

**Nitrogen use efficiency**

**in**

**intensive grassland farming**

CENTRALE LANDBOUWCATALOGUS



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40951

1990

1991

1992

Promotor: dr. ir. L. 't Mannetje  
hoogleraar in de graslandkunde

Co-promotor: dr. ir. E.A. Lantinga  
universitair hoofddocent theoretische productie-ecologie

NN08201, 1788.

**Ontvangen**

**30 MEI 1994**

**UB-CARDEX**

P.J.A.G. Deenen

**Nitrogen use efficiency in intensive grassland farming**

**Proefschrift**

ter verkrijging van de graad van doctor  
in de landbouw- en milieuwetenschappen  
op gezag van de rector magnificus  
dr. C.M. Karssen  
in het openbaar te verdedigen  
op donderdag 9 juni 1994  
des namiddags te half twee in de Aula  
van de Landbouwniversiteit te Wageningen

ISN 100060

**BIBLIOTHEEK  
LANDBOUWUNIVERSITEIT  
WAGENINGEN**

**CIP-GEGEVENS KONINKLIJKE BIBLIOTHEEK, DEN HAAG**

Deenen, P.J.A.G.

Nitrogen use efficiency in intensive grassland farming / P.J.A.G. Deenen

Thesis Wageningen, -With ref. - With summary in Dutch.

ISBN 90-5485-270-4

subject headings: grazing, nitrogen

## ABSTRACT

**P.J.A.G. Deenen, 1994. Nitrogen use efficiency in intensive grassland farming.**

Doctoral thesis, Department of Agronomy, Agricultural University, Wageningen, The Netherlands, x + 140 pp., English and Dutch summaries.

This thesis describes the effects of fertilizer nitrogen on herbage yield under rotational and continuous grazing of perennial ryegrass swards with beef cattle and dairy cows, and under cutting only on both a sand and a silty loam soil. Furthermore effects are described of nitrogen input and grassland management on yield of perennial ryegrass swards after severe winters on both soils and the effects of dung and artificial urine on nitrogen uptake and herbage accumulation on a sand soil.

Differences in both the apparent nitrogen recovery and the response of grassland production to fertilizer nitrogen applied could be related to treatment (cutting versus grazing), soil type (loam versus sand), length of the growing season, the amount of soil inorganic nitrogen in spring, sward quality and, in case of grazing, recycling of excretal nitrogen. The calculated economical optimum fertilizer application rate was on average 430 and 510 kg N ha<sup>-1</sup>yr<sup>-1</sup> for 4-weekly cutting on the sand soil and the loam soil, respectively. Under grazing and on a whole-farm scale (integrated grazing and mowing for silage) on the sand soil the optimum rate was some 200 kg ha<sup>-1</sup> less. Under grazing, especially on sand, nitrogen enhanced sward deterioration due to treading, poaching and especially urine scorching, leading to a loss of productivity. On loam, nitrogen had on average a much smaller deleterious effect. Tiller densities were highest under continuous grazing. Efficiency of use of ingested nitrogen varied from 23 to 31% for dairy cows and was less than 10% for beef cattle at a fertilizer level of 250 kg N ha<sup>-1</sup>yr<sup>-1</sup>. Efficiency decreased with increasing N rates.

Divergent relationships were found between the level of nitrogen input in the preceding year and spring herbage growth after a severe winter. Differences were only temporary. In case of a negative relationship, reductions in first cut dry matter yields were smaller in frequently defoliated (weekly cutting and continuous grazing) than in less frequently defoliated swards (4-weekly cutting and rotational grazing). Positive effects of urine and dung on nitrogen uptake and herbage growth on the sand soil were only observed in a low N sward (250 kg N ha<sup>-1</sup>yr<sup>-1</sup>) and were confined to 15 cm from the edge of the dung and urine patches.

**Keywords:** artificial urine, beef cattle, grazing, cutting, dairy cows, dung, enclosure cages, herbage intake, *Lolium perenne* L., nitrogen recovery, nitrogen response, nitrogen use efficiency, perennial ryegrass, spring growth, sward quality, tiller density, tiller distribution, winter damage

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## **CHAPTER 1**

### **GENERAL INTRODUCTION**

## GENERAL INTRODUCTION

The use of fertilizer nitrogen (N) on grassland in the Netherlands has increased substantially over the last decades up to the mid-eighties. This increase resulted in higher productivity of grassland and allowed higher stocking rates. However, only a fraction of the N used on grassland actually appears in products at the farm gate. The remainder enters the natural environment in forms that may eventually have detrimental effects.

### The nitrogen balance of grassland

The flow of N can be conceptualized as a balance between inputs and outputs at the farm gate (Table 1). Much of the input of N is through fertilizers and concentrates and some N is fixed by clover. About 30 to 50 kg N ha<sup>-1</sup>yr<sup>-1</sup> is deposited from the atmosphere. The surplus of N of about 470 kg ha<sup>-1</sup>yr<sup>-1</sup> is a result of a serious imbalance between inputs of N in purchased fertilizers, concentrates and roughage and outputs in milk and meat. On Dutch dairy farms, output represented in the mid-eighties on average about 14% of the input for N. Although since 1984 the process of intensification has halted due to the introduction of the milk quota system, the annual average N surplus remains still high, 399 kg N ha<sup>-1</sup>yr<sup>-1</sup> in 1991-1992 (Agricultural Economics Research Institute, unpublished data). The surpluses inevitably constitute a loss from the system. The ways in which N is lost are (i) volatilization of ammonia to the atmosphere, (ii) conversion of nitrate into gases through denitrification, and (iii) leaching and runoff of nitrate.

Losses of N from agricultural sources have both economic and environmental significance. Losses have also been linked to human health issues. Either directly as in the case of nitrates in groundwater, or indirectly as in the case of nitrous oxide which may contribute to ozone depletion, thereby increasing UV-B radiation. Gaseous N emissions also contribute to N deposition and the impact of this on undisturbed ecosystems, especially on nutrient poor and weakly buffered soils, can be significant.

Table 1. Average annual nitrogen balances ( $\text{kg N ha}^{-1}$ ) of specialized dairy farms on sand and clay soils in the Netherlands, 1983-1986 (from Aarts et al., 1988).

	sand	clay
INPUT		
fertilizer	331	340
concentrates	137	122
purchased roughage	44	28
deposition	48	39
miscellaneous	8	9
total	568	538
OUTPUT		
milk	67	60
sold livestock	14	11
miscellaneous	1	1
total	82	72
input - output	486	466
output/input (%)	15	13

Dairy farming appears to be the major source of ammonia volatilization and associated acidification in the Netherlands (Heij et al., 1991).

A major part (60%) of the total N input is from purchased inorganic fertilizers applied to stimulate grass growth. Thus, improvement of the N use efficiency of the grazing management system (i.e. the fraction of the total N input in animal products) may contribute significantly to a reduction in N losses on dairy farms and consequently to the reduction of the national N losses, since the greater part of these N losses on the national scale can be attributed to grassland farming (63% of the total N losses in 1985-1986; Van der Meer & Meeuwissen, 1989).

## **Societal demands and legislation**

Societal demands on dairy farming systems with respect to N losses are becoming more stringent, requiring more efficient nutrient utilization. In addition, health and well-being of men and animals, nature and landscape should be taken into account. Public concern about these issues has been a driving force for the expanding range of national and European Union regulations which are influencing N use in agriculture. Currently, there is no legislation which directly influences fertilizer use. The European Union has passed a directive on nitrate only (Anonymous, 1991). In Dutch legislation importance has been given to animal manures (storage and timing and manner of application), phosphates and ammonia emissions. Recently the Dutch government has presented target values for the near future for emissions of N into the air and into the groundwater, and for additions of P to the soil (Anonymous, 1990, 1993). For ammonia volatilization it is set at a reduction of 70% compared to the level of 1980. The nitrate concentration in the water at a depth of 2 m below groundwater level should be below 11.3 mg nitrate-N l<sup>-1</sup>. Total P application in inorganic fertilizer and manure should not exceed output in crop products (equilibrium fertilization).

These generally formulated targets can be converted into quantitative criteria at farm level. A reduction of the ammonia volatilization of at least 70% compared to the average situation in 1980 implies an upper limit of 40 kg N ha<sup>-1</sup>yr<sup>-1</sup>. For a well-drained sand soil and an annual precipitation surplus of 300 mm, nitrate leaching should not exceed 34 kg N ha<sup>-1</sup>yr<sup>-1</sup> to comply with the standard of 11.3 mg N l<sup>-1</sup>. Total annual losses, also including denitrification and runoff should not exceed 128 kg N ha<sup>-1</sup>.

## **Nutrient management in intensive farming**

Until recently, grassland farmers were advised to apply dressings of 400 kg N ha<sup>-1</sup>yr<sup>-1</sup> on sand, clay and wet peat soils and 250 kg N ha<sup>-1</sup>yr<sup>-1</sup> on well-drained peat soils (Prins, 1983). The recommendations were rather general, differences were only made between well-drained peat soils and other soils and for individual cuts between a light cut of about 1700 kg DM ha<sup>-1</sup> (grazing) and a silage cut of about 3000 kg DM ha<sup>-1</sup>. The

recommendations for N fertilizer use on grassland were based on the results of cutting trials, and did not take into account the poorer responses to applied N under grazing due to specific grazing effects as excretal returns, treading, poaching, urine scorch and sod pulling. Thus there was good reason to question the validity of the previous N fertilizer recommendations, which appear to be inappropriately high, particularly in view of the environmental implications of N losses.

In 1994 a new N fertilization guide-line was introduced (Nijsten et al., 1993; Vellinga et al., 1993). This new fertilizer recommendation scheme takes into account soil N availability, soil water availability and weather conditions (rainfall), yields of the individual cut, time of application in the growing season and individual target annual N application rates. However, specific grazing effects are still not accounted for.

#### *high N use efficiency under cutting*

The apparent recovery of N fertilizer is generally measured as the fraction (%) of fertilizer N applied which is harvested in herbage receiving N minus N harvested in herbage receiving no fertilizer N. Recorded recovery levels in grassland under mowing conditions are over 70% (Van der Meer & Van Uum-van Lohuyzen, 1986). The response of mown grass swards to fertilizer N has been comprehensively investigated. Since the forties effects of annual dressings higher than 200 kg N ha<sup>-1</sup> have been the subject of many studies. Herbage production responses to fertilizer N were studied with N applications up to 1000 kg N ha<sup>-1</sup>yr<sup>-1</sup> (Sibma & Alberda, 1980; Prins et al., 1981) and even up to 1800 kg N ha<sup>-1</sup>yr<sup>-1</sup> (Mulder, 1949). Cutting trials on sand and clay soils showed that maximum dry matter yields were often not reached with applications of 450-500 kg N ha<sup>-1</sup>yr<sup>-1</sup> and that the greatest response was in the range of 0-300 kg N ha<sup>-1</sup>yr<sup>-1</sup> (Boxem, 1973; Van Steenbergen, 1977).

In the early seventies a series of field trials was commenced to elaborate the effect of N dressings on productivity, sward quality, soil mineral N status and groundwater quality. Based on results of these cutting experiments, Prins (1983) concluded that at an assumed marginal profitability of 7.5 kg dry matter per kg N applied the 'optimum' application rate in long-term trials on sand and clay soils appeared to be 420 kg N ha<sup>-1</sup>yr<sup>-1</sup>, with a range of 360-520 kg N. At the 'optimum' application the risks of nitrate

concentrations above 0.75% NO<sub>3</sub> in herbage dry matter and of soil inorganic N accumulation were minimal. The 'optimum' application rate is close to the recommended rate of 400 kg N ha<sup>-1</sup>yr<sup>-1</sup> on sand and clay soils in the Netherlands. In the United Kingdom, in the classical GM 20 series of experiments, Morrison et al. (1980) studied the response of perennial ryegrass swards to N fertilizer in relation to climate and soil. These experiments formed the basis of advice to dairy farmers in the United Kingdom. The mean 'optimum' N rate was 388 kg N ha<sup>-1</sup>yr<sup>-1</sup> (assuming a marginal profitability of 10 kg dry matter per kg N applied).

*low N use efficiency under grazing: the animal factor*

Due to the low N use efficiency of the grazing ruminant about 80% of the N ingested with the herbage is excreted, the greater part of it in the urine. This N is rapidly converted to ammonium, which partly escapes to the atmosphere in the form of ammonia.

Urine scorching, treading and poaching damage often limits the uptake of the N in the soil. Furthermore, excretal N is returned in local concentrations which are far beyond the demand of the herbage. Consequently, nitrate accumulates in the soil during the grazing season. This nitrate is lost during the following autumn and winter through denitrification and leaching.

Responses to N fertilizer under grazing conditions are more difficult to evaluate due to the inherent problems of grazing experimentation relating to intake measurements, and to the effects of the grazing animal (treading, poaching, defaecation and urination). Therefore, experimental data in the literature on the yield response to N under grazing are scarce and often conflicting. Besides, most of these studies were carried out with sheep. Baker et al. (1986) estimated from experiments in the United Kingdom that the optimum N input was 100 kg N ha<sup>-1</sup>yr<sup>-1</sup> less for continuous grazing with beef cattle than for cutting conditions. For the Dutch situation there is only the study of Boxem (1973) who compared the response in a system where grazing was alternated by mowing for conservation with that of cutting only. From a series of rotational grazing experiments in the United Kingdom Jackson & Williams (1979) came to the tentative conclusion that maximum yields are achieved with about 200 kg N ha<sup>-1</sup>yr<sup>-1</sup> less under grazing than cutting management. Increasing the understanding of the fate of N in intensive grassland farming

demands a priori a better understanding of herbage and animal production responses to fertilizer N and the fertilizer N use efficiency under grazing over a wide range of fertilizer N treatments at various soil types.

In 1984, John Ryden (1984) presented a comprehensive review concerning the flow of N in grassland. This review emphasized the profound effect of the grazing animal on the N flow, the low recovery of N in milk and meat products and the large losses which occurred. Knowledge of the limiting factors in the utilization of N from fertilizer and the utilization of N from herbage by the ruminant is of major importance to improve the efficiency of N utilization, and thus preventing or diminishing the unwanted emissions of N to the environment.

### **Evaluating the N balance**

In view of the pressures which are likely to apply on grassland farms in the 1990's, the time is opportune to re-evaluate the role of N fertilizer on farm inputs. Environmental pressures to reduce the losses of N and other elements from farming systems focussed attention on the inefficiency of N use in intensive grassland systems. Rising financial pressures on farmers will arise from the reduced financial support from the European Union and stimulate improving N use efficiency on grassland farms.

In de mid 1980's a joint research project on N flows in grazed grassland was started in the Netherlands. Participants were the Department of Agronomy (Wageningen Agricultural University), which coordinated the research, the Institute for Soil Fertility (IB-DLO), the Institute for Land and Water Management Research (ICW-DLO), the Centre for Agrobiological Research (CABO-DLO), the Nutrient Management Institute (NMI) and the Department of Botanical Ecology and Evolution Biology of the Utrecht University. Objectives of this joint research project on N flows in intensive grassland farming were twofold: (i) to quantify the flows in order to obtain reliable estimates of the losses and (ii) to investigate how these losses are affected by the interactions between soil type, weather conditions and management. Only with this information it is possible to devise measures to minimize the losses by managerial actions.

In this thesis the agronomic aspects of the research project are presented. Herbage and animal production responses to fertilizer N in perennial ryegrass swards under

continuous grazing and cutting (Chapter 2) and under rotational grazing and cutting (Chapter 3) are described and related to sward quality and discussed in relation to management and N use efficiencies. Opportunities for controlling and directing loss processes are considered. Effects of intensive grassland management on sward characteristics and spring growth of perennial ryegrass swards after severe winters are presented and discussed in Chapter 4. In Chapter 5 effects of cattle dung and urine on N uptake and yield of perennial ryegrass are discussed. Finally, Chapter 6 presents an overview and a general discussion in relation to the objectives of the research project and the practical implications.

## CHAPTER 2

# HERBAGE AND ANIMAL PRODUCTION RESPONSES TO FERTILIZER NITROGEN IN PERENNIAL RYEGRASS SWARDS. I. CONTINUOUS GRAZING AND CUTTING

P.J.A.G. DEENEN<sup>1</sup> & E.A. LANTINGA<sup>2</sup>

<sup>1</sup>Department of Agronomy, Wageningen Agricultural University, Wageningen,  
Netherlands

<sup>2</sup>Department of Theoretical Production Ecology, Wageningen Agricultural University,  
Wageningen, Netherlands

Published in: Netherlands Journal of Agricultural Science 41: 179-203

# HERBAGE AND ANIMAL PRODUCTION RESPONSES TO FERTILIZER NITROGEN IN PERENNIAL RYEGRASS SWARDS. I. CONTINUOUS GRAZING AND CUTTING

## 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<sup>-1</sup> under grazing and from 0 to 700 kg ha<sup>-1</sup> 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<sup>-1</sup>yr<sup>-1</sup> 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<sup>-1</sup> yr<sup>-1</sup> was 23%. Higher rates of fertilizer N effected a slight decrease in fertilizer N use efficiency (19% at 700 kg N ha<sup>-1</sup> yr<sup>-1</sup>) 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, enclosure 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, 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<sup>-1</sup>yr<sup>-1</sup>) 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<sup>-1</sup>yr<sup>-1</sup>. 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<sub>3</sub>) 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<sup>-1</sup>. 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 enclosure 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<sup>-1</sup>. 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<sup>-1</sup> 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<sup>-1</sup>.

*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 enclosure 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) concentration according to the method of Novozamsky et al. (1983). In-vitro digestibility of organic matter ( $D_{\text{vitro}}$ ) was estimated by the method of Goering & van Soest (1970). Apparent in-vivo digestibility ( $D_{\text{om}}$ ) could be calculated from  $D_{\text{vitro}}$  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<sup>2</sup> 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<sup>-1</sup> 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).

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

where:

$$\begin{aligned} E_h &= \text{Energy content of the herbage (VEM kg}^{-1} \text{ DM);} \\ ME &= \text{Metabolizable Energy (kcal kg}^{-1} \text{ DM);} \\ ME &= 3.4 * \text{DOM} + 1.4 * \text{CP} \\ \text{DOM} &= \text{Digestible Organic Matter (g kg}^{-1} \text{ DM);} \\ \text{CP} &= \text{Crude Protein (g kg}^{-1} \text{ DM).} \end{aligned} \quad (2)$$

In 1988, herbage accumulation under enclosure 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 enclosure cage and initial herbage mass at the start. Before the enclosure 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 enclosure 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 enclosure 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):

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

where:

- HI = herbage intake (kVEM ha<sup>-1</sup>);
- Y<sub>t</sub> = herbage mass in paddock at t (kVEM ha<sup>-1</sup>);
- Y<sub>t+1</sub> = herbage mass in paddock at t+1 (kVEM ha<sup>-1</sup>);
- U = herbage accumulation under the enclosure cage from t to t+1 (kVEM ha<sup>-1</sup>).

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 (equation 1), and the N concentration and D<sub>om</sub> of the hand-plucked samples. The maintenance requirement for housed cattle (E<sub>m</sub>) 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:

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

where:

- E<sub>m</sub> = energy requirement for maintenance (VEM d<sup>-1</sup>);
- W<sub>0.75</sub> = metabolic liveweight (kg).

The daily energy requirement for milk production and liveweight gain (E<sub>p</sub>) was calculated according to Van Es (1978):

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

where:

$E_p$  = energy requirement for production ( $\text{VEM d}^{-1}$ );

FPCM = 4% fat- and 3.3% protein-corrected milk ( $\text{kg d}^{-1}$ );

G = liveweight gain ( $\text{kg d}^{-1}$ ).

*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.

cumulative precipitation  
(mm)

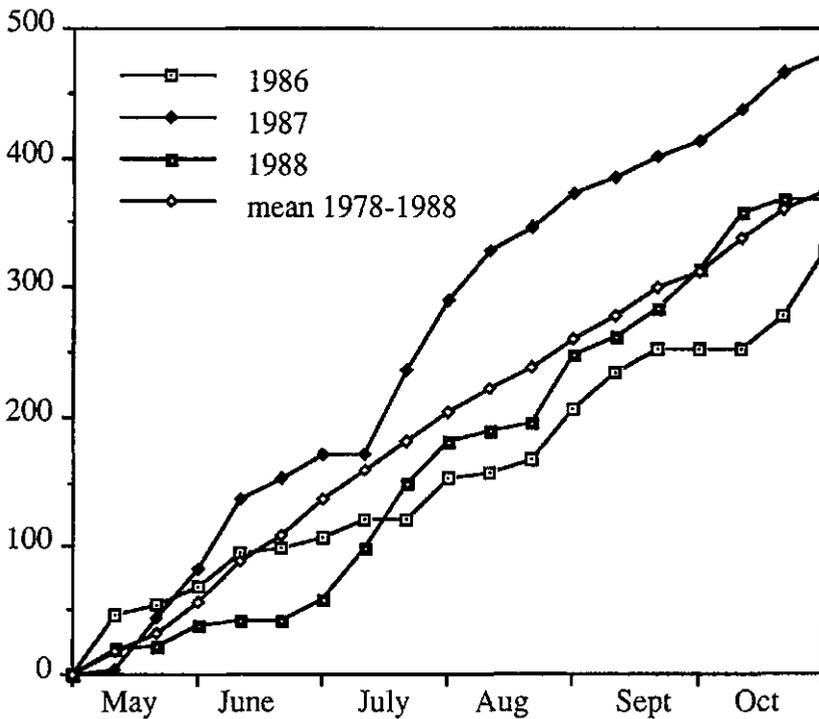


Fig. 1. Cumulative precipitation (mm) for 1 May-1 November in 1986, 1987, 1988 and the mean cumulative precipitation for 1978-1988 measured at the meteorological station at Swifterbant.

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

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

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

## 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 canceled, 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<sup>-1</sup>yr<sup>-1</sup>, 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<sup>-1</sup>yr<sup>-1</sup> as reported by Gordon (1983). However, in the experiment of Gordon the mean milk 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.

tillers  $\text{dm}^{-2}$

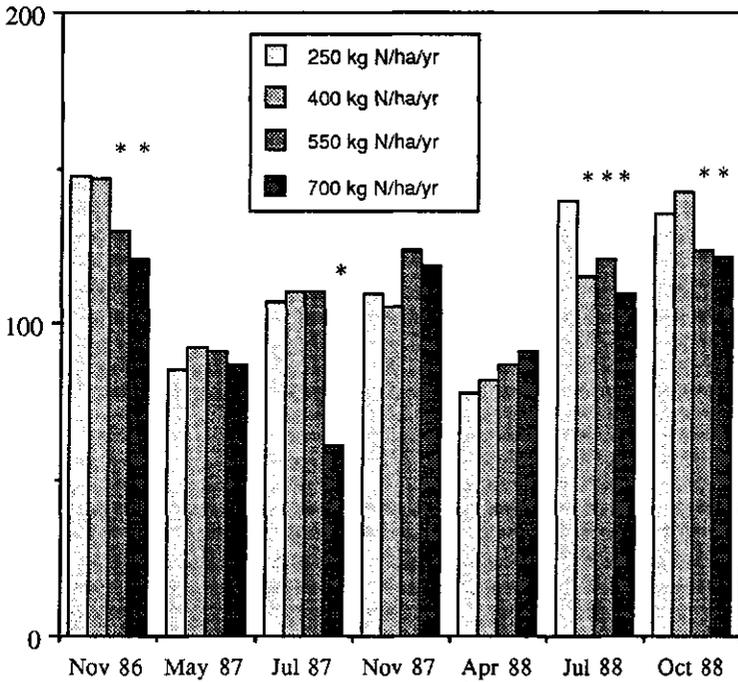
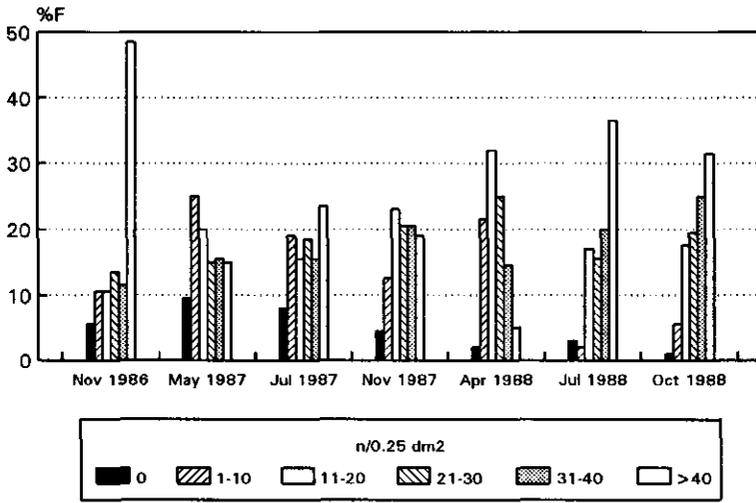


Fig. 2. Mean tiller density of perennial ryegrass for continuously grazed swards. Asterix (\*) denotes a significant ( $P < 0.05$ ) difference with the 250 N sward according to Kruskal-Wallis (One-Way Analysis by Ranks).

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  $\text{dm}^2$ , respectively in the 0 N, 250 N, 400 N, 550 N and 700

### 250 N



### 700 N

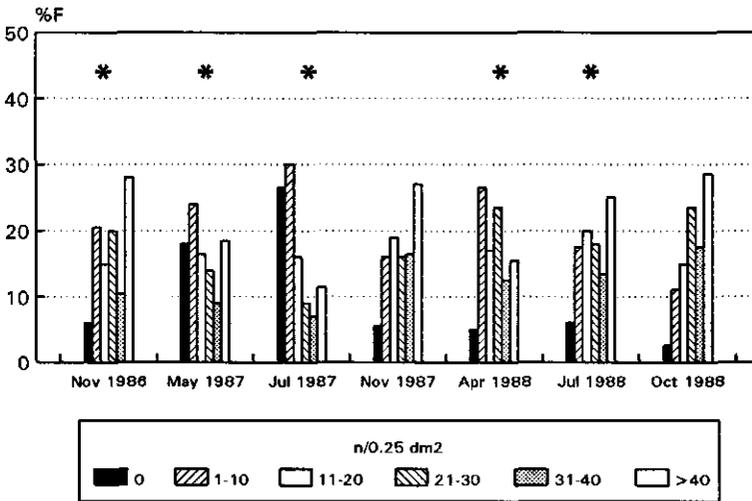


Fig. 3. Frequency distribution of the number of tillers in cores of 0.25 dm<sup>2</sup> in the 250 N and 700 N swards. Asterix (\*) denotes a significant ( $P < 0.05$ ) difference with the 250 N sward according to Chi-Square.

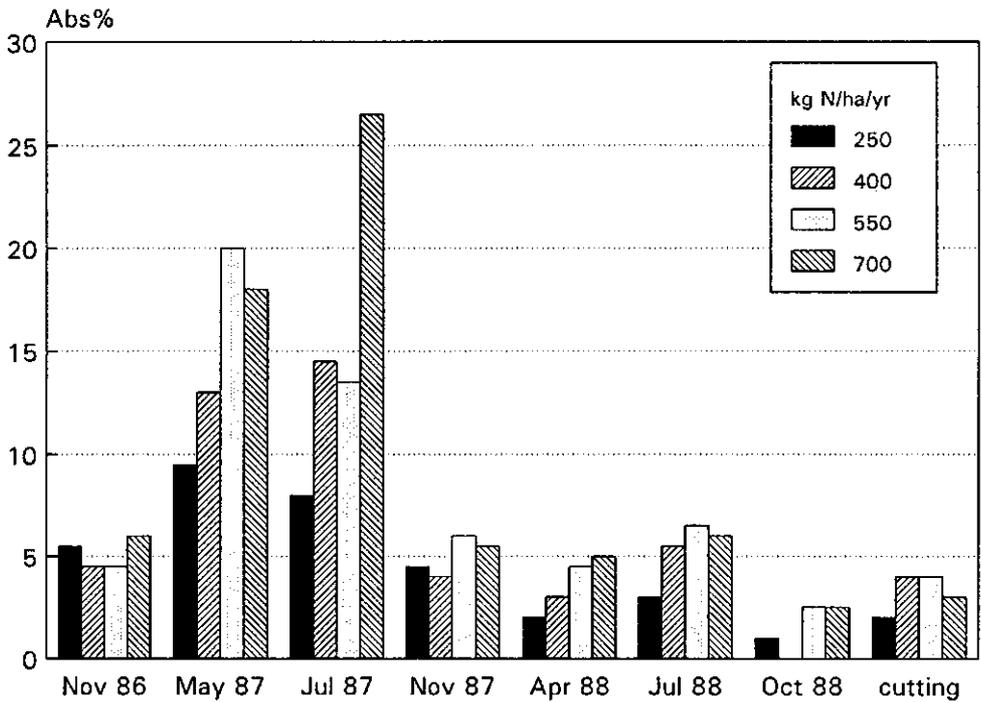


Fig. 4. Absence frequency (Abs%) of perennial ryegrass tillers in 0.25 dm<sup>2</sup> plugs in the grazed swards throughout the experiment and in the cut swards at the end of the experiment (October 1988).

