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

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Summary

In three long-term nitrogen fertilization experiments with total applications of up to 1 120 kg N per ha per year and cutting at a set stage of growth the productivity of all-grass swards was studied. The productivity was found to decrease with increasing rates of nitrogen application in the pre-treatment year(s). This decrease in productivity was associated with a deterioration of the sward as evidenced by a more open sward and a lower number of tillers. Annual applications of 400 to 480 kg N per ha were found to be a good compromise between yield and sward condition. The study showed that one-year experiments with very high nitrogen applications do not allow general conclusions as to long-term effects, because one-year experiments may give too optimistic a picture of the response to nitrogen.

Introduction

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

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

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

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

Materials and methods

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

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

Pre-treatment year(s)

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

Table 1. General data on trials.

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

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

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

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

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

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

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

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

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

Results

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

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

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

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

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

Productivity and sward characteristics, Trial 1 (1978)

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

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

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

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

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

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

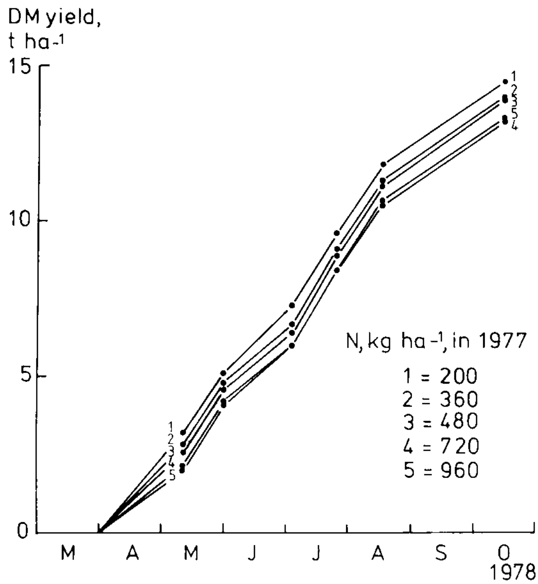

Fig. 1. Trial 1. Effect of intensity of nitrogen and cutting regime (5 times 40, 6 times 60, 80, 120 and 160 kg N per ha per cut) in 1977 on productivity in 1978, expressed as cumulative DM yields per cut at one rate of nitrogen application (120 kg N per ha per cut).

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

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

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

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

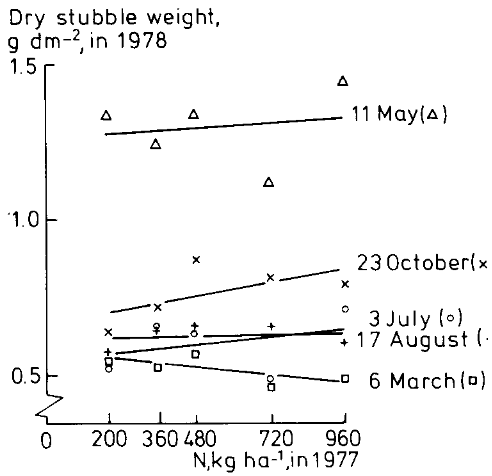

Fig. 2. Trial 1. Effect of intensity of nitrogen and cutting regime (5 times 40, 6 times 60, 80, 120 and 160 kg N per ha per cut) in 1977 on stubble DM weight per unit of area at the start of spring growth (March), the 1st, 3rd, 5th and last cut in 1978, at one rate of nitrogen application (120 kg N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

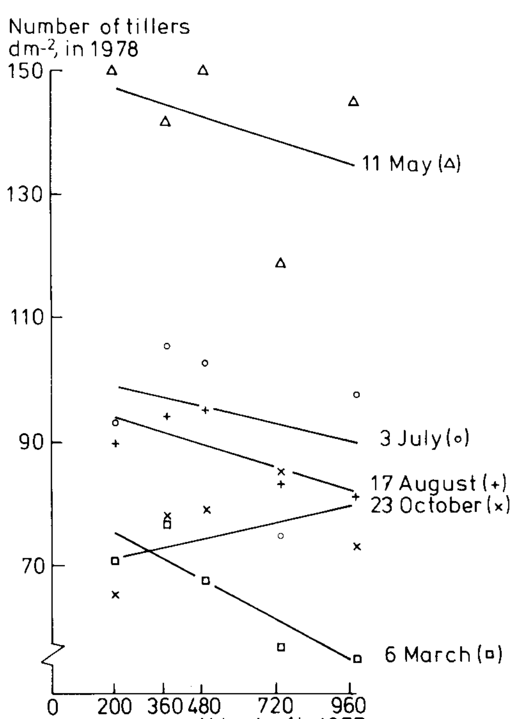

Fig. 3. Trial 1. As in Fig. 2 but now for the number of tillers.

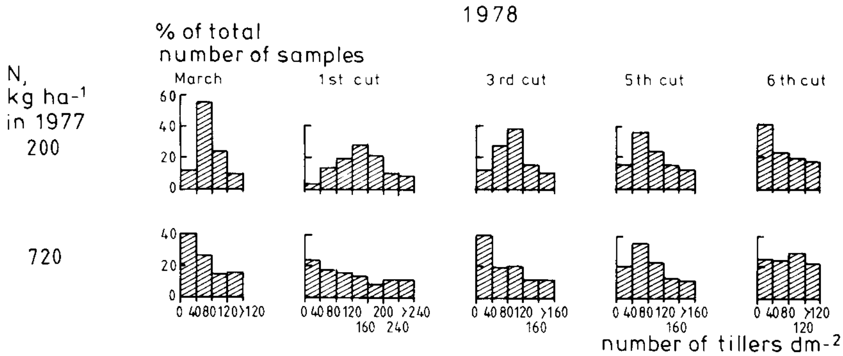

Fig. 4. Trial 1. Effect of pretreatment nitrogen application on 'low N' and 'high N' swards with 5 times 40 and 6 times 120 kg N per ha per cut in 1977, respectively, on the frequency distribution of the number of tillers in 1978 at one rate of nitrogen application (120 kg N per ha per cut).

Weight per tiller in the stubble. From the number of tillers and the stubble weight per dm^2 the weight per tiller in the stubble can be deduced (Fig. 5). Throughout the season, except after the last cut, the weight per tiller in the stubble increased significantly ($P < 0.05$) with increasing pre-treatment nitrogen applications.

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

Sward characteristics, Trial 3 (1978)

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

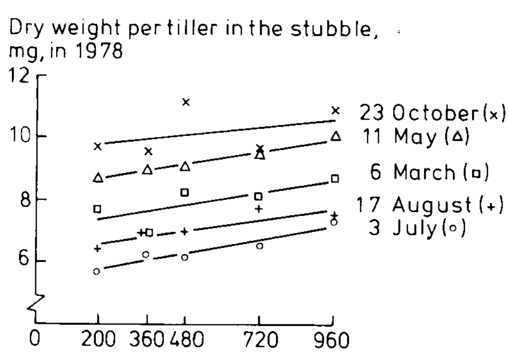

Fig. 5. Trial 1. As in Fig. 2 but now for the DM weight per tiller in the stubble.

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

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

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

Discussion

Productivity

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

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

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

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

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

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

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

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

Sward characteristics

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

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

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

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

Effect of cutting and grazing management

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

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

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

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

Conclusions

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

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

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

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

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