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Herbage and animal production responses to fertilizer nitrogen in perennial ryegrass swards. I. Continuous grazing and cutting

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Abstract

The effects of fertilizer nitrogen (N) application on herbage intake and animal performance under a continuous grazing management with dairy cows, and on herbage accumulation under a weekly and an approximately 4-weekly cutting regime have been studied in the period 1986-1988 in reseeded perennial ryegrass grassland on a silty loam soil in Oostelijk Flevoland. Annual fertilizer rates of N varied from 250 to 700 kg ha^{-1} under grazing and from 0 to 700 kg ha^{-1} under cutting. At an assumed marginal profitability of 7.5 kVEM per kg N applied the optimum N application rate was on average 511 and 308 kg ha^{-1} yr^{-1} for 4-weekly cutting and continuous grazing, respectively (1 kVEM = 6.9 MJ Net Energy for lactation). However, especially under grazing, there was a great variation in response to N between years which could be related to soil N availability, length of the growing season and sward quality. Throughout the experimental period the mean tiller density in the grazed swards was hardly affected by the level of N application. However, there were temporary differences in openness of the sward which increased with the level of N application, leading to a loss of productivity as a result of impeded N uptake. Herbage N was poorly converted into animal products. The average efficiency of use of ingested N at a fertilizer level of 250 kg N ha^{-1} yr^{-1} was 23%. Higher rates of fertilizer N effected a slight decrease in fertilizer N use efficiency (19% at 700 kg N ha^{-1} yr^{-1}) but a steep rise in the calculated amount of N excreted per ha.

Keywords: nitrogen response, continuous grazing, dairy cows, herbage intake, cutting, perennial ryegrass, *Lolium perenne* L. cv. Wendy, exclosure cages, sward quality, tiller density, tiller distribution, nitrogen use efficiency

Introduction

Much research on continuous grazing has been concentrated upon the effects of different grazing pressures on animal intake and production (e.g. Castle & Watson,

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1978; Le Du et al., 1981; Kibon & Holmes, 1987). The last decade detailed studies have been devoted also to the response of the sward to continuous grazing in terms of tiller development, herbage production and the physiology of the grazed sward (Arosteguy et al., 1983; Grant et al., 1983; Bircham & Hodgson, 1983; Parsons et al., 1983a, 1983b, 1988; Lantinga, 1985a; Orr et al., 1988). Apart from the studies of Arosteguy et al. and Lantinga, these studies were carried out with sheep. Comparative trials with rotational grazing systems carried out with beef or dairy cattle at high nitrogen (N) application rates and high stocking rates (Ernst et al., 1980; Schlepers & Lantinga, 1985) have failed to give evidence of a consistent superiority of any one grazing system over another.

Few studies have examined the herbage and animal responses to N of perennial ryegrass swards continuously grazed with cattle. Most of these studies were carried out with beef cattle (Horton & Holmes, 1974; Large et al., 1985; Baker, 1988; Tallowin et al., 1990). Only Gordon (1974; 1983) studied responses with dairy cows. However, this was done over a relatively narrow range of three N levels (150-450 kg N $ha^{-1}yr^{-1}$) with the response being assessed via its effect on cow grazing days and milk yield. For experiments to provide reliable information on animal and herbage responses, Large et al. (1985) recommended that response curves could be fitted with an acceptable degree of precision if there was at least one low, one very high, and two intermediate levels of N. To our knowledge, no detailed response curves have been established over a wide range of fertilizer N under continuous grazing with dairy cows in terms of net energy output or herbage intake.

Although changes in tiller density and tiller demography in continuously grazed pastures are now well documented for relatively high N input levels (Grant et al., 1983; Bircham & Hodgson, 1984; Parsons et al., 1983a; Tallowin et al., 1989), little is known about the responses of tiller density and tiller distribution to N over a wide range of N levels under a continuous grazing management.

Both economic and environmental concerns demand a better understanding of the fate of N in intensive grassland management systems in order to increase the N use efficiency and to reduce the losses to the environment. The purpose of the present experiment was to increase the understanding of herbage and animal production responses to fertilizer N and the fertilizer N use efficiency under continuous grazing with dairy cows over a wide range of fertilizer N treatments. This response was compared with that under cutting, where cumulative herbage accumulation was determined at harvest intervals of approximately four weeks. Under such a cutting regime, Prins (1983) observed that at an assumed marginal profitability of 7.5 kg dry matter (DM) per kg N applied the optimum application in long-term trials on sand and clay soils in the Netherlands was on average 420 kg N $ha^{-1}yr^{-1}$. The effect of the different treatments (continuous grazing versus cutting) on tiller density and tiller distribution were examined and will be discussed in relation to herbage yield. Furthermore, the N use efficiency will be discussed. In a second paper the response under rotational grazing, grazing alternated by cutting and cutting only is described.

Material and methods

Site characteristics and treatments

The trials were carried out on a well drained young sedimentary calcareous silty loam soil in Oostelijk Flevoland. The soil (0-5 cm layer: pH-KCl 7.1; 10.0% $CaCO_3$) was reclaimed from the sea only 30 years ago and had been under grass for more than 20 years. In August 1985 the sward was reseeded with perennial ryegrass (*Lolium perenne* L.; cv. Wendy).

Grazing. In 1986 N response experiments under continuous grazing, cutting every week and cutting every 4 weeks were started; continuous grazing and 4-weekly cutting were continued in 1987 and 1988.

In spring 1986, 2 blocks of four paddocks (1-1.5 ha) each were fenced off. Fertilizer treatments were four rates of N annually: 250, 400, 550 and 700 kg ha^{-1}. The paddocks were stocked with spring-calving Friesian dairy cows according to a 'put and take' continuous grazing system. Four randomly selected 'core' animals were allocated to each paddock, and remained on the paddock throughout the grazing season. Stocking rates were adjusted regularly on each paddock by adding or removing extra cattle depending upon whether the sward height was increasing or decreasing from the target height, respectively. Target was a compressed sward height of 6 cm on the frequently grazed areas (mean overall sward height about 7 cm), in order to sustain a constant quantity of good quality herbage available across treatments and to achieve closely the potential maximum for herbage intake and animal production (Ernst et al., 1980). Compressed sward height (i.e. an integrated assessment of both sward height and density) was measured about twice-weekly using a falling plate meter (diameter 50 cm; weight 340 g). Per paddock 100 measurements were made. The number of cattle on each paddock was recorded throughout the grazing season and the data were accumulated to provide the total number of animal grazing days (per ha) for each treatment. Milk yield of all animals was measured daily in the milking parlour and the milk was analysed weekly for fat and protein concentrations. All animals were weighed on two consecutive days at the start and the end of the grazing season and at monthly intervals in between. During the grazing season concentrates were supplied at a rate of 1 kg per animal per day. Herbage intake was calculated from animal performance data. A possible drawback of this method is the difficulty to assess the energy requirements associated with the process of grazing. Nevertheless, this method is useful for obtaining relative measures of herbage intake in pastures (Baker, 1982). An alternative technique to estimate herbage intake under continuous grazing is to measure herbage accumulation under exclosure cages over a short period of time (Frame, 1981). In 1988, both methods were compared on two paddocks within one block (the 250 N and the 550 N paddock). On each paddock nine cages were used.

