Herbage and animal production responses to fertilizer nitrogen in perennial ryegrass swards. II. Rotational grazing and cutting

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Abstract

The yield response of grass swards to fertilizer nitrogen (N) differs under cutting and grazing, as grazing cattle exert positive and negative effects on pasture production, with varying negative effects on different soil types. Nevertheless, current N fertilization recommendations in the Netherlands are based mainly on economic cost-benefit analyses of long-term cutting trials in small plots. To contribute to formulation of improved N fertilizer recommendations for grassland, experiments were carried out on two soil types and under different management regimes. The effect of fertilizer N application on grassland production and sward quality in perennial ryegrass swards was studied during a number of consecutive years under both rotational grazing and 4-weekly cutting. Experiment 1 was performed with dairy cows on a loam soil at 250 and 550 kg fertilizer N ha^{-1} yr^{-1}. Experiment 2 was performed with beef cattle on a sand soil and fertilizer rates varying from 250 to 700 kg N ha^{-1} yr^{-1} under grazing and from 0 to 700 kg N ha^{-1} yr^{-1} under cutting. The results indicate that on loam, N had no effect on sward quality. In the second experimental year, total herbage yield under grazing was almost 10% higher than under cutting at 250 kg N ha^{-1} yr^{-1} due to recycling of N, whereas at 550 kg N ha^{-1} yr^{-1} the yield under grazing and cutting was the same. On sand, the economically optimum fertilizer application rate was on average 430 kg N ha^{-1} yr^{-1} for 4-weekly cutting. Under grazing and at whole system level (integrated grazing and mowing for silage), the optimum rate was below 250 kg N ha^{-1} yr^{-1}. Under grazing on the sand soil, N aggravated sward deterioration due to treading, poaching and especially urine scorching. This was reflected in an increased absence frequency of rooted perennial ryegrass tillers in quadrats with an area of 1 dm^2 at increasing fertilizer N application rates. It is concluded that current fertilizer N recommendations for grassland can be further refined by taking into account the positive and negative effects of grazing cattle, in dependence of soil type and level of N supply.

Keywords: nitrogen response, rotational grazing, dairy cows, beef cattle, herbage intake, cutting, perennial ryegrass, *Lolium perenne* L., nitrogen use efficiency, sward quality, absence frequency

Introduction

Increased input of nitrogen (N), mainly through fertilizer N, has contributed signifi-
cantly to the increase in grassland productivity since World War II, especially in the
Netherlands. Until the early 1990s, the N fertilizer recommendation for intensively
managed grasslands was 400 kg N ha^{-1} yr^{-1}. Since then, differences between soil
types in non-fertilizer N supply (NFNS) and impeded N uptake during dry periods
are also taken into account (Unwin & Vellinga, 1994). NFNS comprises N mineral-
ized from soil organic matter during the growing season, inorganic N in the soil pro-
file in spring, N in dry and wet deposition, and N$_2$ fixation by free living and symbi-
otic microbes (Hassink, 1995). The methods developed by Hassink (1995) to predict
NFNS of mineral soils have been introduced recently, to further improve fertilizer N
recommendations for grassland in The Netherlands.
    Despite these refinements, the current recommendations are still based mainly on
economic cost-benefit analyses of long-term cutting trials with an approximate cut-
ting interval of four weeks (e.g. Prins, 1983). In these trials the recovery of fertilizer
N in harvested herbage was about 80% and there was hardly any accumulation of
soil inorganic N up to an application rate of 420 kg N ha^{-1} yr^{-1}. However, in Dutch
dairy farming, with predominantly grazing in the growing season, only 16% of the
total N input in fertilizer and purchased feeds is converted in milk and meat (Van
Keulen et al., 1996). A substantial, though variable part of the N not incorporated in
animal products is incorporated in soil organic N (Aarts et al., 1999), reducing po-
tential losses to the environment. After converting arable land to grassland, accumu-
lation of soil N can proceed at 190 kg N ha^{-1} yr^{-1} under grazing management (Hatch
et al., 1991; Cuttle & Bourne, 1992). This accumulation of soil N may be considered
as a positive aspect, since in the long term net N mineralization rates will increase.
However, when very old grassland is ploughed up, soil organic N may decrease dur-
ing the first five years with about 2000 kg N ha^{-1}, causing substantial nitrate leach-
ing losses (Whitmore et al., 1992).
    The yield response of a grass sward to fertilizer N differs under defoliation by cut-
ting or by grazing, as grazing cattle exert positive and negative effects on pasture
production. The larger quantities of N circulating in grazed swards should in theory,
be reflected in (i) higher yields at the same fertilizer N application rate, (ii) maxi-
mum or optimum yield responses to fertilizer N at lower application levels, and (iii)
higher N concentrations in the herbage. At low to medium levels of N fertilization,
the response of the sward to applied N under grazing is enhanced by an increased to-
tal supply of N (Norman & Green, 1958; During & McNaught, 1961). Richards
(1977) observed in a one-year experiment on a soil with a very low rate of N miner-
alization (25 kg N ha^{-1} yr^{-1}), a positive effect of grazing on herbage yield up to a fer-
tilizer N rate of 300 kg ha^{-1} yr^{-1}. Another feature is a higher N mineralization rate
under grazing, especially on sandy soil, where a difference of 110 kg N ha^{-1} yr^{-1} has
been observed between cutting and grazing (Hassink, 1992).
    Generally, the negative effects of sward damage through treading, poaching, urine
scorch and sod pulling increase with increasing rates of fertilizer N (Edmond, 1966;
Wilkins & Garwood 1986; Tallowin et al., 1986; Deenen & Middelkoop, 1992). Due