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).

#### *Grassland response to fertilizer N under cutting and grazing*

The relationships between fertilizer N application, N yield and total herbage accumulation (cutting) or total herbage intake (grazing) are presented in Fig. 5.

The efficiency of fertilizer N use can be expressed in two ways. First, as the apparent recovery of N (ANR) which is the increase in the amount of N contained in the harvested herbage, expressed as a percentage of that applied in fertilizer. Secondly, as the

apparent effect of N (ANE), which is the increase in the amount of harvested herbage per kg N applied in fertilizer. For the cutting experiment ANR and ANE values are calculated from the respective differences in N yield and herbage yield between the fertilizer treated plots and the untreated control (nil N) plots. Since the grazing experiment comprised no control (nil N), marginal ANR values and marginal ANE values were calculated as the increase in N yield and herbage yield per kg N applied, respectively, for a specified fertilizer increment.

#### *Apparent recovery of fertilizer N*

*Cutting.* In the cutting treatments the relationship between N application and N yield was linear over the whole range of fertilizer applications in 1986, up to 400 kg N ha<sup>-1</sup>yr<sup>-1</sup> in 1987 and up to 550 kg N ha<sup>-1</sup>yr<sup>-1</sup> in 1988 (Fig. 5; quadrants IV). Under weekly cutting in 1986, N yield was significantly ( $P < 0.05$ ) lower than under 4-weekly cutting except for 700 kg N ha<sup>-1</sup> yr<sup>-1</sup> (Fig. 5; quadrant IV). Probably the more dense and leafy unharvested stubble in the weekly cutting treatments represents a larger sink for the absorbed N than the stubble in the 4-weekly treatments. In all three years ANR values under cutting were high (>80%) even at the highest N application rates, and in some cases ANR values of over 100% were found (in 1987 in the 400 N sward and in 1988 in the 400 N and 550 N sward). This may indicate an increased fraction of the assimilates and N allocated to aboveground parts of the grass crop with increasing N application rates as was suggested by Ennik et al. (1980). These high ANR values agree with Sibma & Alberda (1980), who found N recoveries of the same order in a perennial ryegrass ley on a loam soil in Oostelijk Flevoland.

*Grazing.* In the grazing treatments, there was on average over the three experimental years a significant ( $P < 0.05$ ) increase in N yield up to fertilizer N application rates of 550 kg ha<sup>-1</sup>yr<sup>-1</sup>; N yields were lower than in the 4-weekly cut swards (Fig. 5; quadrants IV). Besides, N yield curves in quadrant IV levelled off stronger in 1986 and 1987. At the lower N application rates N uptake was probably promoted by positive effects of excretal N (Chapter 5) and at the highest fertilizer N application rates N uptake was impeded by an open sward structure as a result of adverse grazing effects. Great differences in the

response of N yield to fertilizer N applied were found in the grazed swards (Fig. 5; quadrants IV). In 1988, marginal ANR values were extremely high: values were 0.81, 0.66 and 0.25 kg N per kg N applied, whereas the mean values over the other two years were 0.55, 0.32 and 0.14 kg N per kg N applied for increments 250 to 400, 400 to 550 and 550 to 700 kg N ha<sup>-1</sup>yr<sup>-1</sup>. In 1988, these high values were amongst others due to a relatively low amount of available soil N. In March before fertilizer N was applied, inorganic soil N was on average 103 kg N ha<sup>-1</sup> in 1986, 108 kg N ha<sup>-1</sup> in 1987 and only 30 kg N ha<sup>-1</sup> 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 nil N cutting treatment was about half the amount of that in 1986 and 1987.

#### *Apparent effect of fertilizer N*

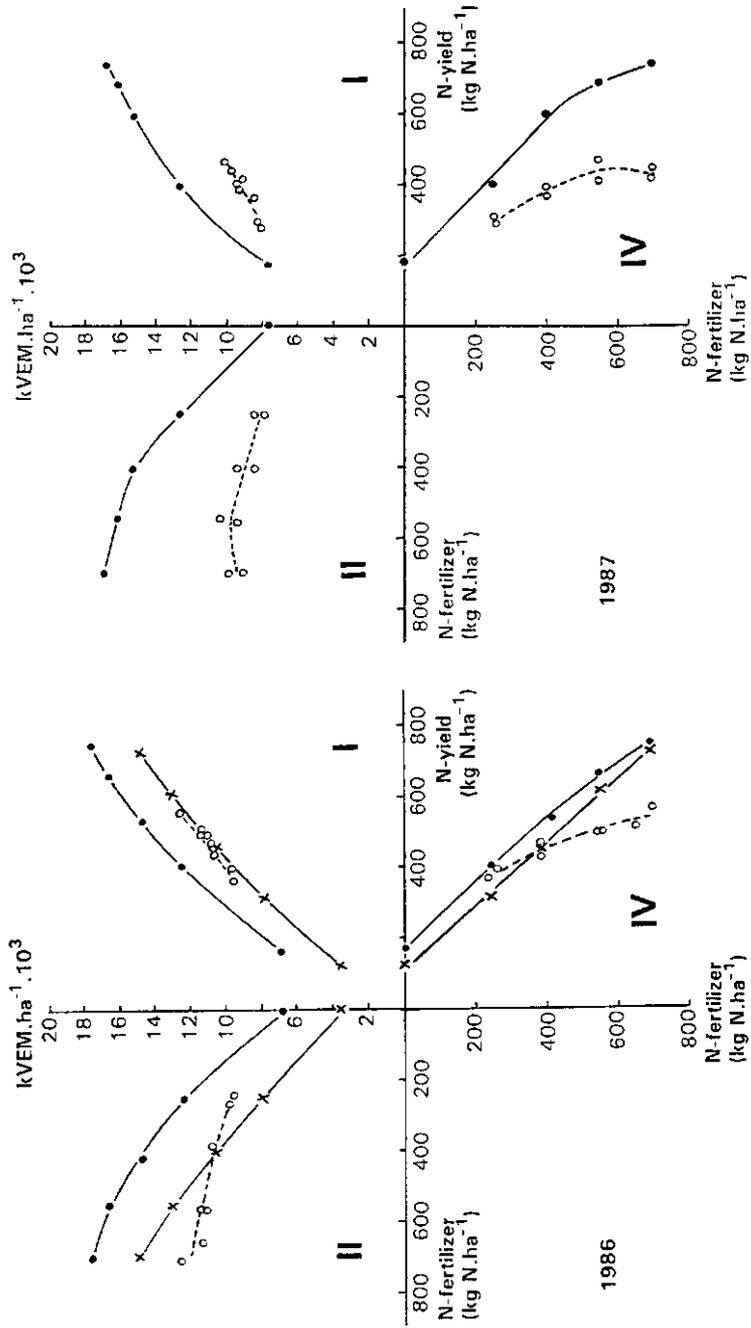
*Cutting.* In all three years there was a significant response of herbage yield to fertilizer N applied (Fig. 5; quadrants II). In 1988, herbage yield at nil N was lower than in 1986 and 1987 due to a relative low amount of available soil inorganic N in that year. This low

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<sup>-1</sup>yr<sup>-1</sup>; spring application 60 kg N ha<sup>-1</sup>.

	Harvest date	Yield (kg DM ha <sup>-1</sup> )
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 <sup>-1</sup> yr <sup>-1</sup>				
250	63	64	64	64
400	72	60	59	65
550	79	55	61	67
700	85	54	56	66



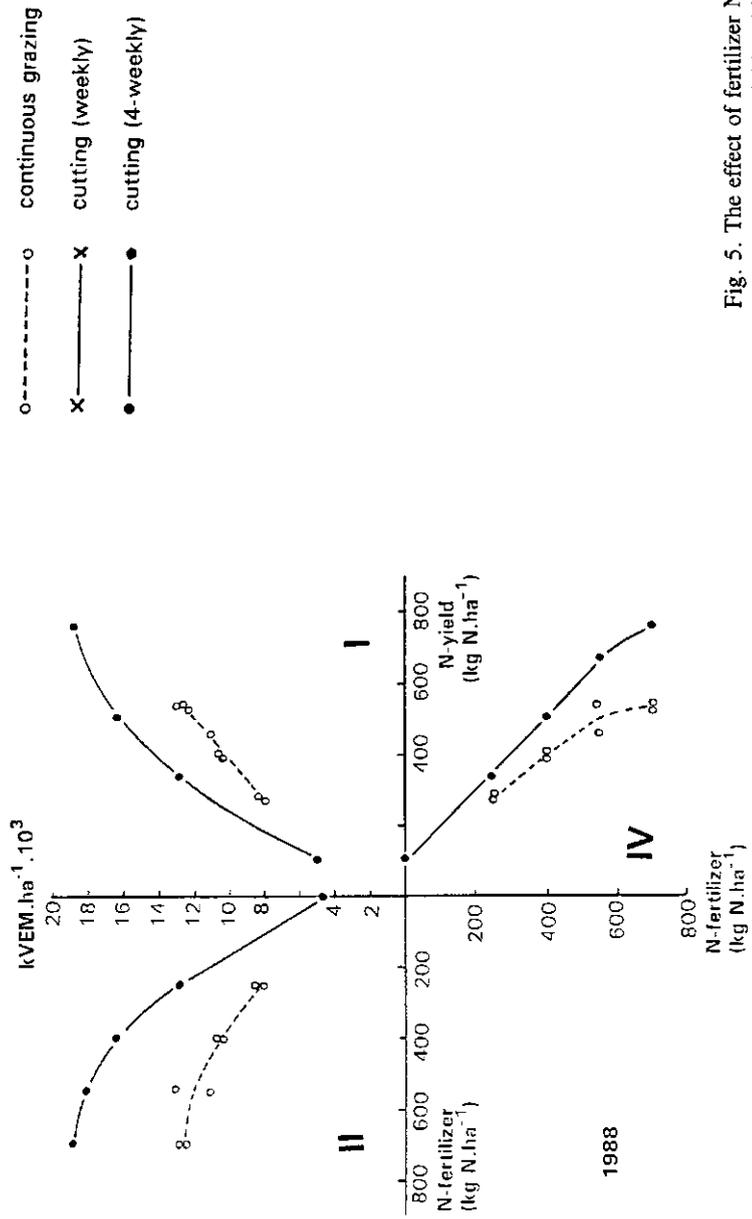


Fig. 5. The effect of fertilizer N application on N yield and herbage yield and herbage intake expressed in kVEM (1 kVEM = 6.9 MJ Net Energy for lactation) under cutting and continuous grazing. For cutting, data are averages over 4 replicates; for grazing, data per paddock are presented.

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<sup>-1</sup>yr<sup>-1</sup> 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<sup>-1</sup> yr<sup>-1</sup>, 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 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<sup>-1</sup> 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<sup>-1</sup> yr<sup>-1</sup>, 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<sup>-1</sup> yr<sup>-1</sup>. 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 (Chapter 5) 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<sup>-1</sup> yr<sup>-1</sup> 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<sup>-1</sup>yr<sup>-1</sup> 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):

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

where:

$$Y = \text{yield (kVEM ha}^{-1} \text{ yr}^{-1}\text{);}$$

$$x = \text{fertilizer N (kg N ha}^{-1} \text{ yr}^{-1}\text{);}$$

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 ha<sup>-1</sup>, 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<sup>-1</sup>yr<sup>-1</sup>. Prins (1983) found a mean marginal profitability of 7.5 kg DM per kg N applied at 420 kg N ha<sup>-1</sup> yr<sup>-1</sup> 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<sup>-1</sup> yr<sup>-1</sup> with a corresponding  $Y_{10}$  value of 10.8 t DM ha<sup>-1</sup>. In the present experiment these values were 430 kg N ha<sup>-1</sup> yr<sup>-1</sup> and 15.6 t DM ha<sup>-1</sup> 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<sup>-1</sup> yr<sup>-1</sup>. In 1986 and 1987, the  $N_{7.5}$  values were considerably lower, viz. 160 and 290 kg N ha<sup>-1</sup> yr<sup>-1</sup> respectively. Under continuous grazing the mean  $N_{7.5}$  value was 308 kg N ha<sup>-1</sup> yr<sup>-1</sup>.

Table 4. The fertilizer N rate at which an incremental response to a 1 kg increase in applied N of 7.5 kVEM ha ( $N_{7.5}$ ) 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 (kg N ha <sup>-1</sup> yr <sup>-1</sup> )		Yield (10 <sup>3</sup> kVEM ha <sup>-1</sup> yr <sup>-1</sup> )	
	$N_{7.5}$	$N_{10}$	$Y_{7.5}$	$Y_{10}$
<i>weekly cutting</i>				
1986	950 <sup>1</sup>	700	16.5 <sup>1</sup>	14.9
<i>4-weekly cutting</i>				
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
<i>continuous grazing</i>				
1986	160 <sup>1</sup>	- <sup>2</sup>	9.1	- <sup>2</sup>
1987	290	210	8.3	7.9 <sup>1</sup>
1988	475	420	11.3	10.5
mean	308	- <sup>2</sup>	9.6	- <sup>2</sup>

<sup>1</sup> Extrapolated. <sup>2</sup> Not determined.

#### *Exclosure cages*

In 1988, herbage accumulation under the exclosure cages was 8716 and 14275 kVEM ha<sup>-1</sup>, whereas herbage intake calculated from animal production data was 7963 and 11129 kVEM ha<sup>-1</sup> 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<sup>-1</sup> yr<sup>-1</sup> 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.

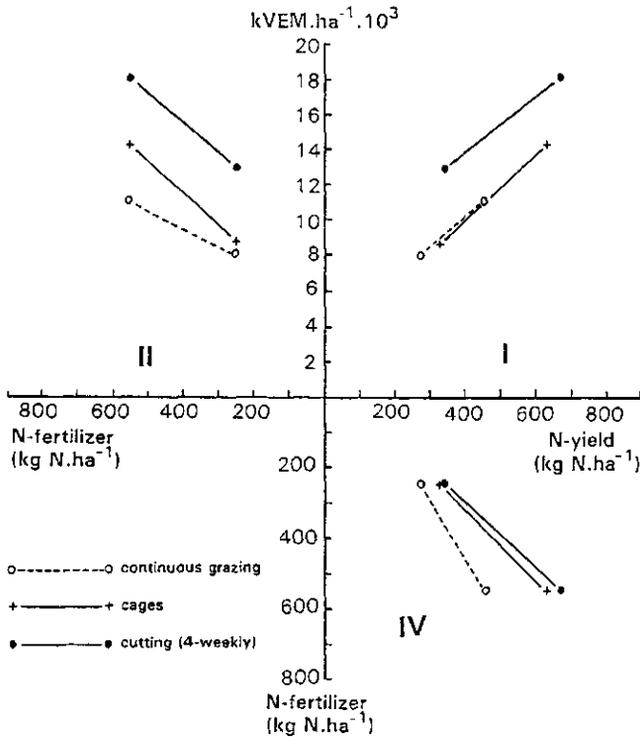


Fig. 6. The effect of fertilizer N application on N yield and herbage yield in a 4-weekly cutting experiment and under enclosure cages and on N yield and herbage intake under continuous grazing. Herbage yield and intake expressed in kVEM (1 kVEM = 6.9 MJ Net Energy for lactation)(1988).

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<sup>-1</sup> (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<sup>-1</sup> could

kVEM ha<sup>-1</sup>

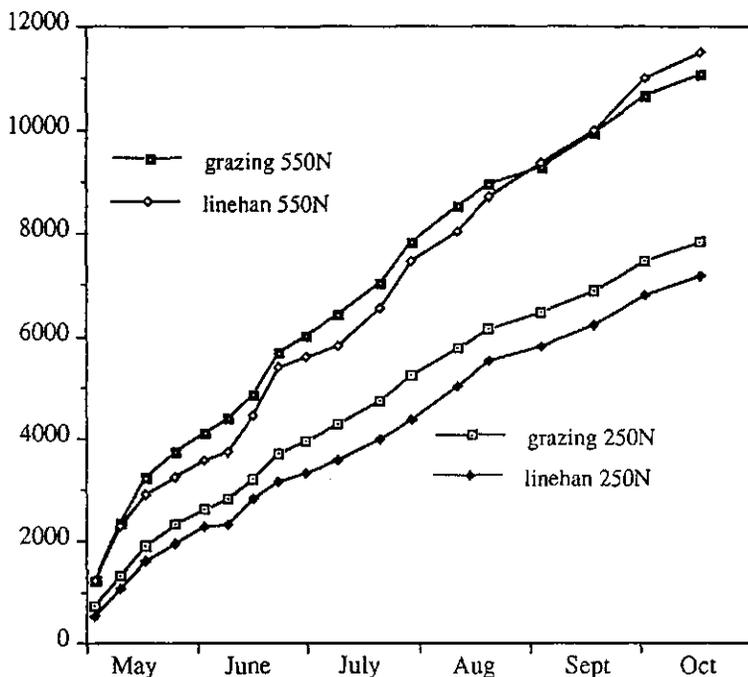


Fig. 7. Cumulative herbage intake under continuous grazing calculated from animal performance data and cumulative herbage intake calculated according to the formula of Linehan from herbage accumulation under the enclosure cages (1988).

be calculated in the 250 N and 550 N paddock, respectively. The cumulative herbage intake calculated from animal production data and cumulative 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 concentration 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 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 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

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

	1986			1987			1988			mean 1986-1988						
<b>A. INPUT</b>																
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>B. INTAKE</b>																
	320	385	413	439	305	391	449	442	290	414	513	551	305	397	458	477
<b>C. OUTPUT</b>																
animal growth <sup>1</sup>	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	140	159	175	197												
total	143	159	175	197	71	77	87	82	72	94	107	113	94	110	123	130
<b>D. EXCRETION</b>																
dung <sup>2</sup>	68	74	76	80	69	76	84	80	72	89	99	102	70	80	86	87
urine <sup>3</sup>	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
<b>E. EFFICIENCY OF N USE</b>																
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

<sup>1</sup> N retention: 30 g N per kg liveweight (Lantinga et al., 1987).

<sup>2</sup> N excretion in faeces: 0.8 g N per 100 g DM eaten (Barrow & Lambourne, 1962).

<sup>3</sup> Urine N excretion calculated as: N intake - (N retention in animal growth and milk) - dung N.

der Meer (1983) 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 (Chapter 5) 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<sup>-1</sup>yr<sup>-1</sup> 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 enclosure cages. The data of herbage accumulation under the enclosure 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 environmental 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<sup>-1</sup> yr<sup>-1</sup> in the period March 1986 to March 1989, irrespective of the level of fertilizer N applied. Although this figure

is unrealistic high (the difference between input and output of N in the 250 N sward was on average only  $208 \text{ kg ha}^{-1} \text{ yr}^{-1}$ ; 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.

## CHAPTER 3

# HERBAGE AND ANIMAL PRODUCTION RESPONSES TO FERTILIZER NITROGEN IN PERENNIAL RYEGRASS SWARDS. II. ROTATIONAL GRAZING AND CUTTING

P.J.A.G. DEENEN<sup>1</sup> & E.A. LANTINGA<sup>2</sup>

<sup>1</sup>Department of Agronomy, Wageningen Agricultural University, Wageningen,  
Netherlands

<sup>2</sup>Department of Theoretical Production Ecology, Wageningen Agricultural University,  
Wageningen, Netherlands

submitted to: Netherlands Journal of Agricultural Science

## HERBAGE AND ANIMAL PRODUCTION RESPONSES TO FERTILIZER NITROGEN IN PERENNIAL RYEGRASS SWARDS. II. ROTATIONAL GRAZING AND CUTTING

### Abstract

Effects of fertilizer nitrogen (N) application on herbage accumulation in perennial ryegrass swards under rotational grazing and 4-weekly cutting have been studied in two experiments. Experiment 1 was performed with dairy cows on a loam soil (1987-1988) at 250 and 550 kg N ha<sup>-1</sup>yr<sup>-1</sup>. Experiment 2 was performed with beef cattle on a sand soil (1986-1989) and fertilizer rates varied from 250 to 700 kg N ha<sup>-1</sup>yr<sup>-1</sup> under grazing and from 0 to 700 kg N ha<sup>-1</sup>yr<sup>-1</sup> under cutting. Differences in the apparent N recovery (ANR) and the response of grassland production to N applied could be related to treatment (cutting versus grazing), soil type (loam versus sand), length of the growing season, the amount of soil inorganic N in spring, sward quality and, in case of grazing, recycling of excretal N. Highest ANR values and herbage yields were found under cutting on the loam soil. On sand, the calculated economical optimum fertilizer application rate was on average 430 kg N ha<sup>-1</sup>yr<sup>-1</sup> for 4-weekly cutting. Under grazing and on a whole-farm scale (integrated grazing and mowing for silage) the optimum rate was estimated to be some 200 kg ha<sup>-1</sup> lower. Under grazing on sand, N enhanced sward deterioration due to treading, poaching and especially urine scorching. On loam, N had hardly any effect on sward quality. At both sites tiller densities were highest in the cut swards. Efficiency of use of N input varied from 24 to 31% for dairy cows and was less than 10% for beef cattle at a fertilizer level of 250 kg N ha<sup>-1</sup>yr<sup>-1</sup>. Efficiency decreased with increasing N rates.

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

## Introduction

The increased input of nitrogen (N) has made an important contribution to the improvement of grassland productivity since World War II, especially in the Netherlands where fertilizer N is extensively used on grassland. Recommended annual rates are up to about 400 kg N ha<sup>-1</sup> for grasslands on sand, clay and wet peat soils and about 250 kg N ha<sup>-1</sup> on well drained peat soils (Anonymous, 1987). These recommendations have been derived mainly from cutting trials with an approximate cutting interval of four weeks (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 of 420 kg N ha<sup>-1</sup>yr<sup>-1</sup>. However, a study of the N balances of a number of intensive dairy farms in the Netherlands with predominantly grazing in the growing season revealed that only 16% of the total N input in fertilizer, purchased feed and precipitation (equivalent to 533 kg N ha<sup>-1</sup>yr<sup>-1</sup>) was removed in animal products (Van der Meer, 1983). High application rates in combination with a low N use efficiency can therefore result in large losses of N to the environment through ammonia volatilization, nitrate leaching and denitrification.

The yield response of a grass sward to fertilizer N differs whether the sward is defoliated by cutting or by grazing. Grazing cattle exert positive and negative effects on pasture production. The greater quantities of N circulating in grazed swards should in theory, in comparison with cut swards, be reflected in (i) higher yields at the same fertilizer N application, (ii) maximum or optimum yield responses to fertilizer N at lower application levels, and (iii) a higher N concentration 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 total supply of N (Norman & Green, 1958; During & McNaught, 1961). However, recent studies on soils with mineralization rates in the order of 150 kg N ha<sup>-1</sup>yr<sup>-1</sup> demonstrated that there is no significant short-term beneficial effect from excretal N for the pasture as a whole at fertilizer N inputs greater than about 250 kg N ha<sup>-1</sup>yr<sup>-1</sup> (Lantinga et al., 1987; Chapter 5). Richards (1977) observed in a one-year experiment on a soil with a very low rate of N mineralization (25 kg N ha<sup>-1</sup>yr<sup>-1</sup>) that grazing had a positive effect on herbage yield up to a fertilizer N rate of 300 kg ha<sup>-1</sup>yr<sup>-1</sup>.

About the long-term effects, Hassink (1992) reported higher rates of N

mineralization in grazed swards than in cut swards four years after the start of the treatments. This was accompanied by a greater amount of microbial biomass under grazing than under cutting. Therefore, Hassink concluded that the optimum N fertilizer application rate should be considerably lower under grazing than under cutting.

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; Tallwin et al., 1986; Chapter 5). Due to these detrimental effects N uptake is impeded at higher application rates, causing a reduction in herbage yield in comparison with cutting. Even under a cutting management Prins & Neeteson (1982) found a decreasing productivity with increasing rates of N application in the preceding years. This decrease in productivity was associated with a deterioration of the sward as evidenced by a more open sward and a lower tiller density. Studies on yield responses to fertilizer N under grazing and especially rotational grazing, which is the most employed grazing system for dairy cows in the Netherlands, are scarce. In the Netherlands, Boxem (1973) compared the response in a system where grazing was alternated by mowing for conservation with that under cutting only. Only small differences were observed. However, dry matter yields under the alternated 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 because they contribute to the yield of the next cut it might very well be that the reported dry matter yields are an overestimation of the real productivity of the grazed swards. 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<sup>-1</sup>yr<sup>-1</sup>). However, in their experiments the quantities of herbage on offer were lower than under normal farming practice resulting in abnormal animal behaviour with a high probability of adverse effects from trampling and fouling (R.D. Baker, pers. comm.). For this reason, their tentative conclusion that "maximum yields are achieved with about 200 kg N ha<sup>-1</sup>yr<sup>-1</sup> less under grazing than cutting management" may be doubtful.

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 rotational grazing with dairy cows and beef cattle over a wide range of fertilizer N treatments at various soil types. This response was compared with that under cutting, where cumulative herbage accumulation was determined at harvest intervals of approximately four weeks. The effect of the different treatments (rotational 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.

## **Material and methods**

### *Site characteristics and treatments*

*Experiment 1* was carried out in 1987 and 1988 on an approximately 20 year old perennial ryegrass (*Lolium perenne* L.) sward containing some volunteer *Poa* spp. The location was a well drained young sedimentary calcareous silty loam soil at the A.P. Minderhoudhoeve (experimental farm of the Agricultural University) in Oostelijk Flevoland. The soil (0-5 cm layer: pH-KCl 7.1; 10.0% CaCO<sub>3</sub>) was reclaimed from the sea only 30 years ago.

In the pre-experimental year (1986) two paddocks of 1 ha each receiving 250 and 550 kg N ha<sup>-1</sup>yr<sup>-1</sup> 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. Prior to each grazing in the measuring paddock the cows grazed in a conditioning paddock receiving the same level of fertilizer N as the measuring paddock. Number of animals in the measuring paddocks was adjusted to have a grazing period of 1 to 2 days and an average daily herbage allowance above 4 cm cutting 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 the uneaten grass was removed by cutting at a height of about 6 cm. In both years detailed measurements of herbage accumulation under grazing were made.

Table 1. Scheme of management treatments and measurements of herbage accumulation in experiment 2 during pre-experimental year 1985 and experimental years 1986-1989.

	1985	1986	1987	1988	1989	estimation of herbage
continuous grazing	x					animal performance
rotational grazing		x	x			sward cutting technique
weekly cutting	x					sward cutting technique
4-weekly cutting		x	x	x	x	sward cutting technique
whole-farm (rotational grazing and cutting)		x	x	x	x	animal performance and herbage mass of the silage

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 in the cutting-only trial were harvested at the end of each grazing period.

*Experiment 2* was conducted from 1986 to 1989 inclusive on a sand soil near Wageningen. The soil (0-5 cm layer: pH-KCl 5.0; particle fraction < 0.050 mm = 17.2%) had been under grass for many years receiving 400 to 500 kg N ha<sup>-1</sup>yr<sup>-1</sup>. In 1981 the old sward was reseeded with a mixture of perennial ryegrass containing equal amounts of the cultivars Pelo, Vigor and Splendor (Anonymous, 1982). The grassland management scheme and the type of measurements are summarized in Table 1. In the pre-experimental year (1985), the treatments were introduced and comprised two management systems: grazing only and cutting only and four rates of fertilizer N in the grazing trial (250, 400, 550 and 700 kg N ha<sup>-1</sup> yr<sup>-1</sup>). In the cutting trial a 0 N treatment was also included. Both trials were laid out according to a randomized block design with two (grazing) or four (cutting) replicates. In the pre-experimental year 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. Stocking rates were adjusted regularly to maintain a target compressed sward height of about 6 cm on the frequently grazed areas (mean overall sward height about 7 cm) to keep the infrequently grazed component below 20% in order to sustain a constant quantity of herbage available across the 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 in each paddock was recorded throughout the grazing season. Animals were weighed without fasting on two consecutive days at the start and at the end of the grazing season and at monthly intervals in between.

