300 and 600 kg N per ha per year were applied. The plots were lying on peat soil with 20 to 25 % organic matter. The extent of scorching in % per year of the total area is given in Table 12.

Table 12. Nitrogen fertilization and urine scorch (in % of the total area).  

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>150</th>
<th>300</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>0.1</td>
<td>1.4</td>
<td>2.3</td>
<td>4.2</td>
</tr>
<tr>
<td>1978</td>
<td>0</td>
<td>1.4</td>
<td>1.6</td>
<td>4.9</td>
</tr>
<tr>
<td>1979</td>
<td>0.1</td>
<td>0.2</td>
<td>1.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>
It is clear that, in accordance with the literature, the higher the nitrogen fertilization the higher the urine scorch damage. This negative influence of nitrogen fertilization on urine scorching may be exerted in a direct way but partly also by the increasing number of grazing days with increasing rate of nitrogen fertilization and with increasing stocking rate.

Animal influences

Observations with 10 cows in 1977 and 1978 during 13 days, spread over the season, showed that any cow can cause urine scorching. However, there is a difference in the extent of the damage between the cows. The cause of this difference is not clear.

Time of the day

If the data from the daily observations of those 10 cows are collected and divided in approximately three similar parts during the day, the results show that the urinations during the first hours in the morning cause more damage than during the later hours of the day (Table 13). The percentage scorch is highest in the morning hours and also the degree of scorching is then more serious.

Table 13. Effect of time of day on urine scorching (data of 8 days).

<table>
<thead>
<tr>
<th>Time (h)</th>
<th>6.15-10.30</th>
<th>10.30-13.30</th>
<th>13.30-16.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of urinations</td>
<td>129</td>
<td>206</td>
<td>223</td>
</tr>
<tr>
<td>Patches with scorch (in %)</td>
<td>7%, 53%, 51%</td>
<td>7%, 53%, 51%</td>
<td></td>
</tr>
<tr>
<td>Scale of scorching (in %):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light scorch</td>
<td>39</td>
<td>33</td>
<td>31</td>
</tr>
<tr>
<td>Medium scorch</td>
<td>22</td>
<td>18</td>
<td>17</td>
</tr>
</tbody>
</table>

The chemical composition of the urine

In 1977 urine samples were taken from a number of cows. The samples were analysed for N, K, Na and pH and specific gravity. It appeared that the N and K contents of the urine in the first hours of the morning were higher than the urine of the later hours. These results agree with the higher scorching percentages of the morning urinations.

Consequences of urine scorch

Marked urine scorch developed in the months June, July and August 1977. The regrowth and botanical composition were estimated during that year and the following year. Patches with scorch developed in the months June and July filled in mainly in the same year. When the scorching originated from August or from autumn the regrowth was less in the same and more in the next year.

The regrowth on scorched patches consisted in the first place mainly of the grass Poa annua (more than 75 %) and partly of the weed species Stellaria media and Taraxacum spec. (sometimes Elytrigia repens invaded). Fifteen months after development, Lolium perenne increased to 25 %, but Poa annua was still the most important species (50 % to 60 %).

At this stage of the investigation it is clear that there is only limited practical solution to the problem of urine scorching. Further research seems necessary, especially fundamental research. In the Netherlands this fundamental work has started in 1979.

Fouling herbage cut for silage

In Ireland the effect of slurry on silage production and quality was studied over a number of years. In one experiment cattle slurry, pig slurry and chemical fertilizers were compared for quality and production of grass silage. There were a total of 30 plots of 0.4 hectares each with ten replicates for each treatment. Slurry plots received slurry at the rate of approximately 45 tonnes per hectare in early April, seven weeks before first cut silage, and again in late May or early June, seven weeks before second cut silage. Slurry plots received no fertilizer nitrogen.

The total grass yields for the two cuts for the three years, 1976 to 1978, are shown in Table 14. The average total annual nitrogen in cattle slurry and pig slurry and fertilizer was 297, 315 and 160 kg nitrogen per hectare, respectively.

Table 14. Grass silage yields, from two cuts, in tonnes dry matter per hectare.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cattle slurry</th>
<th>Pig slurry</th>
<th>Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>7.66</td>
<td>8.84</td>
<td>10.35</td>
</tr>
<tr>
<td>1977</td>
<td>5.49</td>
<td>7.24</td>
<td>8.12</td>
</tr>
<tr>
<td>1978</td>
<td>6.10</td>
<td>7.31</td>
<td>8.05</td>
</tr>
</tbody>
</table>

The mean total yield for the two cuts over the three years for cattle slurry, pig slurry and fertilizer was 6.42, 7.80 and 8.83 tonnes dry matter per hectare per annum respectively. These differences are statistically significant and indicate that on average the fertilizer treatment gave over 2 t DM/ha more than the cattle slurry treatment and about 1 t DM/ha more than the pig slurry treatment. Both first and second cut silages from the three treatments were fed to three groups of beef animals with an initial average liveweight of 425 kg. The silage was fed ad lib. and supplemented with 2 kg meals per animal per day.

The results of this experiment over the three years, 1976 to 1978, are summarized in Table 15.
The results in Table 15 show that the fertilizer treatment gave significantly better animal performance than cattle slurry for cut 1, cut 2 and also overall for cut 1 plus cut 2.

Silage analyses showed no significant difference between the three treatments. The lower animal performance on the slurry treatments may have been due to decreased silage intake. It was possible to see slurry fragments in the silage at harvesting.

In a study of the effects of manure on pasture on grazing animals, it was found that cattle slurry decreased intake and animal performance (Collins, 1980). There was also a change in the grazing pattern with animals spending more time grazing.

There is concern over risks of spreading disease with cattle slurry on grassland, and minimum intermediary guidelines have been proposed on storage time and rest period between spreading on pasture and subsequent grazing (Kelly, 1978).

**General considerations**

Cattle manure is not to be regarded as an onerous waste but as a valuable source of plant nutrients, of which full economic utilization is indispensable. The basis for a profitable utilization of manures is a reliable evaluation of the nutrient capacity. Therefore, it has been the first aim of this paper to improve data on nutrient production, nutrient content of manures and efficiency of manure nutrients as a prerequisite for a successful incorporation of manure nutrients into the fertilizing regime.

There is wide agreement on equivalence of phosphorus and potassium in manures and fertilizers, but this holds true only in regard to long-term application. The results of the experiments in the Netherlands show in accordance with those of van der Goes and Murphy (1974) that there can exist situations of phosphorus deficiency in which it may not be possible to reach optimum yields immediately by manure application.

From the long-term trials of Gumpenstein data on apparent nitrogen efficiency were obtained which may serve as a basis for planning a suitable fertilizing regime under Austrian conditions.

In relation to fertilizer-N the immediate (direct) efficiency of slurry-N was about 45% in the Gumpenstein trials, but this figure originates from long-term slurry application and includes some residual efficiency from slurry application in the preceding years. Hence, immediate efficiency of nitrogen of 1:0.5 diluted slurry (related to a growth period of 40 days) in comparison to fertilizer-N should be in the order of 35% (one third of total slurry-N). This figure should be used when it is intended to dress one cut with slurry (degree of dilution about 1:0.5) and additionally with fertilizer-N. The value of 35% agrees well with the average value of 38% of the split plot experiment in Ireland.

The annual apparent efficiency of slurry-N in the Gumpenstein trials was on average about 7 kg DM/kg N on mixed swards, dressed only with slurry (+PK), and about 11 kg DM/kg N on the plots dressed with slurry (+PK) + fertilizer-N. In relation to fertilizer-N the annual efficiency was 61 and 57%, respectively.

Basically the residual efficiency of slurry-N is positive but with spring application of slurry the residual efficiency of nitrogen is generally negative on mixed swards through suppression of legumes or reduction of rhizobium activity. Especially when slurry is applied during summer, residual efficiency should be considered in mineral nitrogen fertilization to the following cut by slight reduction of the dressings, when normally heavy dressings of nitrogen are applied.

The differences in apparent efficiency of slurry nitrogen depending on sward type or fertilizing regime are worthy of further consideration. When only slurry is applied, without fertilizer-N, absolute efficiency of slurry-N (expressed in kg DM/kg N) can be disappointing. This is shown clearly in the experiments 484 and 489 of Gumpenstein (Table 6; annual apparent efficiency of slurry-N 5.5 and 3.5 kg DM/kg N respectively). However, the efficiency of mineral nitrogen can be disappointing too under these circumstances, especially when only moderate amounts of fertilizer-N are applied. Dilz (1965) has shown that such disappointing results of moderate N-dressings are more normal than exceptional on mixed grass-legume swards.

In quantitative well-balanced combinations of slurry-and fertilizer-N the efficiency of one of the two components is usually satisfactory. It depends on the lay-out of the experiment or on the point of view which of the two components of the combination is responding good or bad. However, in practice slurry has generally to be spread on grassland, and therefore the small efficiency can be ascribed to the slurry component.

In spite of the moderate absolute efficiency of slurry-N on mixed swards (7 kg DM/kg N) the relative efficiency in comparison to fertilizer-N was surprisingly high in the Gumpenstein trials, namely 81% on average with 1:0.5 diluted slurry. Obviously slurry-N combines generally, but not always, better
with legume-N than does fertilizer-N, as can be seen for example in Figure 2. Therefore, high values of relative efficiency for slurry-N may be the consequence of high dilution rates, as they were used frequently in former time, and/or the result of the specific conditions on mixed swards.

The annual apparent efficiency of cattle slurry-N in the order of 57%, calculated from the results of the NPK-series of Gumpenstein, agrees well with the results of other workers. Gisiger (1961) evaluated nitrogen efficiency of cattle slurry at 55 and 62% (winter and summer slurry). Tietjen & Vetter (1972) found a usual range of 60 - 70 %. Käding & Kreil (1970) stated that on grassland on past annual efficiency of slurry-N was 9.6 - 12.1 kg DM/kg N or 60 - 65 %.

However, it is important to consider that the average values from Gumpenstein originate from long-term trials and the efficiency of nitrogen was increasing in these trials in the course of time by accumulated residual efficiencies. Therefore, the annual efficiency of nitrogen of 1 : 0.5 diluted cattle slurry without the residual efficiencies of the preceding slurry applications is in the order of 50% on intensively fertilized swards. That means, only about 50% of the applied slurry-N becomes available within one year.

In the long term a total of about 65% of the nitrogen of 1 : 0.5 diluted slurry should become available on intensively managed grassland swards. The remainder of about 35% (one third of total-N or two third of ammonia-N) is probably lost, mainly by ammonia volatilization.

Spreading cattle manure on grassland provides conditions favorable for the loss of ammonia by volatilization. The ammonia is soluble in the water in the slurry, but as the slurry dries out on the grass surface the ammonia is lost to the atmosphere. This frequently occurs when undiluted slurry is applied and the weather is dry and windy after slurry application. The economic loss associated with this is very high, particularly when it is considered that the ammonia is the most readily available nitrogen fraction in manure. There is urgent need for further research to reduce or eliminate the loss of ammonia from cattle manure on grassland. Laboratory studies at Johnstown Castle Research Centre show that ammonia volatilization can be reduced by reducing the pH of the slurry (Tunney, 1978).

Another possibility of reducing nitrogen losses by volatilization is dilution of slurry. Indeed, it does not seem encouraging to use this method according to the results from Gumpenstein. But, dilution may reduce also the danger of fouling herbage and thereby animal performance can be improved as it is shown by the Irish experiments. Thus, dilution of cattle slurry to a degree of about 1:1 should be taken into consideration, especially at dry and windy weather conditions and at minor distances to the fields.

The results of the experiments in the Netherlands show convincingly that cattle manure has properties which can impair nutrient efficiency and yield capacity of grassland. The results of the split plot experiment in Ireland seem to confirm these findings. Coating of grass by faces appears to be the main cause, but we can not yet exclude that chemical ingredients are involved occasionally, especially on mixed swards, because the roots of legumes seem to be more susceptible to detrimental effects of cattle manures than the grass roots (Kutschera-Mitter, 1974). It is not yet clear, which chemical ingredients of cattle manure are detrimental to the sward under particular circumstances, but there is some indication that application of cattle manure in late winter or early spring (during cold weather conditions) may be more detrimental than application at the other times of the year. Possibly, even greater amounts of ammonia may be detrimental under these circumstances. It may be of importance also that root growth of herbage plants can be inhibited by ethylene production in the soil when large amounts of slurry are applied to grassland (Kofoed, 1977).

Because of these detrimental properties of cattle manure and because of the danger of excessive potassium supply it is advisable to avoid large dressings or at least to split them when application is inevitable. It is wrong to supply a high requirement of P or N by large cattle manure dressings, because the increased nutrient supply may be cancelled by an increased effect of the negative properties of the manures.

The best nutrient response will certainly be obtained by skillful combinations of manures and fertilizers. Thereby, 25 m³ undiluted cattle slurry or equivalent amounts of diluted slurry per cut should not be surpassed (Schechtner, 1974). The maximum rates per year should be adapted to the potassium requirement of the sward, that is about 25 - 30 kg K₂O per t DM on cutting areas (Schechtner, 1977).

The danger of coating the sward and fouling the herbage, which seems to be in the fore with cattle manure according to the results obtained in the Netherlands and Ireland, can partly be reduced mechanically by mowing-harrows or by dilution of slurry. Experiments on the efficiency of newer methods to overcome these difficulties, like washing off the manures after application or ventilation the slurry, or injecting the slurry into the soil, are in progress.

The significance of injurious ingredients in the excreta of cattle is further elucidated by the study on urine scorching, but even in this special case it could not yet be clarified completely which constituents of urine are essentially responsible for the damage. Since urine scorching is increasing
with increasing application of nitrogen, this problem is becoming increasingly important. Further fundamental research may give practical solutions, but in the present situation short day pasturing or zero-grazing may help to overcome the problem.

Two negative aspects of cattle manure could not be stressed in this paper because they are too specific and the authors have too little experience on it: the danger of spreading disease and weeds with manures on grassland. It has been proved that these dangers exist and therefore preventive measures are advisable, such as applying manures, wherever practicable, not to grassland which is to be used for grazing or zero-grazing but to recycle it to areas producing silage or hay (Willinger, pers. comm.). The most efficient means to prevent spreading of weeds by manures is a good control of weeds in the field, but partial successes may be obtained also by a fairly long storage period of the manures (Rieder, 1966).

References


NITRATE CONTENT OF HERBAGE IN RELATION TO NITROGEN FERTILIZATION AND MANAGEMENT

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Summary

Information is presented which shows that chances for nitrate accumulation in herbage rise appreciably if nitrogen supply reaches or exceeds about 500 kg N ha\(^{-1}\) a\(^{-1}\).

In contrast to most literature on nitrate reduction, this paper presents circumstantial evidence that in a grass crop much nitrate is reduced in root and stubble rather than in the leaves as long as sufficient soluble carbohydrate is present. So:
- there is a good correlation between uptake and reduction without much interference from the nitrate already accumulated
- continuous high irradiance gives less accumulation, but short term changes in irradiance have little influence on nitrate content; perhaps soil temperature and water supply interfere
- a high temperature gives more nitrate, either by greater uptake or by less reduction because of short supply of carbohydrate in the roots
- great differences in nitrate content are found between species. Grasses with few large tillers contain more nitrate than grasses with many tillers and roots
- herbage of newly sown pastures has little stubble and root, and is rich in nitrate. In later cuts, stubble and root fraction is greater, and nitrate content of herbage is lower
- short cutting intervals give a greater yield of nitrogen with less nitrate accumulation than long intervals, apparently because tiller and root density is greater and the stubble greener
- defoliation results in high nitrate content of regrowth, presumably because root and stubble are deprived of soluble carbohydrate.

These results lead to the conclusion that with ample supply of nitrogen, nitrate accumulation can be kept low if cutting intervals are kept short and if profusely tillering species are used.

Introduction

Almost 20 years ago Van Burg (1962) reported that herbage production was not retarded by lack of nitrogen as long as nitrate contents of 0.3 to 0.6% \(\text{NO}_3\) (3 to 6 g \(\text{NO}_3\) per kg dry mass) were maintained. So a certain nitrate content seems to be necessary for maximum growth.

On the other hand Kemp et al. (1978) pointed out that 5 g \(\text{NO}_3\) per kg dry mass is the upper limit if no nitrate is permitted in milk and only 2-3% methaemoglobin of haemoglobin in blood. If 25% methaemoglobin is accepted as the upper limit then nitrate content must not be higher than 12.5 g kg\(^{-1}\) and lethal concentrations are as high as 25 g kg\(^{-1}\) for cows fed indoors with hay or other conserved roughages. Toxic levels seem to be somewhat higher for cattle grazing fresh grass. Little is yet known about the relationship between nitrate and carcinogenic nitrosamines.

However, it is well known that large amounts of nitrogen from chemical fertilizer and from slurry and manure are the main causes of high nitrate in herbage and forages. But with the same N supply to the crop a wide scatter of nitrate contents can be found. So other factors also influence nitrate content. Since these contents sometimes approach or exceed dangerous levels in the Netherlands, more information is required in order to keep nitrate contents within safe limits.

This paper presents some observations on these factors.

Incidence of nitrate accumulation

Nitrate accumulation rarely occurs with N supply up to 400 kg ha\(^{-1}\) a\(^{-1}\), either from the soil, industrial fertilizer or farm manures. Toxic levels in north-west Europe may only be reached with nitrate supplies of over 500 kg ha\(^{-1}\) a\(^{-1}\). An example is presented in Table 1 from trial PAW 970 (van Steenbergen, in preparation) which consisted of 24 experimental fields (9 on clay, 9 on sand and 6 on peat) over 10 years. Only the nitrate contents of herbage from plots treated with 500 kg N ha\(^{-1}\) a\(^{-1}\) are presented. Herbage with less N showed considerably less nitrate in dry matter.

Table 1 shows that on average about 13% of the samples showed nitrate contents reaching toxic levels. The majority were found in the first and second cut, presumably because of high N supply. There were great differences between years. First cuts of 1964 and 1965-1971 were high in nitrate but those of
Table 1. Relative incidence (%) of high nitrate contents in dry matter (> 12 g NO₃ kg⁻¹) from a series of cuts from trial PAW-970 with 500 kg N ha⁻¹ a⁻¹.

<table>
<thead>
<tr>
<th>Cut</th>
<th>N supply per cut (kg ha⁻¹)</th>
<th>Number of samples</th>
<th>Relative incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200</td>
<td>189</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>184</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>75</td>
<td>189</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
<td>166</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>155</td>
<td>4</td>
</tr>
<tr>
<td>All cuts</td>
<td>500</td>
<td>883</td>
<td>13</td>
</tr>
</tbody>
</table>

1965–1967 were low. These nitrate contents showed a small negative correlation with rainfall in winter. Also nitrate content of the second cut in 1966 and 1967 was rather low.

Young leaves are low in nitrate and old leaves generally contain more nitrate (Darwinkel, 1975). Nitrate contents of petioles, leaf sheaths and stems can be very high, as can be inferred also from a number of IBS trials in which herbage was cut in layers of 5 cm (Figure 1). The trend was always the same, with low nitrate contents in the top increasing towards the bottom. Slopes were steeper when average nitrate content was lower. This phenomenon is expected, since flow of nitrate into the leaves continues during their life span, whereas nitrate reductase declines very rapidly with age (Darwinkel, 1975). So the young top leaves are low in nitrate and older, bottom leaves higher. The conclusion from these data is that if ruminants graze from top to stubble in a rotational grazing system, danger of nitrate toxicity increases towards the end of the grazing period.

Nitrogen fertilization and reduction

Effect of supply and age

With increased nitrogen supply nitrate content rises whereas with age it declines. With a small supply nitrate content reaches a low peak quickly and declines soon and rapidly; with an ample supply a high peak is reached later and decline is slower. Figure 2 (after Prins & Van Burg, 1979) shows an example of this.

Figure 2. Effect of nitrogen application and age on nitrate (NO₃) content (g kg⁻¹) of herbage. Cutting and N-application on 2 June 1972 (Treatment IS3 of the Trial IB 1572 of Prins & Van Burg (1979)).

This decline with age is rather rapid in spring and summer, but may be slow or even non-existent in late autumn. Consequently it is not always helpful to take precautions against nitrate toxicity by delaying harvesting of the crop in autumn.

Dynamics of nitrogen assimilation

Since nitrate accumulation represents the difference between N uptake and reduction, it is necessary investigating the dynamics of dry matter production and of nitrogen uptake and reduction during regrowth. The example is again extracted from Trial IB 1572 of Prins & Van Burg (1979, Table 2).

Similar results were found in other treatments of this trial as in other trials, even when additional nitrate was supplied in later stages of regrowth. Table 2 shows that up to 9 kg N ha⁻¹ d⁻¹ can be absorbed from the soil during active growth and with abundant supply of nitrogen. In most published experiments maximum N uptake amounts to about 7 kg N ha⁻¹ d⁻¹ but in other parts of the same trial of
Table 2. Course of dry matter (DM) production and nitrogen assimilation of herbage dressed with 200 kg N ha⁻¹ on 12 May 1972 (treatment ES2).

<table>
<thead>
<tr>
<th>Time after cutting and N dressing (d)</th>
<th>Yield (kg ha⁻¹)</th>
<th>Rates of processes (kg ha⁻¹d⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DM</td>
<td>N</td>
</tr>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>580</td>
<td>32</td>
</tr>
<tr>
<td>24</td>
<td>1910</td>
<td>94</td>
</tr>
<tr>
<td>32</td>
<td>3580</td>
<td>144</td>
</tr>
<tr>
<td>39</td>
<td>5280</td>
<td>168</td>
</tr>
<tr>
<td>46</td>
<td>6200</td>
<td>177</td>
</tr>
<tr>
<td>59</td>
<td>6870</td>
<td>168</td>
</tr>
</tbody>
</table>

Prins and Van Burg, N uptake also exceeded the 7 kg N ha⁻¹d⁻¹ as in some trials of Darwinkel (1975). According to Table 2 the greater part of the nitrate was reduced and only about 1 kg NO₃-N ha⁻¹d⁻¹ accumulated. Later on, when N uptake declined, reduction decreased also, even when there was still sufficient nitrate in the herbage. Apparently this accumulated nitrate had been translocated to sites where nitrate could no longer be reduced (old leaves?). Only in a late stage of growth, when supply of nitrogen from the soil was almost exhausted, did the decrease become faster than uptake and accumulation declined. This decrease may have been due to some reduction of accumulated nitrate but it is more likely that nitrate was leached out of the dead material during rain. Rainfall was indeed extremely high between day 46 and 59.

Sites of reduction

The dynamics in Table 2 suggest a close relationship between nitrate uptake and reduction without much interference by the accumulated nitrate. Perhaps much nitrate reduction takes place in the same tissues as N uptake, the roots. However, the great activity of nitrate reductase in the leaves, especially at high irradiance suggests that most nitrate is reduced in the leaves (Viets & Hageman, 1971; Darwinkel, 1975). Similarly in maize (Dijkshoorn, 1971) in controlled conditions on water culture with nitrate, almost all nitrogen in the xylem sap was found in the form of nitrate. However, wheat seems to reduce more nitrate in the roots than maize grown hydroponically under controlled conditions.

Effect of environmental conditions

Irradiance

Darwinkel (1975), Viets & Hageman (1971) and many others have found large activity of nitrate reductase in leaves, especially in young ones. These enzymes are adaptive to nitrate, and enzyme activity is greatly stimulated by high irradiance. In this, irradiance may act directly (photochemically as in CO₂ reduction) and indirectly by energy supply through carbohydrate. The latter must be the system in the roots. Consequently it is generally found that nitrate content of herbage is low with high irradiance, both in tropical and temperate species (Table 3, Deinum 1976, unpublished data).

Table 3. Effect of irradiance on nitrate content of herbage of some grasses after 5 weeks of regrowth with ample supply of nitrogen and day and night temperature of 24 and 18°C, respectively.

<table>
<thead>
<tr>
<th>Irradiance J cm⁻²d⁻¹</th>
<th>Nitrate content in dry matter g kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lolium multi-florum</td>
</tr>
<tr>
<td></td>
<td>Brachiaria ruiziziensis</td>
</tr>
<tr>
<td></td>
<td>Setaria sphacelata</td>
</tr>
<tr>
<td>715</td>
<td>65.5</td>
</tr>
<tr>
<td>1515</td>
<td>39.9</td>
</tr>
<tr>
<td>3000</td>
<td>38.5</td>
</tr>
<tr>
<td>13.3</td>
<td></td>
</tr>
<tr>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>4.4</td>
<td></td>
</tr>
</tbody>
</table>

However, in most trials with different light intensities biomass production is so stimulated by high irradiance that nitrogen supply is not sufficient and the available amount is diluted over the larger yield causing very low nitrate and low protein contents. Only in a few trials, in which nitrogen supply was sufficient,
there was indeed a lower nitrate and a higher protein content (= reduced nitrate) with higher irradiance (Deinum, 1971).

Temperature

It has often been proved that it is difficult to detect true effects of temperature, because the effect of temperature on nitrate content is often masked by the release of nitrogen from the soil and by the dilution of the available nitrogen over the herbage produced. Alberda (1965) found a small positive effect of temperature on nitrate content in ryegrass on nutrient solution, as did Crijns (1979 unpublished data, Figure 3) in oats. Plants were grown hydroponically at 12 and 20°C. Figure 3 shows that at 20°C nitrate content of the shoot was higher and contents of organic N and soluble carbohydrate were lower. However, nitrate content of the roots (not shown) was higher at 12°C. As nitrate content is the difference between uptake and reduction, these data suggest that uptake in this trial was not affected much by temperature, but N reduction was less at higher temperature, possibly because of a short supply of carbohydrate as substrate in the roots. Some of Alberda's experiments (1965) show the same. Others with a higher content of soluble carbohydrate in the roots, show that the positive effect of temperature on nitrogen uptake seems to dominate over the negative effect on reduction.

Such temperature effects are also present in the field. So Sibma found a positive correlation between air temperature and nitrate content in the weekly cuttings of Trial CABO 47-1976 (Table 7). Similarly, highest nitrate contents were found in mid summer in the fields of a large grazing trial with a total application of 1000 kg N ha⁻¹ (Keuning, 1979, personal communication).

Water supply

Most trials show higher nitrate contents with dry conditions, since in moist treatments nitrogen supply was depleted and the nitrogen was diluted over a greater biomass. However in conditions of abundant nitrogen supply, Van Burg (1962) and Deinum (1966) found more nitrate in moist conditions. Then nitrate uptake is apparently more inhibited in dry conditions than is photosynthesis.

Fluctuations in irradiance

The relation between nitrate reductase in the leaves and irradiance has often suggested that nitrate content of herbage would be low after a bright day and high after a cloudy day. This suggestion has rarely been substantiated by the facts. The results of Trial CABO 47-1976 even sometimes indicate a positive correlation between irradiance and nitrate content. So other factors seem to be involved, including perhaps soil temperature and water supply.