to these detrimental effects, N uptake is impeded at higher application rates, causing lower herbage yields than under cutting. Even under cutting management, Prins & Neeteson (1982) found lower yields, following increasing rates of N application in the preceding years. This decrease in productivity was associated with deterioration of the sward as evidenced by a more open structure and lower tiller density.

Studies on yield responses to fertilizer N under grazing and especially rotational grazing, the most widely used grazing system for dairy cows in the Netherlands, are scarce. In the Netherlands, Boxem (1973) comparing the response in a system where grazing was alternated by mowing for conservation with that under 4-weekly cutting, found only small differences. However, dry matter yields under the alternating grazing and mowing system were estimated as the sum of all pre-grazing yields added to the grass mown for conservation. Grazing residues were not always removed by cleaning cuts and as they contribute to the yield of the next cut, it may well be that the reported dry matter yields of the grazed swards are overestimated. Jackson & Williams (1979) observed in a multi-site experiment in the United Kingdom that grazed swards produced less dry matter than cut swards and that the differences were larger at higher N input levels (range 200 to 600 kg N ha^{-1} yr^{-1}). However, in their experiments the quantities of herbage on offer were lower than under normal farming practice, resulting in abnormal animal behavior with a high probability of adverse effects from trampling and fouling (R.D. Baker, IGER, UK, personal communication). Hence, their tentative conclusion that 'maximum yields are achieved with about 200 kg N ha^{-1} yr^{-1} less under grazing than cutting management' may be doubtful.

Economic and environmental concerns demand a better understanding of the fate of N in intensive grassland management systems, to increase N use efficiency and to reduce losses to the environment. The purpose of the experiments described in this paper was to increase understanding of herbage and animal production responses to fertilizer N and fertilizer N use efficiency under grazing with dairy cows and beef cattle over a wide range of fertilizer N treatments on a sand and a loam soil. The results for continuous grazing have been presented earlier (Deenen and Lantinga, 1993), and this paper, that has been delayed due to personal circumstances, focuses on rotational grazing. The effects are compared to those under cutting, with harvest intervals of approximately four weeks. The effects of the different treatments on sward quality are examined and discussed in relation to N recovery and herbage yield. Furthermore, data on N use efficiency are presented.

Materials and methods

Site characteristics and treatments

Experiment 1 was carried out in 1987 and 1988 on a permanent perennial ryegrass (*Lolium perenne* L.) sward containing some volunteer *Poa* spp on a well-drained young sedimentary calcareous silty loam soil at the A.P. Minderhoudhoeve, the experimental farm of Wageningen Agricultural University in Oostelijk Flevoland. The

soil (0–5 cm layer: pH-KCl 7.1; 72% clay+silt; 4% organic matter) was reclaimed from the sea in the late 1950s, and had been under grass for more than 15 years.

In the pre-experimental year (1986), two paddocks of one ha each received 250 and 550 kg fertilizer N ha^{-1} yr^{-1} and were grazed continuously by heifers. In 1987, the paddocks were reduced in size to about 0.2 ha and were included in a rotational grazing system with Dutch Friesian spring calving dairy cows. The fertilizer N treatments were continued. Prior to each grazing event in the experimental paddock the cows grazed in a conditioning paddock receiving the same level of fertilizer N. Number of animals in the measuring paddocks was adjusted to a grazing period of one to two days and an average daily herbage allowance above 4 cm height of about 23 kg organic matter (OM) per animal per day. Concentrates with a low protein concentration were supplemented at a rate of one kg per cow per day. After every second grazing period the residual grass was removed by cutting at a height of about 6 cm. In both years herbage production under grazing was closely monitored, using a sward-cutting technique. In 1988, the edges of the grazed paddocks were fenced-off and used to measure the response to fertilizer N under cutting (per N treatment four strips of about 6 m long and 0.88 m wide). The strips were harvested at the end of each grazing period.