In 1986, the experiment started and continuous grazing was changed into rotational grazing. It was aimed at grazing periods of 3 to 4 days per paddock and the paddocks were halved to 0.20 ha. Therefore, from 1986 onwards each N treatment comprised two measuring paddocks which were grazed-only. After every second grazing the uneaten 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. In the preceding years the extra paddocks were fertilized annually with 400 to 500 kg N ha<sup>-1</sup>. In these extra paddocks also silage cuts were taken. The yield of the silage cuts was determined for each paddock separately and samples were taken for chemical analysis. Animals were weighed as described above. Data about animal performance and grass harvested for silage were pooled for each N treatment in order to calculate the response to fertilizer N as grassland output in terms of net energy on a whole-farm scale. The cutting-only plots were harvested at the end of each grazing period in the measuring paddocks. In the 0 N treatment four or five cuts per year were taken.

*Fertilization.* At both locations, spring fertilizer N (calcium ammonium nitrate: 27% N) was applied when the accumulated mean daily air temperature above 0 °C since 1 January approached 200 °C (Jagtenberg, 1970). Thereafter, applications were made in diminishing amounts every three weeks (continuous grazing and weekly cutting) or immediately following defoliation (rotational grazing and 4-weekly cutting) until target rates were reached. The 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 analysis. Grass for silage was cut with a rotary drum

mower leaving a stubble of about 7 cm. All samples were analysed for ash, N and in-vitro digestibility of organic matter ( $D_{\text{vitro}}$ ).  $D_{\text{vitro}}$  was estimated by the method of Goering & van Soest (1970). Apparent in-vivo digestibility of organic matter ( $D_{\text{om}}$ ) could be calculated from  $D_{\text{vitro}}$  of standard samples of known in-vivo digestibility determined with wethers. The samples of the cutting-only plots and the pre-grazing samples were also analysed for phosphorus (P) and potassium (K). The determination of ash, N, P and K was done according to the method of Novozamsky et al. (1983).

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

### *Sward quality*

In experiments 1 and 2, tiller density was estimated at the beginning, halfway and at the end of the grazing season. With the exception that in experiment 2 tiller density was not estimated halfway the grazing season in 1988. Per paddock one hundred  $0.25 \text{ dm}^2$  plugs were taken (De Vries, 1940) according to a systematic line-sampling technique and tillers within each plug were counted. The cutting only plots of both experiments were sampled in autumn 1988. Per N treatment 25 plugs per replicate were taken and tillers within each plug were counted.

On a number of occasions, in both experiments absence frequencies of rooted perennial ryegrass tiller bases from concentric sampling quadrats were recorded according to the method of Neuteboom et al. (1992). Absence frequencies were recorded in a concentric ring with an area of  $1 \text{ dm}^2$  (radius 5.6 cm). Per paddock 100 measurements were made. In the cutting only plots 25 measurements per replicate were taken.

### *Herbage accumulation and grassland output*

The total annual herbage accumulation under rotational grazing was assessed as the sum of herbage accumulation over all grazing cycles, the amount of herbage removed by cleaning cuts and the residual herbage at the end of the grazing season. Herbage mass and herbage accumulation 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 accumulation over a single grazing cycle can be calculated as:

$$HA = (Y_{s(t)} - Y_{e(t-1)}) + f_L * (Y_{u(t)} - Y_{s(t)}) \quad (1)$$

where:

HA = herbage accumulation (kg OM, kVEM or kVEVI ha<sup>-1</sup>);

Y<sub>s(t)</sub> = herbage mass at start of grazing period t (kg OM, kVEM or kVEVI ha<sup>-1</sup>);

Y<sub>e(t-1)</sub> = herbage mass at end of grazing period t-1 (kg OM, kVEM or kVEVI ha<sup>-1</sup>);

f<sub>L</sub> = accumulation factor;

Y<sub>u(t)</sub> = herbage mass at end of grazing period t in an ungrazed area (kg OM, kVEM or kVEVI ha<sup>-1</sup>).

The difference between Y<sub>u(t)</sub> and Y<sub>s(t)</sub> is termed the 'undisturbed accumulation' (Meijs, 1981). The herbage accumulation during the grazing period can be expressed as a fraction of this 'undisturbed accumulation'. In case of rotational grazing this fraction equals (Lantinga, 1985b):

$$f_L = [(Y_e/Y_s) - 1] / \ln(Y_e/Y_s) \quad (2)$$

where:

f<sub>L</sub> = accumulation factor;

Y<sub>s</sub> = herbage mass at start of grazing (kg OM, kVEM or kVEVI ha<sup>-1</sup>);

Y<sub>e</sub> = herbage mass at end of grazing (kg OM, kVEM or kVEVI ha<sup>-1</sup>);

Y<sub>u</sub> was calculated by means of a dynamic simulation model (Lantinga, 1985b). Y<sub>s</sub> and Y<sub>e</sub> were determined by use of the double sampling concept (Back et al., 1969). The average sward height (50 measurements per paddock) was used as an estimator of herbage mass by means of local regressions relating herbage mass to height. Local regressions were 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. The average sward height within a strip was determined by 10 measurements. The distance between the pre- and

post-grazing strips was about 0.5 m. In experiment 2, grassland output per N treatment on a whole-farm scale (i.e. the sum of herbage intake and ensiled herbage in terms of net energy) was calculated from data about animal performance using standards for net energy requirements for maintenance and growth and the yield and energy value of ensiled herbage. The net energy requirement for maintenance and growth was calculated using the standard equation derived for young male animals and adapted for grazing steers according to correction factors derived from Van Es (1978) and a correction factor for grazing (Meijs, 1981):

$$NE = \frac{(500+6*LW)*G}{1-(G*0.3)} * c * d + 78.87 * LW^{3/4} \quad * a * b \quad (3)$$

1.65

where:

- NE = net energy requirement expressed as Dutch Feed Unit for beef cattle (kVEVI);
- LW = liveweight (kg animal<sup>-1</sup>);
- G = growth (kg animal<sup>-1</sup> day<sup>-1</sup>);
- a = multiplication factor for the energy requirement at different growth rates (0.8365 + 0.222\*G - 0.04\*G<sup>2</sup>);
- b = multiplication factor for the energy requirement at different liveweights (0.933 + LW/3000);
- c = multiplication factor for fat deposition (1.15 for steers);
- d = multiplication factor for maintenance due to grazing activity (1.20).

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

## Weather data

Cumulative precipitation at Wageningen is shown in Fig. 1. The growing season of 1987 had a more than average amount of rainfall. The growing seasons of 1986 and 1988 were relatively dry. The winters 1985/1986 and 1986/1987 were very cold.

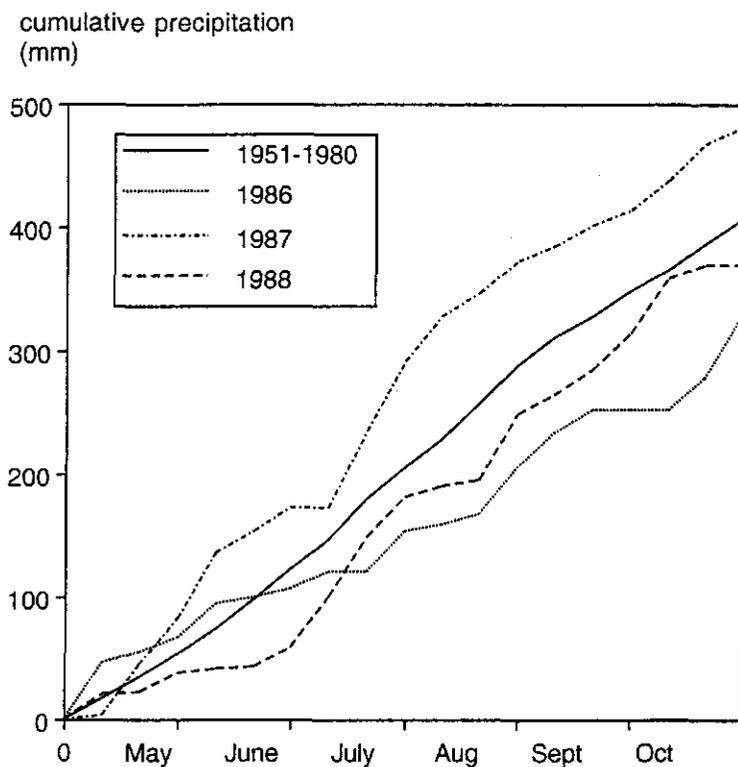


Fig. 1. Cumulative precipitation (mm) for 1 May - 1 November in 1986, 1987, 1988 and the mean cumulative precipitation for 1951-1980 measured at the meteorological station at Wageningen.

Table 2. Experiment 1. Effect of fertilizer N on animal performance of dairy cows on perennial ryegrass swards under rotational grazing.

	1987		1988	
kg N ha <sup>-1</sup>	250	550	244	540
cow grazing days ha <sup>-1</sup>	791	908	580	938
milk production (kg FPCM cow <sup>-1</sup> d <sup>-1</sup> )	21.5	19.7	22.1	21.8
milk production (kg FPCM ha <sup>-1</sup> )	17,054	17,882	12,814	20,441

## Results and discussion

### *Grazing management and animal performance*

*Experiment 1.* During the two experimental years, grazing periods varied from 1 to 2 days. The rest period ranged from 12 days in spring to about 33 days at the end of the grazing season. In 1986 and 1987 pre-grazing herbage mass was approximately 2000 kg OM ha<sup>-1</sup> above 4 cm cutting height. Mean sward heights at the start and the finish of a grazing period were 15.2 and 7.3 cm, respectively. There were significant differences in cow grazing days and milk production per ha between the two N treatments with a marked difference between the two years (Table 2).

*Experiment 2.* In 1985 the paddocks were grazed continuously during a period of 180 days. Total live weight carried (LWC) increased with increasing fertilizer N application rates (Fig. 2). Since there is a linear relationship between net herbage accumulation under grazing and LWC (Large et al., 1985) this increase gives evidence for a response to fertilizer N up to about 700 kg N ha<sup>-1</sup>yr<sup>-1</sup>.

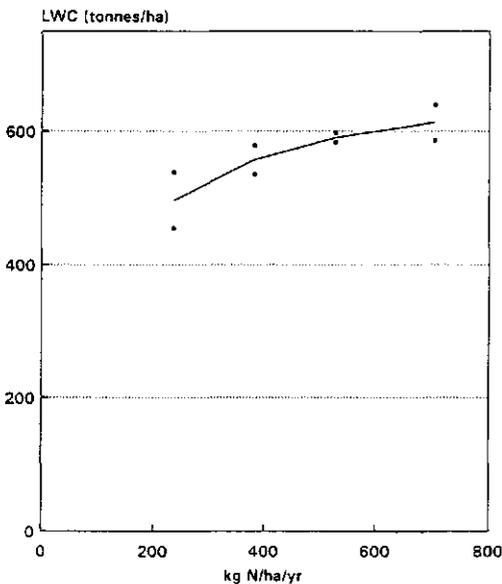


Fig. 2. The effect of fertilizer N application on liveweight carried (LWC) under continuous grazing in the pre-experimental year (1985).

Grazing periods were about 4 days in 1986 and about 3 days in 1987. In both years the rest period ranged from 18 days in spring to about 40 days at the end of the grazing season. Due to a severe winter and a cold spring in 1986, 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. The target N application rates of 550 and 700 kg N ha<sup>-1</sup>yr<sup>-1</sup> could not be attained in the respective treatments (actual application rates were 510 and 655 kg N ha<sup>-1</sup>yr<sup>-1</sup>). In 1986 and 1987 pre-grazing herbage mass was approximately 1600 kg OM ha<sup>-1</sup> above 4 cm cutting height. Mean sward heights at the start and the finish of a grazing period were 14.2 and 7.0 cm, respectively.

### *Sward quality*

*Experiment 1.* The tiller density of perennial ryegrass fluctuated strongly during the course of the experiment. In three cases tiller density was significantly higher in the 550 N sward, in one case significantly lower and in two cases there was no difference with

Table 3. Experiment 1. The effect of fertilizer N on mean tiller density of perennial ryegrass (tillers dm<sup>-2</sup>), the frequency of 0.25 dm<sup>2</sup> plugs containing nil tillers of perennial ryegrass (% F) and the absence frequencies of rooted perennial ryegrass tiller bases from a concentric sampling quadrat with an area of 1 dm<sup>2</sup> (radius 5.6 cm)(% ABS) for rotationally grazed swards.

fertilizer kg N ha <sup>-1</sup> yr <sup>-1</sup>	tillers dm <sup>-2</sup>		%F		%Abs	
	250	550	250	550	250	550
<i>grazing</i>						
May 1987	52	75 *	20	21	-	-
July 1987	57	46	15	25 #	-	-
November 1987	40	63 *	21	12 #	-	-
May 1988	45	59 *	17	18	-	-
July 1988	69	49 *	3	7 #	0	0
November 1988	54	60	2	8 #	0	2
<i>cutting</i>						
November 1988	66	74 *	0	5 #	0	1

\* denotes a significant difference ( $P < 0.05$ ) between N treatments according to Kruskal-Wallis (One-Way Analysis by Ranks).

# denotes a significant difference ( $P < 0.05$ ) between N treatments according to a binomial model.

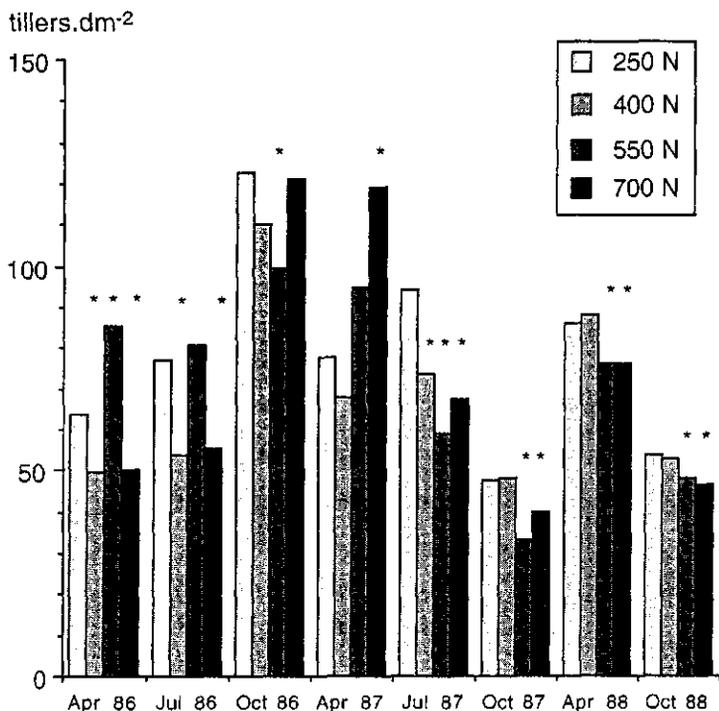


Fig. 3. Experiment 2. Mean tiller density of perennial ryegrass for rotationally grazed swards. Asterix (\*) denotes a significant ( $P < 0.05$ ) difference with the 250 N sward according to Kruskal-Wallis (One-Way Analysis by Ranks).

the 250 N sward (Table 3). From July 1988 onwards the frequency of plugs containing nil tillers was low, especially in the 250 N sward. Furthermore, absence of tillers was confined to small areas. At the end of the experiment tiller density was also determined in the cutting trial. At that time tiller density was significantly ( $P < 0.05$ ) higher in the cut swards than in the grazed swards (Table 3).

*Experiment 2.* In all swards perennial ryegrass was the dominant species although the swards were invaded by *Poa* spp., especially in the patches where perennial ryegrass had vanished as a result of urine scorching or poaching. Variations in tiller density in relation to N treatments were much smaller than the fluctuations in tiller density during the course of the experiment (Fig. 3). In May 1986, tiller densities were low due to winter damage (Chapter 4). In autumn 1986, tiller density had increased strongly in all swards.

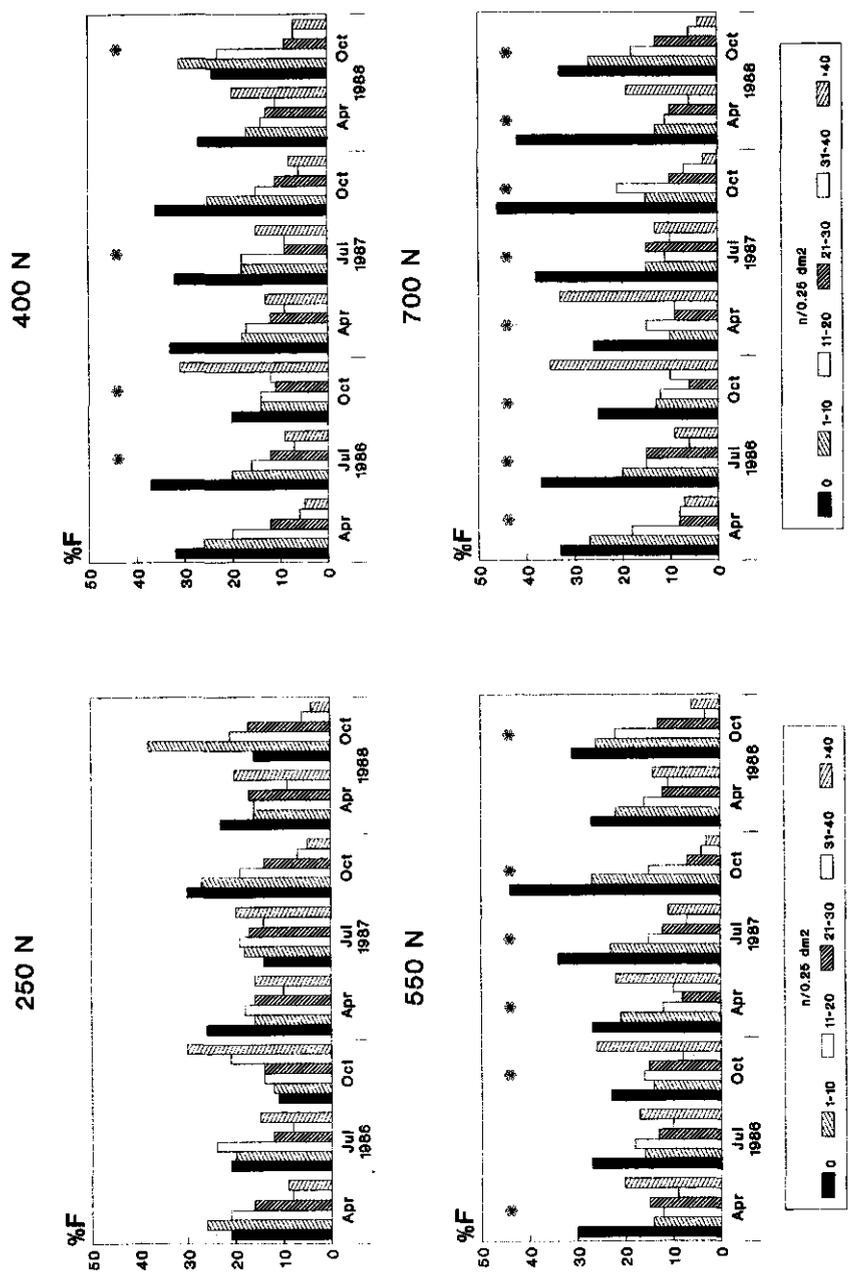


Fig. 4. Experiment 2. Frequency distribution of the number of tillers in cores of 0.25 dm<sup>2</sup> in the 250 N, 440 N, 550 N and 700 N swards. Asterisk (\*) denotes a significant (P < 0.05) difference with the 250 N sward according to Chi-Square.

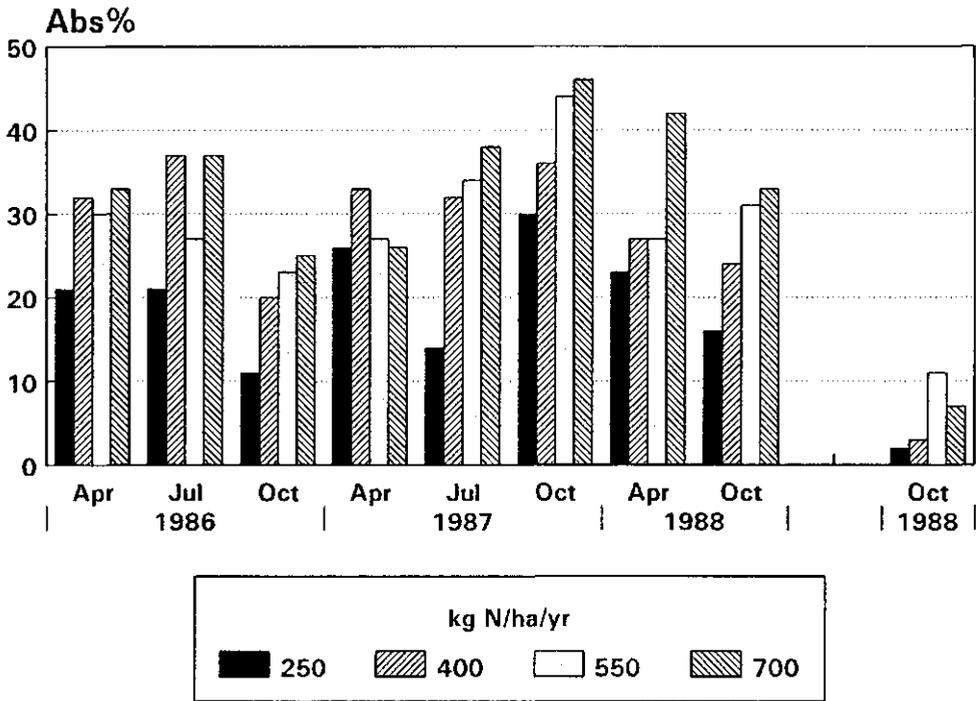
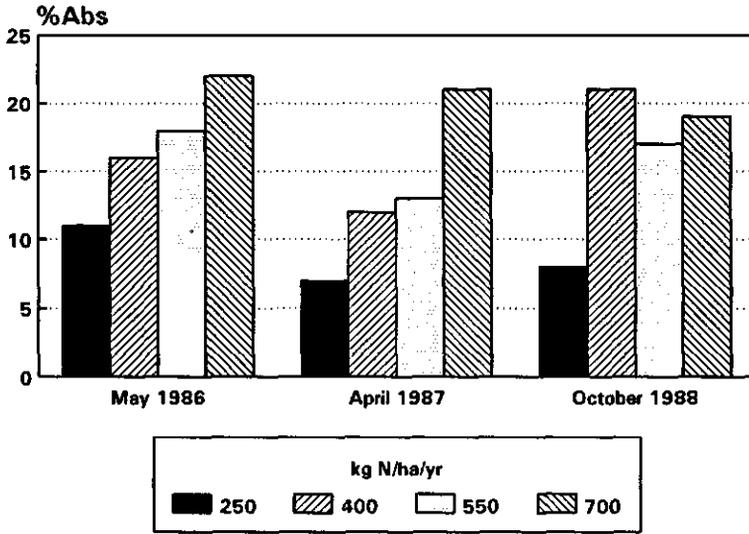


Fig. 5. Experiment 2. Absence frequency (Abs%) of perennial ryegrass tillers in 0.25 dm<sup>2</sup> plugs in the grazed swards throughout the experiment and in the cut swards at the end of the experiment (October 1988).

Although the net changes in tiller numbers showed a great similarity in all swards, the 400 N, 550 N and 700 N swards were more open and the frequency of plugs containing nil tillers was about twice as high as in the 250 N sward (Figs. 4 and 5). The 400 N, 550 N and 700 N swards had a strongly clumped tiller distribution, expressed in a high proportion of plugs containing nil tillers together with a high proportion of plugs containing a large number of tillers (Fig. 4).

In 1987, there was a strong decrease ( $P < 0.05$ ) in tiller density during the grazing season (Fig. 3) due to the extremely wet weather conditions (Fig. 1). In the 550 N and 700 N sward the decrease started already in early summer. The decrease in tiller density was also strongest in these swards. At the end of the grazing season tiller density was low in all swards (Fig. 3). The openness of the sward increased with increasing rate of fertilizer N (Fig. 5).

grazing R = 5.6 cm



cutting R = 5.6 cm

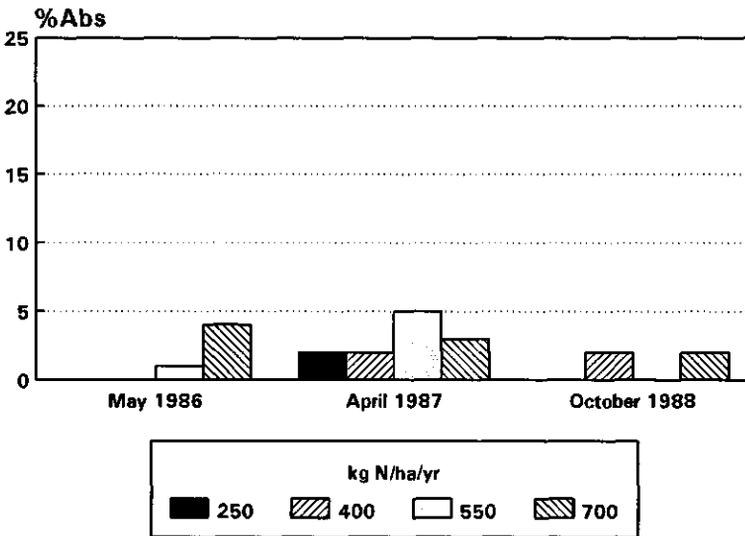


Fig. 6. Experiment 2. Absence frequency (Abs%) of perennial ryegrass tillers in quadrat with radius 5.6 cm (area 1 dm<sup>2</sup>) in the grazed and cut swards throughout the experiment.

In spring 1988, tiller density had increased in all swards but in autumn 1988 it had decreased again (Fig. 3). Under grazing the absence of perennial ryegrass tillers was not confined to areas of  $0.25 \text{ dm}^2$  only. Estimates with concentric quadrats showed a much greater degree of patchiness or openness in the grazed swards than in the cut swards (Fig. 6). Patches in which perennial ryegrass was absent with an area of at least  $1 \text{ dm}^2$  were already present in spring 1986. The degree of patchiness was generally positively related to N application rate.

Tiller densities under cutting in November 1988 were 62, 90, 93, 70 and 62 tillers per  $\text{dm}^2$  in the 0 N, 250 N, 400 N, 550 N and 700 N sward, respectively. At that time tiller density was significantly ( $P < 0.05$ ) higher and the tiller distribution was much more homogeneous under cutting than under grazing (Fig. 5).

### **Grassland response to fertilizer N under cutting and grazing**

The efficiency of fertilizer N use can be expressed in two ways. First, as the apparent recovery of N (ANR) which is the increase in the amount of N contained in the harvested herbage, expressed as a percentage of that applied in fertilizer. Secondly, as the apparent effect of N (ANE), which is the increase of harvested herbage per kg N applied in fertilizer. For the cutting treatment in experiment 2, ANR and ANE values were calculated from the respective differences in N yield and herbage yield between the fertilizer treated plots and the untreated control (0 N) plots. Since the grazing experiments and the cutting treatment in experiment 1 comprised no control (0 N), marginal ANR values and marginal ANE values were calculated as the increase in N yield and herbage yield per kg N applied, respectively, for a specified fertilizer increment.

#### *Apparent recovery of fertilizer N*

*Experiment 1.* The effects of fertilizer N on N yield and total herbage yield are presented in Table 4. Large differences in N yield were found between years and treatments (cutting versus grazing in 1988) at 250 N. In 1987, the high N yield under grazing at  $250 \text{ kg ha}^{-1}$  of  $479 \text{ kg ha}^{-1}$  was probably due to a high amount of available soil N in spring, due to the relatively dry previous winter, which resulted in lower leaching losses than during the

Table 4. Experiment 1. The effect of the rate of fertilizer N on N yield, organic matter (OM) yield, N concentration in the herbage, marginal apparent N recovery (marginal ANR) and marginal apparent N effect (marginal ANE) under grazing (1987 and 1988) and cutting (1988).

	grazing				cutting	
	1987		1988		1988	
fertilizer N (kg ha <sup>-1</sup> )	250	550	244	540	244	540
N yield (kg ha <sup>-1</sup> )	479	653	389	660	332	647
OM yield (kg ha <sup>-1</sup> )	12711	13529	10950	14601	10094	14756
N concentration (g N kg <sup>-1</sup> DM)	34	44	32	41	29	39
marginal ANR (kg N kg <sup>-1</sup> N)	0.58		0.92		1.06	
marginal ANE (kg (OM kg <sup>-1</sup> N)	2.7		12.3		15.8	

very wet winter and early spring period of 1988. In a cutting trial in an adjacent sward on the same soil type, N yield at the 0 N treatment was 177 and 91 kg N ha<sup>-1</sup>yr<sup>-1</sup> in 1987 and 1988, respectively (Chapter 2). Hardly any differences in N yield between years and treatments were found at 550 N (Table 4). In 1987, the marginal ANR value was only 0.58 kg N per kg N applied for the increment 250 to 550 kg N ha<sup>-1</sup>. This low ANR value was due to (i) a higher degree of winter damage in the 550 N sward, (ii) a high amount of soil inorganic N in spring and (iii) a relative short growing season. In 1988, N yield at the 250 N treatment was higher under grazing than under cutting indicating a positive effect of grazing on N yield. The marginal ANR was 0.92 under grazing and 1.06 under cutting. These high values of ANE and ANR were the result of a low amount of inorganic soil N in spring, a long growing season and a good sward quality throughout the year.