For example, it is well known that nitrogen mineralization, nitrification and root functions are stimulated by higher soil temperature. High irradiance can increase temperature of the top layers of the soil much more in the short term than does air temperature. So, when much solar energy reaches the soil surface, soil temperature will rise appreciably and so will nitrogen supply to the roots. Solar energy also stimulates transpiration and, since a great part of the nitrate, enters the plant as mass flow, nitrate uptake may increase appreciably with higher irradiance. If also the role of nitrate reductase in the leaves has been over-emphasized in the past the sometimes positive correlation between irradiance and nitrate is explained. Similarly, a positive correlation between irradiance and nitrate may be found if high irradiance induces water shortage.

Yet the inverse relation between irradiance and nitrate content in the short term does exist (Deinum, 1965, unpublished data, Table 4). In this trial, soil temperature was not affected since the small swards of Lolium perenne (diam. 20 cm) were grown on bare soil in which the low irradiance was achieved with PVC cylinders 20 cm wide around the herbage. Only after 4 to 5 days significant effects of change in irradiance on nitrate content were found in this well fertilized grass. Content of water-soluble carbohydrate reacted sooner. This time lag of 4 to 5 days seems to be rather general, since it also takes 4 to 5
Effect of change of irradiance on content of nitrate (NO₃⁻) and water-soluble carbohydrate (wsc) both in g kg⁻¹ on successive days.

<table>
<thead>
<tr>
<th>Irradiance (J cm⁻² d⁻¹)</th>
<th>400 → 2000</th>
<th>2000 → 400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time after switch (d)</td>
<td>NO₃⁻ wsc</td>
<td>NO₃⁻ wsc</td>
</tr>
<tr>
<td>0</td>
<td>23.6 h</td>
<td>9.8 h</td>
</tr>
<tr>
<td>1</td>
<td>29.8 68</td>
<td>9.6 85</td>
</tr>
<tr>
<td>2</td>
<td>24.6 68</td>
<td>12.7 73</td>
</tr>
<tr>
<td>3</td>
<td>15.6 120</td>
<td>17.2 40</td>
</tr>
</tbody>
</table>

Table 3 showed some differences between species in nitrate content, with Lolium multiflorum being very rich in nitrate, whereas differences in yield were small. Wilman and Wright (1978) found more nitrate in L. multiflorum than in L. perenne, whereas Darwinkel (1975) detected higher nitrate in annual than in Italian ryegrass. Behaeghe and Carlier (1976) investigated several species and found that Festuca pratensis and L. multiflorum were richest in nitrate, followed in decreasing order by Phleum pratense and Dactylis glomerata, L. perenne hay type and pasture type.

Ranking on tiller density is generally opposite, strongly suggesting that profuse tiller formation (and root formation?) is negatively correlated with nitrate content of the herbage. Similarly, the B. caesia (Table 3) had a smaller root production than s. gracilis. Presumably there is always sufficient root activity for nitrate uptake, but not for nitrate reduction. Perhaps it is because of their smaller root and stubble system that the annual cereals normally contain more nitrate than the perennial grasses in an old sward.

Interspecific differences

Table 3 showed some differences between species in nitrate content, with Lolium multiflorum being very rich in nitrate, whereas differences in yield were small. Wilman and Wright (1978) found more nitrate in L. multiflorum than in L. perenne, whereas Darwinkel (1975) detected higher nitrate in annual than in Italian ryegrass. Behaeghe and Carlier (1976) investigated several species and found that Festuca pratensis and L. multiflorum were richest in nitrate, followed in decreasing order by Phleum pratense and Dactylis glomerata, L. perenne hay type and pasture type.

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Management aspects

Not only nitrogen supply and environmental factors are important for the nitrate content of herbage, but management aspects appear to be of significance too.

Reseeding

Herbage of newly sown pastures often has a high nitrate content with lethal effects to cattle. Darwinkel (1976) showed that these nitrate contents decline with later regrowth cycles, concomitant with a greater root and stubble system (Table 5).

Table 5. Nitrate content of herbage in relation to stubble and root weight on 5 consecutive cuts at intervals of 3 weeks for newly sown Lolium multiflorum grown in water culture with an ample supply of 8000 g N in 5-litre pots.

<table>
<thead>
<tr>
<th>Cut</th>
<th>Stubble + root per pot (g)</th>
<th>Ratio of stubble to root</th>
<th>NO₃⁻ content (g kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.31</td>
<td>1.49</td>
<td>73.5</td>
</tr>
<tr>
<td>2</td>
<td>7.63</td>
<td>1.32</td>
<td>56.2</td>
</tr>
<tr>
<td>3</td>
<td>9.99</td>
<td>1.26</td>
<td>54.9</td>
</tr>
<tr>
<td>4</td>
<td>15.04</td>
<td>0.92</td>
<td>41.4</td>
</tr>
<tr>
<td>5</td>
<td>17.81</td>
<td>0.91</td>
<td>37.2</td>
</tr>
</tbody>
</table>

Apparantly the young seedlings have a small root system that absorbs nitrate well but reduces little and translocates much to the herbage. In later cuts, the expanding root and stubble system may accommodate more nitrate and also reduce more into organic form. So again tiller density seems important for nitrate assimilation.

These results indicate that nitrogen supply to newly sown pastures should be moderate. Excessive applications of organic manures before ploughing, as often happens, followed by an abundant N dressing as a starter are very risky.

Cutting interval

Sibma extensively investigated the effect of cutting interval and nitrogen supply on herbage production and quality of which the complete results will be published elsewhere. Only some data will be mentioned here.

Cutting interval has a distinct effect on N assimilation (Table 6). Cutting intervals were 5, 7.5 and 10 weeks and the N supply of 600 kg ha⁻¹ was distributed equally over the successive cuts.

Table 6. Effect of cutting interval on yield of dry matter (DM) and of nitrogen and on nitrate content of the herbage with 600 kg N ha⁻¹ (Results from Trial IBS 11-70-1971).

<table>
<thead>
<tr>
<th>Cutting interval (weeks)</th>
<th>Total yield (DM) (kg ha⁻¹)</th>
<th>Total yield (N) (kg ha⁻¹)</th>
<th>NO₃⁻ (g kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>17.6 570</td>
<td>1.2 3.1</td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td>18.0 530</td>
<td>2.8 8.4</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>17.5 460</td>
<td>2.1 13.2</td>
<td></td>
</tr>
</tbody>
</table>

The 5-weeks cutting interval showed the highest N-yield and the smallest nitrate.
accumulation. Similar results were found in Trial CABO 167-1976. There cutting intervals were 1, 3, 5 and 7 weeks with several N applications. Again data are presented for 600 kg N ha⁻¹a⁻¹ (Table 7).

Table 7. Effect of cutting interval on yield of dry matter and of nitrogen and on nitrate content of herbage with N 600 kg N ha⁻¹a⁻¹ (Results from Trial CABO 167-1976).

<table>
<thead>
<tr>
<th>Cutting interval (weeks)</th>
<th>Total yield DM (t ha⁻¹)</th>
<th>N (kg ha⁻¹) 1st cut</th>
<th>Last cut</th>
<th>NO₃ (g kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.2</td>
<td>617</td>
<td>1.8</td>
<td>5.5</td>
</tr>
<tr>
<td>3</td>
<td>14.0</td>
<td>580</td>
<td>1.8</td>
<td>12.0</td>
</tr>
<tr>
<td>5</td>
<td>17.0</td>
<td>554</td>
<td>2.1</td>
<td>23.2</td>
</tr>
<tr>
<td>7</td>
<td>19.0</td>
<td>597</td>
<td>3.9</td>
<td>25.5</td>
</tr>
</tbody>
</table>

The phenomena were even more pronounced with N dressings of 800 and 1000 kg ha⁻¹a⁻¹. This table suggests that with short cutting intervals yield is low, but N-uptake is high and nitrate content is low. Secondly, in first cuts nitrate content is already somewhat higher after longer intervals, because of the greater stemness of the crop and not so much by the greater N application per cut, since a recent trial of Sibma showed that frequency of N application did not affect nitrate content.

Table 7 as well as Table 7 also show a great effect of cutting interval on nitrate accumulation in the last cut. This is certainly accompanied by effects on tiller density and on leafiness of the stubble. With short cutting intervals, number of tillers increases with more green tissue left in the stubble. So conditions for nitrate reduction seem good as nitrate content is low. However with long intervals the number of tillers declines and a bare stubble is left after cutting, and regrowth is slow. So here again, high nitrate content coincides with a small tiller density, like described in the paragraph on interspecific differences.

This unfavourable effect of long cutting interval is once again demonstrated in Trial CABO 167-1977 with delayed cutting treatments after two different pretreatments: half the trial was cut every two weeks until 11 July, giving 6 cuts and the other half was cut every 6 weeks giving only 2 cuts. Then on 11 July, after the 12-weeks conditioning period, cutting intervals of 2 and 6 weeks were initiated for the whole trial and the results are shown in Table 8.

Table 8. Effect of two pretreatments and of cutting interval after 11 July on rate of dry matter (DM) production and on nitrate content of herbage with 800 kg N ha⁻¹a⁻¹ (Trial CABO 167-1977).

<table>
<thead>
<tr>
<th>Cutting interval before 11 July (weeks)</th>
<th>Cutting interval after 11 July (weeks)</th>
<th>DM prod. (kg ha⁻¹a⁻¹)</th>
<th>NO₃ (g kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>25 July</td>
<td>5.7</td>
<td>10.3</td>
<td>74</td>
</tr>
<tr>
<td>8 Aug.</td>
<td>5.7</td>
<td>11.3</td>
<td>85</td>
</tr>
<tr>
<td>8 Aug.</td>
<td>8.7</td>
<td>17.4</td>
<td>85</td>
</tr>
<tr>
<td>22 Aug.</td>
<td>7.7</td>
<td>14.2</td>
<td>90</td>
</tr>
</tbody>
</table>

Each of these three sets of data (Tables 6-8) leads to the conclusion that, with long cutting intervals and high nitrogen dressing, nitrate content can become dangerously high, especially in autumn. So a management leading to an active and healthy stubble and root system seems beneficial for a good herbage production and nitrate reduction.

Discussion
Agronomic aspects of nitrate accumulation
The data from Table 7 clearly show that with a nitrogen dressing of 600 kg ha⁻¹a⁻¹, and an even distribution (20 kg ha⁻¹a⁻¹ for each cut with 7-week cutting interval and 150 kg ha⁻¹a⁻¹ for each cut with 7-weeks cutting interval) nitrate content was higher with 7-week than with 1-week interval and that accumulation increased regularly with season. By contrast Table 1 shows that with nitrogen distribution better adjusted to grass growth most accumulation occurred in spring and summer.

This leads to the following broad conclusions:
- With an even distribution of nitrogen over the season, the ratio of supply of nitrogen to yield is small in spring, but high in autumn and nitrate content is opposite as a consequence.
- With this even distribution and with different cutting intervals, leafiness of herbage is greater with short than with long intervals. Since leaves are normally low in nitrate and stems and old tissues high, accumulation will be greater with longer intervals. It may even happen that the annual leaf production is greater with the 1-week than with the 7-weeks cutting interval.
- In the Netherlands, common practice is to give large dressings in spring when grass growth is high. Later fertilisation is smaller when the grass grows less. So in fact ratio of N supply to yield should be rather constant. However in spring and summer, a stemmer crop is harvested, which
may be richer in nitrate as a consequence.

These broad conclusions may be refined by considering the physiological aspect of nitrate accumulation.

Physiological aspects

Many papers assume that nitrate reduction mainly takes place in the leaves because most nitrate reductase activity is found there. In most of these trials, plants were grown in controlled conditions and often hydroponically. However, the experimental results presented in this paper from grass crops in the field cannot be explained in this way as they show that:

1. Nitrogen uptake and nitrate reduction are well correlated (Table 2) which suggests that much nitrate may be reduced in root or stubble as well; and

2. That nitrate content of herbage is negatively correlated with tiller density (Tables 5-8) again indicating the importance of root or stubble for nitrate reduction.

If most of the nitrate of a grass crop is reduced in root and stubble, then it is also certain that this reduction is a respiratory process, at the expense of soluble carbohydrates. So if insufficient carbohydrate is translocated to root and stubble, as can easily happen in controlled environment, less nitrate is reduced there and more is translocated to aerial parts. The most severe deprivation of carbohydrate to the root and stubble occurs by defoliation. If this coincides with nitrogen fertilization like in rotational grazing or cutting, high nitrate contents are expected in the new regrowth. Alberda (1960) showed this already in defoliated herbage, whereas nitrate content hardly increased in the plant with leaves. Contents of soluble carbohydrate reacted comparably but in the opposite direction.

From these phenomena, it may be expected that no great nitrate accumulation will occur when carbohydrate supply to stubble and root remains sufficient through the whole growing season, even with an ample supply of nitrogen. This may be so with well controlled continuous grazing; tillering is profuse, herbage remains short and there is always sufficient green leaf with active photosynthesis (Deinum, 1979, unpublished data). Some preliminary observations of P.H. Shaw (North Wyke Exp. Sta, Okehampton, Devon, 1979, personal communication) suggest this already since he found only a slight increase in content of total N (nitrate was not measured) after N application to a continuously grazed sward.

Unfortunately, these aspects of nitrate accumulation and reduction in leaf, stubble and root of a grass crop in relation to tillering and rooting and to stubble formation have not yet been investigated and the suggestions presented are based only on circumstantial evidence. Proof of the relations awaits the conclusive results of experiments.

Some conclusions and recommendations

The results presented in this paper have shown different ways of preventing excessive nitrate accumulation:

- Chances for high nitrate content remain small with nitrogen dressing up to 400-500 kg ha\(^{-1}\) a\(^{-1}\), but greatly increase if supply exceeds this value on well managed swards.
- Nitrogen supply to newly sown pastures should be less than 400 kg N ha\(^{-1}\) a\(^{-1}\).
- Short cutting intervals that lead to high tiller density induce less nitrate accumulation.
- Profuse tillering grasses also show less accumulation.

Some farmers apply much more than 400-500 kg N ha\(^{-1}\) a\(^{-1}\), since they supply not only this amount of chemical fertilizer, but also large amounts of organic manure, urine and slurry. The result is not a greater grass production but a poor sward, especially when regrowth periods become long. Herbage on such swards may be rich in nitrate.

Such dangers can be prevented by careful management like short cutting and short grazing intervals, which give good sward quality and by proper use of farm manure and chemical fertilizer attuned to growth rate.

In such conditions, herbage of good quality and yield can be produced for a long time (Minderhoud et al., 1976).

References


PRODUCTION AND UTILIZATION OF ENERGY AND PROTEIN IN GRASS IN RELATION TO NITROGEN RATE, GREEN CROP FRACTIONATION AND DAIRY FEEDING SYSTEMS

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Centre for Agrobiological Research (CABO), Wageningen, the Netherlands

Summary

Results are given of experiments on the effect of nitrogen fertilization on the yield and quality of grass. Although large amounts of grass, rich in net energy for lactation, are necessary to meet the demands of high yielding dairy cows, the digestible crude protein content of intensively fertilized grass is always higher than required.

It is shown that fractionation offers the possibility to use at least a part of the excess protein as a food or feed component. Pressed forage, fed to dairy cows, proved to result in increased dry matter intake and in a better performance.

Calculations on the utilization of grass protein in different dairy feeding systems showed, depending on the productivity level of the animals, utilization efficiencies of 41-49% for grazing animals and 67-82% for cows fed on pressed grass.

Effect of nitrogen on herbage yield and quality

The numerous experiments on the effect of nitrogen fertilization on grass production show remarkable differences in response. Some results, representing two main trends, are shown in Fig. 1. The high-response curves (Reid, 1970, 1972; Sibma & Alberda, 1980) were obtained on perennial ryegrass leys on soils with a low N content, which explains the low yields on the zero N plots. The time-based
cutting system, used in these experiments, also led to reduced yields on the low N plots. The other two response curves (Van Steenbergen, 1977; Boxem, 1973) correspond to experiments on permanent pastures, more or less under farm management. The sites included N-rich soils as well as sandy soils; some swards contained small amounts of white clover in the zero N fields. Here, the cutting system was based on dry matter (DM) yield, leading to more cuts per year as a result of increasing amounts of fertilizer N. Thus the relatively high DM yields on the zero N plots and the smaller influence of fertilizer N on production may become clear.

One of the reasons for the difference in yield response to N at high fertilizer N-levels (> 300 N) may be the fact that the low-response curves are averaged over years and soil types. The line of Sibma and Alberda represents a series of field experiments in the new polders on a high quality clay soil with ample water supply. The data of Boxem are averages over 3 experiments (peat, clay and sand) and 8 years. The plots were mainly grazed with the exception of 1 or 2 cuts per year for hay or silage. The N-response curve of Van Steenbergen is the average result of 24 experiments, including 8 soil and vegetation types, carried out over a period of 10 years (1964-1973).

Since most of the grasslands in the Netherlands are permanent pastures, the N-response curves of Boxem and Van Steenbergen can be considered representative for farming practice in the Netherlands. Because the results of Van Steenbergen's experiments play an important part in this paper a short description is given. More detailed information on the selection of the sites and the experimental procedure is given by De Boer (1966).

The 8 soil and vegetation types were located on peat, clay-on-peat and on sandy soils with respectively 2, 3 and 3 drainage or moisture-supply levels as indicated by the vegetation. Old permanent pastures with a good management status were selected. Each experiment was divided into 5 blocks with 6 levels of N application each. Every year another block was used for the yield measurements and the 4 remaining blocks, on which the N levels were maintained, were managed by the farmer. This was done to prevent swards from degrading by continuous mowing. Phosphate and potassium were applied according to soil analyses. The N-application scheme is presented in Table 1.

In this system the main part of the nitrogen dressing was given in spring and early summer to utilize the high production potential in this period. In years of rapid growth it was possible to obtain one or two extra cuts. In these years additional applications of 0, 10, 15, 20, 25 and 30 kg N per ha were given to the 6 nitrogen levels, respectively. At all N

<table>
<thead>
<tr>
<th>Nitrogen kg/ha</th>
<th>Cut number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>200</td>
<td>80</td>
</tr>
<tr>
<td>300</td>
<td>120</td>
</tr>
<tr>
<td>400</td>
<td>160</td>
</tr>
<tr>
<td>500</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 1. Distribution of N fertilization over the growing season (Van Steenbergen, 1977).

levels the first cut was taken at a DM yield of approximately 4000 kg per ha (hay stage), the following cuts were harvested at grazing stage (1500-2000 kg DM/ha). An exception was the fourth harvest of the 3 highest N levels, which was taken at a silage stage of approximately 3000 kg per ha.

The main results of these experiments are summarized in Table 2.

Table 2. Effect of rate of N application on annual herbage yield and quality of permanent grassland.

<table>
<thead>
<tr>
<th>Nitrogen kg/ha</th>
<th>Yield (t/ha)</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FW(^1)</td>
<td>DM (^1)</td>
</tr>
<tr>
<td>0</td>
<td>52</td>
<td>8.8</td>
</tr>
<tr>
<td>108</td>
<td>63</td>
<td>10.4</td>
</tr>
<tr>
<td>218</td>
<td>74</td>
<td>11.4</td>
</tr>
<tr>
<td>323</td>
<td>83</td>
<td>12.6</td>
</tr>
<tr>
<td>411</td>
<td>87</td>
<td>12.8</td>
</tr>
<tr>
<td>518</td>
<td>91</td>
<td>13.1</td>
</tr>
</tbody>
</table>

\(^1\)FW = Fresh weight
\(^2\)DM = Dry matter in g/kg
\(^3\)CP = Crude protein in g/kg DM
\(^4\)NEL = Net energy for lactation in VEM/kg DM

There were considerable differences in yield between soil types and years. However, the shape of the different N-response curves was essentially the same, and therefore the average values are used in this paper. Table 2 and Fig. 1 show an almost linear increase in DM yield with N rates increasing to about 300 kg. Higher N applications only resulted in a yield increment of 2-3 kg DM per extra kg N applied.

However, the CP yield and content showed a considerable response even up to the highest N level. The benefit of the high CP content is doubtful. A CP content of 160 g/kg grass DM is sufficient to meet the requirement of a high-yielding cow. This level is almost attained without fertilizer N at all (Table 2). It should be noted that there is a large vari-
ation in CP content over the season and over soil types. As an example the frequency distribution at 2 N levels and 2 stages of growth is presented in Fig. 2.

The influence of the N rate on this ratio is shown in Fig. 3 in comparison with the values required by lactating cows. It clearly shows the occurrence of a protein surplus.

Fig. 2. Influence of N rate and stage of growth on the frequency distribution of crude protein in grass.
A = hay and silage stage ≥ 2.5 t DM/ha
B = grazing stage: < 2.5 t DM/ha
n = number of samples.

Fig. 3. Influence of N rate on the NEL/DCP ratio in grass. The ratios required by grazing cows at different levels of milk production are indicated by the dotted lines. NEL in VEM/kg DM; DCP in g/kg DM.
- - - data from Table 2
x-x data from Wieringa, 1978 (cutting interval 4 weeks).

It is of interest to consider the moisture and nitrate contents of fertilized grass. Heavy applications of N decreased the DM content of the grass (Table 2) and increased the level of nitrate (Table 3). Although data on critical DM levels are scanty, there are strong indications that a low DM content decreases DM intake by cattle and sheep (Sevenster, unpublished data, CABO, 1971).

### Table 3. Influence of N rate on the nitrate content of grass (Van Steenbergen, pers. comm.)

<table>
<thead>
<tr>
<th>N rate kg/ha</th>
<th>Number of samples</th>
<th>Percentage of samples with NO₃⁻&lt; 7.5</th>
<th>7.6-15</th>
<th>&gt; 15 g/kg DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>732</td>
<td>100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>100</td>
<td>818</td>
<td>100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>200</td>
<td>878</td>
<td>99</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>300</td>
<td>867</td>
<td>95</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>400</td>
<td>879</td>
<td>84</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>500</td>
<td>799</td>
<td>66</td>
<td>27</td>
<td>7</td>
</tr>
</tbody>
</table>

According to Kemp and Geurink (pers. comm.) nitrate (NO₃⁻) levels in fresh and in preserved grass should not exceed 15 and 7.5 g/kg DM, respectively, in order to avoid the ill effects of nitrate poisoning. From the figures in Table 3 relating to 7 of the 10 years of the 24 fertilizer experiments, it can be con-
cluded that critical levels of nitrate only occur at high fertilizer-N applications. A further analysis of the data shows that the occurrence of a high nitrate content is strongly related to a high CP content (Van der Meer and Van Steenbergen, in preparation).

The fractionation of grass and the utilization of pressed grass

The fractionation of herbage, by cell rupture and subsequent compression, into a protein-rich juice and a fibre enriched pressed residue, is a process described already in 1773 by Rouelle. Since the second world war the pioneer work of Pirie (1971) initiated research on protein extraction in many parts of the world. More detailed information can be found in the proceedings of a recent symposium (Wilkins, 1977). The knowledge to construct efficient extraction machinery is available. The protein (either directly or after coagulation) can be used as a feed or food component, and the pressed crop can be used as a feed for ruminants. Much more work has been done on the protein fraction (= juice fraction) than on the pressed crop fraction. Therefore, experiments were carried out on the process of fractionation and on the utilization of pressed grass by dairy cows.

Fractionation experiments

Laboratory fractionations were carried out on the subsequent cuts of a N-rate and cutting frequency experiment on permanent grassland (Wieringa, 1978). Annual N applications of 200, 400, 600 and 800 kg/ha and cutting intervals of 2, 4 and 6 weeks resulted in grass yields widely ranging in quantity and quality. DM yields of 5-12 t/ha and CP yields of 1-3 t/ha were found. The yields obtained with the 4 and 6 week cutting intervals were in good agreement with average yields from the permanent pastures of Van Steenbergen (1977). Fig. 4 shows the influence of cutting frequency and N-rate on NEL and DCP content of the annual yields.

Shorter cutting intervals resulted in increased NEL values and even more increased DCP contents. The fertilizer N-rate had a much more pronounced effect on the DCP than on the NEL level. The NEL/DCP ratios of the 4-week cutting interval are also plotted in Fig. 3 to show the similarity in quality to the results of Van Steenbergen (1977).

All the samples were submitted to a standard laboratory-scale fractionation. In spite of the great variation in quality characteristics, grass DM content appeared to be the predominant factor determining the DM extraction ratio ($E_{DM}$). This is in agreement with literature (Heath and King, in Wilkins, 1977), but other factors may play a part also (Wieringa, 1978). Fig. 5 shows $E_{DM}$ values from 0.12-0.30. This means that 12 to 30% of the crop DM yield can be obtained in the juice fraction dependent on grass DM content. Irrespective of grass DM however, a fairly constant amount of about 30 g of juice DM was extracted per kg fresh grass.

Fig. 4. Effect of N rate and cutting interval on the average NEL and DCP content of grass. N rate in kg/ha: □ 200; x 400; o 600; △ 800. Cutting intervals: --- 2 weeks; -.- 4 weeks; —— 6 weeks.

Fig. 5. Influence of dry matter content on the extraction ratio of water, dry matter and crude protein from fresh grass.

$E_{DM} = \frac{\text{juice DM yield}}{\text{grass DM yield}}$, $E_{CP} = \frac{\text{juice CP yield}}{\text{grass CP yield}}$, $E_{W} = \frac{\text{juice water yield}}{\text{grass water yield}}$. 
From Fig. 5 it is clear that the chemical composition of the juice DM depends on grass DM content as well as on grass DM composition:

\[
CP_{\text{juice}} = \frac{CP_{\text{grass}} \times E_{CP}}{E_{DM}} \quad \text{(in g/kg juice DM)}.
\]

It can be calculated from the lines in Fig. 5 that the juice CP content is from 1.25 to 1.65 times higher than the CP content of the grass from which it was produced. The more-soluble compounds, like sugars, ash and nitrate with E-values almost as high as Ey are being concentrated in the juice DM by a factor 2 or even more.

The chemical composition of the pressed forage can be calculated in the same way. The crude fibre (CF) which is non-extractable will increase by a factor 1.11-1.33, the CP will be lowered by a factor 0.75-0.97 and the water soluble compounds by a factor 0.50-0.75 dependent on grass DM content.

Feeding experiments with pressed grass

Pressing grass modifies chemical composition and also structure. Both factors may influence voluntary intake and rumen function. Therefore feeding trials were carried out to measure ad lib intake, eating behaviour and production of dairy cows fed pressed grass. Three crossover experiments with 2 groups of 3 animals each were carried out to compare the feeding of fresh grass with that of fresh pressed grass from the same origin. Grass quality was fairly constant in these experiments; nitrogen was applied at 80 to 100 kg N/ha per cut (depending on time of the year) and the cutting interval was 4 weeks. Fractionation of grass was carried out three times a week with a Bentall screw press fitted with a conical grass outlet. The roughage was stored anaerobically in plastic bags at 5-10 °C. Details of these experiments will be published elsewhere.