Experiment 2 was conducted in the period 1986–1989 on a sand soil near Wageningen. The soil (0–5 cm layer: pH-KCl 5.0; 9% clay+silt; 5% organic matter) had been under grass for many years, receiving 400 to 500 kg N ha^{-1} yr^{-1}. In the pre-experimental year (1985), the fertilizer treatments (250, 400, 550 and 700 kg N ha^{-1} yr^{-1}) and two management systems were introduced: grazing-only and cutting-only. In the cutting trial also a zero N treatment was included to measure NFNS. Both trials were laid out according to a randomized block design with two (grazing) or four (cutting) replicates. In 1985, the cutting-only plots were cut weekly and the paddocks (0.40 ha) were grazed with young steers according to a 'put and take' continuous stocking system, to improve sward quality (Lantinga, 1985a).

In 1986, continuous grazing was replaced by rotational grazing. It was aimed at grazing periods of three to four days per paddock of 0.20 ha. Therefore, from 1986 onwards each N treatment comprised two measuring paddocks which were grazed-only. After every second grazing period the residual grass was removed by cutting at a height of about 6 cm. The total experimental area was extended to about 8 ha, comprising ten paddocks of about 0.20 ha for each N treatment according to a randomized block design. In the preceding years the additional paddocks had been fertilized annually with 400 to 500 kg N ha^{-1}. These additional paddocks were not only grazed but also cut for silage, yields being determined for each paddock separately and sampled for chemical analyses. Animals were weighed without fasting on two consecutive days at the start and at the end of the grazing season and at monthly intervals. Data on animal performance and silage cuts were pooled for each N treatment to calculate the response to fertilizer N as grassland output in terms of net energy at total system level (1986–1989). The cutting-only plots (10 * 0.88 m each) were harvested at the end of each grazing period in the corresponding N treatment (1986–1988). The zero N treatment was cut only four or five times per year. In the

grazed-only measuring paddocks, herbage production under grazing was carefully measured in 1986 and 1987, using a sward-cutting technique.

Fertilization. At both locations, spring fertilizer N (calcium ammonium nitrate: 27% N) was applied when accumulated mean daily air temperature above 0 °C since 1 January approached 200 °C (Jagtenberg, 1970). The remainder was applied in decreasing doses immediately following defoliation until target rates were reached. Application of nutrients other than N was based on soil analysis. In experiment 2 the paddocks were irrigated by sprinklers during dry periods in 1986 only.

Harvesting technique and chemical analyses. On all occasions, the plots in the grazing-only and the cutting-only trials were harvested with a reciprocating motor mower leaving a stubble height of about 4 cm. From each strip, samples of 200-300 g fresh material were taken for chemical analyses. Grass for silage was cut with a rotary drum mower leaving a stubble of about 7 cm. All samples were analyzed for ash, N and in-vitro digestibility of organic matter (D_{vitro}) by the method of Goering & van Soest (1970). Apparent in-vivo digestibility of organic matter was calculated from D_{vitro} of standard samples of known in-vivo digestibility determined with wethers.

Sward quality

On a number of occasions, in both experiments, absence frequencies of rooted perennial ryegrass tiller bases from concentric sampling quadrats with an area of 1 dm^2 (Neuteboom *et al.*, 1992) were recorded. Per paddock 100 measurements were made according to a systematic line-sampling technique. In the cutting-only plots 25 measurements per replicate were taken.

Herbage production and grassland output

Total annual herbage production under rotational grazing was assessed as the sum of herbage intake over all grazing periods, the amount of herbage removed by cleaning cuts and the residual herbage at the end of the grazing season. Herbage mass and herbage intake are expressed in organic matter (OM) or in Dutch Feed Units (Van Es, 1978). One Dutch Feed Unit for lactating animals (VEM) contains 6.9 kJ Net Energy for Lactation and one Dutch Feed Unit for beef cattle (VEVI) contains 6.9 kJ Net Energy for Maintenance and Growth. Under intensive grassland management, one kVEM or one kVEVI corresponds with about 1 kg of dry matter of perennial ryegrass.

Herbage intake over a single grazing period can be calculated as:

$$HI = (Y_s - Y_e) + f_L*(Y_u - Y_s) \tag{1}$$

where:
HI = herbage intake (kg OM, kVEM or kVEVI ha^{-1});
Y_s = herbage mass at start of grazing (kg OM, kVEM or kVEVI ha^{-1});

Y_e = herbage mass at end of grazing (kg OM, kVEM or kVEVI ha^{-1});
f_L = herbage accumulation factor;
Y_u = herbage mass at end of grazing in an ungrazed area (kg OM, kVEM or kVEVI ha^{-1}).