*Experiment 2; cutting.* In the 4-weekly cutting experiment (1986-1988) there was a significant ( $P < 0.05$ ) increase in N yield up to 550 kg N ha<sup>-1</sup>yr<sup>-1</sup> (Figs. 7 and 8). N yield in the 0 N treatment ranged from 108 to 126 kg N ha<sup>-1</sup>yr<sup>-1</sup>. Under 4-weekly cutting ANR values were high (>90%) up to 400 kg N ha<sup>-1</sup>yr<sup>-1</sup> in 1986 and up to 550 kg N ha<sup>-1</sup>yr<sup>-1</sup> in 1987 and 1988. In 1986 only a small increase in N yield was found above 400 kg N ha<sup>-1</sup>yr<sup>-1</sup> due to winter damage and a short growing season. In 1987 and 1988 hardly any increase in N yield was found for the fertilizer increment 550 to 700 kg N ha<sup>-1</sup>yr<sup>-1</sup>.

*Experiment 2; grazing.* N yields at 250 kg N ha<sup>-1</sup>yr<sup>-1</sup> under grazing and cutting were equal in both years (Fig. 7). At higher rates of N application N yields under grazing were lower and the difference increased with the level of N application. Especially in 1987 the difference between grazing and cutting was large, due to adverse grazing effects. Marginal ANR values under grazing were low in both years. Probably, at the lower N application rates excretal N had a positive effect on N yield and compensated the negative grazing effects. At higher N rates the lack of response was the result of a short growing season (especially 1986) and sward deterioration (due to urine scorching, poaching and treading). Urine scorching has the greatest negative effects on sand soils and its frequency of occurrence and its impact is strongly correlated with the rate of N application. It may result in large open patches which are subsequently invaded by less productive volunteer species like *Poa annua* (Lantinga et al., 1987).

#### *Apparent effect of fertilizer N*

*Experiment 1.* In 1987, marginal ANE under grazing for the increment 250 to 550 kg N ha<sup>-1</sup> was small, which was due to a high N yield at 250 N (Table 4) and a reduced N effect at 550 N as a result of winter damage. Until the fourth cut there was a negative response of the cumulative herbage yield to fertilizer N applied. Due to a relatively short growing season in 1987 and less favourable weather conditions in the second part of the growing season N was probably utilized less efficiently in 1987 than in 1988. This resulted in a higher N concentration in the herbage and a lower marginal ANE value than in 1988 (Table 4). In 1988, N yield and herbage yield at 250 kg N ha<sup>-1</sup> were higher under grazing than under cutting at 250 kg N ha<sup>-1</sup> (Table 4). The difference in herbage yield between grazing and cutting in 1988 (about 900 kg OM ha<sup>-1</sup>) occurred in the second part of the growing season and can be associated with a combined positive effect of excretal N (mainly urine N) and a better regrowth facilitated by a relatively large mass of residual herbage at the end of the grazing periods.

*Experiment 2; cutting.* There were great differences in the response of herbage yield to fertilizer N applied under cutting between the years (Figs. 7 and 8). In 1986, only a small response to additional fertilizer N was found above 250 kg N ha<sup>-1</sup>yr<sup>-1</sup>. Due to winter

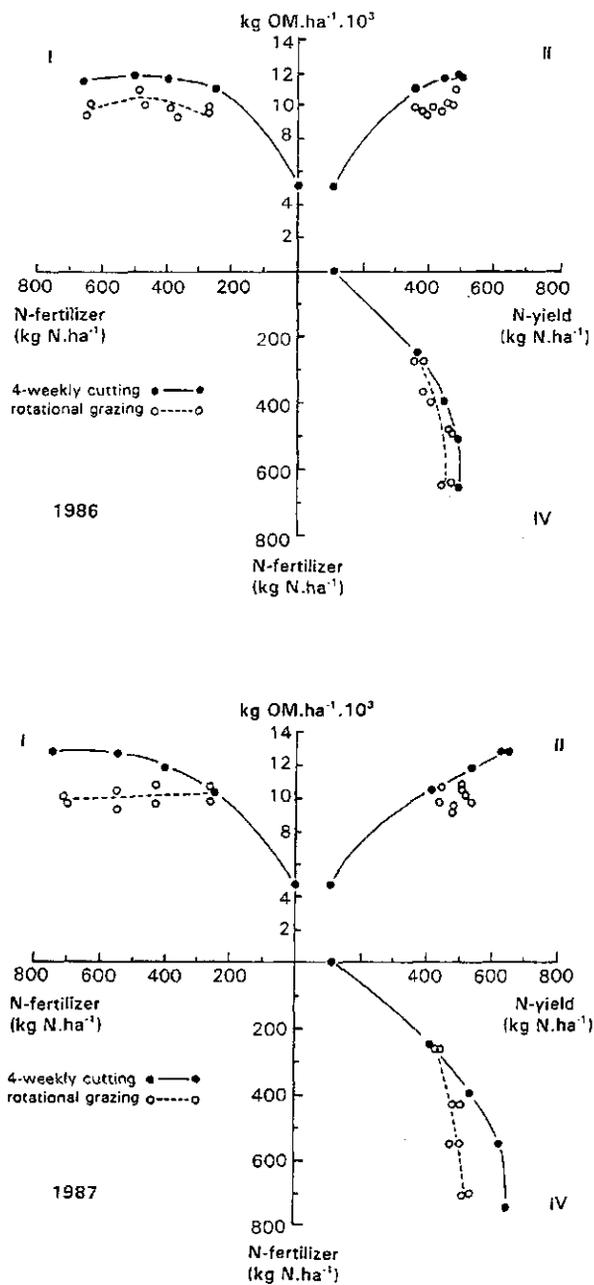


Fig. 7. Experiment 2. The effect of fertilizer N application on N yield and herbage yield expressed in Organic Matter (OM) under cutting and rotational grazing in 1986 and 1987. For cutting, data are averages over 4 replicates; for grazing, data per paddock are presented.

damage there was a negative response of herbage yield to fertilizer N in the first two harvests and this yield depression could not be compensated for in later cuts, certainly because the growing season 1986 was short. Herbage OM yields in the first cut (22 May) were 2536, 2379, 2140 and 2170 kg OM ha<sup>-1</sup> in the 250 N, 400 N, 550 N and 700 N sward, respectively. Greatest response of herbage yield to fertilizer N applied under 4-weekly cutting was found in 1988 (Fig. 8). Although N yield was lower than in 1987, the 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 g N per kg DM in 1988. This better apparent effect of N was due to an extremely early spring and favourable weather conditions in 1988.

*Experiment 2; grazing.* In 1986, herbage accumulation under grazing was not significantly affected by the level of N application (Fig. 7). Over the whole fertilizer range herbage accumulation under grazing ranged from 82 to 89% of that under 4-weekly cutting. In the grazed swards, first cut (21 May) yields responded positively to fertilizer N; OM yields were 1412, 1671, 1905 and 2309 kg OM ha<sup>-1</sup> in the 250 N, 400 N, 550 N and 700 N sward, respectively. However, the response diminished 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 under grazing. Herbage accumulation under grazing expressed as a percentage of the herbage accumulated under cutting decreased from 99% at 250 N to 77% at 700 N. This decrease in relative herbage yield can be ascribed to negative grazing effects like urine scorching and poaching (1987 was extremely wet).

#### *Whole-farm*

Total net herbage yield on a whole-farm scale was lower than herbage yield under cutting or grazing due to field losses of the silage cuts and grazing losses (Fig. 8). There was only a weak response of total net herbage yield to fertilizer N in all four years. In 1986, annual herbage yield on a whole-farm scale was about 70% of the annual yield under 4-weekly cutting, irrespective of level of N application. In 1987, relative yield declined

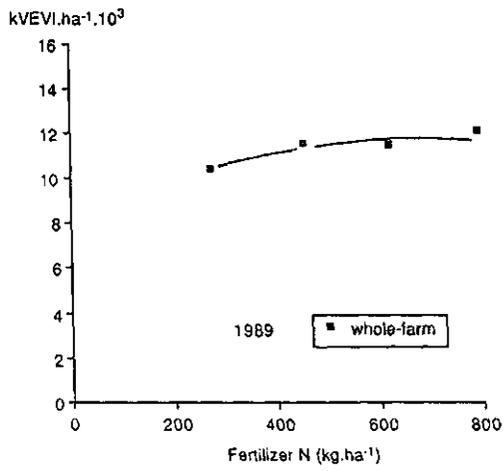
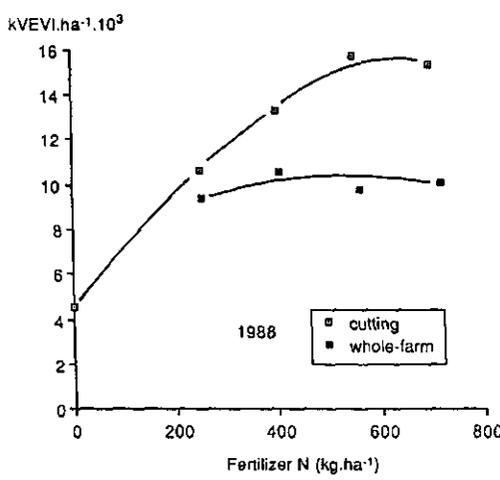
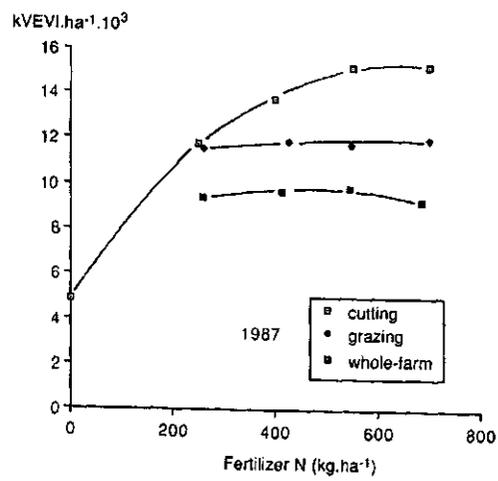
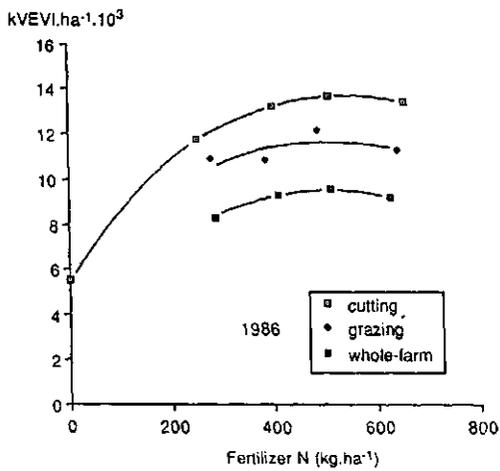


Fig. 8. Experiment 2. The effect of fertilizer N application on herbage yield on a whole-farm scale, under cutting and grazing.

from 94% at 250 N to 64% at 700 N. In 1988 relative yield on a whole-farm scale declined from 79% to 61%.

### *Optimum N application rate*

Recommendations of N application rates in the Netherlands are based on economic cost-benefit analyses of long-term cutting trials in small plots, which at current prices leads to a marginal profitability of 7-8 kg dry matter per kg N applied. Yield response curves of the cutting treatments of experiment 2 were fitted to each treatment-year combination (for grazing-only and whole-farm the number of replicates was insufficient). The form of the curve which was used to fit the data was an inverse polynomial (Sparrow, 1979):

$$Y = (a + bx)/(1 + cx + dx^2) \quad (4)$$

where:

Y = yield (VEVI or OM ha<sup>-1</sup>yr<sup>-1</sup>)

x = fertilizer N (kg N ha<sup>-1</sup>yr<sup>-1</sup>)

a, b, c and d are constants.

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

Under the 4-weekly cutting regime the  $N_{7.5}$  value was on average 430 kg N ha<sup>-1</sup>yr<sup>-1</sup>. Assuming one kVEVI is approximately equivalent to 1 kg DM this optimum rate is close to the optimum rate of 420 kg N ha<sup>-1</sup>yr<sup>-1</sup> found by Prins (1983). The  $Y_{7.5}$ -values varied from 13,100 kVEVI ha<sup>-1</sup> in 1986 to 14,800 kVEVI ha<sup>-1</sup> in 1988. On average over the three years  $Y_{7.5}$  was 13,900 and  $Y_{max}$  14,900 kVEVI ha<sup>-1</sup>. Under grazing and on a whole-farm basis the response of herbage yield to fertilizer N was much weaker or even absent and the yields were much lower compared to those under cutting (Fig. 8). It is estimated that the optimum fertilizer application rate under grazing and on a whole-farm basis will be some 200 kg ha<sup>-1</sup> lower than under cutting only.

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

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

<sup>1</sup> N retention: 30 g N per kg liveweight (Lantinga et al., 1987).

<sup>2</sup> N excretion in faeces: 0.8 g N per 100 g DM eaten (Barrow & Lambourne, 1962).

<sup>3</sup> Urine N excretion calculated as: N intake - (N retention in animal growth and milk) - dung N.

### *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 ingested N contained in animal products.

*Experiment 1.* Herbage N was poorly converted into animal products by the grazing dairy cows (Table 5). Some 16 to 20% of the ingested N was recovered in animal products. These findings agree with data from other experiments (Van Vuuren & Meijs, 1987;

Table 6. Experiment 2. The effect of fertilizer N application (kg N ha<sup>-1</sup>yr<sup>-1</sup>) on the N balance under rotational grazing of steers.

	1986				1987			
<b>A. INPUT</b>								
fertilizer	277	385	487	642	259	426	547	701
precipitation	40	40	40	40	40	40	40	40
total	317	425	527	682	299	466	587	741
<b>B. INTAKE</b>								
	354	382	436	403	425	487	472	506
<b>C. OUTPUT</b>								
animal growth <sup>1</sup>	24	27	28	23	29	26	26	20
<b>D. EXCRETION</b>								
dung <sup>2</sup>	81	81	85	77	88	90	83	83
urine <sup>3</sup>	249	274	323	303	309	371	363	403
total	330	355	408	380	397	461	446	486
<b>E. EFFICIENCY OF N USE</b>								
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

<sup>1</sup> N retention: 30 g N per kg liveweight (Lantinga et al., 1987).

<sup>2</sup> N excretion in faeces: 0.8 g N per 100 g DM eaten (Barrow & Lambourne, 1962).

<sup>3</sup> Urine N excretion calculated as: N intake - (N retention in animal growth and milk) - dung N.

Chapter 2). All these data are far from the theoretical maximum efficiency of 40-45% (Van Vuuren & Meijs, 1987). When total N input increased by about 300 kg N ha<sup>-1</sup>yr<sup>-1</sup>, output in animal products increased by only 6 and 42 kg N in 1987 and 1988, respectively. The N use efficiency of the 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 (166 and 236 kg N ha<sup>-1</sup>yr<sup>-1</sup> in 1987 and 1988, respectively).

*Experiment 2.* Table 6 presents the N balances of experiment 2. Since the marginal recovery of N decreased strongly, especially in 1986 and 1987 (Fig. 7; quadrant IV), there was not a large increase in the N intake by the grazing animals with an increasing

rate of fertilizer N. Consequently, there was no strong increase in the amount of N voided in the excrements. Efficiency of use of ingested N was below 10% for the beef cattle already at a fertilizer level of  $250 \text{ kg N ha}^{-1}\text{yr}^{-1}$ . The N use efficiency of the total input declined strongly with increasing N rates. As a consequence of the low recovery of fertilizer N in the herbage, a low retention of N in animal products and a low recovery of excretal N (Chapter 5) the potential amount of N susceptible to loss from the system through ammonia volatilization, denitrification and leaching increased substantially.

## Conclusions

Differences were found in the apparent N recovery and the response of grassland production to N applied between treatments (cutting versus grazing) and soil types (loam versus sand). Highest ANR values and herbage yields were found under cutting on the loam soil. Differences in ANR values could be related to length of the growing season, the amount of soil inorganic N in spring, recycling of excretal N and sward quality. Grazing on the sand soil enhanced sward deterioration due to treading, poaching and especially urine scorching at increasing N application rates.

On both locations, tiller density at the end of the experiment was highest in the cut swards. On the loam soil the grazed swards became more irregular at the highest N rate although neither tiller density nor sward productivity declined. On the sand soil sward deterioration occurred in all grazed swards; openness and patchiness increased generally with the rate of N application, whereas tiller density was on average not affected by the level of N application.

Under the 4-weekly cutting regime on the sand soil the optimum fertilizer N application rate was on average  $430 \text{ kg N ha}^{-1}\text{yr}^{-1}$ . Under grazing and on a whole-farm scale the response of herbage yield to fertilizer N was much weaker or even absent and the yields were much lower compared to cutting. It is estimated that the optimum fertilizer N application rate under grazing and on a whole-farm scale was some  $200 \text{ kg ha}^{-1}$  lower than under cutting only. No optimum fertilizer rate could be derived for the rotational grazing and cutting experiment on loam.

However, these application rates are optimal from an economical viewpoint only. From an environmental point of view the aim is to minimize losses of N from the

grassland system. Under the 4-weekly cutting management about 90% of the applied N was recovered in the herbage up to fertilizer rates of 400 kg N ha<sup>-1</sup>yr<sup>-1</sup>. In this case, the amount of fertilizer N remaining in or lost from the soil will be low. However, under grazing conditions (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) the N use efficiency of the ingested N at an annual fertilizer rate of 250 kg N ha<sup>-1</sup> was already below 10% for beef cattle and between 24 to 31% for dairy cows . This implies large amounts of excess dietary N concentrated in dung and urine patches liable to loss from the system. A net effect of excretal returns on N uptake was confined to the 250 N treatment in two out of three cases of which only one resulted in a higher herbage yield (experiment 1; loam soil).

Therefore, the optimum application rate should be based rather on the amount of residual inorganic N at the end of the growing season than on an economical cost-benefit analysis (Lantinga & Van der Putten, 1994).

## **CHAPTER 4**

# **SWARD CHARACTERISTICS AND SPRING GROWTH OF INTENSIVELY MANAGED PERENNIAL RYEGRASS SWARDS AFTER SEVERE WINTERS**

P.J.A.G. DEENEN<sup>1</sup>, J.H. NEUTEBOOM<sup>1</sup> & E.A. LANTINGA<sup>2</sup>

<sup>1</sup>Department of Agronomy, Wageningen Agricultural University, Wageningen,  
Netherlands

<sup>2</sup>Department of Theoretical Production Ecology, Wageningen Agricultural University,  
Wageningen, Netherlands

Submitted to: Netherlands Journal of Agricultural Science

## **SWARD CHARACTERISTICS AND SPRING GROWTH OF INTENSIVELY MANAGED PERENNIAL RYEGRASS SWARDS AFTER SEVERE WINTERS**

### **Abstract**

After the winters 1985/1986 and 1986/1987 several cases of severe damage to perennial ryegrass (*Lolium perenne* L.) swards were reported in the Netherlands. In ongoing field experiments divergent relationships were found between nitrogen (N) fertilization in the preceding year and first cut dry matter (DM) yields in early spring. In three out of ten studied cases a positive relationship was found. In two cases there was no relationship and in five cases a clear negative relationship. The rotationally grazed swards on sand had generally a more open sward; openness increased with the rate of N application. However, the differences in DM yield between the N treatments were only temporary. The observed higher death rates of tillers in two grazing experiments in early spring clearly indicated a higher vulnerability of high N swards for winter damage. However, since tiller death occurred, especially on sand, on patches where long grass had entered the winter, it is suggested that taking cleaning cuts before winter is a good measure to reduce the risk of winter damage. In cases of a negative relationship, reductions in first cut DM yields were smaller in frequently (weekly-cutting and continuous grazing) than in less frequently defoliated swards (4-weekly cutting and rotational grazing). This suggests that a more frequent defoliation regime, especially in autumn, is a measure to reduce the risk of winter damage. Water soluble carbohydrate (WSC) concentrations in crown tissue decreased during the winter but did not differ between N levels and thus showed no correlation with winter damage.

*Keywords:* *Lolium perenne* L., perennial ryegrass, nitrogen, carbohydrates, cutting, grazing, sward structure, tiller death, winter damage, spring growth

## Introduction

Perennial ryegrass (*Lolium perenne L*) has a relatively poor winter hardiness (Fuller, 1980), although considerable variation exists among cultivars (Fuller & Eagles, 1978; Humphreys & Eagles, 1988). Winter hardiness is defined as the ability of plants to survive the whole complex of severities of winter in the field, and therefore includes cold tolerance (the ability of plants to withstand low temperatures) as well as aspects which can not easily be distinguished from it, such as resistance to desiccation and diseases (e.g. snow mould). The degree of cold tolerance developed by the plant is dependent on many physiological and environmental factors. A negative relationship was observed between the level of nitrogen (N) fertilization and winter hardiness of perennial (Charles et al., 1975) and Italian (Hides, 1978a,b) ryegrasses. However, it may be questioned whether these results can be extrapolated to field conditions since the above mentioned experiments were conducted in controlled environment chambers or with spaced plants in micro swards. Grassland management can have direct effects on tiller density and tiller distribution and these effects possibly become more visible after a severe winter. However, the possible negative implications on the yield of open swards after winter should not be exaggerated because of the strong recovery potential of perennial ryegrass. A distinction has to be made between leaf damage through frost, from which plants can recover and the actual death of whole plants which can lead to an irretrievably open sward and permanent lower dry matter (DM) yields.

In the mid 1980's three consecutive severe winters in the Netherlands subjected perennial ryegrass swards to high levels of winter stress. This paper describes measurements of the effects of the last two of these winters (1985/1986 and 1986/1987) on spring growth and sward characteristics of perennial ryegrass in some ongoing grassland experiments during that time.

In the Netherlands, recent studies on winter survival are scarce. Tentative estimates of cover and botanical composition on a number of farms have been made by Keuning et al. (1988). However, no data are available illustrating effects of N input, grassland management on yield and botanical composition of grazed swards after severe winters. To our knowledge extensive studies on winter damage in grazed swards have not been reported in the literature.

## Literature

Low temperature is often the most important factor causing winter damage in perennial ryegrass swards. This is supported by good correlations between estimates of cold tolerance of perennial ryegrass under controlled conditions and field estimations of winter damage (Fuller & Eagles, 1978; Reheul, 1987; Humphreys & Eagles, 1988; Tcacenco et al., 1989). Cold tolerance refers to the capability of plants to avoid intracellular ice formation which can damage membrane systems within the plant cell (ice tolerance). Since the leaf blade is more susceptible to freezing and more exposed to extremes of temperature than the growing point (Fuller & Eagles, 1978), leaf damage (winter burn) is the most commonly observed symptom of frost damage, but this can even occur in mild winters without freezing (Charles et al., 1975; Hunt et al., 1976). Although biomass is reduced by winter burn, the number of growing points and the coherent spring growth potential is relatively unaffected (Hunt et al., 1976). This is different from winter kill which refers to the death of tillers and whole plants, leading to reduced herbage growth in the following year. Winter damage is a general term including both winter kill and winter burn as well as other forms of winter injury (e.g. diseases).

Generally, the ability of plants to survive winter and the degree of damage to plants is dependent upon the level of hardiness achieved by the plant. Cold hardiness develops most rapidly under conditions of shortening days and/or decreasing temperatures, which prevail during autumn in temperate regions. It appears that a temperature threshold, which varies among species and cultivars, exists above which hardening does not occur (Levitt, 1972; Fuller & Eagles, 1981). Eagles (1989) suggested a graded response instead of distinct threshold temperatures. Genotype differences in hardiness can also be related to morphological differences. Wood & Cohen (1984) found a significant negative correlation between the genetically determined subcrown internode length in laboratory-germinated perennial ryegrass seedlings and winter survival of the same cultivars in the field. In the Dutch list of recommended varieties for agricultural crops (Anonymous, 1992), vegetative stem elongation is mentioned as one of the factors contributing to winter damage. Excessive autumn growth or long lasting undisturbed growth of rejected herbage around dung patches may lead to vegetative internode elongation before winter and to the subsequent death of tillers through frost (Baker, 1956;

Jones, 1988).

Interactions between grassland management before winter and winter hardiness have been reported by several authors (Charles et al., 1975; Hunt et al., 1976; Hides, 1978a,b). Factors contributing to this effect are a low harvest frequency, high annual N application rates and/or late N applications in combination with late harvesting in the autumn. Thomson (1974) and Charles et al. (1975) observed that swards regularly mown through summer and autumn and entering winter in a short leafy stage were relatively unaffected in contrast to less frequently cut swards. Culleton & Lemaire (1985) found evidence that the frequency of grazing in autumn was more important than the actual date of final closure. Frequent grazing encourages tillering and reduces subcrown internode elongation and increases winterhardiness. These two factors have a positive effect on sward recovery in early spring.

The level of N applied and the hardiness achieved are highly negatively correlated (Årsvoll & Larsen, 1977; Hides, 1978b). Hunt et al. (1976) and Hides (1978a) suggested that prolonged autumn growth through N can interfere with cold acclimation. When cutting or grazing is practiced during the hardening period regrowth may result in the utilization of photosynthate for growth rather than carbohydrate storage, which is supposed to be important in winter survival and/or spring recovery (Levitt, 1972). According to Årsvoll & Larsen (1977) fertilizers other than N like potassium (K) and phosphorus (P) can increase cold tolerance by aiding the hardening process. Gusta & Fowler (1979) reported that P encouraged carbohydrate accumulation in the crown and suggested that P may actually rather increase spring recovery from freezing injury than promote cold hardiness.

The capacity of plants to withstand cold stress is sometimes related to their concentration of water soluble carbohydrates (WSC) (Alden & Herman, 1971). In herbage species the results are conflicting. Studies by Lawrence et al. (1973) and Pollock et al. (1988) in perennial ryegrass and Hides (1978b) in Italian ryegrass failed to show a consistent relationship between overall plant carbohydrate status prior to freezing and hardiness. The difficulty to establish significant correlations between WSC levels and cold hardiness is probably due to the complexity of carbohydrates both in their chemical configuration and their functions within the cell (Paquin, 1985). A further complication is the existence of interactions between cultivar, N and WSC concentration (Thomson,

1974).

Some winter damage can occur during mild winters which are predominantly dull and wet (Thomas & Norris, 1979). During periods of low irradiance and mild temperatures, respiratory losses are high and may outweigh assimilate production. Depletion of the winter store of carbohydrates can lead directly to tiller death (Thomas & Norris, 1979).

## Materials and Methods

Effects of N fertilization and grassland management on winter survival of perennial ryegrass and subsequent spring growth were studied in experiments originally designed to study the DM yield response to applied fertilizer N under grazing and cutting.

*Experiment 1:* The predominantly perennial ryegrass sward in this experiment was located on a well drained young sedimentary calcareous silty loam soil in Oostelijk Flevoland (0-5 cm layer: pH-KCl 7.1; 10.0% CaCO<sub>3</sub>). The soil was reclaimed from the sea only 30 years ago, and under grass for over 20 years. N was applied at an annual rate of 400 kg ha<sup>-1</sup> up to and including 1984. In a one-year experiment in 1985 the DM yield was determined under continuous grazing and weekly cutting (annual N application rates: 250, 400, 550 and 700 kg ha<sup>-1</sup>, the cutting experiment included a nil N treatment) and 4-weekly cutting (0, 290, 460, 630 and 800 kg ha<sup>-1</sup>), respectively. In spring 1986 all treatments were given the same N application of 125 kg ha<sup>-1</sup> for the first cut and 65 kg ha<sup>-1</sup> for the second cut. Herbage DM yields were determined at both cuts.