Cutting. In 1986, two cutting trials (weekly and 4-weekly cutting) were laid out according to a randomized block design with four replicates. Treatments were five rates of fertilizer N annually: 0, 250, 400, 550 and 700 kg ha^{-1}. The weekly cutting experiment was carried out in 1986 only and was performed as a simulation for continuous grazing. During all three years DM yield response to fertilizer N was measured in a 4-weekly cutting experiment. In this cutting experiment herbage was harvested at an approximate interval of 4 weeks when a DM yield of about 2000 kg ha^{-1} was reached.

Fertilization. In spring, on all treatments fertilizer N (calcium ammonium nitrate; 27% N) was applied when the accumulated mean daily air temperatures above 0 °C since 1 January approached 200 °C (Jagtenberg, 1970). Thereafter, applications were made in diminishing amounts every three weeks (grazing and weekly cutting experiment) or immediately following defoliation (4-weekly cutting experiment) until target rates were reached. The application of nutrients other than N was based on soil analysis. In spring 1986, 1987 and 1988 phosphorus (P) was applied only in the cutting trials as triple superphosphate (21% P) in one annual dressing of 95 kg P ha^{-1}.

Harvesting technique and chemical analyses. On all occasions, the plots in the cutting trials were cut with a reciprocating motor mower with a 0.88 m wide cutter bar leaving a stubble of 5 cm, whereas under the exclosure cages a stubble of 4 cm was left. From each strip 200-300 g fresh material was sampled for chemical analysis. Periodically herbage samples were taken in the paddocks by hand plucking to the mean grazing depth (i.e. simulated grazing). All samples were analysed for ash , N, P and K (potassium) content according to the method of Novozamsky et al. (1983). In-vitro digestibility of organic matter (D_{vitro}) was estimated by the method of Goering & van Soest (1970). Apparent in-vivo digestibility (D_{om}) could be calculated from D_{vitro} of standard samples of known in-vivo digestibility determined with wethers.

Statistical examination of the results using variance analysis techniques was accomplished using the statistical programme Statgraphics (1986).

Sward quality

In 1986, tiller density was estimated at the end of the grazing season and in 1987 and 1988 at the beginning, halfway and at the end of the grazing season. Per paddock one hundred 0.25 dm^2 plugs were taken (De Vries, 1940) according to a systematic line-sampling technique and tillers within each plug were counted. In autumn 1988, tiller density was also estimated in the plots of the cutting experiment. Per N treatment one hundred plugs (i.e. 25 plugs per replicate) were taken and tillers within each plug were counted.

In 1986, on some occasions percentage cover was determined in the grazed swards by means of vertical point quadrats. Percentage cover is defined, according to Grant (1981), as the number of contacts per 100 pins when only a record is made for any species first contacted as the pin is lowered through the sward.

Herbage accumulation and intake

In all cases herbage accumulation and herbage intake are expressed in Dutch Feed Units (Van Es, 1978). One Dutch Feed Unit (VEM) contains 6.9 kJ NE for lactation. Averaged over the growing season, herbage DM accumulated in growth periods of up to one month contains about 1000 VEM kg^{-1} DM (Meijs, 1981).

Under cutting, herbage accumulation was calculated from harvested DM and the energy content. The energy content of the samples, including the hand-plucked samples in the grazed swards, was calculated according to equation 1 (Van Es, 1978).

$$E_h = \{0.6 + 0.0024 \cdot (ME/44 - 57)\} \cdot 0.975 \cdot ME/1.65 \quad (1)$$

where:
E_h = Energy content of the herbage (VEM kg^{-1} DM);
ME = Metabolizable Energy (kcal kg^{-1} DM);

$$ME = 3.4 \cdot DOM + 1.4 \cdot CP \quad (2)$$

DOM = Digestible Organic Matter (g kg^{-1} DM);
CP = Crude Protein (g kg^{-1} DM).

In 1988, herbage accumulation under exclosure cages in the grazed swards was determined as the difference between herbage mass per unit area above 4 cm cutting height at the end of the growth period under the exclosure cage and initial herbage mass at the start. Before the exclosure cage was placed on the sward, initial herbage mass was estimated on basis of the initial sward height and regression between sward height and herbage mass in strips parallel to the exclosure cage. Using the same double sampling technique (Back et al., 1969) herbage mass in the paddock was estimated with the average sward height on the paddock as an estimator. The growth period under the exclosure cages was one week in spring and early summer and gradually extended to two weeks in October. After each growth period cages were moved and the procedure was repeated. Based on growth curves determined by Parsons et al. (1984) it can be assumed that in a sward released from continuous grazing exponential growth occurs. Therefore Linehan's formula (Linehan et al., 1947) may be used to estimate herbage intake from herbage accumulation data under cages (Lantinga, 1985b):

$$HI = (Y_t - Y_{t+1}) \cdot \ln\{(Y_t + U)/Y_{t+1}\}/\ln(Y_t/Y_{t+1}) \quad (3)$$

where:
HI = herbage intake (kVEM ha^{-1});
Y_t = herbage mass in paddock at t (kVEM ha^{-1});
Y_{t+1} = herbage mass in paddock at t+1 (kVEM ha^{-1});
U = herbage accumulation under the exclosure cage from t to t+1 (kVEM ha^{-1}).

In all three years daily herbage intake was also calculated as the difference between daily requirements for maintenance and production of the grazing animals and the daily energy consumption of the supplemented concentrates. Daily N intake was calculated on basis of the herbage intake, and the N content and D_{om} of the hand-plucked samples. The maintenance requirement for housed cattle (E_m) is 42.4 VEM per kg metabolic weight (Van Es, 1978); the additional energy requirement for grazing activity is assumed to be 20% (Meijs, 1981), thus:

$$E_m = 42.4 \cdot W^{0.75} \cdot 1.2 \quad (4)$$

where:
E_m = energy requirement for maintenance (VEM d^{-1});
$W^{0.75}$ = metabolic liveweight (kg).