The difference between Y_u and Y_s is referred to as 'undisturbed accumulation' (Meijs, 1981). Herbage accumulation during the grazing period can be expressed as a fraction of this value. For rotational grazing it equals (Lantinga, 1985a):

$$f_L = [(Y_e/Y_s)-1] / \ln(Y_e/Y_s) \tag{2}$$

Y_u was calculated by means of a dynamic simulation model (Lantinga, 1985b). Y_s and Y_e were determined using the double sampling concept (Back et al., 1969). Average sward height (50 measurements per paddock) was used as an estimator of herbage mass, based on local regressions derived from eight paired pre- and post-grazing observations of sward height and herbage mass in strips of about 10 m long and 0.58 m wide. Average sward height within a strip was determined from 10 observations. The distance between the pre- and post-grazing strips was about 0.5 m.

In experiment 2, grassland output at system level (i.e. the sum of herbage intake and ensiled herbage in terms of net energy on all ten paddocks per N treatment) was derived from animal performance using standards for net energy requirements for maintenance and growth and yield and energy value of ensiled herbage. Net energy requirement for maintenance and growth was calculated from the standard equation for housed young male animals, adapted for grazing steers according to Van Es (1978) and Meijs (1981):

$$NE = \frac{\dfrac{(500 + 6*LW) * G}{1 - (G * 0.3)} * a + (78.87 * LW^{0.75} * b)}{1.65} * c * d$$

where:
NE = net energy requirement expressed in Dutch Feed Units for beef cattle (VEVI);
LW = live weight (kg animal^{-1});
G = growth rate (kg animal^{-1} d^{-1});
a = correction factor for fat deposition (1.15 for steers);
b = correction factor for maintenance due to grazing activity (1.20);
c = correction factor for the energy requirement at different growth rates: $(0.8365 + 0.222*G - 0.04*G^2)$;
d = correction factor for the energy requirement at different live weights: $(0.933 + LW/3000)$.

Daily LW gain of the animals was determined by linear regression over three or four subperiods during the grazing season. NE content of herbage in terms of VEVI was calculated according to Van Es (1978).

Fertiliser use efficiency

The efficiency of fertilizer N use in herbage production may be expressed in two ways: (i) as the apparent recovery of N (ANR), i.e. the increase in N yield of the harvested herbage with respect to control (0 N), expressed as a percentage of that applied in fertilizer, or (ii) as the marginal apparent effect of N (MANE), i.e. the increase in harvested herbage per kg N applied for a specified fertilizer increment. Since in experiment 1 no zero treatments were included, only marginal values could be calculated for the apparent recovery of N (MANR).

Weather conditions

Cumulative precipitation during the grazing season for the meteorological station at Wageningen is shown in Figure 1. The growing season of 1987 was relatively wet, those of 1986 and 1988 were relatively dry. The winters 1985–'86 and 1986–'87 were very cold, leading to relatively short growing seasons. Rainfall data measured at Swifterbant have been published elsewhere (Deenen & Lantinga, 1993), and showed the same trends as presented for Wageningen.
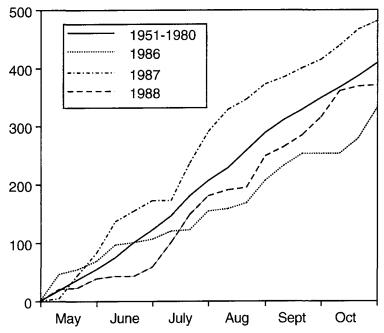
Cumulative precipitation (mm)

Figure 1. Cumulative precipitation during the period 1 May – 1 November in 1986, 1987 and 1988 and the mean cumulative precipitation for 1951–1980 measured at the meteorological station in Wageningen.

Results

Grazing management and animal performance

Experiment 1. Grazing periods varied from 1 to 2 days, with rest periods ranging from 12 days in spring to about one month in autumn. In both years pre-grazing herbage mass was approximately 2000 kg OM ha^{-1} above 4 cm height. Mean sward height at the start and the end of a grazing period was 15.2 and 7.3 cm, respectively. Number of cow grazing days and milk production per ha were significantly higher in 1987 than in 1988 for the low N treatment, while the reverse held for the high N treatment (Table 1).

Experiment 2. Grazing periods were about 4 days in 1986 and about 3 in 1987, with rest periods ranging from 18 days in spring to about 40 in autumn. Due to the severe winter and cold spring in 1985–'86, grazing started in the middle of May (about 3 weeks later than usual), resulting in only 6 grazing cycles in the grazing experiment and 6 harvests in the cutting experiment. As a consequence, realized N application rates were only 510 and 655 kg ha^{-1}, respectively. In both years, pre-grazing herbage mass was approximately 1600 kg OM ha^{-1} above 4 cm cutting height. Mean sward height at the start and the end of a grazing period was 14.2 and 7.0 cm, respectively.

Sward quality

Experiment 1. At the end of the second experimental year (1988), the frequency of sampling quadrats without rooted tillers of perennial ryegrass was only two percent at most, at both N levels under cutting as well as under grazing (Table 2). All swards can therefore be classified as good, with no yield reductions to be expected (Neuteboom *et al.*, 1992).