*Experiment 2:* In 1985, N response trials including continuous grazing and weekly cutting were started on a perennial ryegrass sward (a mixture of the cultivars Pelo, Splendor and Vigor) which had been seeded in 1981. The experiment was located on a sand soil in Achterberg, nearby Wageningen (0-5 cm layer: pH-KCl 5.0; particle fraction < 0.050 mm = 17.2%). Annual application rates of fertilizer N were 250, 400, 550 and 700 kg ha<sup>-1</sup>. The cutting experiment included a nil N treatment. In spring 1986, fertilizer treatments were continued but continuous grazing was changed into rotational grazing and weekly cutting into 4-weekly cutting. In 1986 spring growth (first spring harvest) was measured at different rates of fertilizer N and related to the pre-treatments continuous

grazing and weekly cutting. In 1987, treatments and N application rates were continued.

*Experiments 3 and 4.* At the same location as experiment 1, perennial ryegrass (cv. Wendy) was reseeded in 1985 in an adjacent sward. In 1986, N response trials were started for the management treatments continuous grazing, weekly cutting and 4-weekly cutting. Annual application rates of fertilizer N were 250, 400, 550 and 700 kg ha<sup>-1</sup>. The cutting experiments included a nil N treatment. Weekly cutting in this experiment was only executed in 1986. In 1987 all plots received the same N fertilization rate of 80 kg ha<sup>-1</sup> for the first cut and 80 kg ha<sup>-1</sup> for the second cut. The first and the second cut were harvested at a stage of approximately 2000 kg DM ha<sup>-1</sup>. The results are presented as experiment 3. In 1987, the treatments 4-weekly cutting and continuous grazing were continued. The first cut at 4-weekly cutting was harvested at a stage of about 2000 kg DM ha<sup>-1</sup> (i.e. harvests were taken at different dates). In the continuously grazed swards herbage mass in spring was measured just before grazing started. The results of both treatments are presented as experiment 4.

*Fertilization.* In all experiments fertilizer N was applied as commercially prilled calcium ammonium nitrate (CAN; 27% N). Other nutrients were applied, if necessary, according to soil analysis (Anonymous, 1987).

*Measurements.* Plots were harvested with a 0.88 m wide reciprocating cutter leaving a stubble of about 5 cm height. Fresh herbage from each plot was weighed and sampled for analysis of ash and N concentration according to the method of Novozamsky et al. (1983). For the cutting only plots, on all occasions the experimental design was a split-plot with four replicates. For grazing, herbage DM yield was measured by cutting eight strips per paddock. In 1986, in experiment 1 on some occasions percentage cover was determined by means of vertical point quadrats. Percentage cover is defined 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 (Grant, 1981). During the winter of 1986/1987 tiller density was determined in the grazed swards of the 250 N and the 700 N treatments in experiments 2 and 4. Tiller density was determined by taking one hundred 0.25 dm<sup>2</sup> cores (De Vries, 1940) in each paddock at approximately monthly intervals.

Concomitant samples were taken to determine concentrations of water soluble carbohydrates (WSC) in the crown and leaf fraction of the tillers. Absence frequencies of rooted perennial ryegrass tiller bases from concentric sampling quadrats were recorded according to the method of Neuteboom et al. (1992). Absence frequencies were recorded in 1986 in April, May and June (experiments 1 and 2); in 1987 in April and in 1988 in April, July and October (experiments 2 and 4). Absence frequencies were recorded in concentric rings of the following diameters: 0.125 cm (point quadrat), 1.4 cm, 2.8 cm, 5.6 cm and 11.2 cm.

*Weather data.* Weather data were available from the meteorological stations near Wageningen and Swifterbant. Since differences in temperature between the two locations were small, only temperatures recorded at the meteorological station at Wageningen are presented. Fig. 1 presents 10 days' means of the daily minimum air temperature at screen height and the daily minimum grass temperature (10 cm above ground level) during the winters 1985/1986 and 1986/1987, as well as the 30-year mean of the daily minimum air temperature at screen height (1.50 m). Generally, for winter survival, the minimum air temperatures measured at 10 cm above ground level are considered to be the most relevant, although according to Reheul (1987) temperatures measured at the surface of the leaf may be lower, especially during the night.

## **Results**

In experiments 1 and 3 neither management nor fertilizer treatments were continued after winter. In spring fertilizer N was applied at one uniform rate. The data of these experiments are presented in Figs. 2a and 2b. Those of experiments 2 and 4 in which treatments were continued after winter, are summarized in Figs. 2c and 2d and Table 1.

Divergent relationships were found between the level of N fertilization in the preceding year and spring herbage growth. In five cases there was a significant negative relationship above 250 N ( $P < 0.05$ ): treatments weekly and 4-weekly cutting on loam in 1985 (Fig. 2a; experiment 1), weekly cutting on loam in 1986 (Fig. 2b; experiment 3), weekly cutting on sand in 1985 (Fig. 2c; experiment 2) and continuous grazing on loam in 1986 (Fig. 2d; experiment 4).

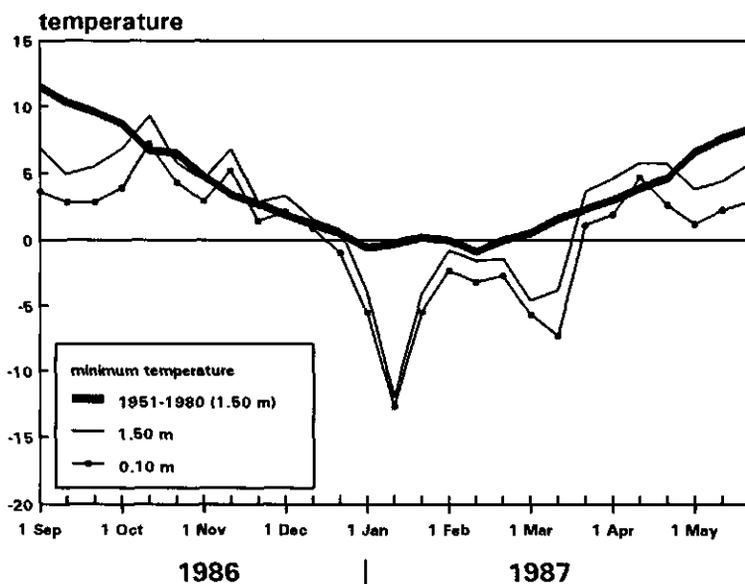
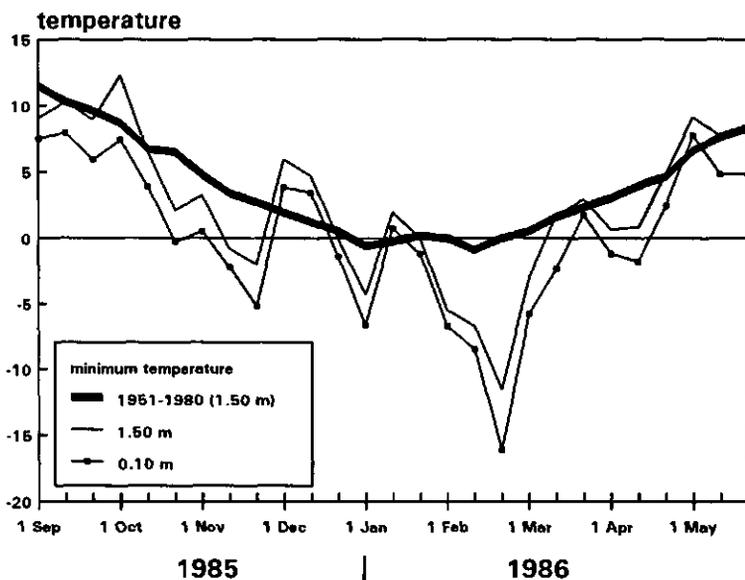


Fig. 1. Minimum temperature ( $^{\circ}\text{C}$ ) at screen height (1.50 m) and minimum grass temperature (0.10 m) for: (a) the winter 1985-1986 and (b) the winter 1986-1987 at the Meteorological Station Wageningen, and 30-year mean minimum temperature at screen height (Meteorological Station De Bilt). Average values over 10 days.

Table 1. Experiment 4. The effect of fertilizer N application on the date and the herbage DM yield of the first harvest, cut at a DM yield stage of approximately 2000 kg ha<sup>-1</sup>.

	N-treatments 1986 (kg ha <sup>-1</sup> yr <sup>-1</sup> )				
	0	250	400	550	700
kg N ha <sup>-1</sup> (spring 1987)	0	50	80	110	140
harvest date (1987)	6 June	22 May	19 May	15 May	15 May
kg DM ha <sup>-1</sup>	1720	2010	2021	1700	1944

In two cases no significant relationship was found above 250 N: continuous grazing on loam in 1985 (Fig. 2a; experiment 1) and rotational grazing on sand in 1986 (Fig. 2d; experiment 2). In three cases spring growth was positively correlated with N ( $P < 0.05$ ): in spring 1986 in the former continuously grazed swards on sand (Fig. 2c; experiment 2), under 4-weekly cutting on sand in 1986 up to about 550 N (Fig. 2d; experiment 2), and in spring 1987 in the 4-weekly cut swards on loam (Table 1). In the latter experiment the positive DM response to N follows from the differences in the harvesting date of the first cut at a stage of approximately 2000 kg DM ha<sup>-1</sup>: 15 May (550 and 700 N), 19 May (400 N), 22 May (250 N), and 6 June (0 N). Since in the last three experiments N treatments had been continued after winter, these positive relationships might be explained from an earlier sward recovery at high N due to enhanced tillering and leaf expansion. On the other hand, as is demonstrated by the curves of the weekly cut swards in Fig. 2c and those of the continuously grazed swards in Fig. 2d, even in cases where N treatments are continued, negative after-effects of N on first cut yields were found. A lower productivity of high N swards after a severe winter can be temporary, as is illustrated in Fig. 3. Plotted are the second cut yields against the first cut yields of the weekly and 4-weekly cut swards of experiment 1. After lower first cut yields higher second cut yields were found, resulting in a small positive effect (weekly cut swards) or a small negative effect (4-weekly cut swards) of N on the sum of the first and second cut yields (upper curves in Fig. 2a). A negative correlation between first and second cut yields is often found in grassland experiments (Alberda & Sibma, 1982; Reheul, 1987) and is generally explained from reduced tiller densities and reduced carbohydrate reserves remaining for regrowth after cutting. However, Davies et al. (1972) and Van Loo (1993) showed that

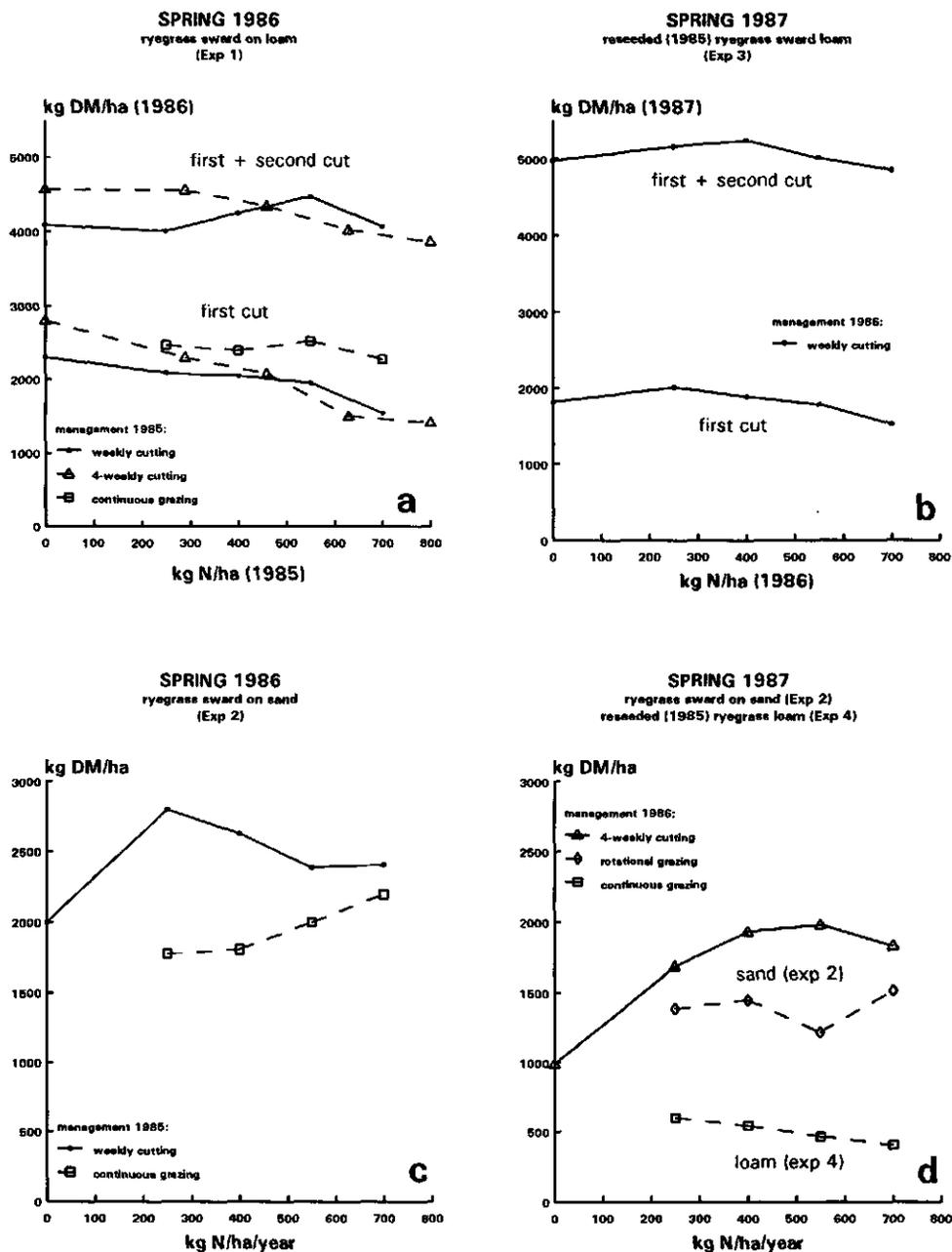


Fig. 2. The effect of nitrogen (N) fertilization and management in the preceding year on dry matter (DM) yields of the first and second harvest in spring 1986 and 1987 at one rate of N application in spring (a and b) and with continued N treatments in spring (c and d).

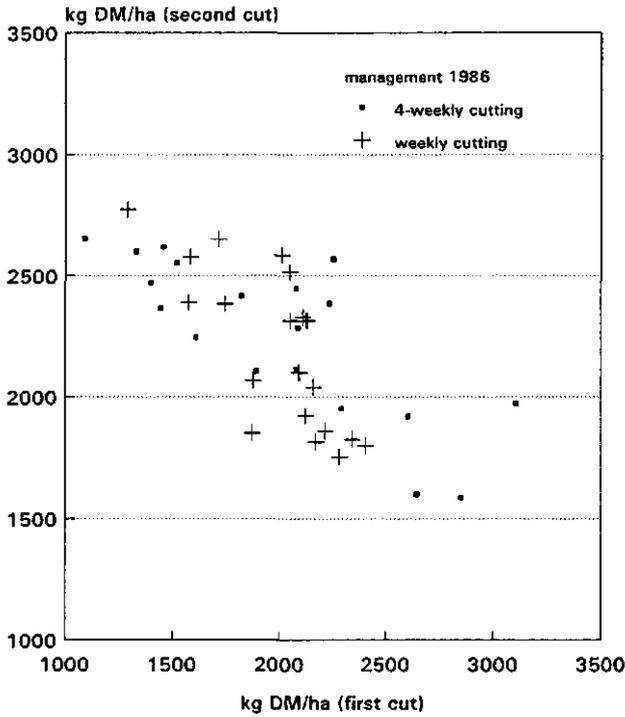


Fig. 3. Experiment 1. Correlation between DM yield of the first cut (14 May) and the second cut (10 June) in spring 1986 of plots cut at a weekly and 4-weekly interval in 1985.

regrowth is only affected at very low levels of WSC. In this experiment, regrowth was probably much more affected by low tiller densities than levels of substrate availability.

High N swards generally have larger tillers which often goes along with a more open sward, and after leaf losses during winter this might become more visible and lead to a lower regrowth rate in early spring. This might have been the case in the mown swards in experiment 1. In experiment 4 herbage mass was negatively correlated with N in early spring (Fig. 2d). However, cumulative herbage intake calculated from animal production was positively correlated with N at the end of May. The lower first cut yields in these treatments were probably due to more severe winter burn, but might also have been the result of a more open sward before winter. The yield recovery in experiments 1 and 4 suggests that there was no permanent greater winter damage in the high N treatments than in the low N swards.

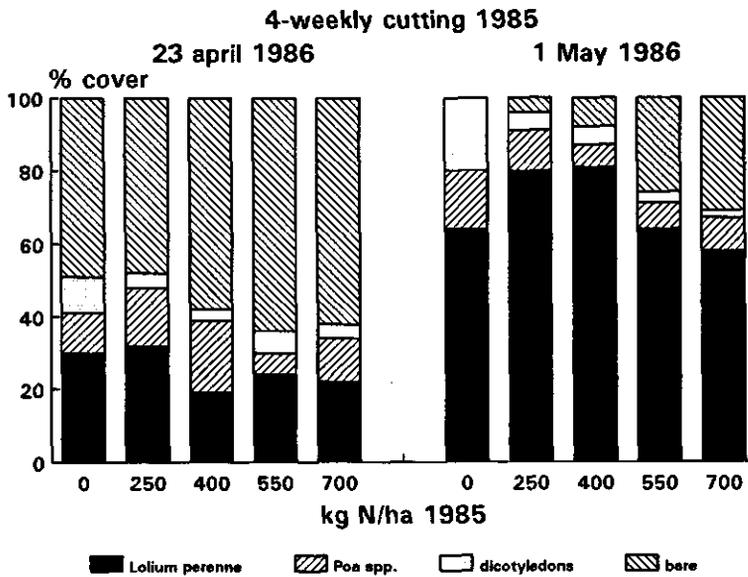
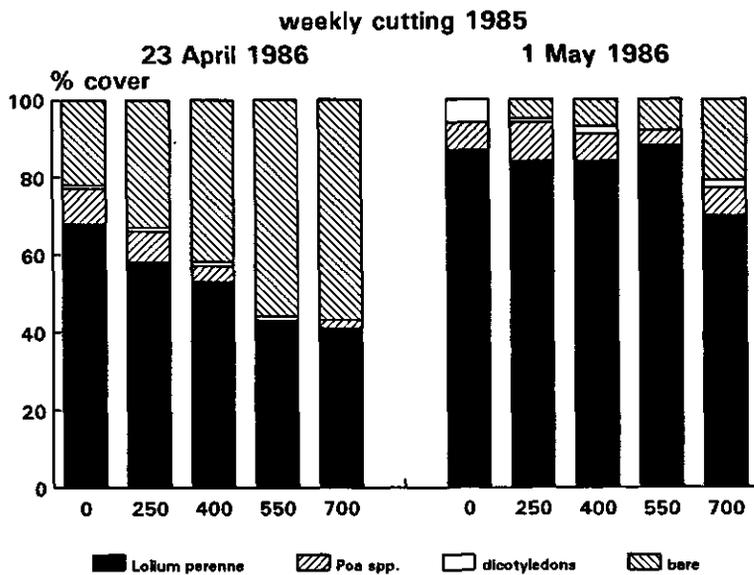


Fig. 4. Experiment 1. The effect of nitrogen (N) fertilization and management in the preceding year on percentage cover on 23 April and 1 May 1986.

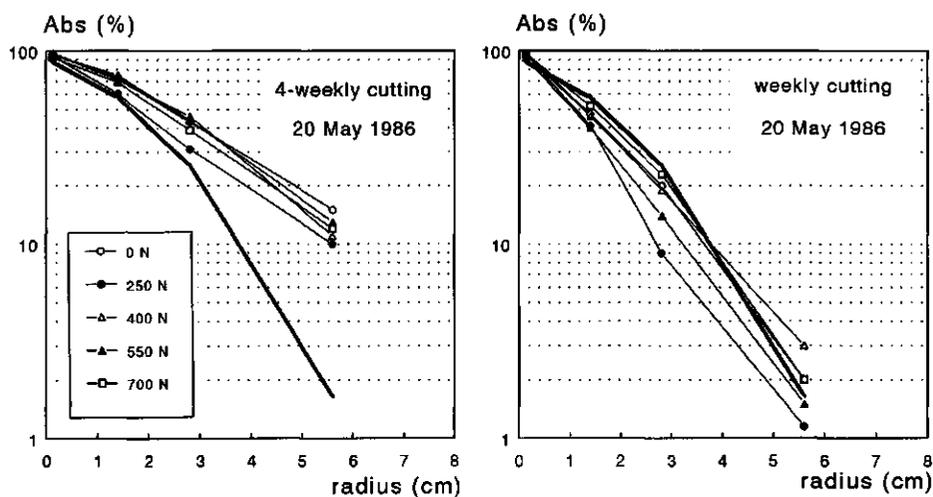


Fig. 5. Experiment 1. Absence frequency percentages (Abs%) of perennial ryegrass tillers from circular sampling quadrats of different radius sizes in weekly and 4-weekly cut swards on loam. The solid line is the theoretical curve for 3 plants per  $\text{dm}^2$  (random plant distribution) and a plant radius of 1 cm.

Fig. 4 illustrates for the weekly and 4-weekly cut swards of experiment 1 the very high percentages bare soil at the end of April, but also the clear tendency of recovery in early May after the severe winter of 1985/1986. The openness of the swards increased with the rate of N fertilization in the preceding year. The more open structure of the 4-weekly cut swards is also clearly reflected in the absence frequency curves of both cutting treatments in Fig. 5 (data collected on 20 May 1986). However, no clear effect of the rate of N fertilization in the preceding year could be observed. Ennik et al. (1980) also found that less frequent cutting can lead to a more open sward.

Fig. 6 shows the changes in tiller density during the winter of 1986/1987 in the rotationally grazed swards on sand in experiment 2 and in the continuously grazed swards on loam in experiment 4. Data were collected in treatments 250 N and 700 N. On loam, tiller density had declined already during December-January, whereas during the same period tiller density on sand had remained unchanged, probably as a result of a protective

winter 1986-1987

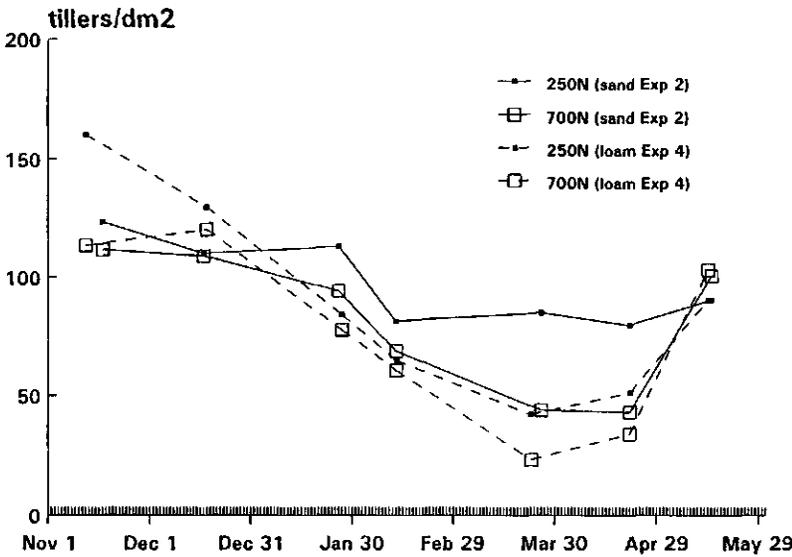


Fig. 6. Mean tiller density of perennial ryegrass for the winter 1986-1987 in rotationally grazed swards on sand (experiment 2) and continuously grazed swards on loam (experiment 4) at two rates of N application (250 and 700 kg N ha<sup>-1</sup>yr<sup>-1</sup>).

snow layer on the sand soil during the greater part of the first frost period. On loam the lower DM yield of the 700 N sward with respect to the 250 N sward (Fig. 2d) correlated with a lower tiller density (23 and 31 tillers on 23 March and 21 April respectively, compared with 42 and 51 tillers per dm<sup>2</sup> in the 250 N sward). However, both treatments had recovered their tiller density by the middle of May up to a level of 90 to 100 tillers per dm<sup>2</sup>, which may be considered as good. A similar but much larger difference in tiller density was found between the 250 N and 700 N treatments in the rotational grazing experiment on sand on 23 March and 21 April (Fig. 6). Also in this experiment tiller density had recovered to a level of 90 to 100 tillers per dm<sup>2</sup> on 15 May. However, Fig. 7 shows that there were differences in the tiller number distribution in the 0.25 dm<sup>2</sup> sampling cores on sand on 5 May. The high N swards had higher frequencies of sampling cores with nil tillers than the low N swards. On sand there was a difference already in November, but the difference increased from February onwards very strongly. On loam a higher frequency of nil tillers was found from March onwards in the high N sward.

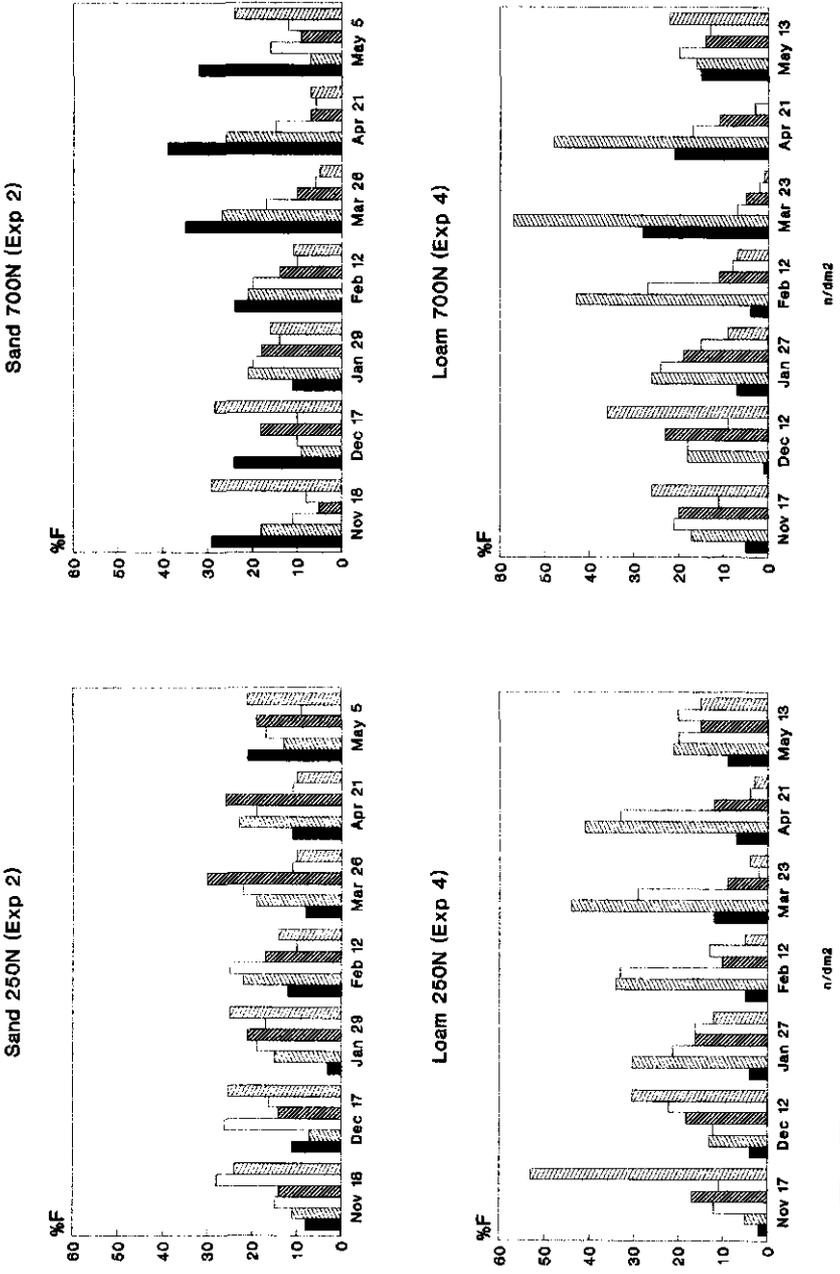


Fig. 7. Frequency distribution of the number of tillers in cores 0.25 dm<sup>2</sup> for the winter 1986/1987 in rotationally grazed swards on sand (experiment 2) and continuously grazed swards on loam (experiment 4) at two rates of N application (250 and 700 kg N ha<sup>-1</sup> yr<sup>-1</sup>).