The daily energy requirement for milk production and liveweight gain (E_p) was calculated according to Van Es (1978):

$$E_p = 442 \cdot FPCM \cdot (0.9752 + 0.00165 \cdot FPCM) + 3000 \cdot G \quad (5)$$

where:
E_p = energy requirement for production (VEM d^{-1});
FPCM = 4% fat- and 3.3% protein-corrected milk (kg d^{-1});
G = liveweight gain (kg d^{-1}).

Weather data

Weather data were available from the meteorological station at Swifterbant. Cumulative precipitation is shown in Fig. 1. The growing season of 1986 was rather dry, whereas 1987 had a high amount of rainfall.

Results and discussion

In May 1986, as a consequence of the disaster of the Tchernobyl nuclear power plant in the Soviet Union, a governmental grazing prohibition was issued. By the time the prohibition was cancelled, herbage on offer was too much to be utilized by the available cattle. Therefore, it was decided to cut the grass on 12 May.

Animal performance

Averaged over the three years, cow grazing days and total milk yield per ha responded significantly ($P<0.05$) to fertilizer N applied (Table 1). The average increase in cow grazing days was 0.55, 0.45 and 0.07 per ha per kg N applied for fertilizer increments 250 to 400, 400 to 550 and 550 to 700 kg N $ha^{-1}yr^{-1}$, respectively. These responses were considerably lower than the linear response of 0.98 cow grazing days per kg of additional applied N at fertilizer application rates up to 450 kg N $ha^{-1}yr^{-1}$ as reported by Gordon (1983). However, in the experiment of Gordon the mean milk

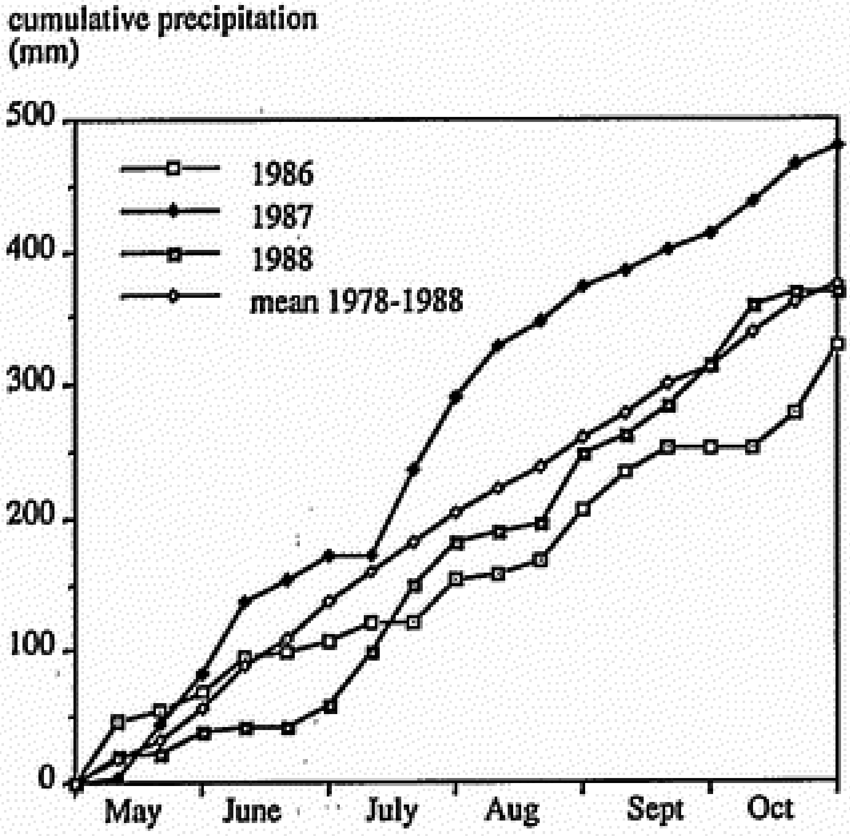


Fig. 1. Cumulative precipitation (mm) for 1 May-1 November in 1986, 1987, 1988 and the mean cumulative precipitation for 1978-1988 measured at the meteorological station at Swifterbant.

Table 1. The effect of fertilizer N application on animal performance per ha per year (1986-1988).

	Fertilizer application (kg N $ha^{-1}yr^{-1}$)			
	250	400	550	700
1986				
cow grazing days	547	590	648	646
live weight gain (kg)	211	201	171	235
milk yield (kg FPCM)	11130	12888	13170	13582
1987				
cow grazing days	531	606	661	654
live weight gain (kg)	191	138	173	148
milk yield (kg FPCM)	11769	13298	14822	14139
1988				
cow grazing days	509	642	731	769
live weight gain (kg)	154	159	210	122
milk yield (kg FPCM)	12218	16261	18324	19758
1986-1988 mean				
cow grazing days	529 a	612 b	680 c	690 c
live weight gain (kg)	185	166	185	168
milk yield (kg FPCM)	11705 a	14149 b	15438 c	15826 c

Different letters within a row denote significant ($P<0.05$) differences according to Tukey.

yield was only 18.6 kg per cow per day. In the present experiment mean daily milk yields were 20.9, 22.0 and 25.0 kg FPCM per cow in 1986, 1987 and 1988, respectively. The mean cow liveweight over the three experimental years at the start of the grazing season was about 530 kg. Neither mean daily liveweight gain, which was 0.28 kg per animal, nor mean daily milk yield per cow was affected by level of N application. In 1988 animals were significantly more productive since higher yielding cows were selected for the experiment.

Sward quality

Occurrence of species other than perennial ryegrass was rare. Therefore, only data of perennial ryegrass are presented. The tiller density of perennial ryegrass in the grazed swards and its changes in the course of the experiment showed great fluctuations with time. Variations in tiller density in relation to N treatments were much smaller and significant on a few occasions only (Fig. 2).

In autumn 1986, tiller density was significantly lower in the 550 N and 700 N sward when compared with the 250 N and 400 N sward (Fig. 2). The lower tiller density was a result of a less dense sward and not due to open gaps (Figs 3 and 4).

In spring 1987, tiller density was relatively low with no differences between the N treatments. Nevertheless, there was a high proportion of plugs containing no tillers and this proportion increased with the level of N application (Fig. 4). The absence of tillers was probably due to winter damage. In July 1987, tiller density had increased in all N treatments except the 700 N sward (Fig. 2). Besides, the number of plugs containing no tillers had increased in the 700 N sward (Fig. 4). This sward deterioration could be associated with poaching due to wet soil conditions (Fig. 1). At the end of the growing season of 1987, the 700 N sward had recovered. Between the N treatments no differences could be observed in tiller density, frequency distribution or number of plugs containing no tillers.