Experiment 2. In all swards, perennial ryegrass was the dominant species although they were invaded by *Poa* spp., especially where perennial ryegrass had vanished as a result of urine scorching or poaching. Absence counts showed much greater open-

Table 1. Experiment 1. Effect of fertilizer N on animal performance of dairy cows under rotational grazing. FPCM is fat (4.0%) and protein (3.3%) corrected milk.

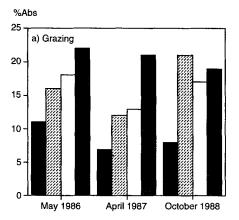|	1987		1988	
Fertilizer N (kg ha^{-1})	250	550	250	550
Cow grazing days ha^{-1}	791	908	580	938
Milk production (kg FPCM cow^{-1}d^{-1})	21.5	19.7	22.1	21.8
Milk production (kg FPCM ha^{-1})	17,054	17,882	12,814	20,441

Table 2. Experiment 1. The effect of fertilizer N on absence frequency percentages of rooted tiller bases of perennial ryegrass from concentric sampling quadrats with an area of 1.0 dm² under grazing and cutting.

Fertilizer N (kg ha⁻¹ yr⁻¹)	250	550
Grazing		
July 1988	0	0
November 1988	0	2
Cutting		
November 1988	0	1

ness in the grazed than in the cut swards throughout the experiment (Figure 2), with the degree of openness positively corrrelated to N application rate. The 250 N sward may be classified as one of moderate quality, whereas the other three were so open that yield reductions of up to about 20% might be expected (Neuteboom *et al.*, 1992).

Grassland response to fertilizer N under cutting and grazing

Experiment 1. N yield under grazing in the 250 N sward was 90 kg ha⁻¹ higher in 1987 than in 1988 (Table 3). This difference is comparable to that observed in a cutting trial in an adjacent sward on the same soil type, with N yields at zero N of 177 and 91 kg ha⁻¹ in 1987 and 1988, respectively (Deenen & Lantinga, 1993). The winter period 1986–'87 was very dry, whereas winter 1987–'88 and early spring 1988 were extremely wet, i.e. conducive to nitrate leaching. N yields at 550 N were hardly different between years and treatments. Hence, MANR was only 0.58 kg N per kg N applied for the increment 250 to 550 kg N ha⁻¹ in 1987, whereas in 1988 the values
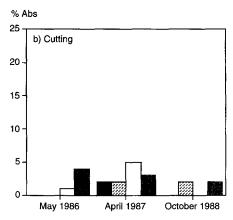

Figure 2. Experiment 2. Absence frequency (%Abs) of perennial ryegrass tillers in concentric sampling quadrats with an area of 1 dm² in the grazed (a) and cut swards (b). Fertilizer treatments: N 250 (■), N 400 (▦), N 550 (□), N 700 (■)

Table 3. Experiment 1. The effect of the rate of fertilizer N on N yield, organic matter (OM) yield, N content of the herbage, marginal apparent N recovery (MANR) and marginal apparent N effect (MANE) under grazing (1987 and 1988) and cutting (1988).

	grazing				cutting	
	1987		1988		1988	
Fertilizer N (kg ha^{-1})	250	550	244	540	244	540
N yield (kg ha^{-1})	479	653	389	660	332	647
OM yield (kg ha^{-1})	12,711	13,529	10,950	14,601	10,094	14,756
N content (g N kg^{-1} DM)	34	44	32	41	29	39
MANR (kg N kg^{-1} N)	0.58		0.92		1.06	
MANE (kg OM kg^{-1} N)	2.7		12.3		15.8	

were 0.92 under grazing and 1.06 under cutting (Table 3). MANE under grazing for the increment 250 to 550 kg N ha^{-1} was small in 1987, due to the relatively high N yield at 250 N (Table 3) and the restricted N response at 550 N as a result of winter damage (Deenen, 1994). Until the fourth cut, the response of cumulative herbage yield to fertilizer N was still negative. As the growing season of 1987 was relatively short, N concentrations in the herbage remained relatively high, so that applied N in the high N treatment was utilized less efficiently than in 1988, resulting in a lower MANE value (Table 3). The higher yields of N (57 kg ha^{-1}) and herbage (about 900 kg OM ha^{-1}) at 250 kg N ha^{-1} under grazing compared to cutting in 1988 may be associated with a positive effect of excretal N (mainly urine).