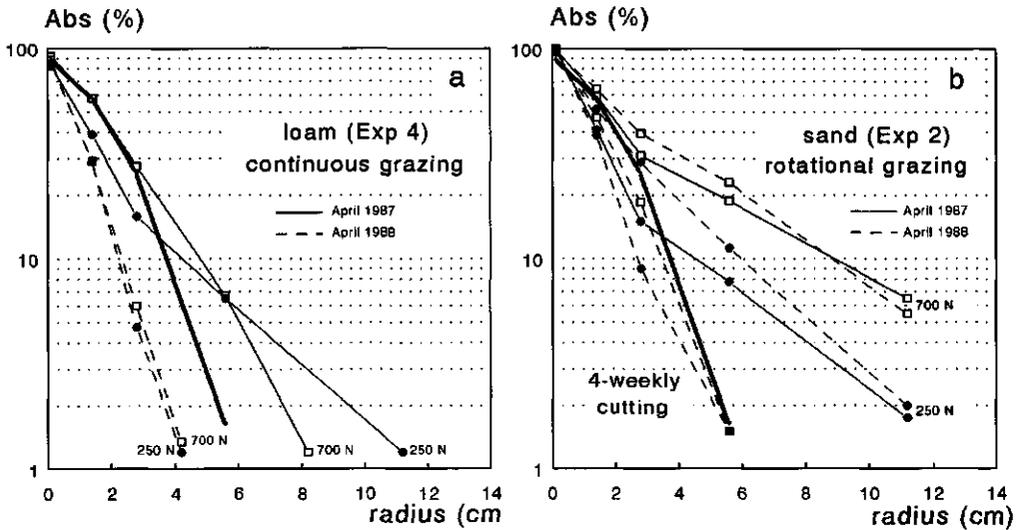


Fig. 8. Absence frequency percentages (Abs%) of perennial ryegrass tillers from circular sampling quadrats of different radius sizes in (a) continuously grazed swards on loam (experiment 4) and (b) rotationally grazed and 4 weekly cut swards on sand (experiment 2) at two rates of N application (250 and 700  $\text{kg N ha}^{-1}\text{yr}^{-1}$ ). The solid line is the theoretical curve for 3 plants per  $\text{dm}^2$  (random plant distribution) and a plant radius of 1 cm.

Fig. 8 presents absence frequency curves of rooted perennial ryegrass tillers in the 250 N and 700 N swards of the continuous grazing experiment on loam (Fig. 8a; April 1987 and April 1988) and the rotationally grazing experiment on sand (Fig. 8b; April 1986 and April 1987). For comparison absence frequency curves are presented of the 4-weekly cut swards on sand in experiment 2 (April 1987) in Fig. 8b. Steep curves with only absence frequencies for small sampling quadrats indicate relatively dense swards. More flattened curves with higher absence frequencies from larger quadrats indicate more open swards with generally lower plant and tiller densities and larger open spaces. The solid line in Fig. 8 is the theoretical absence frequency curve for the density of 3 plants per  $\text{dm}^2$ , which according to Neuteboom et al. (1992) can be considered as the equilibrium density for homogeneous perennial ryegrass swards under mowing over a range of N applications from 200 to 400  $\text{kg ha}^{-1}\text{yr}^{-1}$ . The continuously grazed swards on

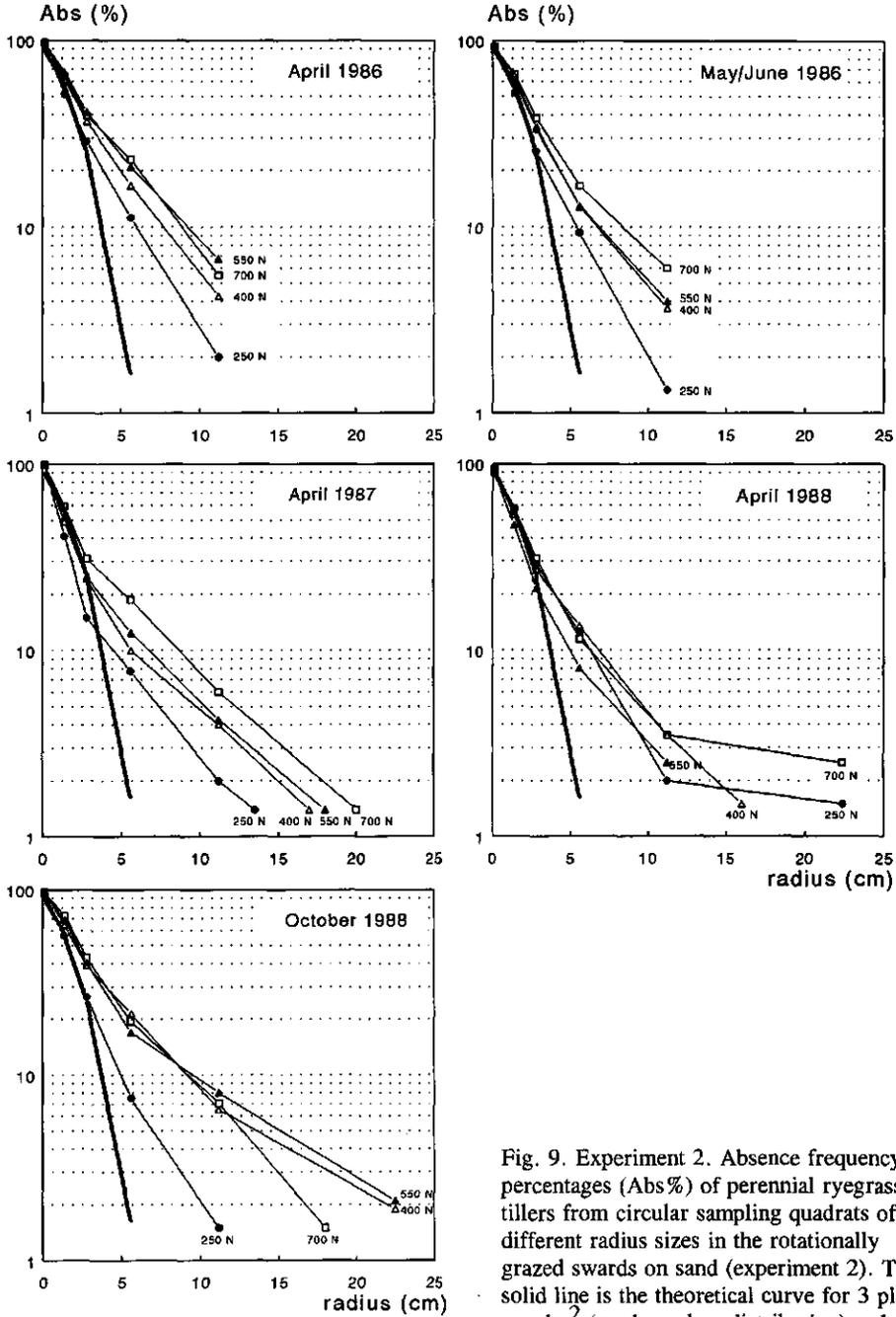


Fig. 9. Experiment 2. Absence frequency percentages (Abs%) of perennial ryegrass tillers from circular sampling quadrats of different radius sizes in the rotationally grazed swards on sand (experiment 2). The solid line is the theoretical curve for 3 plants per  $\text{dm}^2$  (random plant distribution) and a plant radius of 1 cm.

## WINTER 1986-1987

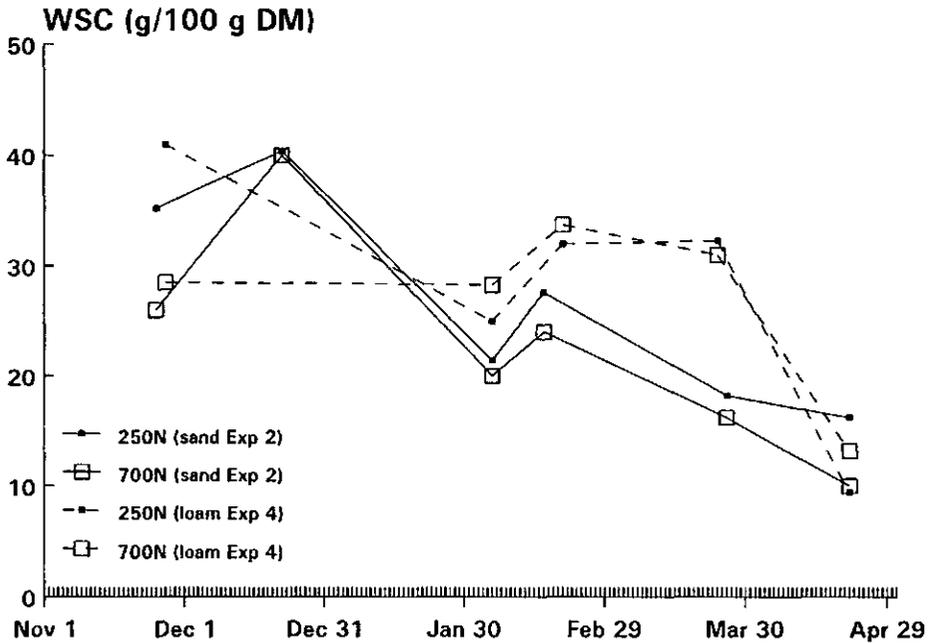


Fig. 10. The concentration of water soluble carbohydrates (WSC) in the crown tissue of perennial ryegrass for the winter 1986-1987 in rotationally grazed swards on sand (experiment 2) and continuously grazed swards on loam (experiment 4) at two rates of N application (250 and 700 kg N ha<sup>-1</sup>yr<sup>-1</sup>).

loam in spring 1988 after the mild winter of 1987/1988 (Fig. 8a) and all 4-weekly cut swards (Fig. 8b) had even steeper curves than the theoretical curve of 3 plants per dm<sup>2</sup>, suggesting that these swards were good and that a high N fertilization per se does not lead to a more open sward, not even after a severe winter. Different are the rotationally grazed swards on sand in spring 1987 (Fig. 8b). These swards were already more open in the autumn of 1986 (Fig. 7). This means that the severe winter of 1986/1987 had not caused any further deteriorating effect on the sward structure. The differences between the curves of the 250 N and 700 N swards in Fig. 8b were significant (chi-square;  $P < 0.01$ ). Fig. 9 illustrates for the rotationally grazed sward on sand (experiment 2) an almost systematic difference in openness of the swards; the openness was generally greatest in the high N swards.

No differences in the concentration of WSC in the crown tissue during winter and early spring were found between N treatments (Fig. 10). Concentrations of WSC

gradually decreased in experiment 2 on sand from December until March, probably due to respiration under the snow cover. WSC concentrations sharply decreased in April in experiment 4 on loam due to spring growth. WSC concentrations of leaf tissue were very variable and did not correlate with the level of N application.

## Discussion

Results from experiments of effects of N on winter damage on plants in controlled environment chambers or with spaced plants in micro swards as mentioned in literature are not consistently supported by the data presented in this paper. In the present experiments divergent relationships were found between N fertilization in the preceding year and first cut DM yields in early spring. In three out of ten studied cases a positive relationship was found. In two cases there was no relationship and in five cases a clear negative relationship. In experiments 1 and 3 where fertilizer N treatments were not continued after winter (i.e. all plots received the same N application in spring) a negative relationship was found between first cut DM yields in early spring and N fertilization in the preceding year. However, lower first cut DM yields may even be found in former high N swards after a relatively mild winter (Prins & Neeteson, 1982).

Although no differences were observed between levels of N application in absence frequency curves in experiment 1 (Fig. 5), there were significant differences in first cut DM yield (Fig. 2a). Probably the high swards contained many new, and thus small, tillers which had only a small contribution to DM yield. However, effects of cutting on sward structure were different from effects of grazing. Grazed swards can be more open at high N as is demonstrated by the absence frequency curves of the rotationally grazed swards on sand in experiment 2 (Fig. 8b). A clear indication that high N swards may suffer more from winter damage is found in the tiller density changes in Fig. 6. In both the rotationally grazed swards on sand (experiment 2) and the continuously grazed swards on loam (experiment 4) tiller numbers had decreased stronger in the high N swards than in the low N swards during the winter of 1986/1987. This gives a clear indication that tiller death and thus, in principle, also plant death during winter is positively correlated with the level of N application. However, there is a strong recovery of tiller numbers in April and May giving evidence that effects of winter damage were only temporary. In early

spring 1986, it was observed in experiment 2 that tiller death had occurred particularly around old dung patches with tall rejected grass. This agrees with observations of Thomson (1974) and Charles et al. (1975) that particularly long grass is vulnerable to frost damage. Field observations during the winter 1985/1986 (Neuteboom, unpublished) clearly showed that winter burn had started in the top of old leaves and thereupon had proceeded into the leaf sheath after which the growing point was damaged. Since many dying tillers had still enclosing young green leaves at their base the real effects of winter damage to the sward was not immediately visible. These kind of observations are interesting for two reasons. First, it might be worthwhile to reconsider the dominant role which is often assigned to carbohydrate reserves with regard to winter damage. The tiller death in experiments 2 and 4 (Fig. 6) could not be explained from reduced carbohydrate reserves (Fig. 10). Second, since tiller death occurred on patches where long grass had entered the winter, it is suggested that taking cleaning cuts before winter is a good measure to reduce the risk of winter damage, even in high N swards.

In experiments 2 and 4, in which N treatments had been continued, a negative or no relationship was found between fertilizer N and first cut DM yield. Moreover, lower first cut yields of high N swards after a severe winter may be largely compensated by higher second cut yields as was illustrated for the weekly and 4-weekly cut swards on loam in Fig. 3 (experiment 1) and also reported for grass swards after a severe winter by Reheul (1987). However, since N stimulates tillering, N application can lead to a recovery of the tiller density after some time. An open high N sward after winter and its effects on yield may therefore be temporary as was found in experiment 4 (continuous grazing on loam). In this experiment, in which N treatments were continued, cumulative herbage intake calculated from animal production was positively correlated with N at the end of May, whereas herbage mass was negatively correlated with N in early spring (Fig. 2d). Lemaire & Salette (1982) and Carton et al. (1988) also concluded that whether a negative or a positive yield response to N is found in the first cut after winter is dependent on the date of harvest of the first cut. In studying causes of winter damage, not only chemical composition and carbohydrate reserves but also morphological features should be included in the program of observations.

## **CHAPTER 5**

# **EFFECTS OF CATTLE DUNG AND URINE ON NITROGEN UPTAKE AND YIELD OF PERENNIAL RYEGRASS**

**P.J.A.G. DEENEN & N. MIDDELKOOP**

Department of Agronomy, Wageningen Agricultural University, Wageningen, Netherlands

published in: Netherlands Journal of Agricultural Science 40: 469-482 (1992)

## EFFECTS OF CATTLE DUNG AND URINE ON NITROGEN UPTAKE AND YIELD OF PERENNIAL RYEGRASS

### Abstract

Effects of artificially placed patches of cattle dung and artificial urine on nitrogen (N) uptake and herbage dry matter (DM) accumulation were studied in perennial ryegrass swards on a sand soil at fertilizer inputs of 250 and 400 kg N ha<sup>-1</sup>yr<sup>-1</sup> over a period of ten months after application in mid-summer. Positive effects were only observed in the 250 N sward and were confined to 15 cm from the edge of the dung and urine patches. Apparent N recovery (ANR) of dung was 8.3% in the 250 N sward and nil in the 400 N sward. The N effect of dung was 3 g DM per g dung N applied in the 250 N sward and nil in the 400 N sward. The effects lasted until the end of the experiment (i.e. 10 months after application). ANR of urine was about 16% in the 250 N sward and insignificant in the 400 N sward. In the 250 N sward the N effect of urine was low and lasted two months (on average 1.7 g DM per g urine N applied). In the 400 N sward the N effect was even negative due to scorching (on average -2.5 g DM per g urine N applied). The scorching effects were still evident at the end of the experiment.

*Keywords:* cattle dung, artificial urine, nitrogen response, nitrogen recovery, herbage accumulation, *Lolium perenne* L., perennial ryegrass

### Introduction

Most of the nutrients ingested by grazing cattle are returned to the pasture via dung and urine. Depending on animal type, animal production level and nitrogen (N) concentration of the herbage about 80 to 95% of the ingested N is excreted, and the major proportion (65 to 80%) is contained in the urine. However, as pointed out by Petersen et al. (1956), the application of excreta by the grazing animal results in a time-space distribution of nutrients over the pasture quite unlike that obtained by the uniform application of fertilizers. Each urine and dung patch contains nutrients collected from a large area but

deposited on a small area. It therefore contains a considerable concentration of nutrients. In intensively managed pastures the areas where urine is deposited contain biologically labile N in the order of  $500 \text{ kg N ha}^{-1}$ , whereas the areas of dung deposition receive inputs equivalent to about  $2000 \text{ kg N ha}^{-1}$  (Lantinga et al., 1987).

The area influenced by urine is often more than twice the area actually wetted directly following urination owing to diffusion of N in the soil and the lateral spread of the roots (Whitehead, 1986). With dairy cows it has been found that the area on which growth was influenced averaged  $0.68 \text{ m}^2$  per urine patch (Lantinga et al., 1987). The quantities of urine deposited on pastures and the composition of the urine are extremely variable. Individual urination from dairy cows may be from 1.5 to 3.5 l, volumes voided range from 14 to  $30 \text{ l day}^{-1}$  and total N concentration of urine may vary from about 6 to  $15 \text{ g N l}^{-1}$  (Holmes, 1989).

On average, the number of defaecations made by an adult cow in a day is about 11 to 12. A typical figure for the amount of dung voided daily by a milking cow is 4.0 kg dry matter (DM) or 28.6 kg faeces if the DM content is 14% (Marsh and Campling, 1970). In different studies the mean size of cattle dung patches varied from 0.02 to  $0.13 \text{ m}^2$  (MacLusky, 1960; MacDiarmid & Watkin, 1972; Bastiman & Van Dijk, 1975). In faeces approximately 0.8 g N per 100 g feed eaten is excreted, regardless of the N concentration of the feed (Barrow & Lambourne, 1962); hence the concentration in the faeces increases as digestibility increases. The influence is most evident in the first 15 cm from the edge of the patch (MacLusky, 1960; MacDiarmid & Watkin, 1971). Assuming a mean area of a dung patch of  $0.05 \text{ m}^2$ , this is equivalent to an affected area of  $0.25 \text{ m}^2$ .

Responses to urine can be attributed mostly to its N component and normally last for 2 to 3 months (Ledgard et al., 1982). Recycling of N via dung is generally much slower than via urine, though the speed of decomposition is very variable (Dickinson et al., 1981). Since the breakdown of dung is relatively slow the availability of the N is low (about 25% in the first year). Therefore, yield responses from dung are observed over a longer period than those from urine (Norman & Green, 1958), though they may be observable under favorable conditions after as little as 15 days (MacDiarmid & Watkin, 1971). The visible effect of dung N may last for up to 2 years (Richards & Wolton, 1976). Although, in total at a whole paddock scale there is only a small beneficial effect on herbage growth (Wolton, 1979). Responses to dung and urine are variable,

nonetheless, many studies have shown that the return of excreta to pastures can markedly stimulate local herbage growth and change botanical composition and can have a marked effect on element concentration.

However, experimental data on the effect of excretal N on herbage growth of pure grass swards receiving relatively high rates of fertilizer N (250-400 kg N ha<sup>-1</sup>yr<sup>-1</sup>), as prevail in the Netherlands, are scarce. Therefore, an experiment was conducted to study the effects of cattle dung and artificial urine on N uptake and herbage accumulation in swards receiving fertilizer N equivalent to 250 and 400 kg N ha<sup>-1</sup>yr<sup>-1</sup>.

### Materials and methods

The experiment was conducted in a formerly cut sward of predominantly perennial ryegrass (*Lolium perenne* L.), on a sand soil (pH-KCl 4.6; organic matter content 6.5%) near Wageningen. The effect of applied dung and artificial urine on N uptake and local herbage growth was studied at two levels of fertilizer N application (250 and 400 kg N ha<sup>-1</sup>yr<sup>-1</sup>) during the second part of the growing season of 1987 and the following spring.

On 22 July, freshly-voided dung was collected indoors from two groups of steers fed fresh grass from swards receiving 250 and 400 kg N ha<sup>-1</sup>yr<sup>-1</sup> respectively. The collected dung per group was thoroughly mixed and used the same day to produce discrete patches (0.07 m<sup>2</sup>) on the sward cut the day before. Contents of DM, N, phosphorus (P) and potassium (K) of the offered herbage and the collected dung are

Table 1. Effect of fertilizer N on DM content and chemical composition of herbage on offer and dung collected from steers. Fertilizer application 250 (250 N) or 400 (400 N) kg N ha<sup>-1</sup>yr<sup>-1</sup>.

	Herbage		Dung	
	250 N	400 N	250 N	400 N
DM (%)	16.0	13.6	13.5	12.0
N (g/100 g DM)	2.4	2.7	3.0	3.4
K (g/100 g DM)	4.1	4.3	2.2	1.8
P (g/100 g DM)	0.4	0.5	1.4	1.2

Table 2. Chemical composition of artificial urine (prepared according to Doak, 1952).

Constituents	Constituent concentrations (g l <sup>-1</sup> )	Total N (g/100 g)
urea	24.0	89.1
hippuric acid	10.0	6.2
creatinine	0.2	0.6
allantoin	0.5	1.4
urine acid	0.1	0.2
ammonium chloride	1.2	2.5
potassium chloride	19.2	-
potassium bicarbonate	14.3	-

presented in Table 1. Each patch comprised 2.5 kg fresh dung which was poured into a 5 cm deep x 30 cm diameter polythene collar positioned in the center of the allotted plot. After application the collar was removed. Per dung patch about 10.2 g N was applied, which is equivalent to 145 g N m<sup>-2</sup> for both treatments.

Nutrient concentrations in urine vary considerably (Lantinga et al., 1987). Therefore artificial urine with a N concentration of 12.8 g l<sup>-1</sup> was prepared (Table 2) according to Doak (1952). By means of dilution three concentrations were obtained (6.4, 9.6 and 12.8 g N l<sup>-1</sup>), and as a consequence all other components were diluted. Urine (2 l) was sprayed onto areas of radius 30 cm (0.28 m<sup>2</sup>). Urine applications corresponded with 46, 69 and 91 g N m<sup>-2</sup>.

For sampling purposes, rings were centered round the patches, 15 cm in radius (R1), 15-30 cm (R2), 30-45 cm (R3), 45-60 cm (R4) and 60-75 cm (R5); the herbage from each concentric 15 cm ring was harvested separately. For the urine treatments the

Table 3. Scheme of fertilizer N application (kg N ha<sup>-1</sup>) for fertilizer treatments 250 (250 N) and 400 (400 N) kg N ha<sup>-1</sup>yr<sup>-1</sup>.

Fertilizer treatments	Harvests 1987						Harvest 1988
	1	2	3	4	5	6	
250 N	50	50	50	40	40	20	50
400 N	50	110	80	60	60	40	80

concentric sampling rings R1 and R2 were combined, since on this area the urine was applied. Herbage mass above a stubble height of 4 cm was determined by cutting with sheep shears at monthly intervals from August 1987 until October 1987 and again in May 1988. Herbage harvested was oven-dried, weighed and analyzed for ash and total N.

The experimental layout was a split-plot design with two N treatments replicated six times, the sub-treatments included two controls, dung and urine with three N concentrations. The fertilizer treatments were started in spring 1987 after the first cut on a sward which had received  $250 \text{ kg N ha}^{-1}\text{yr}^{-1}$  in the preceding years. The fertilization schedule is shown in Table 3. Dung and urine treatments were introduced after the third cut in July. In the analysis of variance the main plot analysis was that of randomized blocks with two N treatments replicated six times. The sub-plot analysis was performed separately for each ring and separately for the dung and urine treatments since the area on which urine and dung were applied differed in size.

## Results

### *Control plots*

In August 1987, DM yields in the control plots were 221 and 203 g DM m<sup>-2</sup> in the 250 N and 400 N sward respectively (Fig. 1). This negative DM response to fertilizer N applied was due to the pre-treatment of the experimental area. Fertilizer N treatments were introduced in spring 1987 after the first cut. In both swards herbage was cut at fixed dates at approximately monthly intervals. In the 400 N sward the higher DM yields of the pre-experimental harvests affected DM yield in August negatively. In September 1987 and May 1988, the N effect on DM accumulation in the control plots was positive and resulted in significant ( $P < 0.05$ ) differences between the N treatments. In September 1987, DM yields in the control plots were 205 and 229 g DM m<sup>-2</sup> in the 250 N and 400 N sward respectively. In October DM yields were about 60 g m<sup>-2</sup> in both treatments (Fig. 1). In May 1988, DM yields in the control plots were 188 and 206 g DM m<sup>-2</sup> in the 250 N and 400 N sward respectively.

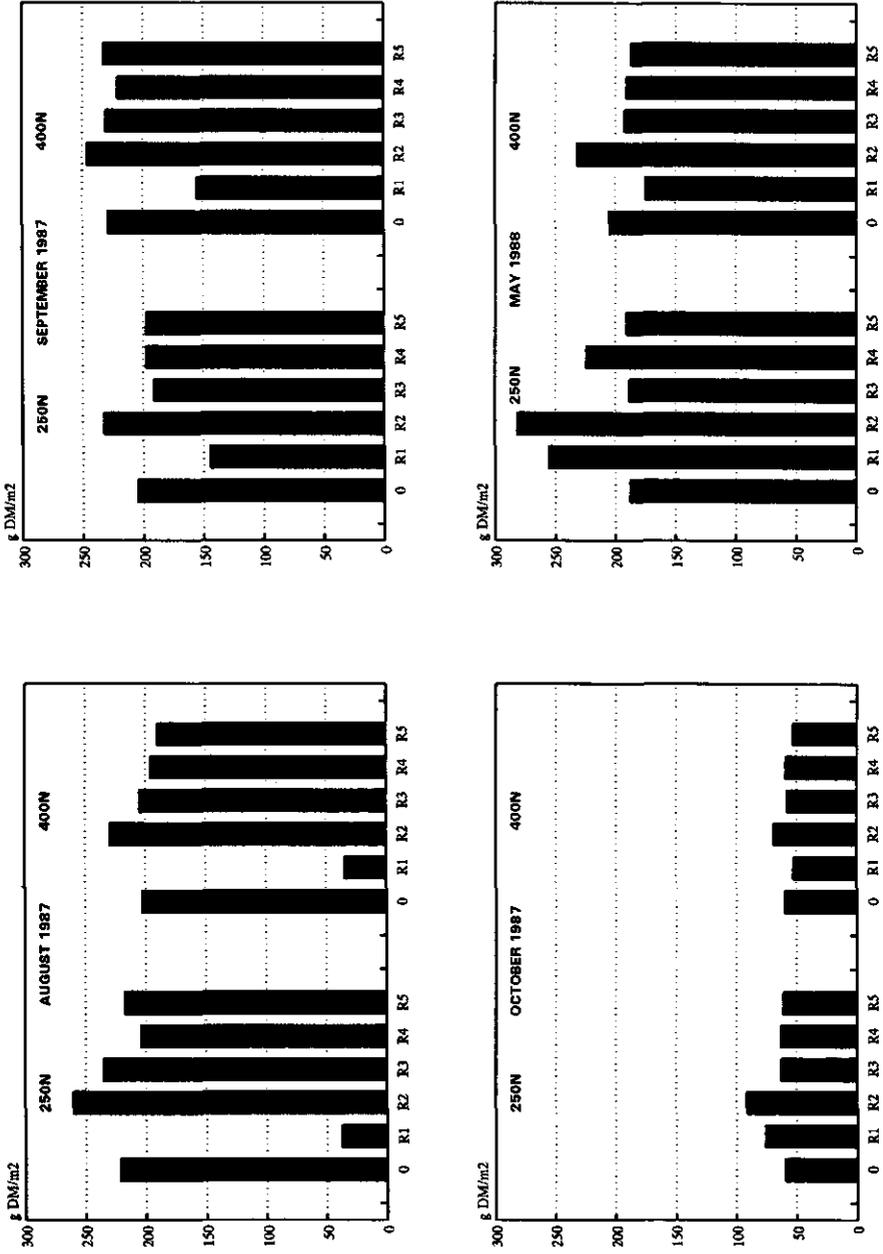


Fig. 1. Dry matter yield ( $\text{g DM m}^{-2}$ ) of the control plots (0) and effect of dung on dry matter yield in each of the five concentric sampling rings: R1, R2, R3, R4 and R5. Nitrogen fertilization 250 (250 N) and 400 (400 N)  $\text{kg N ha}^{-1}\text{yr}^{-1}$ .