In April 1988, tiller density had decreased in all swards. Compared with autumn 1987, this decrease appeared to be the result of sward thinning; there were no differences in the frequency of plugs containing no tillers (Fig. 4). In July tiller density had increased in all swards. The increase was strongest in the 250 N sward, whereas the high N swards remained more heterogenous (Fig. 3). At the end of the experiment there were no differences in the sward structure (Figs 3 and 4), although the low N swards had a higher tiller density than the high N swards (Fig. 2).

Generally, if there were differences in tiller density, these differences were temporarily and in favour of the low N swards. At the end of the experiment (autumn 1988) tiller density was determined in the cutting trial as well. Tiller densities were 56, 90, 69, 74 and 76 tillers per dm^2, respectively in the 0 N, 250 N, 400 N, 550 N and 700 N sward. Tiller densities were significantly lower than under grazing (Fig. 2). In the cutting trials, the lower tiller densities at the higher N levels were likely to be offset by a higher mean tiller weight (Wilman & Pearse, 1984).

amount of available soil N. In March before fertilizer N was applied, inorganic soil N was on average 103 kg N ha^{-1} in 1986, 108 kg N ha^{-1} in 1987 and only 30 kg N ha^{-1} in 1988 (Van der Putten & Van der Meer, pers. comm.). It can also be derived from quadrants IV (Fig. 5) that in 1988 N yield in the 0 N cutting treatment was about half the amount of that in 1986 and 1987.

Apparent efficiency of fertilizer N

Cutting. In all three years there was a significant response of herbage yield to fertilizer N applied (Fig. 5; quadrants II). In 1988, herbage yield at 0 N was lower than in 1986 and 1987 due to a relative low amount of available soil inorganic N in that year. This low amount of soil inorganic N, in combination with the early start of the growing season (Table 2) effected a strong response to fertilizer N in 1988. In 1986 and 1987 yields at 550 and 700 kg N ha^{-1}yr^{-1} were lower than in 1988 due to a later start of the growing season in both years (Table 2) and water shortage in 1986 (Fig. 1).

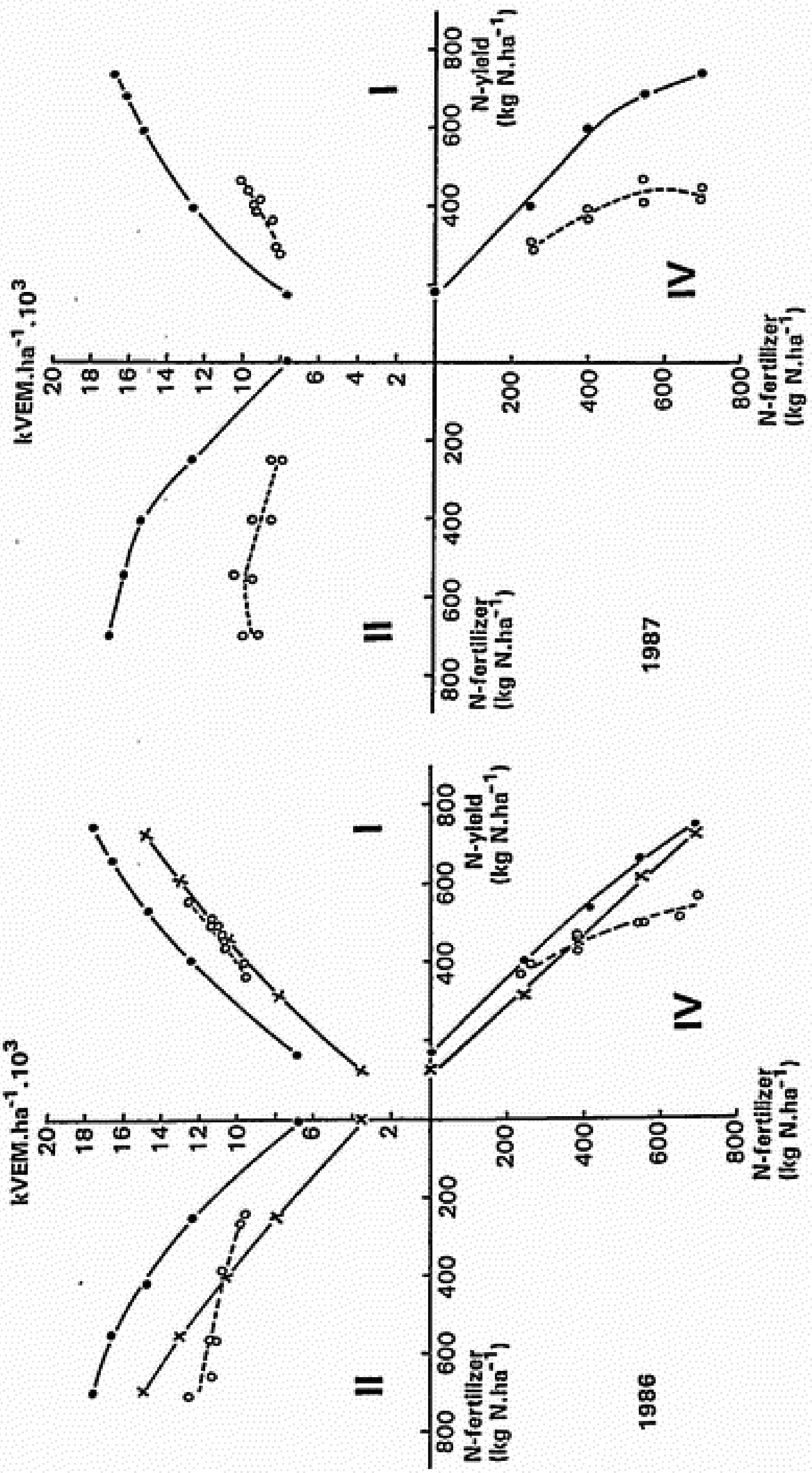
Grazing. Under grazing marginal ANE values were lower than under cutting and differences became greater with increasing rates of N application. Under 4-weekly cutting, the mean marginal ANE values over the three years were 17.8, 10.6 and 5.8 kVEM per kg N applied, whereas under grazing these values were 9.7, 6.5 and 1.9 kVEM per kg N applied for increments 250 to 400, 400 to 550 and 550 to 700 kg N ha^{-1} yr^{-1}, respectively. The increased differences between herbage accumulation (4-weekly cutting) and herbage intake (grazing) with increasing N application rates is also illustrated in Table 3. Annual yields under weekly cutting (1986 only) and grazing are expressed as a percentage of those under 4-weekly cutting at corresponding

Table 2. Harvesting date and dry matter yield of the first cut in the 4-weekly cutting experiment. Fertilizer N application 250 kg N ha^{-1}yr^{-1}; spring application 60 kg N ha^{-1}.