In the experiments where fresh grass was compared with pressed grass, OM intake was higher on pressed grass. Results of one experiment are given in Fig. 6. The NEL value of the pressed grass was almost equal to that of the whole crop and therefore the NEL intake of the animals receiving pressed grass was always higher. During the first period of 6 weeks the coverage of the NEL requirement was 94% and 80% for the groups receiving pressed grass and whole grass, respectively. This resulted in corresponding decreases in milk yield. After the cross-over the NEL coverages were 100% for the whole grass group and 107% for the group fed pressed grass. During the whole experiment DCP coverages were above 100% (see below). Consequently NEL intake determined milk production, which was higher in the pressed grass group in both periods (Fig. 7).

During the experiment the differences in intake between treatments became smaller and there was a tendency to a gradual increase of intake. The same was observed during the other two feeding trials. Although the experiments were not completely comparable, OM intake (especially of fresh grass) was low in
May and June whereas the intake by both groups was satisfactory in July and August. There are two possible reasons for a higher OM intake in the pressed grass treatment: firstly it had a lower moisture content and secondly it was less bulky than whole grass. In both years the early-season grass had a low to very low DM content (140-100 g/kg) and the animals on whole grass did not need drinking water. Because the pressed crop was less bulky it could be ingested at a rate of 18 min/kg DM compared with 24 min/kg DM for whole grass. Ruminating times were in both cases equal (33 min/kg DM). During the experiment rumen function was followed in two fistulated cows. No significant differences in pH or in fermentation pattern were found.

The through-put and the efficiency of the screw press, used in these experiments, were below expectation and much lower than would have been possible with a pulper and belt-press. Consequently the average E$_{DM}$ of 0.14 and E$_{DP}$ of 0.20 were below the values shown in Fig. 5. Throughout the experiment the CP content of the pressed grass was very close to the CP content of the whole grass. For this reason and due to the higher OM intake by the pressed grass group the CP intake by this group was higher than that of the whole grass treatment. Nevertheless in all experiments the ratio NEL/DCP of the pressed grass was higher than of the original crop. Moreover, the lacerating effect of the screw press was comparable to that of other extraction machines, so that it seemed warranted to consider the results to be representative.

The utilization of protein and energy from grass in different feeding systems with milking cows

According to Kemp et al. (1979) calculations were made to compare DCP and NEL utilization from pressed grass feeding with grazing and zero grazing. For reasons of simplicity data from Table 3 on yield and quality of grass, fertilized with 400 kg N/ha, are used. Differences in grass yield - as shown in Table 4 - were introduced to account for differences in stage of growth of grass used in grazing and zero grazing. Due to the fact that stage of growth influences DCP and NEL content of the grass the DCP and NEL yields had to be corrected. Losses of 25% for (rotational) grazing and 5% for zero grazing were estimated and resulted in the net yields listed in Table 4. Data on pressed grass are based on a retention of 65% of the CP and 78% of the DM in the pressed grass. Estimates of the NEL values of pressed grass and juice were based on the assumption that the digestibility of the fraction was equal to that of the whole crop.

For the calculation of the utilization of grass by dairy cows annual milk production levels of 6000, 5000 and 4000 kg were chosen (level A, B and C, respectively in Table 5).

According to Doeksen and Heyboer (1952) February-calving cows produce 2/3 of the annual yield during the grazing season of 184 days, resulting in average daily milk yields of 21.7, 17.9 and 14.1 kg. NEL and DCP requirements for these production levels were calculated according to the standards for cows of 550 kg (CVB tables, 1979).

<table>
<thead>
<tr>
<th>System</th>
<th>DM</th>
<th>NEL</th>
<th>DCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grazing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>grass</td>
<td>11.5</td>
<td>11.2</td>
<td>2.02</td>
</tr>
<tr>
<td>net</td>
<td>8.6</td>
<td>8.4</td>
<td>1.52</td>
</tr>
<tr>
<td>Zero grazing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>grass</td>
<td>12.8</td>
<td>12.2</td>
<td>2.06</td>
</tr>
<tr>
<td>net</td>
<td>11.6</td>
<td>11.1</td>
<td>1.96</td>
</tr>
<tr>
<td>Fractionation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-pressed grass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gross</td>
<td>10.0</td>
<td>9.5</td>
<td>1.34</td>
</tr>
<tr>
<td>net</td>
<td>9.5</td>
<td>9.0</td>
<td>1.27</td>
</tr>
<tr>
<td>-juice</td>
<td>2.8</td>
<td>2.7</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Table 4. Annual gross and net yields of grass, fertilized with 400 kg N/ha, at different feeding systems. Between brackets NEL and DCP contents.

According to CVB 20% increase in NEL requirement for maintenance was accepted for grazing animals. Ad lib DM intakes were estimates, derived from different sources (Luten et al., 1978; Boxem, 1979; Hijink, 1979 and Meys, 1979).

Table 5 shows that under grazing conditions the NEL intake of high yielding dairy cows (level A) is 0.9 kVEM below requirement (= 94% coverage), and it will be clear that in this case the NEL utilization cannot exceed 75% (of gross grass NEL production), due to the accepted grazing losses. In contrast to the NEL shortage the DCP intake of the high yielding grazing cow is 52% higher than requirement, and the utilization is only 49%. With decreasing milk yields (levels B and C) the NEL coverage increased to slightly above 100%, whereas the overconsumption of DCP further increased and the DCP utilization decreased to 41%.

The NEL coverage of an ad lib fed zero grazing animal compares to that of the grazing cow. The overconsumption of DCP is considerable, although slightly lower than with grazing. This is due to the lower DM intake of the stall-fed animal and the lower DCP content of the grass used for zero grazing. The improved utilization of NEL and DCP is mainly caused by the accepted lower losses: 5% feed residues instead of the 25% grazing losses.

Compared to ad lib zero grazing the higher DM intake of pressed grass resulted in a
Table 5. Comparison of the utilization of grass energy and protein in different feeding systems.

<table>
<thead>
<tr>
<th>Feeding system</th>
<th>Level</th>
<th>Intake</th>
<th>Requirement</th>
<th>Balance</th>
<th>Coverage</th>
<th>Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DM kg</td>
<td>NEL kVEM kg</td>
<td>DCP kg</td>
<td>NEL kg</td>
<td>DCP kg</td>
</tr>
<tr>
<td>Grazing</td>
<td>A</td>
<td>15.00</td>
<td>14.6</td>
<td>2.64</td>
<td>15.5</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>14.00</td>
<td>13.7</td>
<td>2.46</td>
<td>13.7</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>13.25</td>
<td>12.9</td>
<td>2.33</td>
<td>12.0</td>
<td>1.26</td>
</tr>
<tr>
<td>Zero grazing</td>
<td>A</td>
<td>14.00</td>
<td>13.3</td>
<td>2.25</td>
<td>14.6</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>13.25</td>
<td>12.6</td>
<td>2.13</td>
<td>12.8</td>
<td>1.50</td>
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<tr>
<td></td>
<td>C</td>
<td>12.75</td>
<td>12.2</td>
<td>2.05</td>
<td>11.0</td>
<td>1.26</td>
</tr>
<tr>
<td>Pressed grass</td>
<td>A</td>
<td>15.00</td>
<td>14.3</td>
<td>2.01</td>
<td>14.6</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>14.00</td>
<td>13.3</td>
<td>1.88</td>
<td>12.8</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>13.25</td>
<td>12.6</td>
<td>1.78</td>
<td>11.0</td>
<td>1.26</td>
</tr>
<tr>
<td>Pressed grass</td>
<td>A</td>
<td>13.00</td>
<td>12.3</td>
<td>1.74</td>
<td>14.6</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>11.20</td>
<td>10.6</td>
<td>1.50</td>
<td>12.8</td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>9.40</td>
<td>8.9</td>
<td>1.26</td>
<td>11.0</td>
<td>1.26</td>
</tr>
</tbody>
</table>

1Limited: intake (from grass) limited to DCP requirement
2Level: annual milk production A: 6000 kg; B: 5000 kg; C: 4000 kg
3Balance: intake (from grass) minus requirement
4Coverage: intake (from grass) in per cent of requirement
5Utilization: net production (from grass) minus luxury consumption in per cent of gross production

Higher NEL intake. According to the calculation low yielding cows showed an overconsumption of 15%, which may result in a weight gain. Because the DCP content of pressed grass is lowered by extraction, the overconsumption of protein was reduced in comparison to zero grazing. However, the DCP coverage was still above 100% and therefore utilization is below the attainable 95%.

A further improvement of DCP utilization could be obtained by the introduction of energy-rich fodders or concentrates in the ration. Calculations on limited intake of grass and pressed grass were included in Table 5. In both cases the roughage intake was restricted just to meet the DCP requirement of the different milk yield levels. As a consequence, NEL and DCP utilization will reach the maximum attainable value of 95%.

The DCP coverage - by definition - will be 100% and the NEL shortage has to be compensated for. Dependent on milk yield there is a considerable energy shortage in the limited zero grazing system. Theoretically 3.6-4.3 kg of concentrates (with a NEL value of 1000 VEM/ kg DM) could meet the demand. In practice however, the protein content of the concentrate would compel a further reduction of grass intake, at least when overconsumption of protein has to be avoided. In comparison to limited zero grazing the limited feeding of pressed grass offers better possibilities.

Roughage DM intake has to be restricted to a much smaller extent and the NEL shortage, ranging from 2.1-2.3 kVEM, can easily be compensated.

It is of interest to keep in mind that in using a system of restricted feeding of pressed grass, there is on the one hand a shortage of NEL while on the other hand a comparable amount of NEL is present in the juice fraction. Here, in fact, the protein rich juice has to be substituted by forages or concentrates with a low protein content.

General discussion

During the last 20-30 years grassland and dairy husbandry in the Netherlands showed a considerable development. The gross grass yields increased by the increased use of nitrogenous fertilizers. Connected herewith the contents of NEL and especially of DCP increased, resulting in a lower ratio NEL/DCP (Table 2 and Fig. 3). It should be realized that the data shown are averages over years and soil types and that a considerable variation in quality occurs between the individual cuts during the season as well as between sites. Furthermore this intensification led to an increased grazing density which resulted in in-
Houseman et al. (1975) reported a slight decrease of the whole crop. In spite of this difference in digestibility between cell walls and cell compressed grass. Regarding the difference in energy caused by saving energy on chewing and a decreased intake which was more than compensated by milk production to such an extent that the capacity of the digestive system is becoming the limiting factor. Therefore, herbage of a high digestibility is needed to fulfill the NEL requirement of a high yielding cow. Without doubt there is a positive correlation between grass quality and intake of DM and NEL by the animal. The question raised here is if intensively grown grass - to extremes - is advantageous for DM intake. There are indications that the high moisture content found in heavily fertilized grass may hamper DM intake. The necessity of avoiding high nitrate levels in grass is beyond dispute (Table 3). But even avoiding the extremes, the DCP content of the grass is higher than required for the high yielding cow. This may become clear by comparing the required NEL/DCP ratios with the ratios occurring in grass (Fig. 3).

Fractionation of grass, yielding 30-35% of the total grass protein as juice, always leads to a decrease of the DCP content of the pressed forage. However, owing to the fact that not only protein but also energy is extracted, the change of the NEL/DCP ratio in the pressed grass is smaller than desirable. A more efficient machinery, with a higher extraction ratio, could lead to a further increase of the NEL/DCP; but even then it will be difficult to produce a pressed grass with a NEL/DCP ratio of 8.5-9 starting from grass with a ratio below 6. Moreover, there are indications that the structure of protein-rich grass and the viscosity of the juice from such grass hamper the extraction.

Pressing of grass appeared to improve OM intake by milking cows in our experiments, but in literature there is no unanimity on this point. Pirie (1971) found a higher intake of pressed forage, whereas Trigg and Bryant (1978) found the opposite. They also found a considerable drop in digestibility of the pressed forage which could be due to selfheating of this very susceptible material. Houseman et al. (1975) reported a slightly decreased intake which was more than compensated by the better digestibility of the pressed grass. Regarding the difference in digestibility between cell walls and cell contents the digestibility of the pressed forage can be expected to be 1-2% lower than that of the whole crop. In spite of this difference the better performance of the animals may be caused by saving energy on chewing and a more efficient fermentation of the crushed forage. Our observations on eating time and ruminating behaviour point in this direction and are in good agreement with Deswysen et al. (1978). The structure, or roughage value, of the pressed forage did not cause any problems so far. The low content of readily fermentable carbohydrates in pressed forage and the increased cellulose content are in favour of a cellulosic rumen flora and will prevent an unwanted lactic acid fermentation.

Approximately 2/3 of the total grass yield in the Netherlands is utilized by grazing ruminants. Grazing losses constitute an important part of the total losses in the conversion of grass to milk and meat. Therefore, pressed grass feeding can best be compared to zero grazing. In the sequence grazing, zero grazing, pressed grass feeding (Table 5) there is not only a gradual decrease in overconsumption of DCP for all milk yield levels, but there is also a striking difference in energy supply in favour of pressed grass. This makes the feeding of pressed grass attractive, especially to high-yielding cows. It should be born in mind that the data from Table 5 were calculated from average daily milk yields and an average grass composition. However, both show a considerable seasonal variation. This means that in a part of the grazing season (e.g. autumn) the overconsumption of protein certainly will exceed the calculated values. It should be mentioned too that the February-calving cows utilize grass protein much more efficiently than autumn-calving and growing animals.

The average daily overconsumption of about 1 kg protein per cow plus the grazing losses total to an annual DCP loss of between 300 and 400 kg per grazing animal. Kemp et al. (1979) already mentioned the influence of excessive amounts of recycling N on scorching and sward deterioration. This and the increasing shortage of fossil energy require a more efficient use of nitrogen and of the total grass yield in future. Supplementing grass with fodders and concentrates with high NEL and low DCP contents improves the utilization efficiency of grass protein. Fractionation is another possibility to improve this efficiency and offers the option of using herbage partly as a protein crop. The feasibility of this process greatly depends on a market for the protein concentrate as a feed or food component. More efficient fractionation machinery has to be developed and more research will be needed on the application of grass fractionation in a farming system.

Literature


FORMATION OF VOLATILE N-NITROSAMINES DURING THE FERMENTATION OF GRASS SILAGES

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Centre for Agrobiological Research (CABO), Wageningen, the Netherlands

Summary

The formation of volatile N-nitrosamines during the fermentation of grass silages was investigated. The silages were prepared from pre-wilted grass cuttings with different nitrate contents. No nitrosamine formation was found in silages with dry matter contents ranging from 500-600 g DM/kg. In silages with about 300 g DM/kg dimethylnitrosamine was detected at levels ranging from 0-5 ug/kg.

Introduction

Since Magee and Barnes (1956) established that nitrosamines are carcinogenic, many investigations have been made into their occurrence in the environment. It was found that nitrosamines are widespread, and in quantities of the order of µg/kg of the sampled materials.

Nitrosamines may be formed by the reaction between a secondary amine and nitrite. Then an acidic medium is required, but they may also be formed at a higher pH through microbial activity (Archer et al., 1978), and also in alkaline solution by the action of nitrogen oxides (Challis et al., 1978).

Research in this Institute concerns the presence and conditions for the formation of nitrosamines in the agricultural environment. It seems likely that the fermentation of grass silages may create conditions suitable for the formation of nitrosamines. The grass may contain much nitrate owing to the heavy dressings of nitrogen occasionally applied to grassland (Kemp et al., 1978). Depending on the silage conditions, during the fermentation process part of the nitrate may be reduced to nitrite and finally to ammonia. Because the pH is low nitrogen oxides may develop as well. This, together with the formation of amines during the degradation of the nitrogenous constituents of the grass (Edwards and McDonald, 1978), would render conditions favourable for the formation of nitrosamines.

Juszkiewicz and Kowalski (1974) have shown in goats that ingested nitrosamines pass from the rumen into the blood and milk. Similarly, nitrosamines present in silage ingested by cows are likely to move into the blood and the milk.

Tate and Alexander (1975) attempted to demonstrate the formation of nitrosamines in maize silages prepared in the laboratory. They found none, even when the precursors dimethyamine and nitrite (100 mg/kg each) were added in advance. Terplan et al. (1978) found diethyl Nitrosamine (3-24 µg/kg) and dipropyl Nitrosamine (3-33 µg/kg) in some silages prepared from turnip leaves, maize or grass. Unfortunately, ensiling conditions of the positive samples were not specified.

In the Netherlands the use of silage continues to increase. Grass is the dominant crop ensiled and there is a preference for wilting to about 500 g DM/kg.

In the present work silage fermentation was simulated in closed glass jars filled with grass samples which differed in initial nitrate and, after pre-wilting, in dry matter content.

Materials and methods

The grass was taken at the end of May from plots on a permanent grassland which had been dressed two months previously at rates of 0, 40, 80, 120 and 160 kg N/ha. In this way herbage with different concentrations of nitrate could be obtained.

The grass was pre-wilted in the field to obtain materials with 300, 400, 500 and 600 g DM/kg respectively.

Silages were produced on laboratory scale in glass preserving jars of 2 l. The pre-wilted grass was mixed, chopped and tightly squeezed into the jars. The jars were hermetically closed and stored in the dark at 30°C (Wieringa, 1958). Separate sets of jars were removed for analysis after 10, 20, 60, 100, 140 and 200 days of fermentation. The jars were opened and the contents stored in plastic bags at -20°C for analysis.

Chemicals of analytical grade were used without further purification. The dichloromethane (DCM) (Baker) was distilled before use.

Nitrate was determined with an ion-specific nitrate electrode (Orion 93-07), a double junction reference electrode (Orion 90-02), and a pH meter (Orion, 801 A). Nitrite was determined by a system designed for automatic analysis (Cenco, Breda) (Vertregt, 1977).

The volatile acids (acetic, propionic, butyric and valeric acid) were determined by means of a Hewlett-Packard 5700 gas chromatograph with FID. The instrument parameters were: injection port: 120°C; column, stainless steel, length 1 m, 5.4 mm o.d., packed with 10% DEGS and 2% H₃PO₄ on Chromosorb W AW 60/80 mesh; isothermal at 105°C; detector at 200°C; carrier gas:
nitrogen.

The volatile N-nitrosamines were determined with a specific system consisting of a gas chromatograph (Packard Becker 427) coupled with a thermal energy analyzer (TEA, model 502 LC, Thermo Electron Corporation) (GC/TEA). The instrument parameters were: GC: injection port: 220°C; column, stainless steel, length 3 m, 3.2 mm o.d., packed with 10% Carbowax 20 M on Chromosorb W HP 80/100 mesh; oven: temperature programmed: initial 120°C (4 min.), 5°C/min., final 180°C (4 min.); carrier gas: argon; inlet pressure: 0.3 MPa (3 atm.).

TEA: pyrolyzer temperature: 450°C; reaction chamber pressure: 133-200 Pa (1-1.5 mm Hg); cold trap (liquid nitrogen-isopentane slurry): -160 to -145°C.

Analysis

First the original materials, fresh and pre-wilted grass, were analysed for volatile nitrosamines. A subsample was dried at 105°C and analysed for contents of dry matter, nitrate, total N and soluble carbohydrates.

The materials collected during fermentation were analysed for dry matter, nitrate, nitrite, ammonia, volatile acids and pH by standard methods and for volatile N-nitrosamines with the specific method.

Nitrosamine analysis

A 200 g sample of the frozen material was cut into small pieces and steam distilled according to the method of Stephany et al. (1978) from 300 ml water. The distillate was acidified and extracted with dichloromethane. The dichloromethane-layer was separated, dried with Na2SO4 and concentrated to approximately 2 ml in a Kuderna-Danish concentrator (T= 52°C). Then 2 ml hexane was added and the evaporation was continued until about 0.5 ml remained. These extracts were used for GC/TEA analysis. The nature of the positive GC/TEA peaks was checked by the method of Doerr and Fiddler (1977) by repeating the determination after irradiation of the samples with UV light. The recovery was estimated by adding in advance a mixture of dimethylnitrosamine, diethylnitrosamine, dipropylnitrosamine and nitrosopiperidine in the µg/kg range to a number of duplicate samples.

To several samples 5 mg of morpholine/kg sample was added as an artifact indicator (Rounbehler et al., 1979). No nitrosomorpholine could be detected. So, there was no indication of artifact formation during the successive steps of the analytical procedure.

In this connection it should be mentioned, that the mineral oil technique (MOT) (Fine, 1978) leads more readily to artifact formation because the voluminous material hinders efficient stirring, which may result in local over-heating when electric heating is applied. This could be avoided by using three times more mineral oil than was prescribed. Because the present work concerned the analysis of very small amounts the steam distillation method for 200 g samples was preferred.

Results and discussion

Data on the composition of the original material are given in table 1. The yield, nitrate and total nitrogen content increased with the N-dressing. There was a parallel decrease in the carbohydrate content.

After wilting, material with DM content of about 300, 500 and 600 g/kg was obtained. The 400 g/kg batch appeared to have a DM content of about 300 g/kg. The material was ensiled as described in the experimental section. The silage quality was monitored by continued analysis of all the samples for pH, butyric acid and ammonia content. The results are shown in table 2. Only small differences were found in relation to the nitrate content. Butyric acid was found in small quantities in samples with low nitrate content. The ammonia content of the silages was rather low, but highest in the low DM silages.

Wieringa investigated the influence of nitrate on the ensilage of fresh grass on laboratory-scale. Silages from grass con-

<table>
<thead>
<tr>
<th>Fertilization</th>
<th>DM content</th>
<th>Yield</th>
<th>NO3</th>
<th>Nt</th>
<th>Sol.carb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg N/ha</td>
<td>g/kg fresh</td>
<td>kg DM/ha</td>
<td>g/kg DM</td>
<td>g/kg DM</td>
<td>g/kg DM</td>
</tr>
<tr>
<td>0</td>
<td>164</td>
<td>4400</td>
<td>1.3</td>
<td>29.0</td>
<td>157</td>
</tr>
<tr>
<td>40</td>
<td>147</td>
<td>4700</td>
<td>4.4</td>
<td>30.6</td>
<td>130</td>
</tr>
<tr>
<td>80</td>
<td>141</td>
<td>5600</td>
<td>8.9</td>
<td>33.9</td>
<td>120</td>
</tr>
<tr>
<td>120</td>
<td>139</td>
<td>6300</td>
<td>16.3</td>
<td>36.9</td>
<td>118</td>
</tr>
<tr>
<td>160</td>
<td>144</td>
<td>6700</td>
<td>21.8</td>
<td>36.9</td>
<td>103</td>
</tr>
</tbody>
</table>
Table 2. Silage quality arranged according to dry matter content of grass, prior to ensilage. Values are averaged for the successive sampling dates.

<table>
<thead>
<tr>
<th>DM g/kg fresh</th>
<th>300</th>
<th>500</th>
<th>600</th>
</tr>
</thead>
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<tr>
<td>pH</td>
<td>4.8</td>
<td>5.8</td>
<td>5.9</td>
</tr>
<tr>
<td>Butyric acid (g/kg fresh)</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ammonia content (g/kg N)</td>
<td>110</td>
<td>90</td>
<td>70</td>
</tr>
<tr>
<td>Number of samples</td>
<td>60</td>
<td>18</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 2. Silage quality arranged according to dry matter content of grass, prior to ensilage. Values are averaged for the successive sampling dates.

Content 6-10 g NO₃/kg DM were of rather good quality according to the pH, butyric-acid values and ammonia fraction, whereas silages from grass with NO₃ content of both <6 and >10 g/kg were of poor quality. Nitrate was rapidly reduced during the silage fermentation (Wieringa, 1966).

Schukking and Hengeveld (1971) investigated the ensilage of unchopped grass with nitrate contents of 10-15 g/kg DM in small field silos. Butyric acid was usually found in silages of 300 g DM/kg and less. Silages with dry matter contents of more than 300 g/kg were very low in butyric acid content but had an increased amount of ammonia. The nitrate in the grass of about 300 g DM/kg was reduced for at least 75% during ensilage. Almost no nitrate was reduced in silages from material with high DM content (>400 g/kg). Sometimes less nitrate was reduced due to a rapid decrease of the pH. This was found in silages from lacerated grass direct cut with a flail-type forage harvester and in maize silages.

As in the present study pre-wilted grass was used the best comparison can be made with the results of Schukking and Hengeveld (1971). It was shown that all silages are of good quality.

A possible explanation for the sometimes low nitrate reduction in our silages is the fact that chopping the grass caused a rapid drop in pH.

During fermentation the formation of ammonia continued somewhat, but without loss of nitrate so that this was probably due to degradation of nitrous oxide contaminants.

The above findings indicate, that formation of precursors of nitrosamines may continue when nitrate reduction has already ceased.

None of the samples contained detectable amounts of nitrite and only a few of the opened jars gave off a smell of nitrogen oxides.

Analysis for nitrate in the successive samples showed that degradation of nitrate only occurred during the first ten days of fermentation (figure 1). At about 300 g DM/kg most of the nitrate (80%) was reduced when the nitrate content was less than 10 g/kg DM. At higher nitrate content the reduction was less. The reason of this phenomenon is unknown.

No nitrate degradation was found in samples with dry matter contents of about 500 and 600 g/kg.

Only samples taken from jars with the lower dry matter contents (300 g/kg) contained more than 0.2 µg nitrosamine per kg, mostly dimethylnitrosamine. All other samples had lower contents, which were difficult to interpret in view of the possible artifacts.

In figure 2 the decrease in nitrate (NO₃) is plotted against the dimethylnitrosamine concentration found in the silages with a dry matter content of about 300 g/kg (60 samples). A low correlation coefficient of 0.49 was found, but the figure reveals that:

a. Even with a relatively large decrease in nitrate the increase in dimethylnitrosamine, less than 5 µg/kg, was small.

b. With relatively small decreases in nitrate content only little nitrosamine, less than 1 µg/kg, was formed.

The complexity of the factors influencing the nitrosamine formation warrants only a qualitative consideration of the relation between nitrate reduction and nitrosamine formation.

As with nitrate degradation, the nitro-
ammonium content did not correlate with the sampling date. Obviously the nitrosamine formation took place in the beginning of the fermentation process. The six consecutive samples from the same original material could therefore be regarded as amenable to the calculation of means and standard deviations within each group of silages. The data given in table 3 show that where more of the nitrate had disappeared higher concentrations of nitrosamines were attained.

One sample had clearly not been sufficiently anaerobic during the fermentation. The material was molded and had a typical smell reminiscent of hay heat. Although the dry matter content was high (600 g/kg) nearly all of the nitrate had disappeared. This sample contained the highest amount of dimethylnitrosamine: 90 μg/kg. The other 5 samples from this group (table 3, 120 kg N, 600 g DM/kg) were also more or less molded and showed a mean dimethylnitrosamine content of 3 μg/kg.

The early results of work on small field scale silages of comparable grass as in this work agree with the present data.

Conclusions

During the fermentation of nitrate containing pre-wilted grass, volatile nitros-

Table 3. The effect of DM content and nitrate content of the pre-wilted grass, prior to ensiling, on nitrate degradation and nitrosamine formation during fermentation. Nitrate and dimethylnitrosamine in the silage, averaged for the successive sampling datesX.