## Dung

The dung-affected area was confined to 15 cm from the edge of the dung patch and equivalent to  $0.28 \text{ m}^2$  (R1+R2)(Fig. 1). The effect of dung on herbage DM accumulation lasted for up to the end of the experiment (i.e. ten months). Up to and including the second harvest in September (two months after application) DM accumulation was significantly ( $P < 0.01$ ) depressed at the place of dung deposition (R1) in both swards. However, distinct differences occurred between the two N treatments since then. These differences were clearly reflected in significant ( $P < 0.05$ ) treatment x N interactions in October and May. Until September, DM accumulation in R1 was mainly reduced by the presence of the dung patch. In this experiment the dung patches took 60 to 90 days to disappear completely. Thereafter, sward quality (i.e. tiller density and cover of perennial

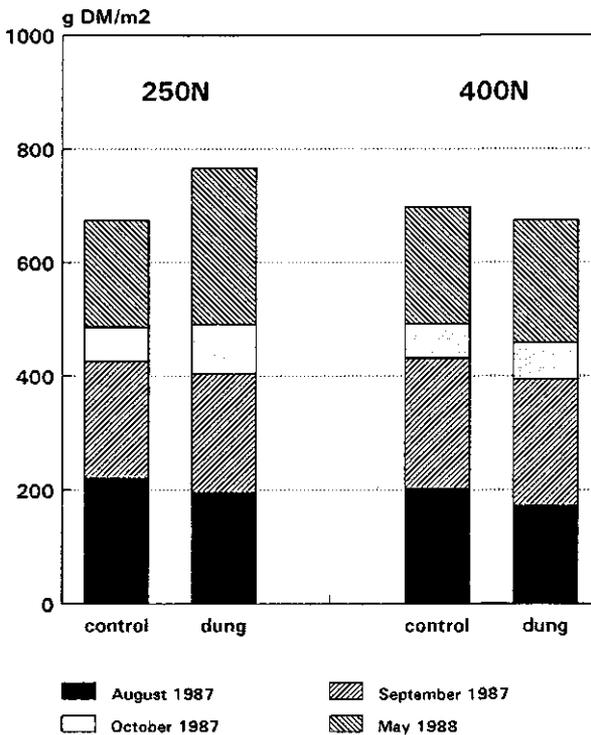


Fig. 2. Total herbage accumulation ( $\text{g DM m}^{-2}$ ) on dung affected area (R1+R2;  $0.28 \text{ m}^2$ ) and contribution of each consecutive harvest in control and fertilized plots. Nitrogen fertilization 250 (250 N) and 400 (400 N)  $\text{kg N ha}^{-1} \text{ yr}^{-1}$ .

ryegrass) became an important factor affecting herbage DM accumulation in R1. In the 250 N sward, herbage growth at the place of dung deposition (R1) was stimulated and outyielded the control in October and May, in contrast to the 400 N sward where herbage growth was depressed until the end of the experiment. In the 400 N sward, lower herbage growth could be associated with stronger damage inflicted upon plants under the dung patches (R1) as well as plants immediately adjacent to the patch (R2). The observed damage showed resemblance with urine scorch. In both swards herbage DM accumulation around the dung patch (R2) was higher than in the controls. Response to dung was greatest in the 250 N treatment in May ( $P < 0.001$ ) (Fig. 1). DM yield was even greater than in the 400 N control due to a larger amount of available inorganic N (fertilizer N and mineralized organic dung N). In May colonization by *Lolium perenne* and *Poa annua* of the sward under the former dung patches was almost complete.

At the end of the experiment, total herbage accumulation on the dung-affected area was 14% higher in the 250 N sward in comparison with the control plot (Fig. 2). This higher yield was mainly accomplished in the final harvest in May. Until October, cumulative yields of the dung-affected area and the control were similar; yield depression in R1 was just compensated for by the stimulated growth in R2. In the 400 N sward, dung had no significant effect on herbage DM accumulation.

The efficiency of use of N from dung or urine is expressed in two ways: (i) as the apparent recovery of N (ANR) which is the difference in N uptake between the treated and untreated plots expressed as a percentage of the N applied in dung or urine, and (ii) as the apparent N effect (ANE) which is the increase of harvested DM per g N applied in

Table 4. Herbage N uptake ( $\text{g N m}^{-2}$ ) in the control plots and the dung-affected area (R1 + R2;  $0.28 \text{ m}^2$ ) and apparent recovery of dung N (ANR). Swards receiving 250 (250 N) or 400 (400 N)  $\text{kg N ha}^{-1}\text{yr}^{-1}$ .

	250 N			400 N		
	control	dung	ANR (%)	control	dung	ANR (%)
August	7.1	7.1	0.0	7.3	7.3	0.0
September	7.0	6.8	-0.5	8.9	9.0	0.2
October	1.9	2.8	2.4	2.0	2.2	0.7
May	5.9	8.3	6.4	6.9	6.6	-0.9
Total	21.9	25.0	8.3	25.1	25.1	0.0

dung or urine. The ANR of dung N was low (Table 4). In the 250 N sward ANR was nil or insignificant in the first two harvests, 2.4% in the third harvest in October and 6.4% in the final harvest in May. Overall ANR at the end of the experiment was 8.3%. In the 400 N sward ANR was insignificant. As a consequence, the overall ANE of dung over the first ten months after application was low (viz. 3 g DM per g dung N applied in the 250 N sward and nil in the 400 N sward).

### *Urine*

In July 1987, the average temperature was approximately 20 °C and the soil was permanently moist due to regular rainfall. These conditions were optimal for plant growth but unfortunately also for urine scorch to occur (Schechtner et al., 1980). Already some days after urine application considerable scorching damage could be observed. Although the degree of scorching varied strongly, scorching was most severe in the 400 N sward and increased with increasing urine N concentrations. In none of the scorched areas perennial ryegrass had disappeared completely. However, tiller density was low and the remaining tillers were irregularly distributed. The open patches were rapidly filled in, mainly by *Poa annua*.

The area affected by urine was confined to 15 cm from the edge of the urine patch: totally 0.64 m<sup>2</sup> (R1, R2 and R3). For the consecutive harvests herbage DM accumulation in the urine-treated area (R1 and R2; 0.28 m<sup>2</sup>) and the surrounding concentric sampling rings (R3, R4 and R5) is presented in Fig. 3. The extent to which urine affected herbage growth was dependent on the level of fertilizer N input and the N concentration in the applied urine. In the first harvest (August) DM accumulation in the urine-treated area was significantly depressed in all treatments. Despite a deteriorated botanical composition in the 400 N sward, herbage DM accumulation recovered during the second regrowth period, probably due to a positive urine N effect (Fig. 3). In the second harvest (September), N uptake increased with increasing urine N concentrations (Table 5). The effect was greatest until two months after application. As a consequence, a significant stimulation of herbage growth due to a positive urine N effect lasted for two months only. In the 400 N sward the effects of urine on N uptake were less evident. In the first harvest, N uptake tended to decrease with increasing urine N concentration due

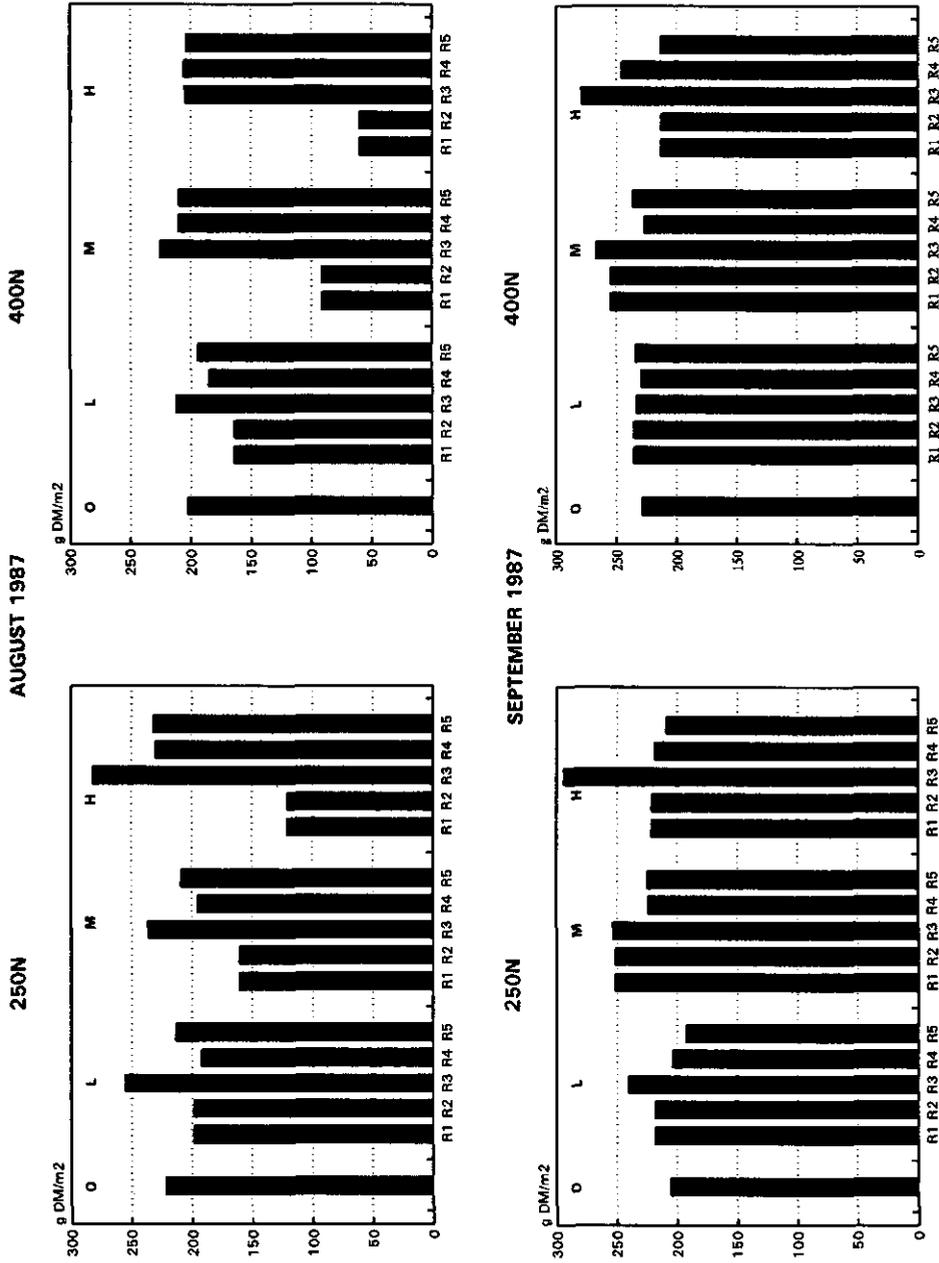
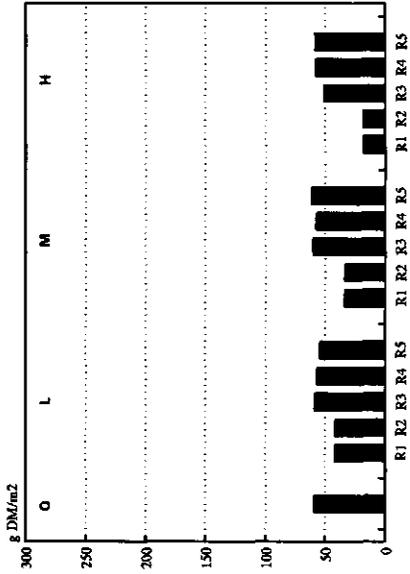
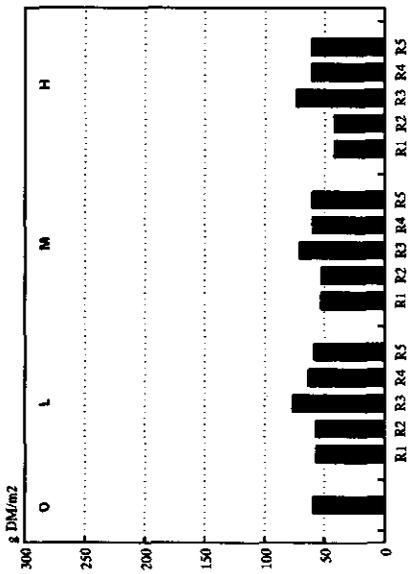


Fig. 3. Dry matter yield (g DM m<sup>-2</sup>) of the control plots (O) and effect of urine N concentration (6.4 (L), 9.6 (M) and 12.8 (H) g N l<sup>-1</sup>) on dry matter yield in each of the five concentric sampling rings R1, R2, R3, R4 and R5. Nitrogen fertilization 250 (250 N) and 400 (400 N) kg N ha<sup>-1</sup>yr<sup>-1</sup>.

250N

OCTOBER 1987

400N



250N

MAY 1988

400N

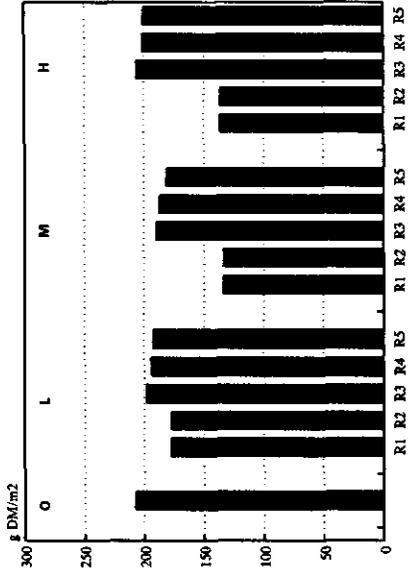
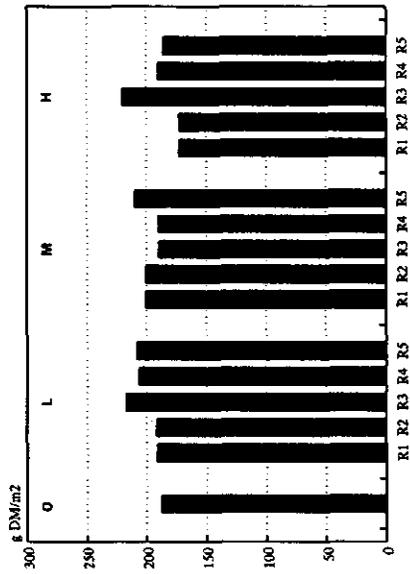


Fig. 3. Continued

Table 5. Effect of urine N concentration on herbage N uptake ( $\text{g N m}^{-2}$ ) in the urine-affected area ( $0.64 \text{ m}^2$ ). Between parentheses apparent recovery of urine N (ANR). Swards receiving 250 (250 N) or 400 (400 N)  $\text{kg N ha}^{-1}\text{yr}^{-1}$ . Urine N concentrations: 0 (O), 6.4 (L), 9.6 (M) and 12.8 (H)  $\text{g N l}^{-1}$ .

	250 N				400 N			
	O	L	M	H	O	L	M	H
August	6.8	8.4	8.1	8.7	6.8	7.7	6.8	6.2
		(7.8)	(4.4)	(4.8)		(4.3)	(-0.3)	(-1.7)
September	6.5	7.8	9.4	10.8	8.6	9.2	10.9	11.0
		(6.3)	(9.7)	(10.7)		(2.7)	(7.4)	(5.9)
October	1.8	2.0	2.0	2.0	1.9	1.6	1.5	1.1
		(0.9)	(0.8)	(0.6)		(-1.3)	(-1.2)	(-1.8)
May	5.7	5.8	5.7	6.1	6.5	5.7	5.0	5.6
		(0.9)	(0.2)	(1.1)		(-3.8)	(-4.9)	(-2.1)
Total	20.8	24.0	25.2	27.7	23.8	24.2	24.2	23.9
		(15.9)	(15.1)	(17.2)		(1.9)	(1.0)	(0.3)

Table 6. Effect of urine N concentration on herbage DM accumulation ( $\text{g DM per g urine N}$  applied) in the urine affected area ( $0.64 \text{ m}^2$ ) at two levels of fertilizer N. Swards receiving 250 (250 N) or 400 (400 N)  $\text{kg N ha}^{-1}\text{yr}^{-1}$ . Urine N concentrations: 6.4 (L), 9.6 (M) and 12.8 (H)  $\text{g N l}^{-1}$ .

	250 N			400 N		
	L	M	H	L	M	H
August	0.2	-0.9	-0.5	-0.6	-1.4	-1.7
September	1.4	1.8	1.6	-0.1	0.9	0.3
October	0.4	0.1	0.0	-0.5	-0.5	-0.7
May	0.7	0.1	0.2	-0.9	-1.5	-0.8
Total	2.7	1.1	1.3	-2.1	-2.5	-2.9

to sward deterioration; only in the low urine N treatment N uptake was higher than in the control. In the second harvest N uptake was higher in all urine treated areas, however, the effect on DM accumulation was insignificant (Fig. 3). In the 400 N sward, the negative effect of sward deterioration on N uptake and DM accumulation was still evident in the third and fourth harvest.

In May the total herbage DM accumulation in the urine-affected area (R1, R2 and R3: 0.64 m<sup>2</sup>) was 5%, 3%, and 8% higher than the control in the 250 N sward, whereas total herbage DM accumulation in the 400 N sward was reduced by 0%, 7% and 12% for urine concentrations of 6.4, 9.6 and 12.8 g N l<sup>-1</sup> respectively in comparison with the control treatment.

Overall ANR of urine N was about 16%, 15% and 17% for fertilizer treatment 250 N and 1.9%, 1.0% and 0.3% for fertilizer treatment 400 N for urine concentrations 6.4, 9.6 and 12.8 g N l<sup>-1</sup> respectively (Table 5). The effects of urine N on herbage DM accumulation were low and even negative in the 400 N sward (Table 6).

## Discussion

As the grazing animal returns a considerable quantity of N and other plant nutrients to the sward, it might be expected that the productivity of the sward would be increased owing to recycling. The results from the present experiment showed that N recycled via dung and urine was not very effective. However, it should be noted that the results were derived from a single experiment carried out at one location where dung and urine were applied in July.

After 10 months only 8% of the dung N was taken up by the herbage in the 250 N sward and nil in the 400 N sward. The area affected by dung was confined to 15 cm from the edge of the dung patch. This agrees well with MacDiarmid & Watkin (1971) and Weeda (1977). In the dung-affected area in the 250 N treatment DM accumulation was increased by only 13% whereas Weeda found an increase in total DM accumulation of about 50%. Both Weeda and MacDiarmid & Watkin found a larger effect since their experiments were performed in unfertilized grass-clover swards. Grass growth in the surrounding area was enhanced by dung N and the enhancement was not the result of a border effect as was indicated by MacDiarmid & Watkin (1971). In the present study the effect of dung was still apparent after 10 months at the end of the experiment. The observed effects might have been greater if the experiment had been continued longer or had been started earlier in the season. The duration of approximately two months of the positive effect of applied urine-N and its recovery of 15 to 17% were comparable to the findings reported by Ledgard et al. (1982). Recent experiments in The Netherlands (Van

der Meer & Whitehead, 1990) with artificial urine and, where no further fertilizer N was applied after urine application, indicated that recovery of urine N in the harvested herbage was at a maximum of 60% after urine applications made in April, May or early June and decreased to less than 20% after applications in August. A simultaneous similar increase of residual inorganic N in the soil was observed, which was subject to leaching and denitrification during the winter.

In the present experiment the low recovery of excretal N could be attributed to the high amount of N deposited on a small area and the relatively slow breakdown of the dung patches and the slow mineralization of the organic dung N. N deposition (fertilizer N plus excretal N) ranged from 71 to 185 g m<sup>-2</sup>. Supply of N was far beyond the demand of the herbage and, marginal recovery of excretal N will be relatively low at higher fertilizer N input rates. Besides, N recovery might have been negatively affected by sub-optimal sward conditions due to scorching. It are the urine-affected areas that afford the greatest potential for N loss. Since approximately 80% of N excreted is contained in urine, most of which is present as urea. Dung N is present as organic compounds less readily hydrolyzable than urea and mainly of bacterial origin, much of which is expected to be incorporated into the soil organic matter by the action of the soil fauna. The relative heavy pre-experimental harvest resulted in a retarded regrowth in the 400 N sward the first experimental yield in August was lower than in the 250 N sward. The effect was confined to the first experimental yield. A more proper pre-experimental sward management might have resulted in somewhat better results in August in the 400 N sward. Inorganic N originating from urine and not lost through ammonia volatilization may be nitrified, resulting in nitrate-N concentrations under the patches equivalent to 200-1710 kg ha<sup>-1</sup> (Ball & Ryden, 1984). Leaching losses from urine-affected areas can occur, as soil N levels are well in excess of plant requirements. Dutch experiments conducted at the same site as the present experiment indicated that grazing cattle increases N leaching losses by a factor 2 (Macduff et al., 1990). Leaching losses from the cut sward were 25 and 30 kg N ha<sup>-1</sup>yr<sup>-1</sup> and from the grazed sward 48 and 61 kg N ha<sup>-1</sup>yr<sup>-1</sup> respectively at fertilizer input rates of 250 and 400 kg N ha<sup>-1</sup>yr<sup>-1</sup>.

Tentative estimations can be made of effects of urine and dung at a whole-paddock scale. Assuming: (i) ten defaecations and ten urination per day made by a cow; (ii) 700 and 750 cow-grazing days ha<sup>-1</sup>yr<sup>-1</sup> at 250 N and 400 N respectively; and (iii) an

application of 10.2 g N per defaecation and 19.2 g N per urination irrespective fertilizer N level. From the results of this experiment it follows that in the 250 N sward the average N effect of urine was 1.7 g DM per g urine N applied and 3 g DM per g dung N applied. In the 400 N sward the effects were -2.5 g DM per g urine N applied and nil for dung. Ignoring overlapping of dung and urine patches, it can be calculated that herbage accumulation will increase by 443 kg DM ha<sup>-1</sup>yr<sup>-1</sup> in the 250 N sward and decrease by 360 kg DM ha<sup>-1</sup>yr<sup>-1</sup> in the 400 sward. It will be evident that an increase or a decrease in herbage accumulation in the order of 350 to 450 kg DM is not of significance. However, when evaluating pasture growth at 250 N and 400 N there is a difference of about 800 kg DM in herbage DM accumulation due to effects of urine and dung which decreases the response to fertilizer N. Since excretal effects on herbage growth were positive at a low fertilizer N (250 N) input and negative at a high fertilizer N (400 N) input, DM yield response to fertilizer N under grazing will be lower than under cutting. From N response experiments at the same site Deenen (1990) reported under cutting a positive DM response up to 550 kg N ha<sup>-1</sup>yr<sup>-1</sup>; whereas, under grazing an N application of more than 250 kg N ha<sup>-1</sup>yr<sup>-1</sup> had no effect.

The conclusion from this study is that in these moderately fertilized swards benefits from the recycling of ingested nutrients by grazing animals are low.

## **CHAPTER 6**

### **SUMMARY AND GENERAL DISCUSSION**

## SUMMARY AND GENERAL DISCUSSION

In this chapter, the experiments and their results will be summarized and evaluated. Practical implications and conclusions are drawn relating to the aims of this study.

### Responses to fertilizer nitrogen

#### *cutting*

The effects of fertilizer nitrogen (N) application on herbage accumulation under an approximately 4-weekly cutting regime have been studied in the period 1986-1988 in perennial ryegrass swards on a silty loam soil in Oostelijk Flevoland (Chapter 2) and on a sand soil near Wageningen (Chapter 3). Annual fertilizer rates of N varied from 0 to 700 kg ha<sup>-1</sup>. At both sites high apparent N recoveries (ANR) were found. ANR's were high (>80%) on the loam soil for all N treatments in all years. On the sand soil ANR's were high (>80%) up to an application rate of 400 (1986) or 550 kg N ha<sup>-1</sup>yr<sup>-1</sup> (1987 and 1988). Differences in ANR values, herbage yields and economical optimum N application rates between years and locations could be related to available inorganic soil N in spring, length of the growing season, rainfall and soil type (i.e. water availability over the growing season).

There was a greater variation between the years in N recoveries on the sand soil than on the loam soil, probably because of the lower water holding capacity of the sand soil. Highest N recoveries and dry matter (DM) yields on the sand soil were found in 1987 when there was abundant rainfall during the growing season, whereas 1986 and 1988 were relatively dry. Responses of herbage yield to applied fertilizer N were strongest on the loam soil. Consequently the optimum N application rate on loam was higher than on sand. Taking a marginal profitability of 7.5 kVEM or kVEVI per kg N applied, the optimum application rate in the 4-weekly cutting experiment appeared to be 511 kg N ha<sup>-1</sup>yr<sup>-1</sup> on the loam soil and 421 kg N ha<sup>-1</sup>yr<sup>-1</sup> on the sand soil. Averaged over the growing season, herbage DM accumulated in growth periods of up to one month contains about 1000 VEM kg<sup>-1</sup> DM (Meijs, 1981). Prins (1983) found a mean marginal profitability of 7.5 kg DM per kg N applied at 420 kg N ha<sup>-1</sup>yr<sup>-1</sup> in a multi-site cutting

experiment: on a sand soil the optimum application rate was 391 kg N ha<sup>-1</sup>yr<sup>-1</sup>, on a clay soil 425 kg N ha<sup>-1</sup>yr<sup>-1</sup> and on a heavy clay soil 445 kg N ha<sup>-1</sup>yr<sup>-1</sup>.

### *grazing*

The effects of fertilizer N application on herbage intake and animal performance have been studied in the period 1986-1988 in perennial ryegrass swards on a silty loam soil in Oostelijk Flevoland (Chapters 2 and 3) and in the period 1986-1989 on a sand soil near Wageningen (Chapter 3). On the loam soil two experiments were conducted: continuous grazing with dairy cows (annual application rates 250-700 kg N ha<sup>-1</sup>yr<sup>-1</sup>) and rotational grazing with dairy cows (annual application rates 250 and 550 kg N ha<sup>-1</sup>yr<sup>-1</sup>). On the sand soil a rotational grazing experiment was performed with beef cattle (annual application rates 250-700 kg N ha<sup>-1</sup>yr<sup>-1</sup>).

Under continuous grazing on loam, N yields increased up to a fertilizer N application rate of 550 kg N ha<sup>-1</sup>yr<sup>-1</sup> but they were lower than under 4-weekly cutting. Besides, N response curves levelled off at lower N rates than under cutting. At the lowest N application rate (250 kg N ha<sup>-1</sup>yr<sup>-1</sup>) N uptake was probably increased by positive effects of excretal N (Chapters 2, 3 and 5) and at higher fertilizer N application rates N uptake was impeded through adverse grazing effects. The optimum N application rate for continuous grazing on loam was on average 308 kg N ha<sup>-1</sup>yr<sup>-1</sup>. Herbage intake under continuous grazing in 1986-1988 varied from 55 to 67% of herbage yield under 4-weekly cutting at corresponding N levels. In two one-year experiments Lantinga et al. (1987) found relative yields under continuous grazing of about 80% of the herbage yield under 4-weekly cutting. These one-year experiments were performed at the same soil type both with very dense swards and at a sward height which was on average 1 cm higher than in the present experiment.

On the sand soil, there was only a weak response of N yield and herbage yield to fertilizer N applied. Except at the N application rate of 250 kg N ha<sup>-1</sup>yr<sup>-1</sup>, both N yield and herbage yield were lower than under cutting. These lower yields could be associated with an open sward, which was for the greater part a result of urine scorching. The optimum fertilizer application rate was estimated to be some 200 kg N ha<sup>-1</sup> lower than under cutting, which is equivalent to about 220 kg N ha<sup>-1</sup>yr<sup>-1</sup>. However, it should be

noted that for the grazing experiment on sand beef cattle was used. Daily herbage intake per dairy cow is about twice as high as that of a beef animal. The grazing pressure with beef cattle is, therefore, about twice as high. Consequently, sward damage through treading and poaching is much greater in a grazing system with beef cattle than with dairy cattle. In the rotational grazing experiment with dairy cows on the loam soil sward damage through treading and poaching was much less than on the sand soil. Besides no urine scorching occurred. As a consequence, there was a positive response of herbage yield to the fertilizer increment 250 to 550 kg N ha<sup>-1</sup>yr<sup>-1</sup> (Chapter 3).

Hassink (1992) estimated that the difference in N mineralization between cut and grazed swards under field conditions was 110 and 40 kg ha<sup>-1</sup>yr<sup>-1</sup> in the sand soil and the loam soil, respectively. This higher mineralization contributed, together with the specific grazing effects, to the lower optimum N fertilizer application rate under grazing conditions than under cutting conditions.

#### *whole-farm*

The response to fertilizer N under integrated grazing and mowing management was assessed as the annual sum of herbage intake and the amount of ensiled herbage from all the paddocks on the sand soil at each N level together (Chapter 3). The weaker response to N on whole-farm compared to that of the cutting only plots was mainly caused by sward deterioration in the grazed paddocks which increased at higher levels of N fertilization. The remainder of the difference was due to herbage removal by cleaning cuts under grazing (about 5% of the herbage accumulated) and relatively high field losses because of too long field periods (about 30% of the mown herbage). Even under a careful management there are inevitable losses and, therefore, the optimum N application rate on a whole-farm scale will always be lower than under cutting only conditions and was estimated to be about 200-250 kg N ha<sup>-1</sup>yr<sup>-1</sup>.