	Harvest date	Yield (kg DM ha^{-1})
1986	12 May	2441
1987	22 May	2009
1988	6 May	2892

Table 3. Relative herbage yield under weekly cutting (W) in 1986 and relative herbage intake under continuous grazing (C) in 1986-1988, expressed as a percentage of herbage yield, expressed in VEM, under 4-weekly cutting (4-weekly cutting = 100).

	1986 W	1986 C	1987 C	1988 C
kg N ha^{-1}yr^{-1}				
250	63	64	64	64
400	72	60	59	65
550	79	55	61	67
700	85	54	56	66


kVEM.ha-1.10^3
N-yield (kg N.ha-1)
N-fertilizer (kg N.ha-1)
N-fertilizer (kg N.ha-1)
I
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1987
kVEM.ha-1.10^3
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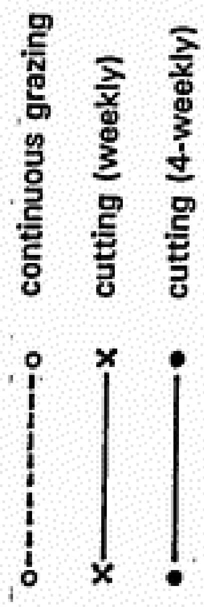

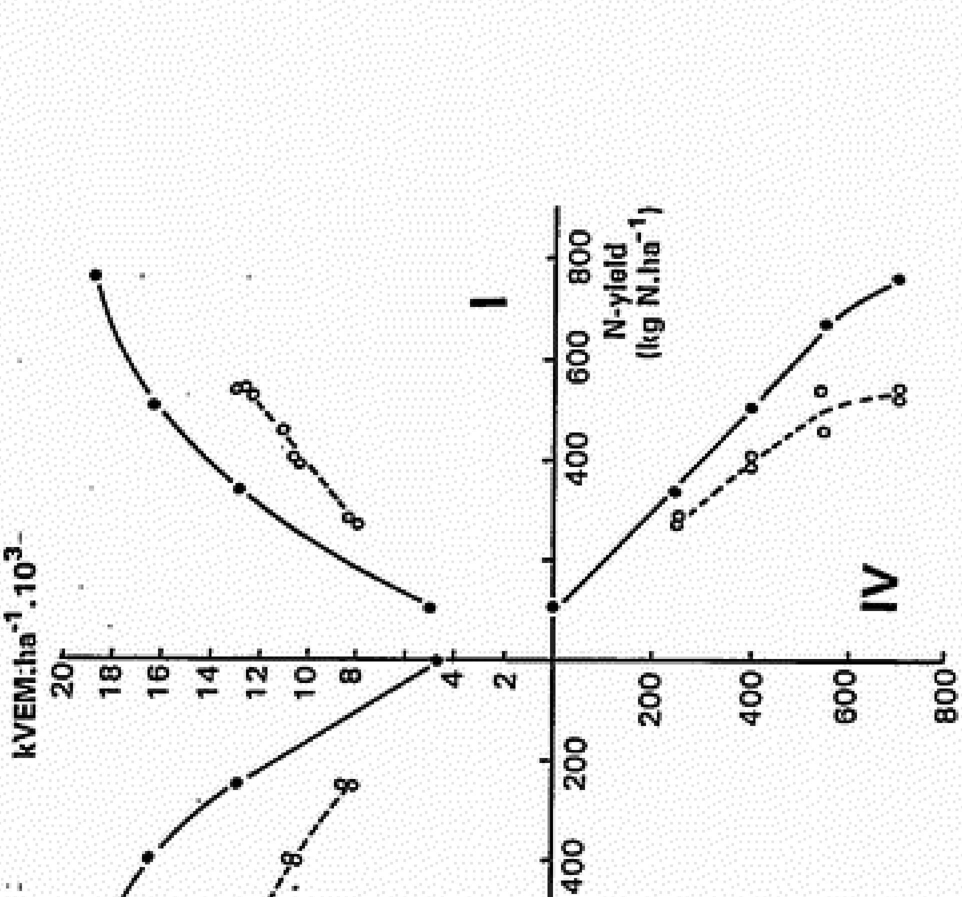

Fig. 5. The effect of fertilizer N application on N yield and herbage yield and herbage intake expressed in kVEM (1 kVEM = 6.9 MJ Net Energy for lactation) under cutting and continuous grazing. For cutting, data are averages over 4 replicates; for grazing, data per paddock are presented.

N levels. Relative yields in the weekly cutting experiment increased with increasing N application. Relative yields under grazing were low (54 to 67%). Lantinga et al. (1987) found relative yields of about 80%, irrespective of fertilizer N level, at a sward height of about 7 cm in two one-year experiments in very dense 15 year old swards dominated by *Lolium perenne* and *Poa trivialis*. Probably a target sward height of 7 cm might have been suboptimal in the present experiment since these reseeded swards were less dense throughout all experimental years, because of the absence of *Poa trivialis*. The relative yields under grazing decreased in 1986 and 1987 and remained constant (1988) with increasing N. This will be analysed below.

In 1986, herbage accumulation under grazing included the herbage harvested for the silage cut. Fertilizer N had a significant ($P<0.05$) effect on the yield of the silage cuts; these were 1728, 1870, 2067 and 2379 kVEM ha^{-1} for the respective N application rates. After the silage cut, especially at the higher N levels, sward thinning could be observed. In June 1986, one month after the silage cut, the percentage of the ground covered by perennial ryegrass in the grazed swards measured with the point quadrat method was 80, 71, 62 and 66 for treatments 250, 400, 550 and 700 kg N ha^{-1} yr^{-1}, respectively. The incidence of other species was insignificant, thus the complement consisted mainly of bare patches and dead herbage. Due to this sward thinning and the drought during early summer (Fig. 1) no significant responses of herbage intake to fertilizer N applied could be calculated until the middle of July. Therefore, marginal ANE values for herbage intake were low in 1986, especially for fertilizer increments 400 to 550 and 550 to 700 kg N ha^{-1} yr^{-1}. As a consequence, the response to applied fertilizer N was weak (Fig. 5; quadrant II). This weak response is also evidenced in the weak response of milk yield per ha to fertilizer N in 1986 (see Table 1).