Experiment 2; cutting. In the 4-weekly cutting experiment, N yield in the zero treatments ranged from 108 to 126 kg N ha^{-1} yr^{-1} over the three years, and increased significantly ($P<0.05$) up to an application rate of 550 kg N ha^{-1} yr^{-1} (Figures 3 and 4). ANR values were high (>90%) up to 400 kg N ha^{-1} yr^{-1} in 1986 and up to 550 kg N ha^{-1} yr^{-1} in 1987 and 1988. In 1986, N yield increased only slightly above 400 kg N ha^{-1} yr^{-1} due to winter damage and a relatively short growing season (Deenen, 1994). The response of herbage yield to fertilizer N differed between years (Figures 3 and 4). In 1986, there was only a small response to additional fertilizer N above 250 kg N ha^{-1} yr^{-1}. Due to winter damage, the response of herbage yield to fertilizer N was negative in the first two cuts and this yield depression could be compensated only marginally more than 100% in later cuts, mainly because the growing season 1986 was short. Herbage yield responded strongest to fertilizer N in 1988 (Figure 4). Although ANR values were lower than in 1987 (data not shown), absorbed N was used much more efficiently: N concentration in the herbage ranged from 23 to 50 g N per kg DM in 1987 and from 20 to 39 in 1988, due to an extremely early spring and favorable weather conditions in 1988.

Experiment 2; grazing. N yields at 250 N under grazing were equal to those under cutting in 1986 and 1987 (quadrant IV in Figure 3). At higher rates of N application, N yields under grazing were lower and the difference increased with level of N application, especially in 1987, leading to low MANR values. In the 250 N paddocks
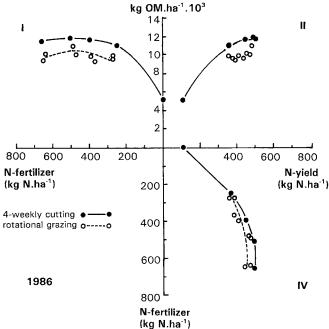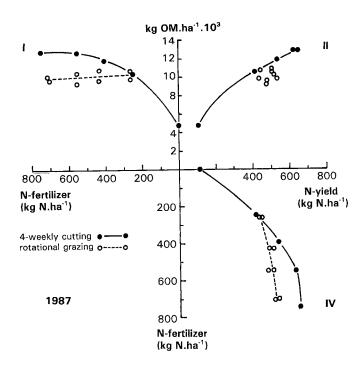
Figure 3. Experiment 2. The effect of fertilizer N application on total N and herbage yield expressed in Organic Matter (OM) under 4-weekly cutting and rotational grazing in 1986 and 1987. For cutting, data are averages over 4 replicates; for grazing, data per paddock are presented.

Net yield (kVEVI/ha*10³)

Net yield (kVEVI/ha*10³)
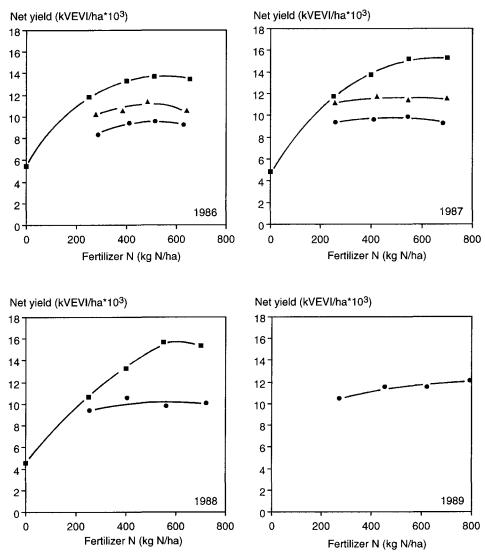
Net yield (kVEVI/ha*10³)

Net yield (kVEVI/ha*10³)

Figure 4. Experiment 2. The effect of fertilizer N application on net herbage yield expressed in Dutch Feed Units for beef cattle (kVEVI) under 4-weekly cutting (■), rotational grazing, i.e. herbage intake (△), and at whole system level (●).

excretal N may have had a positive effect on N yield in undamaged areas of the sward that compensated the negative effects elsewhere. At higher N application rates the lack of response was associated with sward deterioration due to urine scorching, treading and poaching (Table 2). Urine scorching has the strongest negative effects on sandy soils and its frequency and impact are strongly correlated with the rate of N application (Lantinga *et al.*, 1987). It may result in large open patches which are sub-

sequently invaded by less productive volunteer species like *Poa annua* .

In 1986, herbage accumulation was not significantly affected by level of N application (Figure 3). Over the full fertilizer range, herbage yields ranged from 82 to 89% of that under 4-weekly cutting. In the grazed swards, herbage yield at the start of the first grazing cycle on 21 May responded positively to fertilizer N; OM yields ranged from 1412 to 2309 kg ha^{-1} in the 250 to 700 N series. However, the response weakened in the course of the growing season due to sward deterioration (mainly urine scorching).

In 1987, there was no response of herbage yield to fertilizer N applied (Figure 3). Herbage accumulation under grazing expressed relative to that under cutting decreased from 99% at 250 N to 77% at 700 N as a result of negative grazing effects like urine scorching and poaching (1987 was extremely wet).