<table>
<thead>
<tr>
<th>Fertilization kg N/ha</th>
<th>Pre-wilted grass</th>
<th>Silage</th>
<th>Pre-wilted grass</th>
<th>Silage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DM content g/kg fresh</td>
<td>NO3 g/kg DM</td>
<td>DM content g/kg fresh</td>
<td>NO3 g/kg DM</td>
</tr>
<tr>
<td>0</td>
<td>301</td>
<td>1.3</td>
<td>286 (30)XX</td>
<td>0.4 (0.2)XX</td>
</tr>
<tr>
<td>40</td>
<td>292</td>
<td>4.4</td>
<td>281 (73)</td>
<td>0.7 (0.3)</td>
</tr>
<tr>
<td>80</td>
<td>289</td>
<td>8.9</td>
<td>281 (25)</td>
<td>1.3 (0.5)</td>
</tr>
<tr>
<td>120</td>
<td>241</td>
<td>16.3</td>
<td>275 (24)</td>
<td>6.8 (0.9)</td>
</tr>
<tr>
<td>160</td>
<td>304</td>
<td>21.8</td>
<td>290 (25)</td>
<td>18.5 (1.2)</td>
</tr>
</tbody>
</table>

x) The dimethylnitrosamine results were corrected for recovery (70%)

xx) In parentheses are the standard deviations of the mean (6 samples)

xxx) One sample heavily molded with 90 μg nitrosamine/kg and the remainder with 3 μg/kg. See text.
amines were formed at µg/kg concentrations. It is likely, that nitrite, sometimes added as an ensiling aid or preservative, may have a similar effect.

The highest nitrosamine concentrations were found in silages of 300 g DM/kg, in which most of the nitrate was reduced. Here the conditions were more favourable for the production of amines than in the silages with 500 and 600 g DM/kg.

In this connection it should be noted, that Voss (1966) found that the amine content of silages increases with decreasing dry matter content.

The greatest amount of dimethylnitrosamine occurred in the groups containing 8.9 and 16.3 g N0<sub>3</sub>/kg. Here more nitrate was reduced than in the other groups. But this relationship is obscured by the wide range of values within each group, which makes it difficult to define which of the types of the silages had the greatest tendency to form nitrosamines. Obviously the molding under aerobic conditions gave the highest nitrosamine formation.

Acknowledgements

Thanks are due to Mr. L. Sibma for providing the grass material, to Mr. J. Davies for skilful technical assistance and to Mr. S. Schukking for his valuable comments.

References


ANIMAL AND SWARD PRODUCTION UNDER ROTATIONAL AND CONTINUOUS GRAZING MANAGEMENT - A CRITICAL APPRAISAL

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Summary

Herbage dry matter production from rotational and continuous grazed pastures, under the same growing conditions, can be very similar. The ability of the pasture to maintain production under a wide range of management conditions demonstrates the "plasticity" of the grass sward. The chemical composition of the herbage available under both rotational and continuous grazing is very similar.

Examination of a number of results mentioned in the European literature, and of recent unpublished data, shows a benefit to rotational grazing for dairy cows of only 1.5% and for beef cattle of approximately 6%. Herbage intake and animal production close to the potential maximum can be achieved on rotationally grazed swards when a stubble of 8 to 10 cm is left after grazing, and on continuously grazed swards at a mean grass height of approximately 7 cm.

Labour input under continuous grazing can be considerably less than that for rotational grazing and the denser pastures may be more resilient to weed ingress and sward deterioration. It should, however, be stressed that continuous grazing requires considerable management skill if the factors pasture and animal are to be maintained in equilibrium.

Introduction

Controlled grazing management systems were described and indeed recommended more than 200 years ago (Klapp, 1968), but comprehensive research on grazing began much later. The development of grazing systems over the last 40 to 50 years was reviewed recently by Davies (1976). This period has seen a full cycle of management systems on the farm, from uncontrolled grazing, through paddock and strip grazing with now a move back to continuous grazing. It must be stressed, however, that these steps have been part of an evolution, comprising both increases in fertilizer use and stocking density simultaneously and educating the farmer to match the herbage production with the animal requirements. It seems unlikely that these intensifications could have occurred without the intermediate steps and particularly the discipline imposed by tightly controlled grazing systems.

The aim of the grazier must be to optimize the grazing potential of his grassland within both the biological and financial constraints imposed. When doing this he has to adopt a system of management that not only allows him to supply the required nutrients to the livestock, but also encourages the maintenance of viable pastures. He has to consider the animal and the sward in both the short and long term. Research must provide objective information to allow the farmer to do this, information upon which sound management strategies can be constructed.

Comparisons between grazing management systems can be found in profusion throughout the world literature. In isolation few offer guidance in other than general terms, except perhaps in their specific conditions of environment and management. This applies particularly to much of the work undertaken in Western Europe with dairy cows, since most research workers fail to include different stocking rates, the factor soundly established as having an overriding influence on output (McKeeman, 1956; Walsh, 1964). The generalised conclusion that could be drawn from a superficial examination of these trials is that continuous grazing has resulted in a slightly lower level of animal production than that derived from the various forms of rotational grazing. To apply this conclusion without a deeper understanding of the trials would be a grave error. Many of those, in which two or more grazing systems have been compared, were not carried out to demonstrate the superiority, or other-
wise, of one system as opposed to another, but to examine ways of simplifying grazing management. Equally, other trials were carried out to demonstrate that simplified systems could be operated in a given environment at the same stocking rate as applied in the proven management systems at that time.

The more meaningful exercise is not to ask the question "Is one system of management better than another?" but "Under what circumstances can more forage be grown and/or more animal product obtained under one particular system as opposed to another?" We need to examine the criteria which lead to any advantages, to identify the critical aspects of the animal/sward interface and then provide objectively established and tested grazing management guidelines for the grazier. Then he has to select the system which suits best with his farming situation.

In this paper we will attempt to follow this path, drawing particularly on more recent grazing management investigations undertaken in Western Europe.

Herbage production and the sward

Estimates of the amounts of dry matter (DM) produced under grazing vary widely between soil types and climatic regions; for example, the authors observed similar levels of production under both rotational and continuous grazing at their respective centres, spanning the range of 10 (GRI, Hurley) to 15 (Kleve-Kellen) t DM per ha.

In spite of the difficulties involved in making accurate estimations of herbage production under grazing, these observations and the weight of evidence from the literature support the conclusion drawn by Hodgson & Wade (1978) in their comprehensive review of grazing management and sward production: "Annual herbage accumulation is relatively insensitive to variations in grazing management or to variations in stocking rate within the range likely to be of practical interest".

Hodgson & Wade (1978) tendered a hypothesis to explain the variance of this conclusion with the classical theories about the relationship between leaf area, photosynthetic activity and plant growth. They argued that, although varying pasture management may produce swards with substantially different leaf areas and consequent potential differences in photosynthetic activity, the whole sward has considerable powers of compensation, operating by means of changes in the number and size of tillers and leaf primordia, and in rates of death and decay rather than through changes in current photosynthetic activity. This is supported by the fact that the high number of tillers throughout the grazing season is a consistent feature of the high yield of herbage observed under well maintained continuous grazing systems, contrasting with the steady fall seen in both monthly cutting and rotational grazing systems (Figure 1).

![Figure 1. The tiller density of swards of Lolium perenne cv. Endura (a) stocked continuously by dairy cows, (b) mown at monthly intervals and (c) grazed at 28-day intervals (GRI, Hurley).](image)

Table 1. Tiller density (tillers x 1000 per m²) of Lolium perenne swards grazed at three different severities (Wade, 1979). June: normal conditions; July and August: wet conditions.

<table>
<thead>
<tr>
<th>Grazing severity</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>13.8</td>
<td>15.0</td>
<td>13.8</td>
</tr>
<tr>
<td>July</td>
<td>7.5</td>
<td>10.9</td>
<td>11.9</td>
</tr>
<tr>
<td>August</td>
<td>6.2</td>
<td>8.9</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Equally, the under-grazing of swards in early season, that leads to the development of a mosaic of severely and laxly grazed areas in both rotational and continuously
grazed pastures, may ultimately affect dry matter production. The under-grazed areas are characterised by a reduction in tiller density and by the production of aerial tillers. Subsequent defoliation can remove these, further reducing tiller density and in extreme cases leaving open, bare patches in the pasture (Castle and Watson, 1973). Reduction in tiller number is of particular significance to the continuously grazed sward since its productive ability is so reliant upon achieving and maintaining a high tiller population (Table 2).

Table 2. Number of tillers (x 1000 per m²) in a sward after four (Expt. 1) or five (Expt. 2) years grazing, mean of spring and autumn estimate (Kleve-Kellen, 1979).

<table>
<thead>
<tr>
<th></th>
<th>Experiment 1</th>
<th>Experiment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rota- Conti-</td>
<td>Rota- Conti-</td>
</tr>
<tr>
<td></td>
<td>nualous</td>
<td>nualous</td>
</tr>
<tr>
<td>Lolium perenne</td>
<td>3.5</td>
<td>4.9</td>
</tr>
<tr>
<td>Other grasses</td>
<td>11.0</td>
<td>10.7</td>
</tr>
<tr>
<td>All grasses</td>
<td>14.5</td>
<td>15.6</td>
</tr>
</tbody>
</table>

Photosynthetic activity on a well managed continuously grazed area may not be conform to classical theory. In contrast to paddocks in a rotational system, the continuously grazed pasture contains a constant high quantity of young herbage with a high potential for assimilatory activity. According to Koblet (1979) dense, intensively grazed swards, because of a high radiation efficiency, attain daily growth rates close to maximum with a leaf area index (LAI) of 2 to 3. On continuously grazed areas this LAI may be attained at a relatively low sward height. Preliminary work by Deinum (personal communication, 1979), on areas grazed by sheep, indicates that the photosynthetic activity under continuous grazing may be as high as that under rotational management.

There is no very clear evidence that plant growth is depressed as stocking rate increases, but if it is, then it would appear that the effect is approximately balanced by a decrease in decomposition losses. Also, as stocking rate increases, the rate of return and pattern of distribution of plant nutrients from dung and urine will improve, encouraging higher herbage production.

The pulling-up of tillers by the grazing animal, although aesthetically unpleasant, can have little effect on sward density, since many of those removed are dying reproductive tillers, particularly of Poa annua. A quantitative estimation of the tillers lying on the surface of a continuously grazed pasture in August (MAFF, 1977) indicated that they accounted for less than 5% of the total pasture weight.

Maintenance of sward quality under intensive rotational grazing managements on permanent grassland is difficult in some areas of Europe. Sward deterioration is aggravated by the application of large amounts of slurry, unfavourable climatic conditions during both grazing and conservation and by defoliation at too advanced a stage of growth. These practices result in the production of a more open sward, encouraging the ingress of less favoured species.

Chemical composition

The chemical composition of the herbage dry matter available on parallel rotationally and continuously grazed pastures is very similar (Table 3) and the seasonal trends observed under continuous grazing (Table 4) are similar to those reported for intensively managed rotational grazing (Kaufmann et al., 1969; Kemp et al., 1978, 1979). This is not, however, a direct measure of the material actually consumed. The quality of milk produced by dairy cows, grazing on either system, is generally very similar, indicating that fibre levels of the consumed herbage are unlikely to be significantly different. One major concern has been the nitrate content of the herbage. Will this be so high as to cause toxicity under continuous grazing where nitrogen fertilizer is applied at the rate of 50 to 60 kg N per month, totalling 350 to 400 kg N per ha per season? There are no reports either in the scientific literature or from farming practice of nitrate poisoning in cattle at these levels of fertilizer application, and, in general, observed nitrate levels are below those believed to induce poisoning (Kemp et al., 1978; Burschneider et al., 1979).

Animal production

McMeekan's classical comparison of rotational and continuous grazing (McMeekan and Walshe, 1963) has long been held to demonstrate the superiority of the former in terms of animal production, particularly under intensive management. No work on this scale has been undertaken in the very different farming environments of Western Europe but many simple comparisons have been reported for both dairy and beef cattle. These data have been drawn together and the results are presented in diagrammatic form in Figs. 2 and 3 (See also Marsh, 1975). The data for dairy cows are presented in terms of milk yield per head; for beef cattle the outputs are presented per hectare because of the wide variation in animal types between trials.

An analysis of the dairy data indicates that the benefit to rotational grazing is in the order of only 1.5% as compared with the 8% reported by McMeekan and Walshe (1963).
Table 3. Chemical composition (% of DM) of the whole sward under rotational and continuous grazing (R v P Merelbeke, 1977 and 1978).

<table>
<thead>
<tr>
<th></th>
<th>DM</th>
<th>Ash</th>
<th>CP</th>
<th>CF</th>
<th>NDF</th>
<th>OMD</th>
<th>K</th>
<th>P</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>NO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous</td>
<td>21.8</td>
<td>10.3</td>
<td>21.2</td>
<td>24.0</td>
<td>54.7</td>
<td>70.4</td>
<td>2.66</td>
<td>0.29</td>
<td>0.80</td>
<td>0.18</td>
<td>0.34</td>
<td>1.16</td>
</tr>
<tr>
<td>Rotational</td>
<td>18.5</td>
<td>10.5</td>
<td>23.4</td>
<td>23.5</td>
<td>50.3</td>
<td>73.9</td>
<td>2.71</td>
<td>0.31</td>
<td>0.86</td>
<td>0.19</td>
<td>0.37</td>
<td>1.32</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th></th>
<th>DM</th>
<th>Ash</th>
<th>CP</th>
<th>CF</th>
<th>NFE + fat</th>
<th>K</th>
<th>P</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>NO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>18.2</td>
<td>9.6</td>
<td>23.3</td>
<td>20.4</td>
<td>46.7</td>
<td>3.33</td>
<td>0.49</td>
<td>0.75</td>
<td>0.24</td>
<td>0.12</td>
<td>0.67</td>
</tr>
<tr>
<td>June</td>
<td>21.9</td>
<td>8.5</td>
<td>20.5</td>
<td>23.1</td>
<td>47.9</td>
<td>2.65</td>
<td>0.37</td>
<td>0.79</td>
<td>0.23</td>
<td>0.15</td>
<td>0.98</td>
</tr>
<tr>
<td>July</td>
<td>24.9</td>
<td>8.1</td>
<td>18.0</td>
<td>24.4</td>
<td>49.5</td>
<td>2.51</td>
<td>0.36</td>
<td>0.80</td>
<td>0.23</td>
<td>0.14</td>
<td>0.65</td>
</tr>
<tr>
<td>August</td>
<td>23.7</td>
<td>8.6</td>
<td>20.4</td>
<td>24.0</td>
<td>47.1</td>
<td>2.50</td>
<td>0.38</td>
<td>0.98</td>
<td>0.37</td>
<td>0.12</td>
<td>0.98</td>
</tr>
<tr>
<td>September</td>
<td>25.6</td>
<td>10.1</td>
<td>21.2</td>
<td>22.3</td>
<td>46.4</td>
<td>2.31</td>
<td>0.42</td>
<td>1.12</td>
<td>0.44</td>
<td>0.15</td>
<td>0.75</td>
</tr>
<tr>
<td>October</td>
<td>19.9</td>
<td>8.8</td>
<td>22.0</td>
<td>21.5</td>
<td>47.8</td>
<td>2.28</td>
<td>0.45</td>
<td>1.10</td>
<td>0.40</td>
<td>0.14</td>
<td>0.52</td>
</tr>
</tbody>
</table>

It is worth noting, however, that all the trials, except those summarized by McCarthy (1979), were undertaken with high nitrogen regimes. These Irish trials were very similar in management to those of McMeekan, relying almost entirely upon clover nitrogen, and showed, like the New Zealand work, an interaction between stocking rate and management, with an increasing benefit to rotational grazing as stocking rate increased.

The beef data present a slightly different overall story; again, all but the Irish work of Conway (1963) rely heavily upon fertilizer nitrogen. The overall benefit to rotational grazing is approximately 6% and again, where reliance is placed on clover (Conway, 1963), the indications are that this benefit increases with increasing stocking rate.

In the majority of comparisons it is not possible to ascertain from the published information the reasons why one system of management is marginally superior to the other. The conclusion that should be drawn from these data is perhaps not that on balance there is little difference between the two systems, but that there are circumstances when one of the two is more productive. We should then, as suggested in the introduction, try to identify these and construct management guidelines that enable the farmer to avoid problem points in whichever grazing system suits him and his farm circumstances best.

First, therefore, let us examine why beef and dairy cattle appear to react somewhat differently to management systems. The major output of the dairy cow, milk, is buffered against short-term fluctuations in pasture condition by the animal's ability to draw on body reserves and also by the...
willingness of both the farmer and experimenter to offer alternative feeds. Although whole system liveweight change may be monitored and concentrate input deducted from the pasture contribution to output, these two factors can still buffer any critical short-term deficits in herbage availability on either system. For the beef animal, liveweight gain is the sole product and can only be buffered by other feeds which, if given at all, are normally only made available after growth rate has been seriously depressed. These observations may be summarized by saying that grazing severity may have a greater effect upon beef cattle than upon dairy cows. Although this may only be for short periods, it may be critical and therefore have a large effect on total output.

Grazing severity

At this point, a summary of the information on the effects of grazing severity upon herbage intake may be relevant as an aid to further discussion. Baker (1978) summarized the information for rotationally grazed dairy cows, steers and beef cows into the relationship shown in Figure 4, suggesting that herbage intake is within 4% of maximum when approximately half of the herbage on offer has been utilised, and that intake is increasingly depressed as the utilisation of any single allowance is forced higher. This concept may be expressed more simply in terms of residual sward height in that individual animal intake is close to maximum when a stubble of 8 to 10 cm is left after rotational grazing (Baker et al., unpublished data; Le Du et al., 1979) but that when the animals are forced to graze down to 5 cm, intake will be depressed by 10 to 15%.

However, this does result in increased utilisation of the herbage and therefore of output per unit area. The extent of the depression in individual animal production will vary with the duration of the restriction (Le Du et al., 1979). Similarly, with animals grazing continuously, herbage intake is affected by the enforced severity of grazing and can be related to pasture height. Work with both dairy and beef cows has indicated that 95% of maximum intake can be achieved on a sward grazed at a mean height of approximately 7 cm, but that intake is depressed to approximately 80% of maximum at around 5 cm (Figure 5).
This effect upon intake is reflected in milk yield of the dairy cow (Figure 6) with the degree of depression in yield increasing with the duration of the herbage restriction. 

<table>
<thead>
<tr>
<th>Milk yield kg/day</th>
<th>19</th>
<th>18</th>
<th>17</th>
<th>16</th>
<th>15</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sward height cm</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 6. The effect of grazing severity upon milk yield under continuous grazing (GRI, Hurley).

Subjective observations suggest that under-grazing of a continuous sward, with mean heights in excess of 8 to 9 cm, and the associated development of a mosaic of under- and over-grazed areas, may have deleterious effects in terms of sward production later in the season.

These data underline the importance of severity of defoliation in controlling intake and therefore animal production and go a considerable way in quantifying the effects.

Dairy cows

The lack of descriptive information, relating to the grazed swards in many trials under review, makes interpretative comment difficult, but cross-reference with the information does allow partial investigation. For example, the continuously grazing cows of Castle and Watson (1975) were not only forced to graze below the critical height for maintenance of intake throughout the final third of the grazing period, but also under-grazed the sward during the first one-third of the season. The severity of defoliation imposed by the investigations at Merelbeke during August and September would have affected intake for the continuously grazing animals (mean pasture heights 3.4 and 3.3 cm, respectively) but only during September (daily herbage available 12 kg DM per cow) for those grazing rotationally. The data from Kleve-Kellen show a similar pattern, the available herbage under continuous grazing being concentrated very close to the ground in the latter part of the season (below 5 cm), making its harvest by the cows increasingly difficult.

Beef cattle

The influence of grazing severity upon herbage intake by growing beef cattle under rotational management has been outlined above and is similar to that for dairy cows. There is lack of information for continuous grazing but it would be surprising if the guidelines established for dairy cows would not generally be applicable to growing beef cattle.

Pasture information within the beef cattle comparisons is limited but it was apparent in a number of the trials surveyed (Figure 3) that sufficient herbage supply, particularly during mid-season, was more difficult under continuous than under rotational grazing. Decisions upon initial stocking density, the proportion of the total area to be conserved and the requisite stages at which to expand the grazing area are critical in this respect.

Hood and Bailie (1973), in developing an expanding set-stocked system for spring and autumn-born calves, suggested that the initial grazing area should be approximately one-third of the total. Subsequently the animals should be moved into the remainder following conservation and regrowth, with a final expansion into the entire area after a silage cut from the area grazed in early season. At nitrogen application rates of 200 to 250 kg per ha the suggested target liveweight at the start of grazing was 2,000 to 2,400 kg per ha. Under this system of management annual liveweight gains per hectare in excess of 700 kg per ha were obtained.

Slow re-growth following conservation or its entire failure, for whatever reason, will inevitably subject the animal to an increase in grazing severity and a depression in liveweight gain; this occurs under any management system. In this situation decisions upon changes in grazing severity and defoliation policy can be made more frequently under a rotational system permitting more immediate response to variables affecting herbage growth. The stock-piling of grass, which is an inherent feature of rotational management, can therefore be used to delay the point of severe shortage of feed by a policy of deliberate rationing; this is not really possible under continuous grazing.

Climatic and other conditions

Estimates of the time spent grazing by animals in different management systems show that young cattle, dairy cows as well as beef cows seem to spend more time 'harvesting' their food under continuous than under comparable rotational systems (Table 5). This may be interpreted as indicative of more difficult harvesting conditions and therefore a higher effective grazing pressure being exerted in the former, and would suggest that the continuously grazing animal may reach its grazing time threshold at a lower stocking rate.
comparative data are available on the other components of grazing behaviour, bite size and bite rate.

The additional time spent grazing under continuous managements will have only a minor effect on energy demand. Van Es (1974) estimated that the hourly energy requirement for grazing was 1.25% of the resting maintenance needs. Consequently, the total energy requirement of a dairy cow with a daily milk yield of 20 kg would only increase by 0.5% per hour spent grazing.

Table 5. Grazing time under rotational and continuous grazing.

<table>
<thead>
<tr>
<th></th>
<th>Rotational</th>
<th>Continuous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kleve-Kellen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grazing time, h/24 h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young cattle</td>
<td>9.2</td>
<td>10.1</td>
</tr>
<tr>
<td>Dairy cows</td>
<td>8.1</td>
<td>8.8</td>
</tr>
<tr>
<td>GRI Hurley</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grazing time, h during daylight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beef cows</td>
<td>6.8</td>
<td>8.7</td>
</tr>
<tr>
<td>calves</td>
<td>5.2</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Farm management considerations

Ease of management is to a great extent a function of the manager's ability, but we consider that a correct management on a continuous pasture is in general at least as difficult as on a rotational pasture, particularly with beef cattle. There are a number of ill-defined points that can be made relating to the effects of the adoption of one particular grazing system as opposed to another upon overall farm management. This is not the place to document these fully, but there are some aspects that are worthy of mention in that they warrant further investigation. Firstly, there is the claim that continuously grazed pastures may need less frequent reseeding since their denser swards are more resilient to weed ingress, damage and deterioration. The high costs of pasture regeneration make this an important issue. Secondly, most European work on grazing systems for cattle has been carried out with well fertilized, all grass pastures; only the Irish work has relied upon clover. Once again increasing fertilizer costs will make this an important area for study.

Another important point to consider is labour input. Under experimental conditions in Kleve-Kellen (each grazing system 5 ha and 20 cows) continuous grazing management resulted in a definite reduction in labour input for nitrogen fertilizing, fodder conservation and pasture topping, of more than 50% when compared with rotational management (Table 6). Moreover, investment and maintenance costs for fences and water are lower under continuous grazing management.


<table>
<thead>
<tr>
<th></th>
<th>N fertilizing</th>
<th>fodder conservation</th>
<th>pasture topping</th>
<th>total h/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>rotational</td>
<td>11.1</td>
<td>5.4</td>
<td>2.7</td>
<td>19.2</td>
</tr>
<tr>
<td>continuous</td>
<td>3.5</td>
<td>4.2</td>
<td>0.9</td>
<td>8.6</td>
</tr>
</tbody>
</table>

1) on 60% and 2) on 40% of the total area

Conclusions

The weight of evidence suggests that annual herbage accumulation is relatively insensitive to variations in grazing management and stocking rate within the range likely to be of practical significance. Difficulties with measurement techniques make this a tentative conclusion but it is suggested that, if there are variations in growth, these may be compensated for by differential rates of death and decay of herbage and of nutrient circulation within the grazing ecosystem as well as by morphological adaptation by the plants.

Further study is required to ascertain whether long-term changes in botanical composition affect sward growth, this being particularly important in mixed grass/legume swards.

The summary of the surveyed data suggests that animal output is marginally higher on rotational than on continuous grazing systems and that the greater difference between these grazing systems may be the result of a higher overall effective stocking density and the absence of buffering components. It is possible to make a simple estimate of the imposed severity of grazing by reference to the height of either the residual herbage under rotational grazing or the whole sward under continuous grazing and to relate this to herbage consumption and animal production. This allows the livestock production consequences of a particular grazing strategy to be predicted and grazing management guidelines for any set of farm circumstances to be drawn up.
References


NITROGEN AS A FACTOR IN DAIRY FARM MANAGEMENT

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Summary

The dairy farmer is aiming at a management system which guarantees income and continuity. Technical factors affecting the organization of the farm include land, buildings, machinery, labour, concentrates and nitrogen fertilizer. Economical factors are the costs of the technical factors and the prices of the farm products. The factors are interrelated which means that farm management is not determined by one factor alone, but by a combination of factors.

This study discusses the role of nitrogen on grass production within the farming system. First the response of grassland to nitrogen is dealt with, keeping the other factors constant. Secondly the optimum rate of application in relation to the other factors is examined.

1. The rate of nitrogen application affects the growth rate of the grass and consequently the date of reaching a particular yield, both for grazing and conservation. This time-effect is important for farm planning purposes.

Calculations have been made based on an existing model of grass production during the season. In this calculation the effects of various rates of nitrogen application and residual nitrogen, of grazing days, field period at conservation and delay in regrowth, have been evaluated.

Results show that
- the response to nitrogen is higher with continuous cutting at fixed dates than with cutting at a particular yield
- the response to nitrogen is smaller with continuous cutting at grazing stage (1.7 t DM per ha) than with cutting at conservation stage (3.5 t DM per ha)
- assuming a certain grass growth while the cows are grazing, the number of grazing days does not affect the response to nitrogen
- an increasing length of the field period has a negative effect on the response to nitrogen.

It is clear that the response to nitrogen depends to a large extent on the use and utilization of the grassland. A correct approach integrates the response to nitrogen in grassland utilization schemes, fitting different farming situations. These situations include different stocking rates, rates of nitrogen application, grazing days and field periods. Calculations indicated a positive correlation between stocking rate and nitrogen fertilizer application.