In 1987 the decreasing relative yields under grazing (Table 3) could be associated with sward deterioration due to adverse weather conditions during spring and summer. The decreasing relative yields in 1986 and 1987 suggest a positive effect of excretal N on herbage production at 250 N (Deenen & Middelkoop, 1992) and negative effects exerted by the grazing animals at high fertilizer N rates. These negative grazing effects in spring and summer 1987 may have affected herbage yield under grazing, which was significantly ($P<0.05$) lower than in 1986, in contrast to the cutting trials where no significant yield differences between 1986 and 1987 were observed (Fig. 5). Most probably, the very wet spring and summer of 1987 impeded N uptake and thus the response to fertilizer N under grazing due to poaching damage (Fig. 4). The marginal ANR value under grazing for the increment 550 to 700 kg N ha^{-1} yr^{-1} was 0, whereas the marginal ANE value was even negative.

A strong response to fertilizer N applied in the grazed wards was found in 1988 only (Fig. 5; quadrant II). Total herbage intake was significantly ($P<0.05$) higher than in the foregoing years. This year was characterized by a long growing season (Table 2) and favourable weather conditions for grazing (no poaching damage).

Continuous grazing versus weekly cutting

In 1986, the response to fertilizer N was much stronger under weekly cutting than under continuous grazing (Fig. 5). The higher yield at 250 kg N $ha^{-1}yr^{-1}$ under grazing was due to: (i) a greater N uptake, reflecting recirculation of excretal N (quadrant IV), and (ii) a slightly higher efficiency of use of absorbed N (quadrant I). This higher efficiency might have been a consequence of differences in the defoliation pattern between the two treatments. With continuous grazing harvesting is spread over time and space and this heterogeneity may be beneficial for herbage growth (Smith, 1968). At higher N application rates ANR declined sharper under grazing. This was most probably due to both an increased sward openness after the spring silage cut and increasing negative grazing effects on sward quality at higher N levels.

Optimum N application rate

Yields at all levels of fertilizer N varied between treatments and years. Yield response curves were fitted to each treatment-year combination. The form of the curve which was used to fit the data was an inverse polynomial (Sparrow, 1979):

$$Y = (a + bx)/(1 + cx + dx^2) \qquad (6)$$

where:
Y = yield (kVEM ha^{-1} yr^{-1});
x = fertilizer N (kg N ha^{-1} yr^{-1});
a, b, c and d are constants.

Estimates derived from these fitted curves were: $N_{7.5}$ and N_{10} = the rate of N at which an incremental response to a 1 kg increase in applied N of 7.5 or 10 kVEM, respectively, is achieved over the whole season; $Y_{7.5}$, Y_{10} = kVEM yield obtained at a fertilizer rate $N_{7.5}$ or N_{10}, respectively (Table 4). Taking a marginal profitability of 7.5 kVEM per kg N applied, the optimum application in the 4-weekly cutting experiment appeared to be 511 kg N ha^{-1} yr^{-1}. Prins (1983) found a mean marginal profitability of 7.5 kg DM per kg N applied at 420 kg N ha^{-1} yr^{-1} in a multi-site experiment in the Netherlands (1 kVEM equals approximately 1 kg DM). In cutting trials in the United Kingdom, Morrison (1980) found a N_{10} value (i.e. 10 kg DM per kg N applied) of 386 kg N ha^{-1} yr^{-1} with a corresponding Y_{10} value of 10.8 t DM ha^{-1}. In the present experiment these values were 430 kg N ha^{-1} yr^{-1} and 15.6 t DM ha^{-1} respectively.

Especially under grazing a great variation in optimum application rates was found between the three years. In 1988, the $N_{7.5}$ value under grazing was 475 kg N ha^{-1} yr^{-1}. In 1986 and 1987, the $N_{7.5}$ values were considerably lower, viz. 160 and 290 kg N ha^{-1} yr^{-1} respectively. Under continuous grazing the mean $N_{7.5}$ value was 308 kg N ha^{-1} yr^{-1}.

Exclosure cages

In 1988, herbage accumulation under the exclosure cages was 8716 and 14275 kVEM ha^{-1}, whereas herbage intake calculated from animal production data was

Table 4. The fertilizer N rate at which an incremental response to a 1 kg increase in applied N of 7.5 kVEM ($N_{7.5}$) or 10 kVEM (N_{10}) is achieved over the whole season. $Y_{7.5}$ and Y_{10} are kVEM yields obtained at a fertilizer rate $N_{7.5}$ or N_{10} for weekly cutting, 4-weekly cutting and continuous grazing.

	Fertilizer N rate (kg N $ha^{-1}yr^{-1}$)		Yield (10^3 kVEM $ha^{-1}yr^{-1}$)	
	$N_{7.5}$	N_{10}	$Y_{7.5}$	Y_{10}
Weekly cutting				
1986	950 [1]	700	16.5[1]	14.9
4-weekly cutting				
1986	558	462	16.5	15.5
1987	425	345	14.9	14.0
1988	550	500	19.0	18.0
mean	511	436	16.8	15.8
Continuous grazing				
1986	160 [1]	– [2]	9.1	– [2]
1987	290	210[1]	8.3	7.9 [1]
1988	475	420	11.3	10.5
mean	308	– [2]	9.6	– [2]

[1] Extrapolated. [2] Not determined.

7963 and 11129 kVEM ha^{-1} on the 250 N and 550 N paddock, respectively. The relations between N fertilization, N yield and herbage yield are presented in Fig. 6. N yield under cages was only slightly lower in comparison with 4-weekly cutting (quadrant IV). Under grazing N yield was lower, but note that this is ingested N. Herbage accumulation under the 4-weekly cutting regime was highest due to a higher efficiency of the N absorbed (quadrant I) resulting from less frequent defoliation. Marginal ANE values for the increment 250 to 550 kg N ha^{-1} yr^{-1} were quite similar under 4-weekly cutting and under the exclosure cages (17.3 and 18.5 kVEM per kg N applied, respectively). Under grazing the marginal response was 10.6 kVEM per kg N applied.