Whole system level

Experiment 2. Total net herbage yield at system level (integrated cutting and grazing) was lower than under either cutting or grazing due to harvest losses of the silage cuts and grazing losses (Figure 4). Response of total net herbage yield to fertilizer N was weak in all four years. In 1986, net herbage yield at system level was about 70% of the total yield under 4-weekly cutting, irrespective of level of N application. Relative yields in 1987 declined from 79% at 250 N to 61% at 700N, and in 1988 these values were 94% and 64%, respectively.

Optimum N application rate

Experiment 2. Application of current fertiliser recommendations leads, at current prices, to a marginal profitability of 7–8 kVEVI or kVEM per kg N applied. Yield responses of the cutting treatments in experiment 2 were fitted for each treatment-year combination (for grazing-only and system level the number of replicates was insufficient) to an inverse polynomial curve (Sparrow, 1979):

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

where
Y = yield (kVEVI ha^{-1} yr^{-1});
x = fertilizer rate (kg N ha^{-1} yr^{-1});
a, b, c and d are regression coefficients.

Estimates derived from these fitted curves were: $N_{7.5}$ = rate of applied N at which an incremental response of 7.5 kVEVI to a 1 kg increase in applied N is achieved; $Y_{7.5}$ = kVEVI yield at fertilizer rate $N_{7.5}$.

Under the 4-weekly cutting regime, $N_{7.5}$ was on average 430 kg ha^{-1} yr^{-1}. Assuming one kVEVI to be approximately equivalent to 1 kg DM, this optimum rate is close to the optimum rate of 420 kg N ha^{-1} yr^{-1} established by Prins (1983). The $Y_{7.5}$-values varied from 13,100 kVEVI ha^{-1} in 1986 to 14,800 in 1988. Under grazing and

at system level the response of herbage yield to fertilizer N was much weaker or even absent and absolute yields were lower than those under 4-weekly cutting, especially at high N input levels (Figure 4). Hence, for grazing-only and at system level the optimum N application rate derived from this experiment on sand was below 250 kg N ha^{-1} yr^{-1}, or some 200 kg below that under cutting-only.

N use efficiency

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

Experiment 1. Ingested N was converted into animal products by the grazing dairy cows with an efficiency between 16 to 20% (Table 4). These values agree with other observations (Van Vuuren & Meijs, 1987; Deenen & Lantinga, 1993; Van Keulen *et al.*, 1996), but are far from the theoretical maximum efficiency of 40–45% (Van Vuuren & Meijs, 1987). As total N input increased by about 300 kg N ha^{-1} yr^{-1}, out-

Table 4. Experiment 1. The effect of fertilizer N application on the N balance under rotational grazing with dairy cows (kg N ha^{-1} yr^{-1}).

	1987		1988	
A. INPUT				
fertilizer	250	550	244	540
concentrates	20	23	19	29
deposition	40	40	40	40
total	310	613	303	609
B. ANIMAL INTAKE	468	640	361	639
C. ANIMAL OUTPUT				
milk	88	93	69	108
growth[1]	7	8	5	8
total	95	101	74	116
D. ANIMAL EXCRETION				
dung[2]	104	119	98	130
urine[3]	269	420	189	393
total	373	539	287	523
E. EFFICIENCY OF N USE				
input (C/A*100%)	31	16	24	19
intake (C/B*100%)	20	16	20	18

[1] N retention: 30 g N per kg live weight (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: N intake – N in animal growth and milk – dung N

put in animal products increased by only 6 and 42 kg N ha^{-1} in 1987 and 1988, respectively. N use efficiency for total N input decreased from 31 to 16% in 1987 and from 24 to 19% in 1988. This implies a strong increase in excretal N, i.e. 166 and 236 kg N ha^{-1} in 1987 and 1988, respectively.

Experiment 2. Efficiency of use of ingested N was below 10% for the beef cattle already at a fertilizer level of 250 kg N ha^{-1} yr^{-1} (Table 5). N use efficiency for total N input strongly declined with increasing fertilizer N application rates, associated with the very low values of MANR under grazing in both years (quadrant IV in Figure 3).

Discussion

Apparent N recovery (ANR) and response of grassland production to fertilizer N differed between management practices (cutting vs. grazing) and soil types (loam vs. sand). Highest ANR values and herbage yields were recorded under cutting on the loam soil. Differences in ANR values are related to length of the growing season, non-fertilizer N supply, recycling of excretal N and sward quality. Grazing on the sand soil negatively interacted with N application rate and aggravated sward deterioration due to treading, poaching and especially urine scorching. This was reflected in increased absence frequencies of perennial ryegrass tillers in sampling quadrats at

Table 5. Experiment 2. The effect of fertilizer N application on the N balance under rotational grazing with steers (kg N ha^{-1} yr^{-1}).