2. The results obtained with the grassland utilization schemes provided the basis for determining the optimum application of nitrogen fertilizer in relation to the technical and economical factors. For this goal, a linear programming technique was used. Variables in this calculation were rate of nitrogen fertilizer, stocking rate, available grassland area, milk production per cow, and prices of milk, nitrogen and concentrates.

Results of the calculations are presented at the Symposium.

Some literature

THE FATE OF FERTILIZER NITROGEN APPLIED TO GRASSLAND: UPTAKE BY PLANTS, IMMOBILISATION INTO SOIL ORGANIC MATTER AND LOSSES BY LEACHING AND DENITRIFICATION

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I.C.I. Jealott's Hill Research Station, Bracknell, Berkshire, United Kingdom

Summary

This paper presents selected results from three major series of investigations that have been conducted in the U.K. in recent years, with the objective of studying various aspects of the nitrogen cycle in grassland soils. Information obtained from field or lysimeter experiments on the variability of the response of grass to fertilizer nitrogen, recovery of fertilizer in the herbage, incorporation of nitrogen into the roots and soil organic matter, and losses by leaching and denitrification are presented. Tentative nitrogen balances are drawn up for cut and grazed swards.

Introduction

The progressive intensification of grassland management that has occurred during the past 25 years in the United Kingdom has been made possible by increased inputs of fertilizer nitrogen. For example, in England and Wales the average rate of nitrogen applied to permanent pasture has risen from about 10 kg/ha in 1952 to 96 in 1978; corresponding amounts for temporary grassland are 20 kg/ha in 1952 and 161 in 1978 (Church and Lewis, 1977 and Church, 1979). The more progressive dairy farmers are regularly using 200 - 300 kg N/ha each year. Although productivity of grass is readily increased by nitrogen applications the response of grass to fertilizer is variable, whether measured in terms of yield at a given rate of addition or the yield increment obtained from each unit of nitrogen applied. Likewise, the recovery of fertilizer nitrogen in the harvested parts of the grass crop varies widely and on average only 50-60 per cent is recovered. The remainder is either immobilised in roots and soil organic matter or lost by leaching or denitrification.

Woldendorp et al., (1966), reviewing their work on fate of fertilizer nitrogen on permanent grassland soils, concluded that as much as 15-20 per cent of nitrate in the rhizosphere was lost by denitrification. The variation is attributed to factors such as management, environment and to a lesser extent, species and variety; the literature has been exhaustively reviewed by Whitehead (1970). The extent of the variation caused by the physical environment is ill-defined, and we have only a limited grasp of the influence of the biological nitrogen cycle of the soil upon the efficiency with which fertilizer nitrogen is used.

This paper sets out to describe the results of three major field and lysimeter investigations in the United Kingdom studying the fate of nitrogen in grassland soils. These investigations included (a) an extensive series of field experiments carried out at many sites throughout England and Wales to determine the response of grassland herbage to N fertilizer, (b) a detailed study of the effect of high N fertilizer rates applied to grassland on dairy cow performance and health, dry matter production and on drainage water composition, and (c) a lysimeter project which included the use of 15N - labelled fertilizer to distinguish the fate of applied fertilizer nitrogen from that of other sources of nitrogen. The results from these experiments will not be dealt with in their entirety but only within the context of this paper in relation to factors concerned with the fate of fertilizer nitrogen when applied to grassland.

Recovery of nitrogen by the crop

In 1970 the Agricultural Development and Advisory Service of the Ministry of Agriculture, Fisheries and Food, the Grassland Research Institute and other research establishments jointly conducted a series of trials with the objectives of establishing the extent of variation in the yield of Lolium perenne S23 and the response to fertilizer nitrogen, and of interpreting these in relation to environmental variables. The general organization and management of these trials have been described by Jackson (1970).
and results are presented by Morrison et al. (1974), and Morrison et al. (1980). In brief the whole series, which included three different experiments, covered 28 representative lowland sites in Britain. Results are quoted for one experiment in which the test crop was S23 perennial ryegrass with no white clover, cut six or seven times a year at monthly intervals, with fertilizer nitrogen applied at annual rates of 0–750 kg N/ha in three patterns of application. The cutting management was notionally related to grazing. The important and unique feature of the experiment is that treatment, management and grass variety were common at all the sites on which the individual experiments were carried out.

Under most of the circumstances encountered in the experiment the response to fertilizer nitrogen was essentially linear up to 300 kg N/ha. The overall mean response to nitrogen at this rate was 23 kg DM/kg N with a range from less than 10 kg DM/kg N to over 30 kg DM/kg N. It was evident that a satisfactory response could be obtained from annual applications of fertilizer nitrogen at rates up to 300 kg N/ha in most conditions in the U.K. The apparent recovery of fertilizer nitrogen varied widely between sites and to a lesser extent between years at individual sites. 'Apparent recovery' is calculated as the increase in total N harvested from a fertilized sward compared to that of an untreated sward expressed as a percentage of the inorganic nitrogen applied. Recovery tended to be greatest at all sites at 300 kg N/ha and declined with increasing rates of fertilizer nitrogen. The range in mean values of the apparent recovery of 300 kg N/ha was from 45–87 per cent; the mean values over four years and all the sites is shown in Table 1. The apparent recovery of 150 kg N/ha was very variable and was less closely correlated with soil factors and water supply than the recovery of 300 kg N/ha which was near maximum for most conditions.

Table 1. Apparent recovery of fertilizer application. Results are means overall sites, expressed as per cent of fertilizer applied.

<table>
<thead>
<tr>
<th>Pattern of application</th>
<th>Fertilizer nitrogen applied kg N/ha</th>
<th>150</th>
<th>300</th>
<th>450</th>
<th>600</th>
<th>750</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td></td>
<td>62</td>
<td>68</td>
<td>65</td>
<td>57</td>
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<td>60</td>
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<tr>
<td>2**</td>
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<td>72</td>
<td>66</td>
<td>60</td>
<td>51</td>
<td>63</td>
</tr>
<tr>
<td>mean</td>
<td></td>
<td>64</td>
<td>70</td>
<td>66</td>
<td>58</td>
<td>49</td>
<td>61.5</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>15.3</td>
<td>9.4</td>
<td>8.7</td>
<td>7.8</td>
<td>7.7</td>
<td></td>
</tr>
</tbody>
</table>

* Six equal dressings at approximately 4 week intervals from beginning of April.
** Six dressings arranged 1/4, 1/4, 1/8, 1/8, 1/8, 1/8 of the total addition

and can be used as an index of recovery for the sites.

Although there was a positive between-site correlation between the herbage nitrogen yield at zero nitrogen applications (N₀) and fertilizer application rate of 300 kg N/ha, the addition of this term in the regression was not significant and may be associated with negative within-site correlations between N₀ and recovery. Nevertheless there was a noticeable trend for the apparent recovery, particularly at the lower rates of fertilizer application to be directly related to N₀ (Table 2). A greater proportion of the fertilizer nitrogen would be immobilized in roots on the low N soils than on the high N soils.

Table 2. Apparent recovery of fertilizer nitrogen for sites grouped according to mean herbage nitrogen yield at zero nitrogen application (N₀). Recovery as percentage.

<table>
<thead>
<tr>
<th>N₀ kg/ha</th>
<th>Fertilizer applied kg N/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–50</td>
<td>(10 sites)</td>
</tr>
<tr>
<td>51–100</td>
<td>(6 sites)</td>
</tr>
<tr>
<td>&gt;150</td>
<td>(3 sites)</td>
</tr>
<tr>
<td>150</td>
<td>56  65  62  61  48</td>
</tr>
<tr>
<td>300</td>
<td>70  73  68  62  52</td>
</tr>
<tr>
<td>450</td>
<td>83  81  77  62  51</td>
</tr>
</tbody>
</table>

These experiments were concerned with the utilization of fertilizer nitrogen by cut grass and deliberately did not include the effects of the grazing animal. At Jealott's Hill Research Station, on the other hand, grazing animals were used in the form of two herds of 26 and 30 Friesian dairy cows in a detailed and comprehensive long-term investigation which was designed to test the effects of moderate and high rates of nitrogen application, viz 250 and 750 kg N/ha/year, applied to S23 perennial ryegrass on the performance, blood composition, fertility and general health of dairy cows. A subsidiary aim was to monitor the chemical composition of the drainage water issuing from two separate 5 ha areas receiving the N rates mentioned above. Further details and some of the results are given by Hood (1976 a, b, c).

Table 3 presents results from six years of the experiment for yield and nitrogen content of the grass.

These results illustrate further that the dry matter production of grassland grazed or not, is highly variable and greatly influenced by summer weather, being depressed in unusually hot and dry seasons (e.g. 1976). A new experiment has been designed at Jealott's Hill Research Station to determine more precisely the fate of fertilizer...
Table 3. Yield of dry matter and nitrogen uptake of grazed ryegrass swards treated annually with 250 or 750 kg N/ha of fertilizer nitrogen.

<table>
<thead>
<tr>
<th>Fertilizer application rate</th>
<th>250 kg N/ha</th>
<th>750 kg N/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>N applied kg/ha</td>
<td>DM yield t/ha</td>
<td>N in herbage kg/ha</td>
</tr>
<tr>
<td>1971</td>
<td>341</td>
<td>4.9</td>
</tr>
<tr>
<td>1972</td>
<td>390</td>
<td>8.8</td>
</tr>
<tr>
<td>1973</td>
<td>450</td>
<td>14.9</td>
</tr>
<tr>
<td>1974</td>
<td>410</td>
<td>11.4</td>
</tr>
<tr>
<td>1975</td>
<td>358</td>
<td>8.4</td>
</tr>
<tr>
<td>1976</td>
<td>344</td>
<td>4.8</td>
</tr>
</tbody>
</table>

*This includes nitrogen deposition in rainfall and estimates of nitrogen recycled in animal excreta.

This includes nitrogen deposition in rainfall and estimates of nitrogen recycled in animal excreta.

Nitrogen applied to grassland which is cut regularly but not grazed so as to avoid the problems associated with recycled nitrogen. This study is being carried out on three areas each of 0.5 ha which receive 250, 500 and 900 kg N/ha/year. Changes in the total nitrogen content of the soil in the three areas are being determined with statistical precision by taking 800 cores/ha to a depth of 1m from each treatment unit at the beginning and end of the trial. This experiment began in 1978 and results will be available by 1981. In the trial, nitrogen uptake in the grass will be measured accurately and leaching losses of nitrogen will be monitored continuously, as before. Lysimeter experiments are also being conducted in conjunction with the field study; in these, 15N-labelled fertilizer will be used so that a complete nitrogen balance sheet can be drawn up.

In the experiments discussed so far, added inorganic nitrogen could not be distinguished from that native to the plants and soil. Therefore the extent of the contribution made by non-fertilizer sources of nitrogen to the nitrogen nutrition of the fertilized plants could not be estimated with any degree of precision. The only estimate available is provided by measurements of the nitrogen content of the crop that had not been treated with fertilizer, and then assuming that the contribution of non-fertilizer nitrogen to the crop had not been altered by the addition of fertilizer. In lysimeter experiments conducted by the Agricultural Research Council Letcombe Laboratory this difficulty was overcome by using inorganic nitrogen fertilizer labelled with 15N. Two series of experiments have made use of lysimeters containing naturally structured cores of soil (Seford, 1979; Dowdell and Webster, 1976). The first experiment used lysimeters 45 cm in diameter, 110 cm deep containing a freely draining sandy loam soil (Rowland series) that had been under arable cultivation before being sown with perennial ryegrass (Lolium perenne s23) at the beginning of the experiment (Dowdell and Webster, 1980). In the second series of experiments, lysimeters 60 cm in diameter and 135 cm deep were used that contained a clay loam (Salop series) or a silt loam (Bromyard series) on each of which was a permanent pasture consisting predominantly of perennial ryegrass. Both series of experiments set out to study the fate of applied nitrate-N (at 400 kg N/ha as calcium nitrate labelled with 10 atoms per cent 15N). In the case of the first experiment the fertilizer was applied only during the first growing season, whilst in the second experiment the total amount of nitrogen applied was the same in each year, but only the nitrogen added in the first year was labelled with 15N.

In both experiments some lysimeters were not treated with fertilizer N, so that the yield and nitrogen content of an unfertilized sward could be measured.

The apparent recovery of nitrogen fertilizer in the first year of these experiments was 57 per cent for the sandy loam, 51 per cent for the clay and 54 per cent for the silt loam. These values of fertilizer recovery are larger than those measured using 15N (Table 4). This is because the apparent recovery calculation underestimates the contribution made by non-fertilizer sources of nitrogen to the fertilized plants.

The contribution made by the fertilizer to the nitrogen uptake by the plant in the second year declines steeply to values representing 4-8 per cent of the fertilizer applied in the first year. Over the four years on the sandy loam, 63.1 per cent of the fertilizer nitrogen originally applied has been recovered in the herbage. The high values for unlabelled nitrogen taken up in the second year from the clay and silt loam.
Table 4. Percentage uptake of labelled fertilizer nitrogen, applied in year 1 only.

<table>
<thead>
<tr>
<th>Year</th>
<th>Sandy loam*</th>
<th>Clay**</th>
<th>Silt loam**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% of total N in crop applied</td>
<td>% of N in crop applied</td>
<td>% of total N in crop applied</td>
</tr>
<tr>
<td>1</td>
<td>58.4</td>
<td>52.1</td>
<td>56.7</td>
</tr>
<tr>
<td>2</td>
<td>17.9</td>
<td>5.6</td>
<td>5.1</td>
</tr>
<tr>
<td>3</td>
<td>7.8</td>
<td>1.6</td>
<td>7.5</td>
</tr>
<tr>
<td>4</td>
<td>5.5</td>
<td>0.8</td>
<td>46.7</td>
</tr>
</tbody>
</table>

*Years 1–4 are 5 March 1974 to 17 April 1978 (1st expt)
**Years 1–2 are 20 March 1977 to 29 March 1979 (2nd expt)

soils is a reflection of the addition of unlabelled nitrogen in the second year.

Incorporation of nitrogen into roots and soil organic matter

The extent to which applied inorganic nitrogen is immobilized in the soil, either temporarily assimilated into plant roots and micro-organisms or more permanently in the soil humus, has not received a great deal of attention in recent years, particularly under field or near-to-field conditions. Some of the nitrogen contained in living plant roots must of course be considered available to the plant for production of leaf dry matter, but once roots die, the organic nitrogen enters the internal nitrogen cycle of the soil, through the action of growth and decay of micro-organisms.

When the first series of lysimeter experiments described earlier were terminated, the soil and roots were removed from the lysimeters and analysed for $^{15}$N content in horizons 5 cm or 10 cm thick; no attempt was made to separate the roots from the soil. The preliminary results from this analysis presented in Table 5 show that over 25 per cent of the nitrate-N applied at the beginning of the experiment was found within the soil and roots, and of this, two-thirds was within the top 10 cms of the profile where the greatest numbers of roots and micro-organisms reside. These results show that in an arable soil sown to grass, a sizeable fraction of the applied inorganic nitrogen is immobilized in the soil organic matter and is unavailable for crop growth. The extent to which such nitrogen may be released by mineralization after ploughing the sward is not known and awaits future experiments.

However, some estimates of the release of soil organic nitrogen by mineralization during the growth of the sward can be made from these lysimeter experiments. The amount of nitrogen taken up by unfertilized grass in these experiments was 72 kg N/ha on the sandy loam soil, and 120 kg N/ha on both the clay and the silt loam. These compare well with the range of values recorded in the ADAS-GRI experiment described earlier, of 11–157 kg N/ha with a mean value of 60 kg N/ha, or in another study of the nitrogen yield of all grass swards (10–90 kg N/ha) at 38 field sites in the United Kingdom (Brockman, 1969). Consideration of the ratio of labelled to unlabelled nitrogen in the fertilized, harvested grass crop from the lysimeters suggests that the production of inorganic nitrogen in the soil may be even greater than that estimated from the unfertilized crop. In the sandy loam soil, 143 kg N/ha of unlabelled nitrogen was taken up by the crop in the first year of the experiment;

Table 5. Proportions of immobilised nitrogen* contained within various horizons for the sandy loam soil.

<table>
<thead>
<tr>
<th>Depth, cm</th>
<th>0-5</th>
<th>5-10</th>
<th>10-20</th>
<th>20-30</th>
<th>30-40</th>
<th>40-50</th>
<th>50-60</th>
<th>60-70</th>
<th>70-80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer N recovered kg/ha</td>
<td>44.9</td>
<td>23.8</td>
<td>16.3</td>
<td>6.2</td>
<td>2.6</td>
<td>2.9</td>
<td>3.0</td>
<td>2.4</td>
<td>1.9</td>
</tr>
<tr>
<td>Per cent of immobilized N</td>
<td>42.6</td>
<td>22.6</td>
<td>15.4</td>
<td>5.9</td>
<td>2.5</td>
<td>2.7</td>
<td>2.8</td>
<td>2.3</td>
<td>1.7</td>
</tr>
</tbody>
</table>

*104.0 kg N/ha equivalent to 26.7 per cent of that applied
Table 6. The uptake of labelled and unlabelled nitrogen (kg N/ha) by grass treated with 400 kg/ha nitrogen fertilizer labelled with 15N in the first year of the experiments. In the clay and silt loam soils, unlabelled fertilizer (400 kg N/ha) was added in the second year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Sandy loam* labelled</th>
<th>Sandy loam* unlabelled</th>
<th>Clay* labelled</th>
<th>Clay* unlabelled</th>
<th>Silt loam* labelled</th>
<th>Silt loam* unlabelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>201</td>
<td>143</td>
<td>184</td>
<td>140</td>
<td>184</td>
<td>146</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>101</td>
<td>19</td>
<td>344</td>
<td>34</td>
<td>417</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>71</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*See footnote to Table 4.*

The greatest losses of nitrogen were associated with the winter that followed the exceptionally dry winter and summer of 1976; similar observations have been reported by Garwood and Tyson (1977).

Leaching losses of nitrogen

In the experiments conducted between 1971 and 1977 by ICI, losses of nitrogen from grazed fields were measured in the water issuing from the tile drainage system installed in each field. The flow of water from each field was recorded by a V-notch weir equipped with proportional sampling equipment. Two fertilizer nitrogen application rates, 250 and 750 kg N/ha, were compared. The amount of nitrogen lost in the drainage water (almost exclusively as nitrate) is considered to be an underestimate because it is difficult to make allowance for water that moves into deep ground water between the drains. Results for six years of the experiment are presented in Table 7.

Table 7. Losses of nitrogen by leaching from grazed grass fields treated with 250 and 750 kg N/ha annually.

<table>
<thead>
<tr>
<th>Year</th>
<th>Rainfall (1 April-31 March) mm</th>
<th>Fertilizer application rate</th>
<th>250 kg N/ha kg N/ha</th>
<th>750 kg N/ha kg N/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971-72</td>
<td>709</td>
<td>21</td>
<td>73*</td>
<td></td>
</tr>
<tr>
<td>1972-73</td>
<td>422</td>
<td>1</td>
<td>5*</td>
<td></td>
</tr>
<tr>
<td>1973-74</td>
<td>732</td>
<td>10</td>
<td>31*</td>
<td></td>
</tr>
<tr>
<td>1974-75</td>
<td>911</td>
<td>14</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>1975-76</td>
<td>493</td>
<td>21</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>1976-77</td>
<td>804</td>
<td>72</td>
<td>388</td>
<td></td>
</tr>
</tbody>
</table>

*Results for the 750 kg/ha rate these years may be an underestimate due to problems with analytical methods for nitrate.
denitrification as nitrous oxide and dinitrogen ($N_2$) are usually estimated in lysimeter experiments by the difference between that applied and that recovered in plants, soil and water (Allison 1955). It is only in recent years that techniques have been developed which permit relatively easy estimation of nitrous oxide emissions from soil (Dowdell and Crees 1974; Hutchinson and Mosier, 1979; Denmead, 1979; Hutchinson and Mosier, 1979; Burford et al, 1980). There is only one published report of nitrous oxide emission from grassland soils (Denmead et al, 1979). The losses as dinitrogen ($N_2$) are exceedingly difficult to measure but there is some promise that the inhibition of nitrous oxide reductase by acetylene may provide improved estimates of nitrogen loss by this route (Yoshinari and Knowles, 1976; Ryden et al, 1979a; 1979b).

The grassland lysimeters installed at Letcombe Laboratory were specifically designed to enable small losses of nitrous oxide to be detected by direct measurement of nitrous oxide emissions from the soil surface. In the sandy loam lysimeters, nitrous oxide emission did not exceed 0.04 kg N/ha/yr. In the clay and silt loam lysimeters emission was consistently greatest from the clay soil, with peak rates of evolution reaching 0.012 kg N/ha/d in the autumn and only 0.002 kg N/ha/d in the winter. During the summer months however, peaks of nitrous oxide emission were observed on both soils immediately following nitrogen application (Fig. 1), particularly if these coincided with significant rainfall events or irrigation. Peak values often reached 0.25 kg N/ha/d, but did not persist for more than 2-5 days. For comparison, a continuous emission of nitrous oxide at a rate of 100 $\mu$g/m$^2$/h is equivalent to 8.7 kg N/ha/year. On grassland treated with animal slurry or ammonium nitrate, emissions of nitrous oxide during a period in August 1979, were equivalent to 0.4 per cent of the slurry-N and 2.8 per cent of the ammonium nitrate (Sanders, 1980). There is unfortunately no information yet available about the contribution of fertilizer nitrogen to this nitrous oxide loss.

![Fig. 1. The emission of nitrous oxide from a grass sward growing on a clay loam in lysimeters. The dark arrows indicate additions of nitrogen to the fertilized sward (totaling 400 kg N/ha).](image)

The nitrogen balance

It is a formidable task to establish an accurate nitrogen balance for cut or grazed grassland particularly under field conditions, largely due to uncertainties and errors in determining the extent of recycling of nitrogen via excreta of animals and changes in total nitrogen content of the soil. The information derived from the Jealott's Hill studies described previously was used to compile a nitrogen balance sheet for the two 5 ha areas (consisting of 3 x 0.81 ha grazing paddocks and one 2.63 ha area which each year was cut twice for silage and subsequently grazed). The amount of nitrogen that was recycled by the grazing animal was estimated by assuming that about 80 per cent of the ingested nitrogen was voided and that 30 per cent of this was lost by volatilization. The nitrogen balance sheet covering six years of this experiment is given in Table 9.
Table 9. Nitrogen balance of grazed grassland, over a six year period.

<table>
<thead>
<tr>
<th>Inorganic nitrogen application rate</th>
<th>Total kg N/ha/6 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 kg N/ha/year</td>
<td>2293</td>
</tr>
<tr>
<td>750 kg N/ha/year</td>
<td>5613</td>
</tr>
</tbody>
</table>

| Total nitrogen applied* | 2293 | 5613 |
| Nitrogen recovered in:  |      |      |
| herbage                | 1324 | 1913 |
| drainage               | 139  | 652  |
| N unaccounted for      | 830  | 3048 |

*Including nitrogen in rainfall and estimates of recycled nitrogen.

Although the amounts of nitrogen not accounted for are quite large, it is noted that at the lower rate of nitrogen, herbage and leachate account for an amount of nitrogen (1483 kg N/ha) nearly equivalent to the fertilizer applied (1500 kg N/ha), but at the higher rate herbage and leachate only accounted for just over half (2565 kg N/ha) of what had been applied as fertilizer (4500 kg N/ha).

This experiment had not been designed primarily with the intention of determining the fate of applied nitrogen and because it was done on a field scale it was not possible to determine the magnitude of gaseous losses of nitrogen nor the effect of the treatments on the total nitrogen content of the soil.

These estimates of nitrogen that cannot be accounted for are likely to be subject to substantial errors, simply because of the scale of the operation. The amounts of nitrogen involved, however, are large enough to suggest that other sinks for applied fertilizer nitrogen such as immobilization in the soil organic matter and perhaps gaseous losses by denitrification might have some practical significance.

In lysimeter studies not involving animal excreta the problems are considerably diminished, and the major uncertainty that remains is that of estimating gaseous losses, particularly of dinitrogen. The precision of the results as to the fate of fertilizer nitrogen can be further improved by use of 15N-labelled fertilizers. Preliminary results from lysimeter experiments conducted at Letcombe Laboratory (Dowdell and Webster, 1980) are presented for the nitrogen balance of a sown grass on a sandy loam soil (Table 10). The amount of nitrogen not accounted for in this experiment represents 2.4 per cent of that added as fertilizer, and this lies within the errors of the experiment. It is considered that for practical purposes the recovery of the fertilizer nitrogen is complete.

Future work should be aimed at quantifying

Table 10. Preliminary nitrogen balance of perennial ryegrass for a three-year period (1975-78).*

<table>
<thead>
<tr>
<th>Nitrogen applied (calcium nitrate)</th>
<th>kg/ha</th>
<th>% of applied</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>395</td>
<td>100</td>
</tr>
</tbody>
</table>

| Nitrogen recovered in:            |       |              |
| harvested herbage                 | 234   | 69.5         |
| stubble                           | 136   | 32.2         |
| soil and roots                    |       |              |
| Nitrogen lost by:                 |       |              |
| leaching                          | 21    | 5.3          |
| denitrification \(N_2O, NO, N_2\) | <0.04 | <0.01        |
| Total                             | 244   | 62.6         |
| Nitrogen not accounted for        | 51    | 14.4         |

*The fertilizer nitrogen was applied only in the first growing season and results relate to two further growing seasons and three drainage winters.
more precisely the losses of nitrogen as gases, particularly as dinitrogen. Also much more needs to be known about the nitrogen cycle of the soil, especially the effect of immobilization/mineralization cycles on the availability of native inorganic nitrogen and on the efficiency of fertilizer use. These are particularly important in grazed grassland under intensive management where relatively large applications of fertilizer nitrogen are used and considerable amounts of nitrogen are returned in the excreta.

References


NITROGEN EMISSION FROM GRASSLAND FARMS - A MODEL APPROACH

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Institute for Land and Water Management Research (ICW), Wageningen, the Netherlands

Summary

A model approach for the nitrogen balance of a dairy enterprise is used to evaluate the effects of farm intensification, improvement of water management and farming conditions, soil productivity and manure storage during the winter on humus accumulation in the soil, the N-fertilizer requirement and the N-emission to surface waters.

1. Introduction

For centuries animal manures were used as the principal source for maintaining soil fertility. In recent years, however, the appreciation of animal manures as a source of nutrients has decreased in many countries because of the availability of convenient and relatively inexpensive chemical fertilizers.

The technical development in housing systems, mechanization of milking, manure removal and feeding enabled the farmer to enlarge the number of animals per man. The importation of relatively cheap concentrates and maize silage roughage made him independent of the fodder production of his land. The intensification of dairy farming has led to a large production of animal manure. These large quantities, combined with the availability of chemical fertilizers, have given rise to a situation often referred to as the animal manure disposal problem. Storage during the entire winter is expensive, forcing the farmer to spread the slurry also in the winter period. Difficult soil and drainage conditions on part of the farm limit the area suitable for application of slurry and may result in local overdosing.