Linehan's formula (Linehan et al., 1947) was used to estimate herbage intake. The average cutting height under the cages was approximately 4 cm. In rotationally grazed swards this height can be taken as the reference height for the herbage mass, since the assimilatory capacity of the remaining stubble is more or less in balance with the respiratory carbon losses (Lantinga, 1985b). The carbon exchange of a continuously grazed sward with an average sward height of about 7 cm is in balance at about 2 cm sward height due to a more leafy stubble (Lantinga, unpublished measurements); therefore, herbage mass in the sward layer from 2 to 4 cm has to be included too. The amount of DM present in this sward layer is about 1000 kg DM ha^{-1} (Lantinga, unpublished measurements), and added to the herbage determined by cutting above 4 cm. By means of this procedure a total herbage intake of 7200 and 11503 kVEM ha^{-1} could be calculated in the 250 N and 550 N paddock, respectively. The cumulative herbage intake calculated from animal production data and cumula-

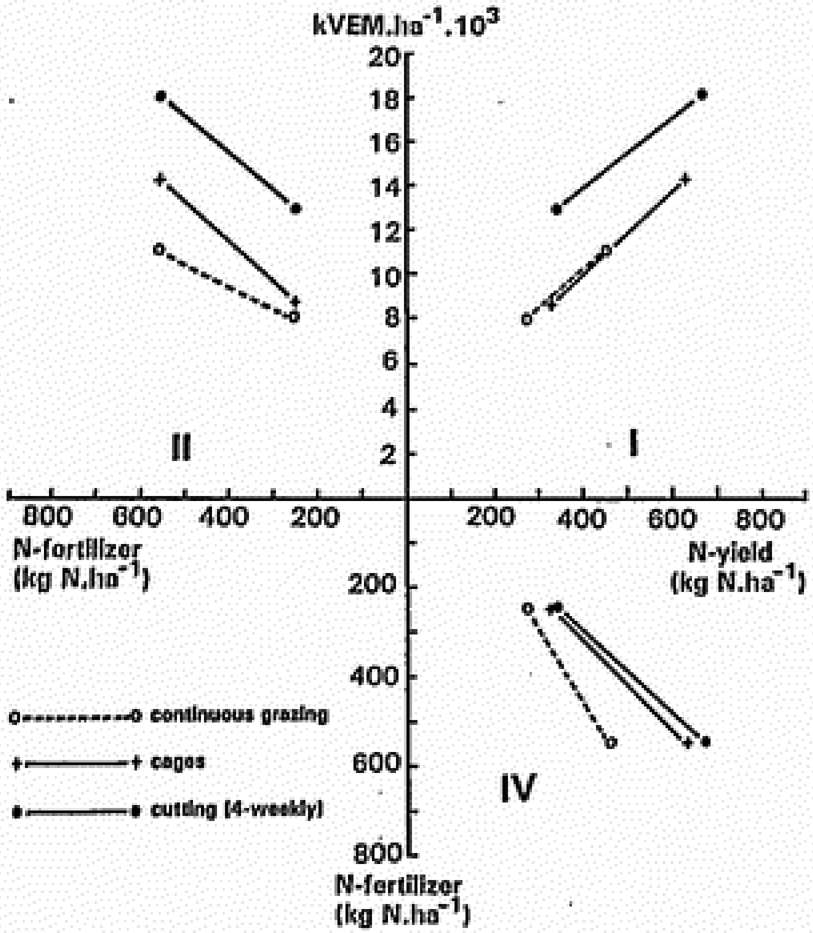

Fig. 6. The effect of fertilizer N application on N yield and herbage yield in a 4-weekly cutting experiment and under exclosure cages and on N yield and herbage intake under continuous grazing. Herbage yield and intake expressed in kVEM (1 kVEM = 6.9 MJ Net Energy for lactation)(1988).

tive herbage intake by means of the formula of Linehan are presented in Fig. 7. The two methods were significantly ($P<0.01$) correlated. Rank correlation coefficients were 0.70 and 0.79 for the 250 and 550 N treatment respectively. The deviation between the two methods in the 250 N treatment may be due to an underestimation of the predicted ME value of the grass grown under the cages at that N level. Compared with values obtained in energy balance methods the predicted ME value based on in-vitro digestibility of fresh and frozen grass appeared to be underestimated with about 10% for some reason (Van der Honing et al., 1977). It is to be expected that this difference will be smaller for grass with a very high N content as in the 550 N treatment. In the formula for calculating the ME value (equation 2), a positive contribution of the digestible crude protein is included, irrespective of its level. This may be not true for N-rich herbage, since a great proportion of the N intake has to be excreted as urinary ureum, which is an energy requiring process.

N use efficiency

For a grazing management system the N use efficiency can be defined either as (i) the fraction (%) of the total N input in fertilizer, concentrates and precipitation contained in animal products (milk and meat); or (ii) the fraction of the total ingested N

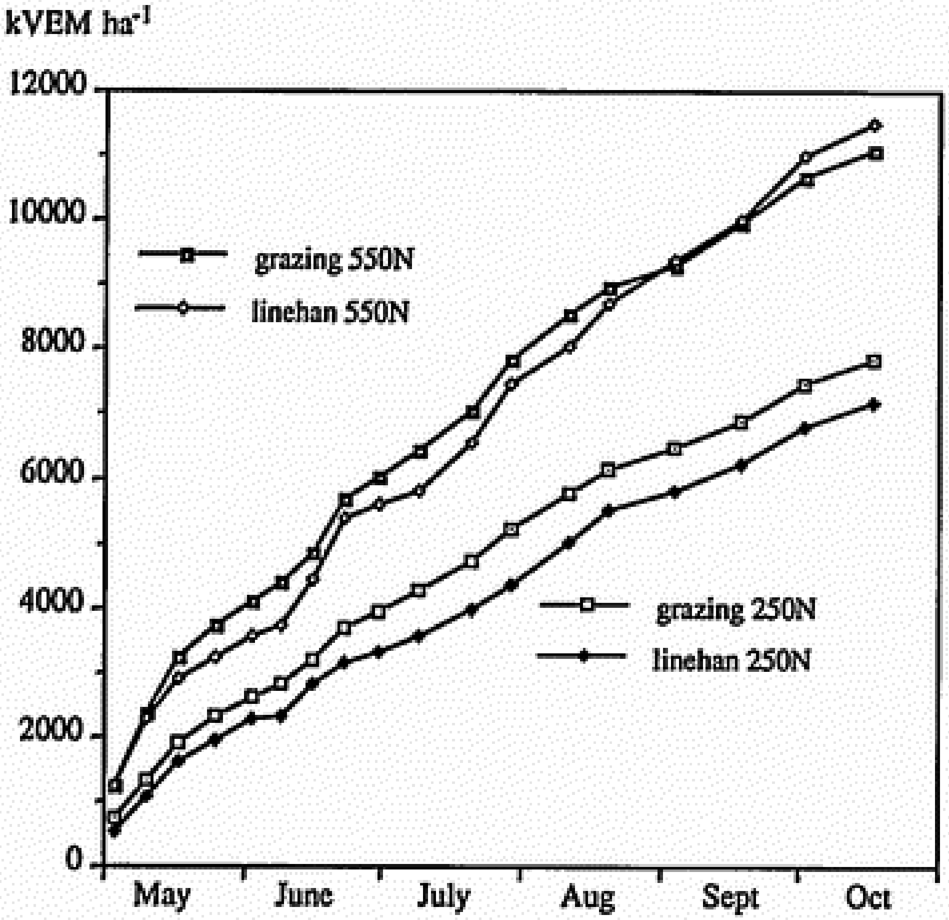

Fig. 7. Cumulative herbage intake under continuous grazing calculated from animal performance data and cumulative herbage intake calculated according to the formula of Linehan from herbage accumulation under the exclosure cages (1988).

contained in animal products.