	1986				1987			
A. INPUT								
fertilizer	277	385	487	642	259	426	547	701
deposition	40	40	40	40	40	40	40	40
total	317	425	527	682	299	466	587	741
B. ANIMAL INTAKE	354	382	436	403	425	487	472	506
C. ANIMAL OUTPUT								
growth[1]	24	27	28	23	29	26	26	20
D. ANIMAL EXCRETION								
dung[2]	81	81	85	77	88	90	83	83
urine[3]	249	274	323	303	309	371	363	403
total	330	355	408	380	397	461	446	486
E. EFFICIENCY OF N USE								
input (C/A*100%)	7.6	6.4	5.3	3.4	9.6	5.5	4.4	2.7
intake (C/B*100%)	6.8	7.1	6.4	5.7	6.7	5.3	5.5	4.0

[1] N in animal growth: 30 g N per kg live weight (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: N intake – N in animal growth – dung N

higher fertilizer N application rates (Figure 2). On loam, N had no significant effect on sward quality (Table 2).

Under the 4-weekly cutting regime on the sand soil, the economically optimum fertilizer application rate was on average 430 kg N ha^{-1} yr^{-1}. Under grazing and at the whole system level the response of herbage yield to fertilizer N was much weaker, suggesting that under these management regimes optimum fertilizer N application rate would be some 200 kg ha^{-1} lower. No optimum fertilizer rate could be derived for the rotational grazing and cutting experiment on loam.

However, these application rates are optimal from an economic viewpoint only. It has been argued, that from an ecological point of view the aim is to minimize losses of N from the grassland system per unit product (De Wit, 1992; Lantinga & Groot, 1996; Van Keulen *et al.*, 1996), though a reaction has been that this only holds when losses per unit area do not exceed ecological thresholds (De Wit, 1993; Van Der Meer, 1993). It is, however, beyond the scope of this paper to participate in that discussion.

Under the 4-weekly cutting regime on the sand soil about 90% of the applied N was recovered in the herbage up to fertilizer rates of 400 (1986) or 550 kg N ha^{-1} yr^{-1} (1987 and 1988). Hence, the amounts of fertilizer N remaining in or lost from the soil are relatively low. However, under grazing, (i) N recovery in the herbage was on average lower than under cutting, (ii) not all herbage N was consumed due to grazing losses, and (iii) N use efficiency of the ingested N was below 10% for beef cattle and between 16 and 20% for dairy cows. The consequence is that large amounts of excess dietary N are concentrated in dung and urine patches susceptible to loss from the system. In the experiment on sand soil this was reflected in large amounts of inorganic soil N in autumn and low amounts in the following spring, indicating large losses through nitrate leaching and denitrification (Van Der Meer, 1996). Lantinga and Groot (1996) analysed the results of the current experiments in terms of the fate on nitrogen in the system. They showed that in the experiment on sand soil in 1987, the ratio of residual inorganic N in the soil (0–60 cm) at the end of the growing season (potential N loss) to cumulative herbage yield (total product) was lowest for integrated grazing and cutting management at a fertilizer rate of about 200 kg N ha^{-1} yr^{-1}. From an ecological viewpoint, therefore, this input level could be considered the optimum. According to Figure 4, this results in only marginal reductions in net output per ha. Under grazing on the loam soil in 1988, marginal apparent recovery of N was 0.92 kg N kg^{-1} N and marginal effect of N was 12.3 kg OM kg^{-1} N for the increment 244 to 540 kg N ha^{-1} (Table 3), whereas milk production per ha increased from about 13 ton FPCM (fat and protein corrected milk) ha^{-1} to more than 20 ton ha^{-1} (Table 1). From an economic viewpoint, these values are very favorable. However, the increase in animal output (milk and meat) was only 42 kg N ha^{-1} (Table 4). The consequence was a steep rise in the amount of N voided in dung and urine from 287 to 523 kg N ha^{-1}. Although in the grazed plots of an adjacent trial an average soil N accumulation of 245 kg ha^{-1} yr^{-1} was found (Hassink & Neeteson, 1991), from an ecological viewpoint also for this site the optimum N input level would be much lower than the economically optimum application rate of 511 kg N ha^{-1} yr^{-1} as established for 4-weekly cutting in the adjacent experiment (Deenen & Lantinga, 1993).

The reasoning followed here indicates, that current fertilizer N recommendations for grassland in the Netherlands should be further refined as, in addition to economic goals, environmental goals should be taken into account. Such refinements may be realized by considering: (i) soil inorganic N levels in spring, (ii) N mineralization rates in grazed vs. cut swards on different soil types, (iii) recycling of N under grazing at low N input levels, and (iv) actual sward quality, and (v) the risk for urine scorching and poaching at a given site. Such judicious management may lead to fertilizer application rates that result in realization of both economic and environmental goals (Aarts *et al.*, 1999)

Acknowledgements

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