The potential of livestock wastes to pollute surface- and groundwater is large, particularly when plant nutrients are supplied in excess of crop requirements. The extent of the problems of manure disposal was not envisaged in the early stages of intensive stocking at dairy enterprises. However, restrictions in landspreading of manures may be expected in future, following the increasing awareness and concern of the public regarding the quality of the environment.

The rapid increase in the costs of inorganic fertilizers at present and a stricter control of all sources of pollution require an efficient use of animal manure for crop production. A large quantity of nitrogen circulates within the farm through grass production

input

<table>
<thead>
<tr>
<th>concentrated feeds</th>
<th>maize silage</th>
</tr>
</thead>
</table>

net fodder production

yield residues roots

biological N-fixation

precipitation

chemical fertilizers

output

<table>
<thead>
<tr>
<th>animal</th>
<th>meat</th>
</tr>
</thead>
<tbody>
<tr>
<td>milk</td>
<td></td>
</tr>
</tbody>
</table>

animal manure

organic N

mineral N

humification

mineralization

denitrification

leaching

Fig. 1. Scheme of the nitrogen balance of a dairy enterprise.
and by the use of animal manure. A nitrogen balance for this type of a dairy livestock farm is given in Fig. 1.

A steady-state situation will be reached, when the farm management remains constant during some generations. In that case the nitrogen input equals the output in the farm and the internal nitrogen turnover need not to be considered. However, no steady-state situations exist because of the increasing stocking rates, the rise in fertilizer use, or increase in grassland productivity through improved drainage conditions and application of sprinkler irrigation. This means that the amount of nitrogen in circulation within the farm is still subject to change. The quantification of the amount of mineral nitrogen in the soil \( N_s \) from the various sources is necessary under these conditions, as part of the nitrogen input in the system is immobilized and accumulates in the soil organic matter. An analysis of the nitrogen balance in this situation requires a quantitative description of:

- the relation between the amount of mineral nitrogen \( (d N_s/dY) \) in the soil and the gross production of grass (chap. 2);
- the relation between the supply of organic nitrogen and both humification and mineralization (chap. 3);
- the effect of water management on denitrification and leaching of nitrogen (chap. 4).

The various aspects of the nitrogen balance will be combined to a model approach in chap. 5. A series of calculated examples will be discussed in chap. 6, to demonstrate the effects of increasing stocking rate, improved grassland production, different drainage conditions and winter storage of slurry on the fertilizer requirement and on the environmental pollution.

2. Mineral nitrogen requirement and gross production of grass

The amount of mineral nitrogen in the soil required for the production of 1 kg dry matter \( (d N_s/dY) \) can be considered as a function of the yield deficit \( (Y_{\text{max}} - Y) \). Experimental data of Frankena (1939), Mulder (1949), Oostendorp (1964) & Boxom (1973) have been used to formulate this relation. The data are given in Fig. 2, showing that the relation can be expressed as:

\[
\frac{d N_s}{d Y} = 62.7 \frac{Y_{\text{max}} - Y}{Y_{\text{max}}} + 0.04
\]

where \( Y_{\text{max}} \) = the maximum dry matter production in kg per ha, at maximum N-supply and dependent on factors like botanical composition, water management conditions, etc.

\( Y \) = the actual dry matter production in kg per ha.

Fig. 2. Relation between nitrogen requirement per kg dry matter \( (d N_s/dY) \) and the production deficit \( (Y_{\text{max}} - Y) \) of grassland (x clay, • peat, o sand)

The data in Fig. 2 indicate that the relation is independent of the type of soil and the value of \( Y_{\text{max}} \).

Integration of eq. (1) yields a relation between the quantity of mineral nitrogen in the soil \( N_s \) in kg per ha and the gross production of grass. This relation can be written expressing \( Y_{\text{max}} \) and \( Y \) in tonnes per ha, as:

\[
\text{gross dry matter production} = \frac{62.7}{Y_{\text{max}} - Y} N_s + 0.04 \frac{Y_{\text{max}} - Y}{Y_{\text{max}}}
\]

Fig. 3. Relation between mineral nitrogen \( (N_s) \) in the soil and gross dry matter production of grass at various levels of \( Y_{\text{max}} \) (x clay, • peat, o sand)
3. Humification and mineralization

The increase in soil organic matter originates mainly from crop and root residues and from animal manure. The crop residue is the part of the dry matter production that remains
in the field after harvesting and grazing. This quantity is generally higher on wet lands than on dry ones. The coefficients for humification of herbage and roots are 0.20 and 0.25, respectively (Kolenbrander, 1974).

So herbage residues of 1000 kg dry matter result in 200 kg 'humus'. With an assumed nitrogen content of 4 percent in the humus the nitrogen immobilization is 8 kg N per 1000 kg herbage residues. The amount of N present in the herbage residues as a result of the discussion in chap. 2, equals 0.53 a N_s, where a is the fraction of herbage residues. The amount of N immobilized in humus equals 8 a Y, so 0.53 a N_s - 8 a Y is the amount of N that mineralizes within 1 year. The nitrogen immobilization through 'humification' of roots equals 14 kg N per 1000 kg dry root material. This 14 kg N in combination with eq. (4) gives the amount of N immobilized by humification of the root residues, while eq. (5) gives the total amount present in the roots.

A dairy cow (inclusive of young stock), producing 4500 kg milk (41 fat) and 192 kg beef is defined in the Netherlands as 1.31 standard livestock unit (SLU). Based on the average N-content and the feeding value of herbage and concentrates such a SLU produces in the cattle slurry 44.6 and 58.0 kg N in winter and summer half year, respectively. According to Sluijsmans & Kolenbrander (1976) 50% of the nitrogen in the cattle slurry is available as mineral nitrogen, 25% mineralizes within 1 year and 25% in following years. The relative balance of the nitrogen present in the slurry is given in Table 1 (Henkens, 1977).

| Table 1. Relative N balance of cattle manure during summer and winter expressed as fraction of the total nitrogen (N_tot), (Henkens, 1977). |
|----------------------------------|----|----|----|----|
| Grazing period                  | Stall period with landspreading in | | |
|                                  | spring | autumn | mean | |
| Volatilization during spreading  | 0.005  | 0.6   | 0.06 | 0.06 |
| Volatilization on ground        | 0.55   | 0.565 | -    | 0.283 |
| Directly available for crop     | -      | -     | 0.34 | 0.17 |
| Mineral N present in autumn     | -      | -     | 0.34 | 0.17 |
| Mineralization in autumn and winter | 0.025 | 0.005 | 0.05 | 0.027 |
| Mineralization next year        | 0.10   | 0.20  | 0.11 | 0.11 |
| Humification                    | 0.25   | 0.25  | 0.25 | 0.25 |
| Total                           | 1.00   | 1.00  | 1.00 | 1.00 |

The nitrogen immobilization by humification is 25 percent of the total amount of nitrogen, present in the animal manure. This amount equals 0.25 x 102.6 kg N per standard livestock unit. Each year a part of the immobile nitrogen in the humus becomes available by mineralization. The amount of mineralization can be assumed to be proportional with the amount of nitrogen present in the humus at the beginning of the year. The yearly net immobilization of nitrogen in the humus equals the sum of amounts of nitrogen immobilized by humification of the herbage residues and the root residues and 25 percent of the nitrogen in the manure minus the nitrogen mineralization of the humus. The yearly net immobilization can be given by the expression:

\[
\frac{dN_H}{dt} = -\gamma N_H(t-1) + \left(8a_t + \frac{14}{0.375Y_t+0.25}\right)Y_t + 25.7n_t \tag{6}
\]

where \(dN_H/dt\) = the net quantity of N immobilized in humus each year
\(\gamma\) = the mineralization coefficient of humus
\(N_H(t-1)\) = the amount of N present in humus in the year \(t-1\)
\(a_t\) = fraction of herbage residues in year \(t\)
\(Y_t\) = gross dry matter production in tonnes per ha in year \(t\)
\(n_t\) = stocking rate in SLU per ha in year \(t\)

The net amount of nitrogen immobilized in humus after successive phases of farm intensification can be given by integration of eq. (6). This gives as result:

\[
N_H(t) = (1-\gamma)^T N_H(0) + \sum_{t=1}^{T} (1-\gamma)(T-t) \left[\left(8a_t + \frac{14}{0.375Y_t+0.25}\right)Y_t + 25.7n_t\right] \tag{7}
\]

where \(N_H(t)\) = amount of nitrogen present in humus in year \(T\) in kg/ha
\(N_H(0)\) = amount of nitrogen present in humus in year 0 in kg/ha

Estimates of the mineralization coefficient \(\gamma\) have been derived from data given by Schothorst (1977), resulting in \(\gamma\)-values equalling 0.004, 0.0075 and 0.015 for poorly, moderately and well drained grasslands, respectively.
4. Losses of nitrogen

Apart from the already mentioned emission due to volatilization, nitrogen is lost from the farm by denitrification and leaching.

4.1. Denitrification

Anaerobic conditions, availability of organic compounds and sufficiently high temperatures have to be present to initiate denitrification. It is convenient to assume for seasonal balances that the rate of denitrification is proportional to the difference between the amount of mineral nitrogen in the soil \( N_s \) and the nitrogen taken up by the plant \( N_{upt} \). This assumption can be given by the equation:

\[
N_d = \alpha_s (N_s - N_{upt})
\]

where \( N_d \) = nitrogen loss by denitrification in \( \text{kg/ha} \)
\( N_s \) = mineral nitrogen in the soil (eq. 2)
\( N_{upt} \) = nitrogen uptake by the plant (eq. 3 + eq. 5)
\( \alpha_s \) = denitrification coefficient in summer

Based on data presented by Steenvoorden & Fonck (1980), values for sand, clay and peat soils for the summer half year are given in Table 2.

<table>
<thead>
<tr>
<th>Log suction PpF</th>
<th>Denitrification coefficient ( \alpha_s ) in sand, clay and peat soils in summer (Steenvoorden &amp; Fonck, 1980).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation</td>
<td>sand</td>
</tr>
<tr>
<td>1.7</td>
<td>0.85</td>
</tr>
<tr>
<td>2.4</td>
<td>0.76</td>
</tr>
<tr>
<td>2.9</td>
<td>0.65</td>
</tr>
<tr>
<td>3.4</td>
<td>0.45</td>
</tr>
</tbody>
</table>

4.2. Leaching of nitrogen

The amount of nitrogen lost by leaching can be calculated, using a model applied by Hamaker (1975) for the calculation of salt leaching in greenhouses. The soil profile is subdivided in a number of layers. Through the boundary of each layer transport of ions takes place by mass transport of water. It is assumed that in each layer a complete mixing of the water present in the layer and the incoming water takes place. Under these assumptions the ion balance of the \( n \)th layer can be written as:

\[
L_0 \frac{dC_n(t)}{dt} = \left[ V_D C_{n-1}(t) - V_D C_n(t) \right] dt
\]

where \( L_0 \) = thickness of the layer in cm
\( \theta_n \) = volumetric moisture content in layer \( n \)
\( V_D \) = flow velocity in \( \text{cm/day} \)
\( C_n \) and \( C_{n-1} \) = ion concentration in layer \( n \) and \( n-1 \)
\( t \) = time in days

Substituting \( A_0 = (L_0 \theta_n)^{-1} \) and rearranging eq. (9) gives:

\[
\frac{d}{dt} \left[ C_n(t) \right] + A_n V_D C_n(t) = A_0 V_D C_n-1(t)
\]

This equation can be solved under the boundary conditions: \( C_n(t) = C_n(t_0) \) for \( t = 0 \). Introduction of a constant moisture volume per layer \( (L_0 \theta_n = \text{constant}) \) gives: \( A_0 = A_1 = A_2 = \ldots \ldots = A_n \). Integration of eq. (10) results in that case in:

\[
C_n(t) = \sum_{k=0}^{n} \left[ C_k(t_0) \right] \exp\left[-AV_D t\right] \left[1/(n-k)\right]
\]

Nitrogen leaching can be calculated from eq. (11) in its relation to the amount of water percolated through the soil. \( V_T \) is the precipitation surplus during winter.

The distribution of nitrogen in the profile in spring can be calculated for different values of the precipitation surplus, when the initial amount of nitrogen in autumn (at \( t = 0 \)) is concentrated in the root zone. In the present study, however, the distribution of nitrogen over the profile is of minor importance compared with the integrated value over the profile depth.

Relative amounts of nitrogen in relation to moisture volume in the soil are presented in Fig. 5 for different values of the precipitation surplus. Moreover the corresponding depths in sand, clay and peat soils are given. The curves drawn in Fig. 5 give the relative amount of nitrogen present in spring in the soil above the corresponding depths.

Kolenbrander (1969) gives data from lysimeter experiments on sandy soils showing that
Fig. 5. Relation between the relative amounts of nitrogen present above certain depths in the profile and winter precipitation surplus. The depth is given as a soil moisture depth in mm, as well as in cm below surface for sand (S), clay (C) and peat (P) soils.

50 percent of the amount of nitrogen was lost by leaching. These lysimeters had a depth of 1 m and the estimated moisture volume of the installation was about 400 mm. The data in Fig. 5 show that at an average precipitation surplus of 350 to 400 mm and a soil moisture volume of 400 mm about 50 percent of the nitrogen remains in the soil.

In poorly drained soils part of the precipitation in winter is discharged by surface runoff and by transport through the shallow top layer of the root zone to the surface water. Under these conditions the residence time of both precipitation surplus and nitrogen in the soil is very short. Therefore, the main part of the nitrogen in the root zone will be transported to the surface waters during winter. Well drained soils generally have a deep percolation of the precipitation surplus and the residence times in the soil of more than 5 years are not unusual. However, when the nitrogen is transported deeply into the soil profile, it does not return to the root zone during the following summer. Practical experience has shown that nitrogen below a depth of 120, 110 and 80 cm in sand, clay and peat soils, respectively, can be considered as being lost for grass growth.

Grasslands are very often shallowly drained by small ditches. In that case the average transport depth in the soil profile reaches to about 60 to 80 cm, resulting also in a relatively short residence time in the soil profile. The nitrogen losses due to leaching under different drainage conditions can be determined with the aid of Fig. 5. The data are summarized in Table 3.

The total loss of mineral nitrogen in winter equals the combined losses due to denitrification in winter and leaching. The relative load to surface water can be given by \((1-\alpha_s)\beta\), where \(\alpha_w\) is the denitrification coefficient in winter and \(\beta\) the leaching coefficient. Due to the long residence time of the precipitation surplus in well drained soils, part of the nitrogen leached is subjected to denitrification during the following summer. Because of this fact the ultimate nitrogen load from well drained soils to surface waters additionally will decrease, compared with poorly and moderately drained soils. The relative nitrogen load to the surface waters can be given by the expression \((1-\alpha_s)(1-\alpha_w)\beta\). If sufficient organic compounds are present in the saturated zone, in that case \(\alpha_s\) equals in the saturated soil 0.85 (Table 2).

Table 3. Relative nitrogen losses by leaching (\(\beta\)) in relation to precipitation surplus during winter for three types of soils with different drainage conditions.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Precipitation surplus in winter in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Sand</td>
<td></td>
</tr>
<tr>
<td>poor</td>
<td>0.55</td>
</tr>
<tr>
<td>moderate</td>
<td>0.09</td>
</tr>
<tr>
<td>good</td>
<td>0.01</td>
</tr>
<tr>
<td>Clay</td>
<td></td>
</tr>
<tr>
<td>poor</td>
<td>0.42</td>
</tr>
<tr>
<td>moderate</td>
<td>0.02</td>
</tr>
<tr>
<td>good</td>
<td>0.00</td>
</tr>
<tr>
<td>Peat</td>
<td></td>
</tr>
<tr>
<td>poor</td>
<td>0.10</td>
</tr>
<tr>
<td>moderate</td>
<td>0.00</td>
</tr>
<tr>
<td>good</td>
<td>0.00</td>
</tr>
</tbody>
</table>
5. A model approach of the nitrogen balance of a dairy farm

A model can be used to evaluate the effects of different measures, e.g. farm intensification, improvement of grass production, changes in water management conditions or provision of manure storage during winter, in terms of nitrogen efficiency and nitrogen emission. The required amount of additional nitrogen in a dairy enterprise can be calculated with the following equation:

\[ N_{\text{add}} = N_s - N_{\text{(net h.res.)}} - N_{\text{(net roots)}} + N_{\text{(net roots)}} - \gamma N(t-1) - N_{\text{man.}} \]  

(12)

where \( N_{\text{add}} \) = additional N supply by fertilizers, precipitation and biological nitrogen fixation in kg/ha

\( N_s \) = mineral nitrogen in the soil, calculated from eq. (2)

\( N_{\text{(net h.res.)}} \) = net amount of mineral nitrogen available within one year through mineralization of herbage residues. The amount of N mineralizing is given in chap. 3. It is assumed that 20 percent of the mineralization occurs in autumn and winter

\( N_{\text{(net roots)}} \) = net amount of mineral nitrogen available through mineralization of dead roots, assuming that 20 percent mineralizes during autumn and winter. The total amount mineralizing equals the quantity calculated from eq. (5) minus 14Y.

\( N_{\text{(res.)}} \) = amount of mineral nitrogen still present in spring as the residue of the quantity \( N_s \) of the preceding year. This amount equals \( (1-\beta)(1-\alpha_{w})(1-\alpha_s)(N_s - N_{\text{upt}}) \) (see eq. (8))

\( \gamma \) = net mineralization coefficient of humus, assuming that 20 percent mineralizes in autumn and winter

\( N_{H}(t-1) \) = total amount of nitrogen present in humus at the end of the preceding year \((t-1)\), calculated from eq. (7) with the substitution \( T = (T-1) \)

\( N_{\text{man.}} \) = amount of mineral nitrogen available from manure. This quantity can be calculated from Table 1 as:

\[ N(\text{direct available}) = 0.55N_{\text{tot}} \] (grazing) + 0.283N_{\text{tot}} \] (stall)

\[ N(\text{mineral present in autumn}) = (1-\alpha_{w})(1-\beta)0.17N_{\text{tot}} \] (stall)

\[ N(\text{mineralizing from prec. year}) = 0.10N_{\text{tot}} \] (grazing) + 0.1N_{\text{tot}} \] (stall)

\[ N_{\text{(not mineralization in winter)}} = (1-\alpha_{w})(1-\beta)(0.025N_{\text{tot}} \] (grazing) + 0.027N_{\text{tot}} \] (stall)

Adding this gives:

\[ N_{\text{man.}} \] (per SLU) = \[ 0.85 + 0.025(1-\alpha_{w})(1-\beta) \] N_{\text{tot}} \] (grazing) + 0.393 + 0.197(1-\alpha_{w})(1-\beta) \] N_{\text{tot}} \] (stall)

With \( N_{\text{tot}} \] (grazing) and \( N_{\text{tot}} \] (stall) equaling 58.0 and 44.6, respectively, gives as expression for \( N_{\text{man.}} \) in kg per ha:

\[ N_{\text{man.}} = [55.2 + 10.24(1-\alpha_{w})(1-\beta)]n_t \]  

(13)

When storage during the winter is present the coefficients 0.283, 0.17, 0.11 and 0.027 for the winter period have to be replaced by the spring spreading coefficients 0.565, 0.02, 0.00 and 0.005 respectively, giving the expression:

\[ N_{\text{man.}} = [63.8 + 1.64(1-\alpha_{w})(1-\beta)]n_t \]  

(13a)

The effect of the assumption that 20 percent of the mineralization of nitrogen takes place in winter, can be approximated by the expression \[ [0.9 + 0.1(1-\alpha_{w})(1-\beta)]N_{\text{(mineralizing)}} \], when the mineralization is proportional with time.

The amount of nitrogen lost by leaching \( N_{\text{leach}} \) depends on the amount of mineral nitrogen present in autumn and on the quantity mineralizing during winter and autumn.

6. Some results of model calculations

A series of calculations have been made for average climatic conditions in the Netherlands, demonstrating the effects of farm intensification, improvement of water management and farming conditions, increase of maximum soil productivity and manure storage during winter on humus accumulation in the soil, the additional nitrogen requirement and the nitrogen load on surface waters. For the data shown in this paper it is assumed that the maximum production level \( Y_{\text{max}} \) equals 10.2, 12.2 and 15.2 tonnes/ha on poorly, moderately and well drained soils, respectively. The fraction of herbage residues equals 0.5, 0.4 and 0.25, respectively.

6.1. Contribution of the various N sources

The model makes it possible to evaluate the contribution of the various internal nitrogen sources to the value of \( N_s \). The contribution of the net mineralization of herbage and root residues, the residual value of \( N_s \) of the preceding year, the net mineralization of humus split up in the contribution of plant and manure components and the available mineral N
Table 4. Relation between gross dry matter production ($Y_t$), the mineral nitrogen in the soil ($N_s$) and the average contribution from the various $N$ sources: net herbage residues ($N_1$), root residues ($N_2$), the residual $N_s$ of the preceding year ($N_3$) net humus mineralization of plant components ($N_4$) and of manure components ($N_5$), and $N_{man}$ ($N_6$).

<table>
<thead>
<tr>
<th>$Y_t$ (tonnes/ha)</th>
<th>$N_s$ (kg/ha)</th>
<th>$N_1$ (kg/ha)</th>
<th>$N_2$ (kg/ha)</th>
<th>$N_3$ (kg/ha)</th>
<th>$N_4$ (kg/ha)</th>
<th>$N_5$ (kg/SLU)</th>
<th>$N_6$ (kg/SLU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poorly drained $Y_{max} = 10.2$ tonnes/ha</td>
<td>$a_t = 0.5$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>296</td>
<td>49</td>
<td>7</td>
<td>2</td>
<td>52</td>
<td>23</td>
<td>56</td>
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<tr>
<td>7</td>
<td>353</td>
<td>59</td>
<td>8</td>
<td>2</td>
<td>56</td>
<td>23</td>
<td>56</td>
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<tr>
<td>8</td>
<td>416</td>
<td>71</td>
<td>10</td>
<td>3</td>
<td>60</td>
<td>23</td>
<td>56</td>
</tr>
<tr>
<td>9</td>
<td>494</td>
<td>86</td>
<td>12</td>
<td>3</td>
<td>64</td>
<td>23</td>
<td>56</td>
</tr>
<tr>
<td>10</td>
<td>647</td>
<td>119</td>
<td>20</td>
<td>4</td>
<td>68</td>
<td>23</td>
<td>56</td>
</tr>
<tr>
<td>Moderately drained $Y_{max} = 12.2$ tonnes/ha</td>
<td>$a_t = 0.4$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>387</td>
<td>52</td>
<td>7</td>
<td>12</td>
<td>56</td>
<td>24</td>
<td>58</td>
</tr>
<tr>
<td>9</td>
<td>444</td>
<td>61</td>
<td>8</td>
<td>14</td>
<td>59</td>
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<td>10</td>
<td>507</td>
<td>70</td>
<td>9</td>
<td>17</td>
<td>62</td>
<td>24</td>
<td>58</td>
</tr>
<tr>
<td>11</td>
<td>585</td>
<td>82</td>
<td>11</td>
<td>20</td>
<td>65</td>
<td>24</td>
<td>58</td>
</tr>
<tr>
<td>12</td>
<td>738</td>
<td>110</td>
<td>18</td>
<td>26</td>
<td>68</td>
<td>24</td>
<td>58</td>
</tr>
<tr>
<td>Well drained $Y_{max} = 15.2$ tonnes/ha</td>
<td>$a_t = 0.25$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>521</td>
<td>45</td>
<td>7</td>
<td>35</td>
<td>55</td>
<td>25</td>
<td>61</td>
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<tr>
<td>12</td>
<td>578</td>
<td>50</td>
<td>7</td>
<td>39</td>
<td>57</td>
<td>25</td>
<td>61</td>
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<tr>
<td>13</td>
<td>644</td>
<td>56</td>
<td>8</td>
<td>44</td>
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<td>14</td>
<td>719</td>
<td>64</td>
<td>10</td>
<td>50</td>
<td>61</td>
<td>25</td>
<td>61</td>
</tr>
<tr>
<td>15</td>
<td>872</td>
<td>82</td>
<td>16</td>
<td>61</td>
<td>63</td>
<td>25</td>
<td>61</td>
</tr>
</tbody>
</table>

6.2. Effects of farm intensification and water management improvement on humus accumulation and additional nitrogen requirement

A humous loamy fine sand and a humous medium coarse sand have been introduced into this example. The mineralization coefficient of the humus equals 0.0075 for the first soil under moderate drainage conditions and 0.015 under good drainage conditions. The mineralization coefficients for the second soil are 0.00125 and 0.015, respectively. The basic data for the calculations in this example are given in Table 5.

When at the time $t = 0$ steady state conditions have been reached for the given farm data, the value of $N_h(0)$ equals 12,300 kg/ha for the first soil and 7400 for the second one. The same scheme of intensification and of water and farm management improvement has

Table 5. Basic farm data for the given example.

<table>
<thead>
<tr>
<th>Time period in years</th>
<th>Stocking rate SLU/ha</th>
<th>$Y_{max}$ (tonnes/ha)</th>
<th>$Y_t$ (tonnes/ha)</th>
<th>Residue fraction</th>
<th>Drainage conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.1</td>
<td>12.2</td>
<td>8.0</td>
<td>0.40</td>
<td>moderate</td>
</tr>
<tr>
<td>1-10</td>
<td>1.5</td>
<td>12.2</td>
<td>10.5</td>
<td>0.40</td>
<td>moderate</td>
</tr>
<tr>
<td>11-20</td>
<td>2.0</td>
<td>12.2</td>
<td>11.5</td>
<td>0.40</td>
<td>moderate</td>
</tr>
<tr>
<td>21-25</td>
<td>2.5</td>
<td>15.2</td>
<td>13.8</td>
<td>0.25</td>
<td>good</td>
</tr>
<tr>
<td>26-..</td>
<td>3.0</td>
<td>15.2</td>
<td>14.8</td>
<td>0.25</td>
<td>good</td>
</tr>
</tbody>
</table>

144
been applied to both soils. The results of the calculations are given in Fig. 6. The nitrogen immobilization in humus is shown in Fig. 6A. The increase in stocking rate results for both soils in a humus accumulation during the first 20 years. The improvement in drainage and farm management conditions after 20 years changes the situation. The breakdown of humus predominates in the soil with the higher humus level, even at a further increase of the stocking rate. In the second soil humus accumulation does not stop. Both soils reach the steady state at \( N_u(\infty) \) equalling 9500 kg/ha when no further change in the farming system takes place. The additional nitrogen requirement in Fig. 6B is similar for both soils till the introduction of improved farm and drainage conditions. In the first year after improvement, the soil with humus breakdown requires 80 kg/ha less nitrogen from additional sources than the other one. The additional requirement equals 330 kg N per ha when both soils reach the steady state again.