As indicated in Table 5, the efficiency of use of the total N input in the grazing treatments was in 1986 about twice as high as in 1987 and 1988 due to the silage cut which was accounted for as output. When no other feedstuffs are supplemented the efficiency of use of ingested herbage N is dependent on animal production. The mean efficiency of use of ingested N in these experiments was 19.3 to 23.0% (Table 5). These results agree with data from other experiments (Van Vuuren & Meijs, 1987). In 1988, the animals were more productive and this resulted in better efficiencies of use of ingested herbage N. However, all these data are far from the theoretical maximum efficiency of 40-45% (Van Vuuren & Meijs, 1987).

Recovery of N in animal products decreased with increasing rates of fertilizer N application. The effect of applied N on DM production is smaller than the effect on crude protein production, leading to an increasing surplus of crude protein in the herbage with increasing rates of fertilizer N. This is illustrated indirectly by the calculated excretion of N in dung and urine. There is only a small increase of the amount of N excreted in dung with increasing rates of fertilizer N application since the amount of N excreted in dung is highly correlated with DM intake (Barrow & Lambourne, 1962). However, there is a dramatic increase in the amount of N voided in urine (Table 5). Since the recovery of excretal N is low (Lantinga et al., 1987), the

Table 5. The effect of fertilizer N application (kg N ha^{-1} yr^{-1}) on the N balance under continuous grazing of dairy cows.

	1986				1987				1988				Mean 1986-1988			
A INPUT																
fertilizer	251	389	558	679	252	405	550	701	251	401	549	701	251	398	552	694
concentrates	12	13	14	14	11	13	14	14	11	14	16	16	11	13	15	15
precipitation	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
total	303	442	612	733	303	458	604	755	312	455	605	757	302	451	607	749
B. INTAKE	320	385	413	439	305	391	449	442	290	414	513	551	305	397	458	477
C. OUTPUT																
animal growth [1])	6	6	5	8	6	4	5	4	5	5	6	4	6	5	5	5
milk	61	71	72	75	65	73	82	78	67	89	101	109	64	78	85	87
silage	73	82	98	114									24	27	33	38
total	140	159	175	197	71	77	87	82	72	94	107	113	94	110	123	130
D. EXCRETION																
dung [2])	68	74	76	80	69	76	84	80	72	89	99	102	70	80	86	87
urine [3])	185	234	260	277	164	238	278	279	147	231	306	336	165	234	281	297
total	253	308	336	357	234	314	362	359	219	320	405	438	235	314	367	384
E. EFFICIENCY OF N UTILIZATION																
input (C/A·100%)	46.2	36.0	28.6	26.9	23.4	16.8	14.4	10.9	23.1	20.7	17.7	14.9	31.1	24.4	20.2	17.4
intake (C/B·100%)	20.9	20.0	18.6	18.9	23.3	19.7	19.4	18.6	24.8	22.7	20.9	20.5	23.0	20.9	19.7	19.3

[1]) N retention: 30 g N per kg liveweight (Lantinga et al., 1987).
[2]) N excretion in faeces: 0.8 g N per 100 g DM eaten (Barrow & Lambourne, 1962).
[3]) Urine N excretion calculated as: N intake – (N retention in animal growth and milk) – dung N.

potential amount of N that can be immobilized or is susceptible to loss from the system through volatilization, denitrification and leaching will be large.

The efficiency of use of the total N input is dependent on the complex animal-plant-soil system (including management). From data of intensive dairy farms Van der Meer (1982) calculated a N use efficiency of about 16% on a farm-scale over a year. This N use efficiency is lower than the efficiencies found in the present experiment since these are only calculated for dairy cows during the grazing season and not taking into account all other farming practices which have an effect on the N use efficiency.

Conclusions

In the cutting experiments very high ANR values and absolute responses to N applied were found in all three years. Under grazing the effects exerted by the grazing animals are added. It is concluded that an eventual small positive effect of excretal N at the lower N application rates (Deenen & Middelkoop, 1992) and an increasingly negative effect at higher N application rates due to treading and poaching (Edmond, 1966; Wilkins & Garwood, 1986) resulted in a levelling off of the response curve. Assuming a marginal ANE of 7.5 kVEM per kg N applied as the optimum application rate from an economical point of view than optimum application rates were on average 511 and 308 kg N $ha^{-1} yr^{-1}$ for 4-weekly cutting and continuous grazing, respectively.

A good agreement was found between calculating herbage intake from animal performance data and calculating herbage intake by means of the formula of Linehan et al. (1947) based on measurements of herbage accumulation under the exclosure cages. The data of herbage accumulation under the exclosure cages itself gave an overestimation of herbage intake. It may be concluded that sward quality strongly affects the absolute as well as the marginal response of herbage production and implicitly animal production to fertilizer N applied, even under a continuous grazing management which is thought to be more resilient to sward damage (Ernst et al., 1980).

Poor conversion of herbage N into animal products resulted in large amounts of excess dietary N concentrated in dung and urine patches (Table 5) and thus increasing the risk of large N losses from the system. Therefore, it may be postulated that the optimum N application rate from an ecological point of view will be much lower than the economical optimum rate. However, Hassink & Neeteson (1991) observed in the grazed plots an average accumulation of 245 kg soil organic N $ha^{-1} yr^{-1}$ in the period March 1986 to March 1989, irrespective of the level of fertilizer N applied. Although this figure is irrealistic high (the difference between input and output of N in the 250 N sward was on average only 208 kg $ha^{-1} yr^{-1}$; Table 5), it points out that this young marine soil serves as a sink for the excreted N and thus reducing the losses through volatilization, denitrification and leaching.

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