6.3. Relation between nitrogen fertilizer supply and purchased maize silage roughage

The model may help to optimize the supply of N fertilizers and the additional purchase of maize silage roughage. For this approach it is assumed that nitrogen fertilizer application is only profitable, when the yield increase in grass equals at least 5 kg dry matter per kg N. The results of the calculations are given in Fig. 7 for the 3 drainage conditions.

Fig. 7 shows the relation between the required amount of maize silage roughage and the nitrogen fertilizer requirements at different stocking rates. The dotted lines connect the points of the optimum ratio between maize silage roughage and nitrogen fertilizer supply. It is obvious from Fig. 7 that the N efficiency increases with improving drainage conditions.

Fig. 6. A, nitrogen immobilization in soil humus in relation to farm intensification and improvement of drainage conditions; B, the additional N requirement in relation to farm intensification and improvement of drainage conditions.
maize silage
tonnes/ha - N.

Fig. 7. Relation between additional nitrogen supply and purchased maize silage roughage for
different stocking rates. A, poorly drained soils; B, moderately drained soils; C, well drained soils.

Table 6. Nitrogen emission to surface waters in relation to dry matter production, stocking
rate and drainage conditions for sand (S), clay (C) and peat (P) soils.

<table>
<thead>
<tr>
<th>Y_t</th>
<th>Stocking rate in SLU per ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>S</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Poor drainage conditions</th>
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<th></th>
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<tbody>
<tr>
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6.4. Effect of stocking rate and drainage
conditions on nitrogen emission to surface waters

The nitrogen emission to surface waters in
relation to stocking rate and drainage conditions has been calculated for sand, clay,
and peat soils. The denitrification in the
saturated zone is of particular interest in
well drained soils, because of the long resi-
dence time of the nitrates. The denitrifica-
tion coefficient \( a_0 \) at saturation can be used
to calculate the ultimately remaining emission
to the surface waters when sufficient organic
compounds are present in the deeper soil lay-
ers. This is always the case in peat soils.

A sufficient supply of oxygen in the deeper
soil layers and a limiting quantity of organ-
ic compounds can restrict denitrification in
medium coarse sandy soils with very deep
groundwater tables. Experimental data show, however, that due to additional denitrification during the residence time in the saturated zone in well-drained sandy soils, the ultimate emission as a reasonably good mean figure reduces by 50 per cent (Rijtema, 1976).

The air-filled pore space in deeper layers of clay soils is already very limited at small depths, so aerobic breakdown or organic compounds is hardly present. This situation causes in well-drained clay soils also a large reduction in nitrogen emission by additional denitrification. The results of the calculations are given in Table 6. The data show that improvement of drainage conditions result in a reduction of the nitrogen emission to the surface waters.

6.5. Effect of winter storage of manure on nitrogen fertilizer requirements and nitrogen emission to surface waters

The efficiency of animal manures increases considerably with early spring application instead of landspreading in autumn and winter. The effect of storage during the winter can be calculated by replacing eq. (13) by (13a). The results of the calculations are given in Table 7, as the reduction in nitrogen fertilizer requirement per SLU and the reduction in emission in kg N per SLU.

It appears from Table 7 that the value of winter storage decreases with improvement of drainage conditions and that both the additional amount of available N and the environmental effect must be considered in the evaluation of the provision of winter storage.

Table 7. Effect of winter storage of manure per standard livestock unit on the reduction in nitrogen fertilizer requirement and on emission in relation to soil type and drainage conditions.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Drainage condition</th>
<th>Reduction in N-fertilizer requirement kg/SLU</th>
<th>Reduction in N-emission kg/SLU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>poor</td>
<td>8.5</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td>moderate</td>
<td>7.4</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>good</td>
<td>5.2</td>
<td>1.7</td>
</tr>
<tr>
<td>Clay</td>
<td>poor</td>
<td>8.5</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>moderate</td>
<td>6.3</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>good</td>
<td>3.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Peat</td>
<td>poor</td>
<td>7.6</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>moderate</td>
<td>4.3</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>good</td>
<td>2.5</td>
<td>0.2</td>
</tr>
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</table>

References

THE ROLE OF NITROGEN IN INTENSIVE GRASSLAND PRODUCTION - THE FUTURE

W. Holmes
Department of Agriculture, Wye College, University of London, United Kingdom

Summary

Problems facing intensive grassland production and animal production in Europe are considered. The components of the efficiency of conversion of fertilizer nitrogen to animal product are outlined.

Targets for grazing management in relation to fertilizer use are given and the influence of supplementary feeds is considered.

In the future further improvements in the utilization of fertilizer nitrogen must be sought, alternative means of exploiting atmospheric nitrogen must be developed and the possible adverse effects of fertilizer nitrogen must be anticipated and prevented.

Introduction

The productive capacity of agriculture in Western Europe now exceeds the requirements of the population for most of the temperate products and serious questions are raised about the need for agricultural expansion when we have to store and dispose of surplus products. In consequence reclamation projects which are technically feasible have been postponed because additional production is not yet required. Since population in Europe is likely to rise more slowly than the productivity of our agriculture there are doubts whether further intensification is justifiable. This particularly affects fertilizer inputs which increase the support energy per unit of food produced (Holmes, 1975). However the individual farmer, in response to falling prices often endeavours to increase production and De Wit (1979) has argued that if fossil fuel is scarce and dear, maximal output per hectare would make the best use of such resources. But there are other handicaps to further intensification of grassland and animal production. Heavy fertilizer use may influence the flora and fauna of an area, and leaching of nitrogen could impair water supplies. Moreover there is a growing concern at the contribution of animal products to the western diet. It is recommended that fats should not contribute more than 30% of energy in the diet. At present 40% is more common (Truswell, 1977). And price resistance is also developing. Although the EEC (1978) foresees a continuing milk surplus and is endeavouring to divert production from milk to beef, Rojko et al. (1978) have suggested that high cost could restrict the consumption of meat products especially those based on grain.

Problems

Nationally and from the Community viewpoint therefore there is pressure to contain milk production and to increase but cheapen meat production. These attitudes are bound to affect the market prices for milk and meat. However, from the point of view of the individual farmer, within the constraints of the overall demand and prices structure, he must devise methods of maintaining his own farm income. This could result from intensification of grassland farming, preferably to release land for other products but in some circumstances to increase production of the products at which he is most expert. This move is supported by the evidence over many years that grass can provide a cheap food for ruminants (Table 1).

Table 1. Relative costs of feed energy for ruminants.

<table>
<thead>
<tr>
<th>Feed type</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grazing</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Early grazing</td>
<td>141</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Grass silage</td>
<td>212</td>
<td>166</td>
<td>166</td>
</tr>
<tr>
<td>Hay</td>
<td>224</td>
<td>224</td>
<td>200</td>
</tr>
<tr>
<td>Home grown cereals</td>
<td>265</td>
<td>395</td>
<td>483</td>
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<tr>
<td>Purchased compounds</td>
<td>682</td>
<td>476</td>
<td>663</td>
</tr>
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</table>

1. Hamilton (1952)
2. ICI (1979)
3. Milk Marketing Board (1976-77)

adjusted relative to silage
A conceptual framework

However, simple statements of average costs are inadequate when considering the economics of fertilizer response. Responses are curvilinear and there are several links in the input/output chain from cost per unit of input (as fertilizer) to value per unit of output (as meat, milk or wool). The major components in this chain are:

1. Price of fertilizer nitrogen plus appropriate mineral nutrients.

2. The response in yield of dry matter per kg nitrogen, which is affected by,

   level of natural fertility
   level of fertilizer input
   soil moisture retention
   summer rainfall and,
   variation in seasonal responses.

This has been the subject of many studies which in general show a linear response to nitrogen applied at up to 300 kg N per hectare over the year and a declining curvilinear response thereafter (Minderhoud et al., 1976; Van Steenbergen, 1977). Morrison et al. (1980) have shown over a range of sites in England and Wales that the response fell below 10 kg DM per kg N at applications of from 317-530 kg N per hectare. Responses on grass-clover swards may be less and have ranged from 4 - 17 kg DM per kg N (Chestnutt & Lowe, 1970). The response also depends on growing conditions which are affected by soil moisture, rainfall and temperature. Very early or late applications in the growing season are less likely to yield high responses and the greatest responses are generally recorded in April-May in West European conditions (Prins & Van Burg, 1979).

3. The proportion of the herbage dry matter which is utilized by animals. This is affected by,

   efficiency of harvesting by animals (related to stocking rate)
   efficiency of mechanical harvesting
   efficiency of conservation
   efficiency of feeding conserved products and,
   contribution of supplementary feeds.

In considering grazing we are concerned with the overall efficiency of utilization for the season, not with a single harvest and as Lane & Holmes (1971) and Leaver (1976) have shown, this can range from under 50 to over 90%. With conservation, field, storage and feeding losses may result in efficiencies of conservation ranging from 40 - 80%.

4. The metabolizable energy (ME) content of grass dry matter. This ranges from about 8 to 12 MJ ME per kg DM, the higher values on grazing and the lower values with conserved products.

5. Feed efficiency. (It is convenient in this paper to express this as MJ of ME per kg animal product although product per MJ of ME is a better measure of efficiency). Feed efficiency varies widely (Holmes, 1977). A population structure which encourages longevity and a low replacement rate reduces total feed requirements. The level of production relative to maintenance requirement is important and high milk yields per cow or growth rates per animal reduce the feed required per unit product and increase efficiency. Conversely breeding herds and flocks, where the female is maintained for the year in order to provide one or two progeny, incur high feed requirements per kg of carcass yield.

These various relationships can be expressed in the equation:

\[ a \times b \times c \times d = f \]

where

a is DM response per kg N
b is efficiency of grass utilization
c is ME content of utilized grass, MJ per kg DM
d is price per kg of product either as pence per kg milk solids or pence per kg carcass
e is MJ of ME required per kg of product

and

f is value of product

See examples in Appendix I.
The return from efficient dairy production would allow considerable increases in fertilizer cost to be absorbed but the relative inefficiency of the suckler beef enterprise renders it unrewarding to increased fertilizer use, and sensitive to increases in the fertilizer:beef price ratio.

The farmer has little control over prices but can, to some extent, vary his level of fertilizer use, efficiency of utilization of pasture and the efficiency of the livestock population.

The use of targets

As an aid to improved utilization, targets or guidelines can be prepared which indicate attainable levels of production. Targets for British conditions are given in Table 2.

Table 2. Targets for grazing for 180 days.

<table>
<thead>
<tr>
<th>Annual fertilizer application (kg N per ha)</th>
<th>Animals per ha</th>
<th>Milk (per cow)</th>
<th>Beef (per cow)</th>
<th>Ewes (per ewe)</th>
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</thead>
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<tr>
<td>150*</td>
<td>8.9</td>
<td>3.6</td>
<td>4.5</td>
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<td>300</td>
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<td>450</td>
<td>11.5</td>
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<td>5.9</td>
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<table>
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<tr>
<th>DM intake (kg per day)</th>
<th>Grazing efficiency assumed</th>
<th>Daily production kg</th>
<th>Production per ha, kg</th>
</tr>
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<tbody>
<tr>
<td>13.0</td>
<td>0.95</td>
<td>15.6</td>
<td>810</td>
</tr>
<tr>
<td>8.7</td>
<td>0.80</td>
<td>1.0</td>
<td>840</td>
</tr>
<tr>
<td>3.0</td>
<td>0.85</td>
<td>0.29</td>
<td>750</td>
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</table>

* or with high clover content

These values apply to average British conditions. They might be raised by 25% in very good conditions and reduced by 25% in poor conditions. Where half the area is to be conserved in May, multiply stocking rates by 0.7. Where the whole area will be cut for conservation, ½ in May and ¼ in July, multiply stocking rates by 0.55.

The basis of such targets is as follows. The level of dry matter production over the growing season is estimated from existing knowledge of the natural conditions for pasture growth, which depend on aspect, summer rainfall, soil moisture retention, the level of fertilizer nitrogen and the response curve to fertilizer nitrogen in these conditions. The appetite requirements are then predicted on the basis of the energy requirements, e.g. MAFF, 1975, and adjusted for the expected efficiency of harvest by the animals.

Supplementation

It has become common in the more intensive grassland farming areas to supplement pasture with concentrated feeds. Whether this will remain worthwhile depends on the responses obtained and on the milk:concentrate price or carcass price:concentrate price ratio. These are likely to decline in the future.

If concentrates are fed in addition to grazing, herbage intake will be reduced by 0.8 to 0.5 kg DM per kg concentrate DM consumed, the greater reduction with herbage of high digestibility (Holmes, 1975).

In a recent study on commercial dairy herds Hawkins & Rose (1979) found that in British conditions the marginal response to concentrate fed to dairy cows was approximately 1 kg milk per kg concentrate; a result which agrees with many earlier studies and which was just worthwhile.

Many studies have shown that it is simpler to increase herbage production than to raise yield per animal by the provision of higher quality feed from grass and forage. However, the possibility remains that concentrates might be replaced by grass and conserved grass. That this is feasible has been shown on several occasions in the past and recently by the Grassland Research Institute with cows yielding 6000 litres of milk and receiving 1.1 tonnes of concentrate (C. Thomas, personal communication) and at Wye College with 18 month dairy beef cattle reaching 225 kg carcass weight in 532 days on diets which were independent of concentrated feeds after 100 days of age.

Alternative supplements such as by-products of the sugar, apple and citrus fruit industries and possibly alkali treated roughages, can also produce alternatives to cereals.

Vadiveloo and Holmes (1979) studied the inter-relations of forage and
concentrates on intake and performance and provided equations to estimate the intake and performance of beef cattle. These predict that for example for a 400 kg animal, hay (or good silage) of 60 or 70% OMD fed in conjunction with 4 kg barley (0.86 DM: 0.96 OM) would consume 9.1 and 9.5 kg OM per day and gain 1.0 and 1.2 kg live weight per day. Alternatively only 2 kg of barley would be required for 1 kg gain per day if hay of 70% OMD were provided.

The future use of fertilizer nitrogen

The data assembled indicate that some scope remains for efficient use of fertilizer nitrogen until price relationships change drastically. However, attention must be given to:

a) the possibility of making even better use of existing fertilizers
b) the direct and indirect adverse consequences of the use of nitrogen fertilizer
c) the discovery of alternative means of harnessing atmospheric nitrogen
d) the use of forage legumes

a. Improved utilization of fertilizers

More accurate assessment of soil nitrogen status could lead to better use of fertilizer nitrogen. The seasonal variations in efficiency of nitrogen utilization (Prins & Van Burg, 1979) are highly dependent on temperature, moisture holding capacity and summer rainfall or irrigation. More attention to these aspects, combined possibly with medium term weather forecasting, might yield dividends. Moreover the optimum time of application and manner of application as solid, liquid on the surface, or liquid by injection, would reward further study. Morrison et al. (1980) indicated that provided moisture is not limiting, useful modifications to the seasonal distribution of herbage can be achieved by applying rather less N for early growth and higher rates in the middle of the growing season. Although Hood (1976) reported large, unaccounted for, losses in nitrogen Dowden et al. (1980) have just reported that they can account for nearly all nitrogen applied. Large quantities, 20-30%, are retained in the soil. The exploitation of this reserve deserves study.

b. Adverse effects

Concern has been expressed that liberal use of fertilizer nitrogen may result in pollution of water supplies. Cooke (1976) reviewed the subject and concluded that losses of nitrate in drainage water were likely to be much less from grassland than from arable land. However, he indicated that annual applications exceeding 300 kg per ha might result in nitrate loss in the drainage water and that heavily stocked pastures in wet periods were also liable to result in nitrate loss. The application of up to 500 kg N per ha is now practised on a few intensive grassland farms. Studies at the Grassland Research Institute and Jealott's Hill show that this may result in significant quantities of nitrate in the drainage water (Hood, 1977). In Britain the Royal Commission on Pollution (1979) recently reported and suggested that it would be more practicable for the water authorities to remove nitrate from the water before distribution than to attempt to prevent the ingress of nitrate to all supplies. In the Netherlands there is much expertise on this subject and Kolenbrander (1972, 1973) has indeed reviewed it.

An important side effect of intensification of grassland use is the increase in the number of animals carried per unit area and consequently an increase in the production of faeces and urine. It is generally held that at up to 3 adult cattle per hectare the grazing, or grazing and arable land, can receive and benefit from these materials but even at this level problems can arise with storage, uniform distribution, run off and pollution of water supplies. (MAFF, 1976). If, because of the size of business, stock numbers are increased above these levels it is almost imperative to arrange for export of waste materials, a costly and energy wasting process (EEC, 1979)

The digestion of farm wastes to provide fuel is feasible. Capital costs are high in relation to the return but increasing fuel costs may make such processes more economic.
c. Alternative methods of nitrogen fixation

At the strategic level work is in progress on alternative methods of nitrogen fixation. Postgate (1977) has reviewed the sources of nitrogen for world agriculture. He suggests that of the global input of 2.4 x 10^8 tonnes of nitrogen per annum one quarter is derived from industrial N fertilizer and two thirds from biological sources.

Since industrial nitrogen fixation is costly in energy and requires high technology he suggests that more emphasis on biological sources is essential. This may come in part from exploitation of existing leguminous plants as sources of grain or pulse and to fix nitrogen for subsequent crops (lucerne is already being used for this purpose) from the exploitation of other nitrogen fixing systems such as blue-green algal associations and in the longer term by exploitation of the nif genes which have already been transferred from Klebsiella pneumoniae to new bacteria and might eventually be introduced to the genome of crop plants.

d. Forage legumes

Although the present evidence is that fertilizer nitrogen may be economically worthwhile at current costs and prices in favourable grassland conditions, unforeseeable changes may render the forecast incorrect. Moreover there are many areas of land and methods of livestock production where intensification is not justified.

The natural sources of nitrogen from the atmosphere contribute 40-60 kg N per ha per year and result in low levels of grass production unless soil nitrogen is high. The normal recycling of nutrients, which on grazing is much more efficient in the sheep flock than in cattle herds, may augment the nitrogen supply but at present only with the inclusion of leguminous plants, can moderate to high levels of herbage production be obtained without fertilizer nitrogen. Leguminous crops may be grown in pure stand or in association with pasture grasses. The pure stands can be managed according to their specific requirements but are subject to weed invasion and are usually regarded as hazardous to animal health. Legume grass mixtures pose particular problems of inter specific competition and maintenance of the optimal species balance. To attempt to combine the use of fertilizer nitrogen in the early season with later dependence on clover is attractive but management to maintain suitable conditions is difficult. Perhaps more work on this is needed.

Some data on the relative productivity of leguminous forage crops are in Table 3.

Table 3. The potential of leguminous forage crops in UK.

<table>
<thead>
<tr>
<th>Yields of dry matter kg ha⁻¹</th>
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<tr>
<td>White clover</td>
<td>4800</td>
<td>6500</td>
</tr>
<tr>
<td>Blanca</td>
<td>6100</td>
<td></td>
</tr>
<tr>
<td>Red clover</td>
<td>11500</td>
<td>9000</td>
</tr>
<tr>
<td>Lucerne</td>
<td>14500</td>
<td>12750</td>
</tr>
<tr>
<td>Sainfoin</td>
<td>9000</td>
<td>9800</td>
</tr>
</tbody>
</table>

1. National Institute of Agricultural Botany (UK), 1979

The influence of white clover in British conditions was reviewed by Chestnutt & Lowe (1970) and recently studied by Richards (1975) who found a maximal clover N yield of 300 kg N per ha, but severe competition from grass.

Of the temperate species lucerne (Medicago sativa) is by far the most productive and work in France (Demarquilly, 1966) and the United Kingdom may result in that crop making a greater contribution to animal feed. It is of course a preferred crop for dehydration but increased fuel costs have reduced the economic attractions of this process. Studies on extraction of leaf protein have been made (Wilkins, 1977) but are discontinued because of high fuel costs. More work is needed on grazing and ensilage of lucerne. Other arable crops such as red clover (Trifolium pratense) and Sainfoin (Onytrichis viciifolia) are of interest but incur high costs since they are short lived. The long term legume on temperate pastures is white clover (Trifolium repens) which has received much
attention in New Zealand and in Britain. It can contribute 100-200 kg N per ha and new cultivars may have even more potential. A series of studies conducted in New Zealand is summarised by Hoglund et al. (1979). This found, contrary to earlier high estimates based on soils of very low nitrogen status, that the annual nitrogen fixation by clover on New Zealand swards was of the order of 185 kg N per ha per year. Problems of maintenance, management and utilization of clover remain, but there is no doubt that such pasture could equal in productivity many of the present nitrogen fertilized pastures of Western Europe.

There has been vigorous study of potential leguminous crops in the tropics with evaluation of species from other homo-climatic zones. An interesting example is Leucaena leucocephala, a leguminous shrub adapted to tropical conditions. The appropriate rhizobial and mycorrhizal inter-relationships have been defined and it is now a valuable crop (National Academy of Sciences, 1977). Has the time come for a re-evaluation of the adapted leguminous plants of the temperate zone, not for use in the best land but for inclusion in the large areas of low grade pasture which can still be a source of many meat animals? This is already the subject of much work at the Hill Farm Research Organisation (HFR0, 1979).

Conclusions

There have been great advances in the technology of grassland fertilization in the past 25 years. We now have most of the data from which we can estimate whether and where nitrogen fertilizers can be utilized economically. Advances especially in alternative methods of nitrogen fixation, improved utilization of fertilizer nitrogen and in the use of leguminous plants must also be expected in the future. Environmental hazards are understood. If care is taken, they can be controlled.

References


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Appendix I on next page.
APPENDIX I

Feed efficiency

Two contrasting examples are shown below:

<table>
<thead>
<tr>
<th>Cow herd</th>
<th>Suckler herd</th>
</tr>
</thead>
<tbody>
<tr>
<td>650 kg milk per cow.</td>
<td>95 calves per 100 cows</td>
</tr>
<tr>
<td>Replacements purchased.</td>
<td>reared to 250 kg</td>
</tr>
</tbody>
</table>

a) 12 8  
b) 0.85 0.75  
c) 11 9  
d) 90 150  
e) 70 250  
f) 140p 32.4p

if cost per kg N is 30p 30p

Benefit:cost 4.8 1.1

a) is DM response per kg N  
b) is efficiency of grass utilization  
c) is ME content of utilized grass, MJ per kg DM  
d) is price per kg of product, as pence per kg milk solids or per kg carcass  
e) is MJ of ME required per kg of product (from Holmes, 1977) and  
f) is value of product
International Symposium of the European Grassland Federation on
THE ROLE OF NITROGEN IN INTENSIVE GRASSLAND PRODUCTION

POSTERS
THE DATE OF NITROGEN APPLICATION TO UPLAND PASTURE IN THE SPRING IN A HIGH-RAINFALL MARITIME CLIMATE

J.R. Garstang
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Low continental winter temperatures and a rapid increase in spring allow the use of 200 day degree C accumulated temperature from January 1 as a guide for the best date of nitrogen application in spring. This technique does not appear suitable for the maritime climate of the United Kingdom. Over a 15 year period at Great House EHF, in NW England, the 200 day degree date (T-sum 200°C) varied from February 13 to April 7 and first harvest herbage dry matter (DM) yields varied by 250 % between years, on plots cut in the third week of May.

The four year trial outlined here was to see if any date of nitrogen fertilizer application consistently produced the best yields of grass for early spring grazing. 75 kg N per ha was applied at eight weekly intervals through March and April. There were no significant differences in herbage DM production. In three of the four years late March applications produced the highest first harvest yields (four year mean 2250 kg DM ha⁻¹ compared with 2050 kg DM ha⁻¹ for all treatments). Simultaneous lysimeter studies showed greatest losses of nitrogen in 1979 following the early March applications when 12.3 kg N ha⁻¹ was lost before the first harvest. The mean N loss in the three previous years following the early March application was only 0.2 kg N ha⁻¹.

A falling-plate grass growth meter was used to measure the start of growth in the spring. By the end of April the early March application had produced an extra 5 mm growth more than the other treatments. This difference disappeared in one or two weeks.

It was concluded that in maritime climates with high rainfall's the best date to apply nitrogen in the spring is six to seven weeks before the first grazing in early May, if ground conditions will allow field work.

TEMPERATURE SUM AND DATE OF SPRING APPLICATION OF NITROGEN ON GRASSLAND - RESULTS IN THE NETHERLANDS

J. Postmus and J.H. Schepers
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Jagtenberg (1966) found that the optimum date of nitrogen application in spring coincides with the start of grass growth. This start is largely determined by the soil temperature, which in its turn is closely related to the air temperature. Jagtenberg concluded that spring growth starts around the time when the accumulated mean daily air temperatures above 0°C, the so-called T-sum, from the 1st of January onwards reaches about 200°C. Grass growth often started earlier on 'dry' soils than on 'wet' soils.

Since 1969 experiments have been carried out to test the T-sum as a guide to determine the optimum date of first nitrogen application in spring. In these trials, generally two rates of nitrogen, 70 and 140 kg N per ha, were applied at T-sums ranging from about 100 to about 500°C. At first these trials were all situated on 'dry' soils in the North, the later trials were spread all over The Netherlands under different moisture conditions.

The T-sum of 200°C was generally reached in March, with extremes in early February (1974, 1975) and mid-April (1970). Despite these differences in weather conditions before and after the application of nitrogen, the T-sum 200°C generally appeared to correspond with the optimum date for nitrogen application, as was demonstrated by the fact that the DM yields after application at T-sum 200°C were in the maximum range.

There was no effect of the rate of nitrogen on the optimum date of application. The higher rate clearly increased DM yields.

Research on the T-sum has almost been completed. The present trials are mainly used for demonstration purposes.

TEMPERATURE SUM AND DATE OF SPRING APPLICATION OF NITROGEN ON GRASSLAND - RESULTS IN THE UNITED KINGDOM

H. Sandford
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In The Netherlands, nitrogen (N) is applied to grassland when the T-sum from 1st January reaches 200°C. Weather conditions in the United Kingdom are rather different as there is a sharper increase in average air temperatures from 1st February than in The Netherlands. It cannot be assumed therefore that the Dutch method will suit U.K. conditions equally well.

An experiment was carried out in 1979 in Shropshire in the West Midlands on a ryegrass sward sown in the previous autumn. Two rates of N (87.5 and 125 kg per ha) were applied at accumulated temperatures from 1st January of 100, 150, 200, 250 and 300°C. The first harvest was taken when the first plots at each temperature sum reached approximately 1,500 kg DM per ha corresponding to the grazing stage of growth. Subsequent cuts were made at 10 day intervals corresponding to the silage and hay stages of growth. With only one exception, highest DM yields were obtained when the N applications were applied at a T-sum of 200°C.

In 1980, two further replicated experiments and eleven non-replicated trials are being carried out in different parts of England and Wales. Results from these trials are included in the poster display.

SPATIAL AND TEMPORAL DISTRIBUTION OF WATER AND NITROGEN UPTAKE BY GRASS

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During the past two decades soil physicists have developed techniques for determining depth distributions of water uptake by roots on the basis of mass balance and Darcy's law. The literature indicates that direct evaporation from the soil surface and a strong preference of the plants for water uptake near the soil surface often cause low surface water contents and steep gradients of the tensiometer pressure in the top 20 cm. As a result of the low water contents, surface-applied nutrients may be poorly available to the roots. Optimal management of the supplies of water and nutrients, particularly nitrogen, requires an understanding and monitoring of the relevant transport processes. Some data from the literature and from a current study on a light loam soil under grass in the North East Polder are used as illustrations.
In the last ten years I have been involved with 27 experiments on field swards, mostly harvested by cutting. The two to seven N levels compared ranged from 0 to 600 kg N per ha per year. The typical plot size was about 10 m². In some experiments individual plots have been harvested repeatedly over one to four years comparing different intervals between harvests. In other experiments particular periods of regrowth, ranging in length from 3 to 14 weeks, have been studied in detail by harvesting a succession of plots at weekly, or shorter, intervals.

The research dealt with the examination of species (e.g. Lolium spp., Festuca spp., Dactylis glomerata and Trifolium repens), plant growth aspects (e.g. number of leaf initials, extension and death of leaves, number of tillers, herbage yield) and nutritive aspects (e.g. digestibility of total herbage and of crop fractions, mineral content).

The poster displays papers describing results of this research and shows some results from two recent experiments.

From one experiment five N levels ranging from 0 to 525 kg N per ha per year were applied to five grasses in 1977 and 1978. The relative shapes and slopes of response curves (means of five grasses and two years) for different parameters such as dry-matter yield, N yield, number of tillers, number of leaves, area per leaf blade and number of leaf primordia, are shown.

From another experiment are shown effects of level of N and swath thickness on the drying rate of herbage in the field during 1978 and 1979.

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**SWARD DENSITY AND PRODUCTIVITY AFTER DIFFERENT INTENSITIES OF NITROGEN FERTILIZATION IN PRECEDING YEARS**

J.J. Neeteson* and W.H. Prins**

Institute for Soil Fertility (IB), Haren (Gr.), the Netherlands

With continuous mowing the sward is generally more dense with a moderate than with an intensive fertilizer nitrogen regime. In a field trial the productivity of swards of various densities were compared at a high rate of nitrogen. Moreover, changes of the swards were investigated. Differences in density had been created by applications of 40, 60, 80, 120 or 160 kg N per ha per cut in pretreatment years (prior to 1978), the extreme applications ranging from 160 or 200 to 800 or 960 kg N per ha per year, corresponding with 4 or 5 to 5 or 6 cuts per year. In the experimental year 1978 these so-called 'low-N' to 'high-N' swards received an equal rate of 120 kg N per ha at each cut, with 6 cuts totalling 720 kg N per ha.

Results in the experimental year showed:

- Differences in dry matter yield only occurred at the first cut (in May): the original 'low-N' swards produced approximately 30 per cent more dry matter than the 'high-N' swards. In later cuts yields did not differ significantly.
- Differences in tiller density between the original 'low-N' and 'high-N' swards had disappeared already at the time of the first cut.
- Good relationships were shown between leaf area cover, tiller density, and dry matter yield.

These observations demonstrate that at a high rate of nitrogen application a previously dense 'low-N' sward is able to produce more dry matter than a more open, 'high-N' sward. At such high N rates after the first cut, however, a 'low-N' sward apparently becomes equal to a 'high-N' sward.

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** Seconded by the Agricultural Bureau of the Netherlands Fertilizer Industry (LBNM)
EFFECT OF REDUCING THE MINERAL STATUS OF THE SOIL ON THE GROWTH AND DEVELOPMENT OF SEEDLINGS OF COUCH (ELYTRIGIA REPENS (L) DESV.) AND PERENNIAL RYEGRASS (LOLIUM PERENNE L.)

J.H. Neuteboom and W. Cramer
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Seedlings of couch and perennial ryegrass were planted outdoors in pots filled with fairly fertile soil, one plant per pot. In one treatment soil fertility was brought to a high level by application of a complete nutrient solution on the basis of 30 meq nitrogen per pot, every 3 weeks. In a second treatment only one third of this quantity and in a third treatment no nutrient solution was applied.

The perennial ryegrass plants showed much stronger tillering than the couch plants. All perennial ryegrass treatments had higher shoot and root dry weights than the couch plants after 3, 6, 9 and 13 weeks of growth. However, due to rhizome formation at the last two harvests the couch plants showed a higher total underground dry matter production.

At the high fertility level the perennial ryegrass plants showed slightly higher growth rates and at the last two harvests also higher total plant dry weights than the couch plants. However, the couch plants had formed many rhizomes which later on are able to form many new plants.

Reducing the mineral status of the soil resulted in lower growth rates and higher root:shoot ratios in both species, but in couch the production of rhizomes initially remained unaffected. This suggests that in distinct cases the rhizomes have priority in the growth and development of the couch plant. The couch rhizomes showed high contents of water-soluble-carbohydrates, up to 45% of the dry weight. In the stubble of perennial ryegrass a higher water-soluble-carbohydrate content was found than in the stubble of couch.

EFFECT OF pH ON RESPONSE OF NITROGEN TO GRASSLAND

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On a sandy soil under grass with Lolium perenne as the dominant species four different pH levels were created by applying considerable amounts of different types of nitrogen fertilizers during a number of years. These pretreatment fertilizers were: sulphate of ammonia, ammonium nitrate, calcium ammonium nitrate, and calcium nitrate. The pH-KCl levels obtained in the upper five cm of soil in three different experimental years were: 4.3, 5.0, 5.2, and 5.6 in 1974; 3.9, 4.9, 5.1, and 5.6 in 1975; and 3.8, 4.5, 4.8, and 5.4 in 1978.

In all three years the yield response was determined with increasing rates of nitrogen, applied as calcium ammonium nitrate (26% N). For the first cut in spring 0 to 200 kg N per ha was applied. Following cuts were taken either from the same plots as the first cut (1974), with nitrogen rates ranging from 0 to 125 kg N per ha per cut, or every time from different plots (1975 and 1978) with nitrogen rates ranging from 0 to 200 kg N per ha per cut.

At the lowest pH level the first cut in all experimental years yielded higher than all other levels - on average 500 kg DM per ha less than at the other pH levels, whereas the subsequent cuts showed no differences (except the last cut in 1978 which was somewhat lower at pH 3.8). The yield depression of the first cuts at the lowest pH levels in 1975 and 1978 seemed to be somewhat stronger at higher than at lower rates of nitrogen, indicating an interaction between pH and rate of nitrogen application.
The phenomenon of urine scorch in grassland is well-known. Up till now a rather limited amount of research has been carried out on this subject and only a few results are available.

In 1977, the Research and Advisory Institute for Cattle Husbandry started an investigation concerning causes and consequences of urine scorch at the LBNM-experimental farm 'De Olde Weije' at Vaassen. The results so far show the following:

**Causes**
- Urine scorch occurs when the moisture content of the soil is high and the average day-and-night temperature is approximately between 15° and 20°C
- Scorching increased significantly at the higher rates of nitrogen fertilization
- Each cow causes urine scorch, but the extent of the damage varies between animals
- Urinations during the first hours of the morning cause more damage than urinations later in the day
- The concentration of N and K in the urine of the early morning is higher than later during the day.

**Consequences**
- Deterioration of the botanical composition of the sward (Table 1)
- Scorched patches produce no or little grass yield in the year of deposition
- The negative effects of scorched patches continue into the following year(s).

Table 1. Effect of urine scorch on changes in botanical composition of swards at Vaassen and Achterberg. Percentages are based on (a) visual estimation and (b) dry weight determination.

<table>
<thead>
<tr>
<th>Species</th>
<th>Vaassen</th>
<th>Urine scorch developed in June 1977</th>
<th>Achterberg</th>
<th>Urine scorch developed in June 1977</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The paddock as a whole in spring 1977 (a)</td>
<td>The paddock as a whole in spring 1977 (b)</td>
<td>observation date in 1978 (b)</td>
<td>observation date in 1978 (b)</td>
</tr>
<tr>
<td></td>
<td>2-6-'78</td>
<td>23-8-'78</td>
<td>12-5-'78</td>
<td>28-9-'78</td>
</tr>
<tr>
<td>Lolium perenne</td>
<td>74</td>
<td>16</td>
<td>91</td>
<td>13</td>
</tr>
<tr>
<td>Poa trivialis</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Poa annua</td>
<td>10</td>
<td>68</td>
<td>+</td>
<td>81</td>
</tr>
<tr>
<td>Alopecurus geniculatus</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Elytrigia repens</td>
<td>2</td>
<td>13</td>
<td>+</td>
<td>1</td>
</tr>
<tr>
<td>Trifolium repens</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Taraxacum sp.</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Stellaria media</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

*Seconded by the Agricultural Bureau of the Netherlands Fertilizer Industry (LBNM).*
THE ROLE OF NITROGEN COMPOUNDS FROM COW URINE IN GRASS AND SOIL

J. Groenwold and J.W. Heringa
Centre for Agrobiological Research (CABO), Wageningen, the Netherlands

Samples of more than 200 urine voids have been analysed for urea, hippuric acid, pH and electric conductivity (as an indication of osmotic value). The patches wetted by the urine were marked and the degree of damage recorded after 10 days. The rate of injury to the pasture, more or less intensively fertilized with nitrogen, was correlated to the rates of the chemical components of the corresponding urine voids.

In subsequent laboratory trials the occurrence of ammonia, nitrite and nitrate in soil, caused by the addition of urea and hippuric acid, was monitored during a number of days. Some aspects of the erratic occurrence of urine scorches have been unraveled and the consequences for losses of nitrogen in grassland are stipulated.

DEVELOPMENT OF ROOT MASS OF SIMPLE GRASSLAND MIXTURES AS AFFECTED BY CATTLE SLURRY AND NITROGEN FERTILIZER APPLICATIONS

Maria Grynia
Academy of Agriculture, Poznań, Poland

The mutual relationship of herbage and root mass explains the phenomenon of high production and of degradation of yields and plant communities. This was confirmed by experiments carried out on plots at A.R.S. Brody and Ziotniki near Poznań in the period 1976-1979. Meadow and pasture experiments at Brody were based on marsh soil and were given 50 to 200 m$^3$ cattle slurry per ha. A pasture experiment at Ziotniki was carried out on light mineral soil with applications of 150 to 600 kg N per ha as mineral fertilizer.

In the third year of the experiments the botanical composition of the different mixtures became more or less equal and the nitrophilous grasses began to dominate.

The root mass of three different meadow and pasture mixtures at Brody increased throughout the years to reach its maximum in the third year after sowing. The greatest root mass development was observed in meadow mixtures at the third cut using 50 m$^3$ cattle slurry per ha, in pasture mixtures at the third cut using 100 m$^3$ and at the fourth cut using 150 m$^3$ cattle slurry.

At Ziotniki the best development of the root mass of the pasture mixture was observed at the second and sixth cuts with 300 kg N per ha. Without fertilizer N and with 600 kg N per ha the development was almost the same but much less than with 300 kg N.

The lower and medium rates of slurry and nitrogen fertilizer application had the best influence on root mass development. The higher rates of 200 m$^3$ cattle slurry and 600 kg N per ha decreased the ratio herbage mass: root mass considerably and also increased sward degradation, as could be seen in the domination of Elytrigia repens.
The effect of cattle slurry (a mixture of faeces, urine and water) was investigated during 1977-1979 at high rates of application on permanent grassland in comparison with nitrogen fertilizer.

The experiment comprised the following combinations:

1. Slurry at 100 t per ha, equivalent to 300 kg N per ha
2. Slurry at 133 t per ha, equivalent to 400 kg N per ha
3. 300 kg N, 80 kg P₂O₅ and 100 kg K₂O per ha as mineral fertilizers
4. 400 kg N, 100 kg P₂O₅ and 120 kg K₂O per ha as mineral fertilizers
5. nil

Slurry and nitrogen fertilizer were every year split into three doses.

Cattle slurry gave about 20 per cent lower DM yields in dry and warm years compared with mineral fertilizer. DM yields were the same for both slurry and fertilizer when the weather in the growing season was wet and chilly, as in 1978. The effect of the slurry was greater with 100 t than with 133 t per ha.

Slurry and fertilizer decreased the number of leguminous plants in the sward to a similar extent. Slurry slightly reduced crude protein content and increased carbohydrate content in comparison with the mineral fertilizer.
EFFECT OF EXTREME RATES OF NITROGEN APPLICATION ON HERBAGE NITRATE CONTENT AND HEALTH OF GRAZING DAIRY CATTLE

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It is well-known that the feeding of turnips, hay or wilted silage with too high nitrate content may cause nitrate poisoning in cattle. Investigations of Kemp et al. (1978) have shown that nitrate poisoning is sooner to be expected from feeding hay with more than 1% $\text{NO}_3$ in the dry matter than from feeding freshly mown ryegrass with the same percentage of nitrate. These investigations were carried out in trials with stall feeding. The animals were fed twice a day. When grass intake is more evenly spread over the day, like with grazing, chances of nitrate poisoning will be even less.

To get more information about the health of cattle grazing on grass, rich in nitrate, investigations were started in 1977 at the Nitrogen Experimental Farm 'De Oide Weiże' at Vaassen with monitoring a number of spring calving cows grazing on pastures, fertilized with extreme applications of 1000 kg N and more per ha per year.

Some results of the still continuing investigations are:

- Nitrate contents of the grass varied almost ever between 1 and 4% $\text{NO}_3$ in the dry matter
- The nitrate contents were highest in summer
- Even when the nitrate contents of the grass varied between 3 and 4%, methaemoglobin levels in the blood were even almost normal (2 to 3% MB); the highest level measured was 6% MB
- The milk production was even slightly higher than was to be expected on the base of the previous year
- The course of the weight of the animals was in good harmony with the lactation period
- It is not yet possible to give a clear picture of the fecundation and pregnancy results.


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

THE EFFECT OF NITROGEN AND STOCKING RATE ON MILK PRODUCTION

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The effect of high nitrogen levels and stocking rate on milk output from grass was studied in 1978 and 1979. A spring calving herd of 80 cows was used; the herd contained 16 first calvers. The comparison was conducted on a total system framework; cows in each experimental group were overwintered on silage conserved from the appropriate experimental area.

Calcium ammonium nitrate (27.5% N) was the nitrogen source; two N levels 272 (N1) and 495 (N2) kg per ha were compared. The N1 treatment was applied at stocking rates of 2.47 and 3.09 cows per ha; the N2 treatment was applied at stocking rates of 2.75 and 3.43 cows per ha.

At 3.09 cows per ha the N1 treatment supported a milk yield of 4254 kg per cow in 1978 and 4296 kg per cow in 1979, giving a milk output per hectare of 13,175 kg and 13,275 kg, respectively. At 3.43 cows per ha the N2 treatment supported a milk yield of 4081 kg per cow in 1978 and 4203 kg per cow in 1979, giving a milk output per hectare of 13,998 kg and 14,416 kg, respectively.

The effect of the different treatments on the amount of herbage dry matter available for grazing and for conservation was also recorded.
SWARD SAMPLING TECHNIQUES FOR MEASURING THE NITROGEN RESPONSE IN GRAZING TRIALS

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The response of grassland to nitrogen has in cutting trials often only been measured as herbage accumulation. It would be advisable to include information on herbage quality and herbage consumption as measured in grazing trials. When the herbage mass and quality are determined at the start and at the end of each grazing period (in the grazed sward and in exclosures) all basic pasture data can be calculated:
- herbage accumulation (between and during grazing periods)
- quality of the selected diet
- herbage consumption per ha
- herbage allowance and consumption per animal
- efficiency of utilization of the herbage.

The suitability of the usual sward sampling technique for the determination of herbage mass was studied in grazing trials during the period 1976-1979 at Lelystad. Cutting with a motor-scythe (stubble height 4.5 cm) underestimated the herbage mass at the end of the grazing period owing to
- an increased stubble length compared with that at the start of grazing
- displacement of part of the material above 4.5 cm into the stubble by trampling, defaecation and laying down of the animals.

These problems could be solved by using a two-step cutting system by combining a motor-scythe and a lawnmower. When strips were cut with a motor-scythe (60 cm wide) and afterwards with a lawnmower (50 cm wide) a constant cutting height of 3.4 cm was achieved. Under comparable weather conditions the stubble masses from 0 to 3.4 cm, determined by cutting all material above ground level by hand, did not differ between pre- and post-grazing strips.

The accumulation of herbage during the grazing period was measured in a fenced area. The formula of Linehan (1952) was used to calculate the accumulation of herbage in the grazed area; preliminary results of experiments by Deinum & Lantinga at Wageningen show reasonable similarity between the herbage accumulation as calculated with Linehan's formula and as measured by photosynthesis.

Pre-trimmed pastures were grazed in intake experiments. At the start of grazing 10 strips of 12 m long were cut; at the end of the grazing period of three or four days 10 paired strips of 15 m long were cut. A coefficient of variation of 5.7% of the intake estimate of a group of animals was obtained. The herbage accumulation during 19 days between grazing periods could be estimated with a coefficient of variation of 5.8%.


FERTILIZER NITROGEN AND OUTPUT ON GRASSLAND FARMS

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GRI/ADAS Permanent Pasture Group, Hurley, Berkshire, United Kingdom

Detailed records of animal output from grassland and fertilizer use on 200 dairy and 250 beef farms were kept for a two-year period. The farms ranged from extensive to very intensive.

The average use of fertilizer nitrogen on dairy farms was 160 kg N per ha and on beef farms was 60 kg N per ha. These levels supported animal outputs of 45 and 40 GJ per ha, respectively, equivalent to approximately 45 and 4 t DM utilized. The difference between dairy and beef farms was smaller than might be expected, due possibly to better utilization on beef/sheep farms.

Within each farm type, level of N input was positively correlated with output. But at any level of input there was very great variation in output - more than would be expected from differences in basal fertility of grassland soils. Variation in climate and soil AWC could explain a proportion of the variation in utilized output. It seems likely that on many farms where yield of grass is high, there is considerable difficulty in utilizing the herbage that is grown.

It appears that clover is not making a substantial contribution to soil N supplies: contribution of clover in swards was 2% on dairy farms and only 4% on beef farms despite low levels of fertilizer nitrogen.
ENERGY USE ON DAIRY FARMS

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For different dairy systems calculations were made of the total fossil energy use, direct as well as indirect. In the standard situation - day and night grazing during 4 days per paddock, 400 kg N per ha, 6000 kg milk per cow per year and 1615 kg concentrates per cow per year - the total energy use was 7.95 MJ per kg milk. This value was divided as follows:

- Fuel: 4%
- Electricity: 8%
- Manufacture of tractors and machinery: 4%
- Buildings, concrete: 5.5%
- Concentrates: 44%
- Fertilizers: 29%
- Storage of roughage: 1.5%
- Bedding material: 2%
- Veterinarian, AI, bookkeeping etc.: 2%

The high value for concentrates is because of the high energy input for the drying of concentrate-ingredients like citrus pulp and beet pulp.

The energy use decreases by applying lower rates of nitrogen, by growing maize for silage, by a lower stocking rate and by a higher production per cow.

Zero-grazing, restriction of the amount of roughage per cow, stabling during the night in the grazing season, sprinkler irrigation and storage of roughage in a tower silo leads to a higher energy use per kg of produced milk.

The intensively managed dairy farms are very sensitive to an increase of energy prices.
MORE PLANT-AVAILABLE NITROGEN THROUGH PHOSPHORUS AND POTASH FERTILIZATION ON GRASSLAND?

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Institut für Pflanzenbau und Pflanzenzüchtung II - Grünlandwirtschaft und Futterbau -, Giessen, Bundesrepublik Deutschland

Plants derive nutrients from natural reserves of the ecosystems and from fertilizers. Application of fertilizer does not only stimulate the growth of plants, but also of other organisms including those mineralizing dead organic matter. Grassland soil is characterized by a comparatively high content of nitrogen (N) most of which has been fixed in the organic matter. Through mineralization of organic matter, N becomes available to plants.

A pasture soil contained 5000 kg N per ha in the 0-10 cm horizon. Fifty-five per cent of this amount of N had been fixed in the dead, partially mineralized, but not yet humified organic matter. Only 2% was available to plants. The effects of applications of phosphorus equivalent to 0-400 kg P₂O₅ per ha, and/or applications of potassium equivalent to 0-1200 kg K₂O per ha on the extent of the N-mineralization were investigated by incubating soil samples at 50% water capacity and 22°C.

After 6 to 8 weeks of incubation phosphorus alone had no effect on the N-mineralization. But potassium alone and the combined application of both nutrients increased the mineralization of nitrogen considerably.

STUDIES ON THE FATE OF FERTILIZER NITROGEN

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Imperial Chemical Industries Limited, Agricultural Division, Research & Development Department, Agriculture Group, Jealott's Hill Research Station, Bracknell, United Kingdom

The poster illustrates the main activities of a three year experiment studying the fate of fertilizer nitrogen applied to 0.4 ha grassland plots. The plots are isolated from the surrounding land by drainage ditches and treated with 250, 500 or 900 kg N per ha as NH₄NO₃. The aim is to construct a complete nitrogen balance by measuring the nitrogen removal in the crop, that leached from the soil, the gaseous losses of N₂/N₂O resulting from denitrification, and any change in the soil total nitrogen over the experimental period.

Simultaneously, monolith lysimeters removed from the plots at the beginning of the experiment are being treated with ¹⁵N labelled fertilizer. Because fertilizer nitrogen can be distinguished from soil nitrogen, these studies allow the actual fate of the fertilizer nitrogen to be determined. There are twelve lysimeters, four from each plot. Two of each set of four are treated with double labelled ammonium nitrate and the remaining two with single labelled, the label being in the ammonium moiety. By comparing the ¹⁵N abundances in the NO₃⁻N leachate from the two treatments, it is possible to determine the proportion of the ammonium fertilizer that has been nitrified over the growing season.
NITROGEN LOSSES FROM SOILS UNDER GRASS AS AFFECTED BY RESIDENCE TIME IN THE GROUNDWATER - LYSIMETER RESULTS

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In 16 grassland lysimeters of 1.20 m depth the groundwater was kept at different levels above the drains (Table 1). For the period 15/3/71 - 15/3/79 the average amounts of drainage water during the winter were nearly equal for all lysimeters, ranging from 380 to 420 mm. Through the different groundwater levels different residence times of nitrogen in the groundwater have been created because the flow distance of ions through the groundwater is longer as the groundwater table is higher.

The leaching losses of nitrogen at the same level of fertilization were greater as the groundwater table was lower (Table 1). On the other hand, leaching of chloride was of the same order of magnitude in all treatments with equal amounts of fertilizer (with the exception of one lysimeter on which much more dry matter was produced, resulting in greater uptake and removal of ions by the crop). The results indicate that under these conditions losses by denitrification are smaller as the groundwater table is lower because the residence time in the water-saturated zone of the profile is shorter.

The fact that the smaller leaching losses of nitrogen are related to greater denitrification may also be deduced from the N/Cl ratio, which increases with increasing depth of the groundwater table (Table 1).

The results seem to be at variance with the model calculations by Rijtema (this Symposium), suggesting that lowering the groundwater table reduces the leaching losses of nitrogen. The explanation for this variance is that, under field conditions, lowering the groundwater table means a greater water storage capacity of the profile, as a result of which the onset of leaching is delayed, and the residence time of nitrogen in the water-saturated zone is extended.

Table 1. N and Cl removal by the crop, leaching losses, and N/Cl ratio in drainage water on lysimeters with different groundwater tables.

<table>
<thead>
<tr>
<th>Period</th>
<th>Number of lysimeters</th>
<th>Groundwater table</th>
<th>Fertilization incl. rainfall kg ha⁻¹ yr⁻¹</th>
<th>Removal by crop kg ha⁻¹ yr⁻¹</th>
<th>Leaching losses kg ha⁻¹ yr⁻¹</th>
<th>N/Cl ratio in drainage water</th>
</tr>
</thead>
<tbody>
<tr>
<td>15/3/71</td>
<td>4</td>
<td>35 below surface, 85 above drains cm</td>
<td>242 N, 300 Cl</td>
<td>155 N, 127 Cl</td>
<td>5 N, 208 Cl</td>
<td>0.024</td>
</tr>
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<td></td>
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<td>5 N, 208 Cl</td>
<td>0.024</td>
</tr>
<tr>
<td>15/3/74</td>
<td>4*</td>
<td>110 below surface, 10 above drains cm</td>
<td>242 N, 300 Cl</td>
<td>174 N, 113 Cl</td>
<td>3 N, 200 Cl</td>
<td>0.015</td>
</tr>
<tr>
<td>15/3/74</td>
<td>4</td>
<td>35 below surface, 85 above drains cm</td>
<td>242 N, 300 Cl</td>
<td>159 N, 119 Cl</td>
<td>4 N, 173 Cl</td>
<td>0.023</td>
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<td></td>
</tr>
<tr>
<td>15/3/74</td>
<td>4*</td>
<td>110 below surface, 10 above drains cm</td>
<td>242 N, 300 Cl</td>
<td>174 N, 113 Cl</td>
<td>5 N, 174 Cl</td>
<td>0.029</td>
</tr>
<tr>
<td>15/3/79</td>
<td>4*</td>
<td>110 below surface, 10 above drains cm</td>
<td>242 N, 300 Cl</td>
<td>164 N, 95 Cl</td>
<td>12 N, 200 Cl</td>
<td>0.060</td>
</tr>
</tbody>
</table>

* On four lysimeters another scheme of fertilization was used in the first period (1) compared with the second period (2); only two of these lysimeters of the second period are shown in the table.
INFLUENCE OF HUMAN ACTIVITIES ON NITROGEN LOSSES FROM GRASSLAND

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Fertilizer nitrogen applied on grassland is taken up by plant roots, immobilized in soil organic matter or emitted to the environment. Four different processes play a role in the losses of nitrogen from the rooting zone:
- denitrification, resulting in emission of N₂ and N₂O to the atmosphere
- volatilization of NH₃
- leaching of NO₃ to the subsoil
- losses of mainly NH₄ and organic N compounds to surface waters by surface runoff.

The role of each of these processes in the total nitrogen balance is more or less influenced by human activities which affect soil moisture condition, type and amount of fertilizer applied, drainage situation and plant production. Information on the quantitative relationships between human activities and nitrogen losses is necessary to improve fertilizer efficiency and to prevent or reduce harm to the environment. Theoretical approaches and field experiments can both be very helpful in understanding the complex relationships in which nitrogen is involved.

THE ROLE OF NITROGEN IN THE LEAN YEARS

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Organic matter in the soil can in many ways have a positive influence on plant growth. This favourable effect is well-known and exploited in practice for the growth of arable crops. For grassland, however, this is still a point of discussion.

In mineral soils the amount of organic matter is usually much higher with grassland than with arable land. When grassland is sown on a soil with a low actual but a higher potential organic matter content, e.g. a previously arable soil, accumulation of organic matter will take place. This accumulation is accompanied by immobilisation of nitrogen, resulting in a lower nitrogen supply from the soil to the grass.

The role of this immobilisation in the so-called lean years is displayed.