Corré & Dijkman (1988) observed in two consecutive years on a clay soil, that for herbage accumulation under a management system involving alternate grazing and silage cutting the marginal yield response was 7.5 kg DM per kg N applied at a fertilizer rate of about 400 kg N ha<sup>-1</sup>yr<sup>-1</sup>. However, in this experiment there was no sward deterioration observed.

## Sward quality

The current intensive management of grassland - with high N inputs and high stocking rates - may easily lead to sward deterioration through urine scorching, treading, poaching and tiller pulling (Edmond, 1966; Wilkins & Garwood, 1986; Tallowin et al., 1986; Lantinga et al., 1987; Chapters 2, 3 and 5). Due to these negative grazing effects tiller densities in grazed swards are lower than in cut swards, given similar frequencies of defoliation (Chapters 2 and 3). Furthermore, grazed swards are often more open and the distribution of tillers is more heterogeneous, especially on sand soils with its greater susceptibility to scorching damage. Herbage yield may be substantially reduced when the distribution of the tillers is heterogeneous, even when tiller densities would be sufficient for maximum herbage growth (Van Loo, 1993). This is clearly illustrated in the grazing experiments described in Chapters 2 and 3. At almost all sampling dates tiller densities in the continuously grazed swards were well above the critical level of 80 tiller per  $\text{dm}^{-2}$  (Van Loo, 1993). However, swards were heterogeneous, especially in summer 1986 and 1987, and heterogeneity increased with the level of N application. Sward quality decreased with increasing N level and resulted in a much weaker response to fertilizer N in 1986 and 1987 than in 1988 when swards were in a good condition. In the rotationally grazed swards on loam (Chapter 3) tiller densities might have been suboptimal occasionally (40 to 70 tillers  $\text{dm}^{-2}$ ) but tillers were homogeneously distributed with hardly any gaps of significance. This is quite in contrast with the swards on the sand soil (Chapter 3). On the sand soil, tiller densities fluctuated strongly, but at almost all sampling dates swards had a relatively low tiller density irrespective of level of N fertilization. During the whole experimental period swards were heterogeneous and heterogeneity was positively correlated with the level of N fertilization.

According to Van Loo (1993) recovery of a perennial ryegrass sward is possible from tiller densities as low as 20 tillers  $\text{dm}^{-2}$  within a few months with light cuts. However, no large open patches should occur and the distribution of tillers should therefore be homogeneous. Reseeding should be considered when tiller distribution is very clumped, i.e. the absence frequency in rings with radius of 8 cm is more than about 5% (Fig. 1; Chapter 4: Figs. 8 and 9).

Relatively low tiller densities and open swards were found after the severe winters

of 1985/1986 and 1986/1987 due to winter damage (Chapters 2, 3 and 5). High N swards appeared to be more vulnerable to winter damage. It is suggested that a frequent defoliation regime (continuous grazing or light cuts) in autumn is a good measure to reduce the risks of winter damage.

Sometimes it is argued that increasing the nitrogen application rate could alleviate some of the negative effects of a low tiller density or a high frequency of open patches on productivity. However, N concentrations in the crop are -with the current application rates- seldom the limiting factor for growth (Van Loo, 1993). Moreover, with decreasing tiller density and increasing frequency of open patches, the nitrogen uptake in harvested herbage declines and the nitrogen concentration in the harvested herbage increases. This increase of the nitrogen concentration further increases the risk of sward damage through trampling and urine scorching. Therefore, nitrogen application rates should be reduced on swards with a low tiller density or a high frequency of open patches, to avoid unnecessary losses of nitrogen to the environment.

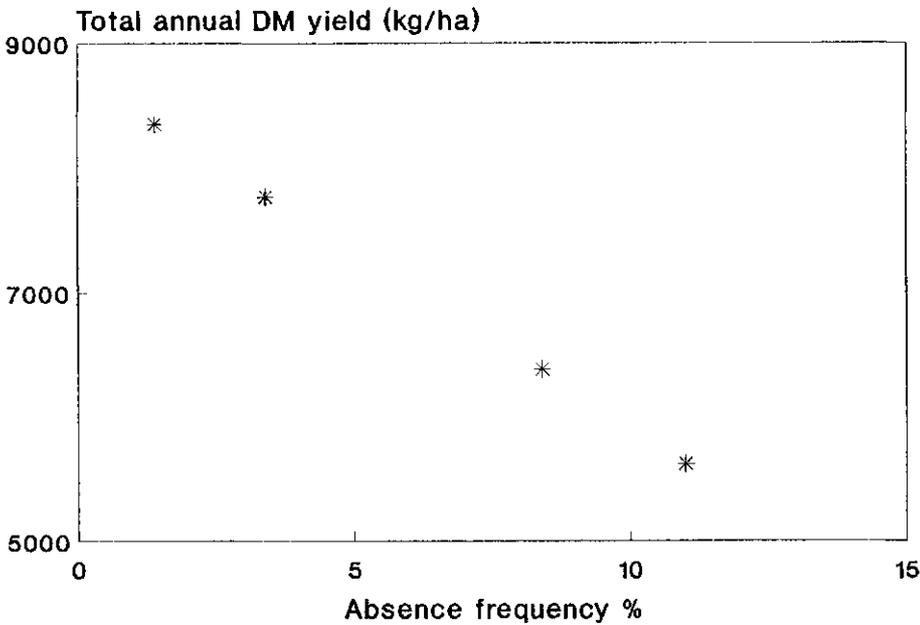


Fig. 1. The relationship between total annual dry matter yield and absence frequency in rings with radius of 8 cm in rotationally grazed swards (from Van Loo, 1991).

## Nitrogen use efficiency

Whereas the apparent recovery of fertilizer N under grazing can be high (>80%), herbage N is poorly converted into animal products. Under continuous grazing the average efficiency of use of ingested N at a fertilizer level of 250 kg N ha<sup>-1</sup>yr<sup>-1</sup> was 23% (Chapter 2). Higher rates of fertilizer effected a slight decrease in N use efficiency of ingested N (19% at 700 kg N ha<sup>-1</sup>yr<sup>-1</sup>) but a rise in the calculated amount of N excreted per ha. Increasing the N application from 250 to 400 kg N ha<sup>-1</sup>yr<sup>-1</sup> resulted in an average increase of N output of only 16 kg N ha<sup>-1</sup>yr<sup>-1</sup> (Chapter 2; Table 5). Efficiency of N use (calculated as the fraction of the total N input present in animal products) under rotational grazing on the loam soil varied from 24 to 31% for dairy cows and was already less than 10% for beef cattle on a sand soil at a fertilizer rate of 250 kg N ha<sup>-1</sup>yr<sup>-1</sup> (Chapter 3). It can be concluded that even at a nitrogen application rate of 250 kg N ha<sup>-1</sup>yr<sup>-1</sup> at least 70% of the N input is lost from the farm system.

During grazing, faeces and urine are excreted in patches, leading to very high N concentrations locally: in urine patches of about 500 kg N ha<sup>-1</sup> and in dung patches of about 2000 kg N ha<sup>-1</sup> (Lantinga et al., 1987). In the mid-eighties it was assumed that approximately 40% of the N in urine and 5% of the N in faeces from grazing cattle volatilizes as ammonia (Buijsman et al., 1986). These percentages suggest that in the grazing season approximately 30% of the excreted N is volatilized as ammonia-N. Data of Bussink (1992) from measurements in the rotationally grazed swards on the loam soil (Chapter 3) indicate much lower ammonia losses. The ammonia loss from the 250 N sward was 8.1 kg N ha<sup>-1</sup> in 1988, which was equivalent to 3% of the N returned to the sward in excreta during the growing season. Losses from the 550 N sward were 42 and 39 kg N ha<sup>-1</sup> in 1987 and 1988 respectively; this was equivalent to 8.5 and 7.7% of the N returned to the sward in excreta during the growing season. Field experiments in the United Kingdom indicated similar small losses of 25 kg N ha<sup>-1</sup>, corresponding to 9% of the excreted N on a sward receiving 420 kg N ha<sup>-1</sup>yr<sup>-1</sup> (Jarvis et al., 1989a,b).

Most urine penetrates into the soil, restricting ammonia volatilization losses from urine (Vertregt & Rutgers, 1988; Van der Molen et al, 1989). It might be expected that the productivity of the sward would be increased owing to the recycling of nutrients. However, experimental results on the sand soil (Chapter 5) showed that N recycled via

dung and urine is not very effective. After 10 months only 8% of the dung N was recovered in the herbage in swards receiving 250 kg N ha<sup>-1</sup>yr<sup>-1</sup> and nil in swards receiving 400 kg N ha<sup>-1</sup>yr<sup>-1</sup>. The N effect of dung was 3 g DM per g N applied in the 250 N sward and nil in the 400 N sward. The ANR of urine N was about 16% in the 250 N sward and negligible in the 400 N sward. The N effect was low, in the 250 N sward 1.7 g DM per g N applied and negative in the 400 N sward due to scorching. In the experiment described in Chapter 5 the positive effect of urine and dung N applied in July on herbage DM accumulation was estimated to be some 440 kg DM ha<sup>-1</sup> in the 250 N sward. The negative effect in the 400 N sward due to urine scorching was estimated to be some 360 kg DM ha<sup>-1</sup>. Thus, DM yield response to fertilizer N under grazing will be lower than under cutting. In plots at the same site a DM response up to 550 kg N ha<sup>-1</sup>yr<sup>-1</sup> was found under cutting, whereas under grazing a N application of more than 250 kg N ha<sup>-1</sup>yr<sup>-1</sup> had no effect. Recovery of N will be higher when dung and urine are applied in spring or early summer. Experiments in the Netherlands (Van der Meer & Whitehead, 1990) with artificial urine but without additional fertilizer N after urine application, indicated that recovery of urine N in the harvested herbage was at a maximum of 60% after urine applications made in April, May or early June and decreased to less than 20% after applications in August. A simultaneous increase of residual inorganic N in the soil was observed, which was subject to leaching and denitrification during the winter. It can be concluded that in moderately fertilized swards (about 250 kg N ha<sup>-1</sup>yr<sup>-1</sup>) the beneficial effect of excretal N is low. At higher N application rates the effect of excretal N is nil or negative on soils which are vulnerable to urine scorching (almost all sandy soils).

Inorganic N originating from urine and not lost through ammonia volatilization may be nitrified, resulting in nitrate N concentrations under the patches equivalent to 200-1710 kg N ha<sup>-1</sup> (Ball & Ryden, 1984). Since too much N is voided for effective recovery by the sward whilst soils usually contain insufficient organic matter to allow appreciable immobilization, the surfeit is lost. For example, under urine-affected areas in a 420 kg N ha<sup>-1</sup>yr<sup>-1</sup> sward at Hurley (United Kingdom), nitrate concentrations in the soil solution frequently exceeded 1000 mg l<sup>-1</sup> against background levels of 40-60 mg N l<sup>-1</sup>. At the same site as described in Chapters 3 and 5, Macduff et al. (1990) measured a twofold increase in the amount of N leached when swards were grazed compared with cutting (Table 1). To comply with the EU-standard of 11.3 mg N l<sup>-1</sup> for groundwater quality,

nitrate leaching should not exceed 34 kg N ha<sup>-1</sup>yr<sup>-1</sup> for a well-drained soil and an annual precipitation surplus of 300 mm. On basis of annual mean nitrate concentrations in drainage the leaching losses from grazing systems on a sand soil receiving fertilizer N inputs above 250 kg N ha<sup>-1</sup>yr<sup>-1</sup> and on a loam soil receiving fertilizer N inputs of about 400 kg N ha<sup>-1</sup>yr<sup>-1</sup> are therefore likely to be unacceptable. Reduced leaching losses from the loam soil compared with the corresponding N levels on the sand soil probably arises from higher apparent N recoveries and higher immobilization and denitrification of N in the loam soil. Besides, on the loam soil more inorganic N is left in the profile at the end of the winter. In the profile of the sand soil on average about 40 kg N ha<sup>-1</sup> was found in spring with only small differences between the nitrogen treatments. In the loam soil, the amount of inorganic N in the profile was on average almost twice as high.

Scholefield et al. (1990) reported denitrification measurements in the United Kingdom and the Netherlands. Denitrification rates in grazed grasslands are low with major peaks of < 2 kg N ha<sup>-1</sup>day<sup>-1</sup> which were associated with fertilizer additions and rainfall events. The level of fertilizer N had a clear and consistent effect on annual denitrification with higher denitrification from the finer textured soils. At a fertilizer N input of 250 kg N ha<sup>-1</sup>yr<sup>-1</sup> annual denitrification on a sand loam over chalk at Hurley was

Table 1. Mean annual nitrate leaching losses and nitrate concentrations between 1986-1989 at a sand soil (De Meenthoeve) and a loam soil (Minderhoudhoeve). Mean annual tile drain output at both sites was 320 mm (from Macduff et al., 1990).

		Fertilizer N (kg N ha <sup>-1</sup> yr <sup>-1</sup> )				
		0	250	400	550	700
Nitrate leaching (kg N ha <sup>-1</sup> yr <sup>-1</sup> )						
sand	cut	10	25	30	73	78
sand	grazed	-	48	61	116	145
loam	grazed	-	8	29	41	49
Nitrate concentration (mg N l <sup>-1</sup> )						
sand	cut	3	8	10	23	24
sand	grazed	-	15	19	36	44
loam	grazed	-	3	9	13	16

about 12 kg N ha<sup>-1</sup>yr<sup>-1</sup> and on a clay soil near Utrecht about 30 kg N ha<sup>-1</sup>yr<sup>-1</sup>. At a fertilizer input of 600 kg N ha<sup>-1</sup>yr<sup>-1</sup> denitrification on a clay soil at Utrecht was about 50 kg N ha<sup>-1</sup>yr<sup>-1</sup>.

Hassink & Neeteson (1991) found in their experiments a considerable increase in soil organic N under the grazed swards on the loam soil. In the period March 1986 to March 1989 they observed an average annual accumulation of 245 kg N ha<sup>-1</sup>, irrespective the level of N fertilization. The amount of organic N increased by about 80 kg N ha<sup>-1</sup> under mowing conditions due to the marine history and the ploughing down of the sward in 1985, the top soil had a low N content in comparison with other loamy grassland soils in the Netherlands. The data suggest that the soil organic matter content of this soil is still far from equilibrium.

## **Management implications**

### *the optimum fertilizer application rate*

Decisions about fertilizer management have to be taken against a background of requirements for economic production and environmental considerations. Optimum application rates are judged against an economic background. The optimum application rate is defined as the rate where an incremental application of 1 kg N has a marginal effect of 7.5 kg dry matter (Prins, 1983).

Nowadays, total N application should be targeted below the point where losses become unacceptable and applications should be timed to ensure that little inorganic N remains in the soil profile at the end of the growing season. Although, identification of the exact rates will be difficult and will depend upon the soil type and the weather. According to Lantinga & Van der Putten (1994) the efficiency with which applied N is used in herbage production is the ratio between residual soil inorganic N at the end of the growing season and total herbage yield. From this environmental viewpoint the optimum level of N input for integrated grazing and cutting management on the sand soil (Chapter 3) appeared to be about 200 kg N ha<sup>-1</sup>yr<sup>-1</sup>. The economical optimum calculated from cutting only plots at the same site was 420 kg N ha<sup>-1</sup>yr<sup>-1</sup>.

### *reducing N losses*

In the near future there will be an increasing legislative pressure on dairy farmers to reduce N emissions to the environment. As a result less N is needed or permissible for the production of herbage.

For many dairy farmers the need for maximum herbage production is diminishing as a result of the milk production limitations (milk quota system). However, farms with an average stocking density of over 2.5 dairy cows per ha grassland and fodder crops, as there are many in the southern part of the Netherlands are facing a great challenge in the next years to come. These farms produce more manure than they are permitted to apply on their own farm. Very intensive farms produce much more milk per ha than less intensive farms partly by more milk per cow, but mainly by means of a higher stocking rate. Despite high fertilizer N inputs these intensive farms have to buy extra roughage and concentrates because of the high stocking rate. As a result the mineral surpluses on these intensive farms are high (Table 2). A lower surplus per 100 kg milk is realized owing to the purchased roughage (mostly maize) of which the N losses of the production itself are not accounted for. To reduce nutrient losses substantially different techniques are available:

1. Taking better account of the standards for fertilization of crops and for feed production;
2. Better utilization of the slurry by low emission application during the growing season, a rapid removal of the faeces and urine in the stall to a covered slurry storage;
3. Reduction of the stocking rate due to a higher milk production per cow;
4. Better utilization of roughage by producing higher quality roughage;
5. Good grassland management;
6. Restricted grazing in combination with supplementary feeding of maize or other low N/high energy feed will reduce the surplus of N in the ration and it can reduce N excretion of the cow by some 30-35% (Van Vuuren & Meijs, 1987; Valk et al., 1990).

Surveys on farm scale indicate that a surplus of N on the mineral balance can be reduced within a couple of years by 25-50%. With a further optimization of the measures a reduction of the N surplus of 70% might be possible, unless the dairy farm is very intensive (over 2.5 cows per ha). In that case manure should be removed from the farm or extra land should be bought. Both options will be expensive. A possible trend might be mixed farming. Less intensive dairy farmers will grow concentrates on their farm. For the intensive dairy farms 'distant mixed-farming' might be an option: exchanging manure for cereals with an arable farmer.

The new fertilizer recommendation scheme (Nijsten et al., 1993; Vellinga et al., 1993) which was introduced in 1994 allows for individual target annual N application rates and takes into account soil N availability, soil water availability and weather conditions (rainfall), target yields, yield of the individual (former) cut, and time of application in the growing season. Despite the fact that specific grazing effects are still not accounted for, this recommendation scheme allows for a better fine-tuning of N fertilization.

Table 2. Intensity of farming on specialized dairy farms, based on milk production per ha and surplus of N in 1986/1987 (from Daatselaar, 1989).

	group (number of farms)			
	1 (81)	2 (104)	3 (93)	4 (64)
milk (kg ha <sup>-1</sup> )	8667	12008	14573	20510
milk (cow <sup>-1</sup> )	5552	6373	6691	6896
fertilizer N on grass (kg N ha <sup>-1</sup> )	397	391	422	442
concentrates (MJ NE cow <sup>-1</sup> )	12.5	13.9	15.6	16.8
purchased roughage (MJ NE cow <sup>-1</sup> )	1.9	4.7	7.9	12.3
surplus N (kg ha <sup>-1</sup> )	376	479	541	650
surplus N (kg/100 kg milk)	4.36	4	3.74	3.23

Table 3. Effects of fertilizer N on nutritive value and N concentration of the herbage in continuously grazed swards on a loam soil (1986-1988)(1 VEM = 6.9 kJ NEL).

fertilizer N (kg ha <sup>-1</sup> )	251	401	549	701
VEM (kg DM) <sup>-1</sup>	998	1014	1025	1027
g N (kg DM) <sup>-1</sup>	36	41	44	45

Cows grazing on well fertilized pastures consume about 4 times more protein than they require (Chapters 2 and 3). As heavily fertilized grass contains a substantial surplus of rumen degradable protein, reducing the protein content is an important option to improve N utilization during grazing (Van Vuuren & Meijs, 1987; Chapters 2 and 3). Practically, the N concentration can be decreased by reducing the N application rate or by feeding more mature grass. A reduction in the N fertilizer application rate has a large effect on the N concentration but only a small effect on the nutritive value of the herbage (Table 3). On the other hand, more mature grass has a lower N concentration but also a substantially lower digestibility and, consequently the energy intake will be less (Van Vuuren & Meijs, 1987).

From a viewpoint of nutritive value a concentration of about 0.02 g N (g DM)<sup>-1</sup> in the diet would be sufficient for dairy cows (Van Vuuren, 1991). However, dry matter yields and nutritive qualities of existing cultivars of perennial ryegrass are too low at such low N concentrations. In studies of Baan Hofman (1988) and Van Loo et al. (1992) on tillering dynamics and regrowth of perennial ryegrass as influenced by N supply indicated the existence of genetic variability towards a higher N use efficiency in perennial ryegrass genotypes.

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## SAMENVATTING

Vanaf 1950 is tot halverwege de jaren tachtig op Nederlandse weidebedrijven het gebruik van kunstmeststikstof en aangekocht (kracht)voer voortdurend gestegen. Hierdoor is de produktiviteit van de bedrijven sterk toegenomen. Echter slechts een fractie (<20%) van de aangevoerde stikstof verlaat het bedrijf weer in de vorm van melk en vlees. De resterende 80% gaat verloren door vervluchtiging van ammoniak, omzetting van nitraat in vooral stikstofgas (denitrificatie) of af- en uitspoeling van nitraat naar oppervlakte- en grondwater terwijl een deel wordt vastgelegd in de bodem.

Om een beter kwalitatief en kwantitatief inzicht te krijgen in de stikstofstromen van grasland onder verschillende omstandigheden (grondsoort, waterhuishouding en bedrijfsvoering) werd midden jaren tachtig onderzoek gestart. In een gezamenlijk onderzoek werd door de vakgroep Agronomie (LUW) samengewerkt met CABO-DLO, ICW-DLO, IB-DLO, NMI en Rijksuniversiteit Utrecht. Dit proefschrift behandelt met name de agronomische aspecten van het onderzoeksproject. De stikstofrespons onder standweiden, omweiden en maaien wordt beschreven. De respons wordt bediscussieerd in relatie met zodekwaliteit, management en stikstofbenutting.

### De stikstofrespons bij maaien

Het effect van kunstmeststikstof (N) op de grasopbrengst bij 4-wekelijks maaien werd onderzocht gedurende de periode 1986-1988 op een jonge zeeklei in Oostelijk Flevoland (Hoofdstuk 2) en op een zandgrond nabij Wageningen (Hoofdstuk 3). De jaarlijkse giften varieerden van 0 tot 700 kg N ha<sup>-1</sup>jr<sup>-1</sup>. Op beide lokaties werden hoge stikstofrendementen gevonden, veelal meer dan 80% van de toegediende stikstof werd door het geoogste gras opgenomen. Verschillen in stikstofrendement waren voornamelijk te wijten aan de hoeveelheid beschikbare bodemstikstof, lengte van het groeiseizoen, neerslag en bodemtype. De grootste variatie tussen de jaren werd gevonden op de zandgrond, vanwege het geringere vochthoudendvermogen van de grond.

Het stikstofeffect was het grootst op de kleigrond, bovendien was de optimale stikstofgift hoger dan op zandgrond. De optimale N-gift op kleigrond was 511 kg N ha<sup>-1</sup>jr<sup>-1</sup> en op zandgrond 421 kg N ha<sup>-1</sup>jr<sup>-1</sup>. Hierbij wordt aangenomen dat bij de optimale

stikstofgift de marginale meeropbrengst 7,5 kg drogestof per kg toegediende N is.

### De stikstofrespons onder beweiden

Het effect van kunstmeststikstof op de grasopbrengst onder beweiden werd onderzocht gedurende de periode 1986-1988 op een jonge zeeklei in Oostelijk Flevoland (Hoofdstuk 2) en op een zandgrond nabij Wageningen (Hoofdstuk 3). Op de kleigrond werden twee beweidingsproeven met melkkoeien uitgevoerd: standweiden (jaarlijkse stikstofgiften 250-700 kg N ha<sup>-1</sup>jr<sup>-1</sup>) en omweiden (jaarlijkse stikstofgiften 250 en 550 kg N ha<sup>-1</sup>jr<sup>-1</sup>). Op de zandgrond werd een omweideproef met vleesvee uitgevoerd (jaarlijkse stikstofgiften 250-700 kg N ha<sup>-1</sup>jr<sup>-1</sup>).

Bij standweiden nam de stikstofopname door het gewas toe tot een bemestingsniveau van 550 kg N ha<sup>-1</sup>jr<sup>-1</sup>. Het stikstofrendement en het stikstofeffect waren echter lager dan in de maaiproef. Bij weiden was niet alleen de stikstofopname door het gewas aanmerkelijk lager dan bij maaien maar bovendien steeg de stikstofopname minder bij een verhoging van de stikstofbemesting. Bij de laagste stikstofgift (250 kg N ha<sup>-1</sup>jr<sup>-1</sup>) werd de stikstofopname door het gewas mogelijk positief beïnvloed tengevolge van stikstof uit mest en urine. Bij de hogere stikstofgiften werd de stikstofopname nadelig beïnvloed door een open zode ten gevolge van beweidingseffecten (betreding en vertrapping). De optimum stikstofgift voor standweiden op kleigrond was gemiddeld 308 kg N ha<sup>-1</sup>jr<sup>-1</sup>.

Op de zandgrond was het stikstofrendement en het stikstofeffect slechts zeer gering bij beweiden. Met uitzondering van de laagste stikstofgift (250 kg N ha<sup>-1</sup>jr<sup>-1</sup>) was zowel de stikstofopname als de drogestofopbrengst aanmerkelijk lager dan bij maaien. Naar schatting lag de optimum stikstofgift ongeveer 200 kg N ha<sup>-1</sup> lager dan bij maaien, dat wil zeggen dat de optimumgift ongeveer 220 kg N ha<sup>-1</sup>jr<sup>-1</sup> was. Er moet echter de kanttekening worden gemaakt dat op de zandgrond de beweiding werd uitgevoerd met vleesvee waardoor de beweidingsdichtheid ongeveer verdubbelt ten opzichte van een beweiding met melkvee. Als gevolg zal zodebeschadiging door vertrapping en betreding ook groter zijn. Op de kleigrond werd in de omweideproef met melkvee wel een duidelijke respons op de stikstofbemesting gevonden wanneer de stikstofgift werd verhoogd van 250 naar 550 kg N ha<sup>-1</sup>jr<sup>-1</sup>. Op deze kleigrond was echter slechts in zeer

geringe mate sprake van zodebeschadiging. Urineverbranding, een typisch probleem van grasland op zandgrond, trad hier niet op. Er kan worden geconcludeerd dat de zodekwaliteit zeer bepalend is voor de stikstofrespons onder een beweidingsregime.

### **De stikstofrespons op bedrijfsniveau**

Het effect van kunstmeststikstof (N) op de grasopbrengst onder gecombineerd weiden en maaien (bedrijfsniveau) werd bepaald in de beweidingsproef op de zandgrond als de som van de totale grasopname door het weidende vee en de opbrengst van de maaisneden voor de voederwinning. Het stikstofeffect was aanzienlijk lager dan in de maaioproef ten gevolge van zodebeschadiging door beweiding en veldverliezen bij de maaisneden. Zelfs met een zeer goed graslandbeheer zijn verliezen onontkoombaar en zal de optimum stikstofgift altijd lager liggen dan bij maaien alleen. De optimum stikstofgift werd geschat op 200-250 kg N ha<sup>-1</sup>jr<sup>-1</sup>.

### **Zodekwaliteit**

Het huidige intensieve graslandgebruik met relatief hoge stikstofgiften en hoge veebezettingen leidt gemakkelijk tot zodebeschadiging ten gevolge van betreding, vertrapping en urineverbranding. Ten gevolge van deze specifieke beweidingseffecten zijn, gegeven een vergelijkbare ontbladeringsfrequentie, de spruitdichtheden bij beweiding altijd lager dan bij maaien. Bovendien is een zode bij beweiding vaker open en zijn de spruiten heterogener verdeeld dan bij maaien (Hoofdstukken 2 en 3). Dit is vooral het geval op gronden die een grotere gevoeligheid hebben voor urineverbranding (zandgronden). Bovendien wordt de zodekwaliteit minder bij hogere stikstofgiften. Ten gevolge hiervan neemt ook het stikstofeffect af. Hierbij blijkt de openheid of de heterogeniteit van de zode een grotere rol te spelen dan het gemiddelde aantal aanwezige spruiten.

Relatief lage spruitdichtheden werden ook gevonden na de strenge winters 1985/1986 en 1986/1987 ten gevolge van winterschade (Hoofdstukken 2, 3 en 5). De omvang van de winterschade nam toe met de mate van stikstofbemesting in het voorgaande jaar. Het bleek dat bij een frequent ontbladeringsregime (wekelijks maaien en

standweiden) in de herfst de kans op winterschade kan worden verkleind.

Het herstel van een open zode kan het beste worden gestimuleerd door frequent ontbladeren (standweiden of lichte maaisneden). Tegelijkertijd moet de stikstofbemesting worden gematigd om te voorkomen dat stikstof verloren zal gaan en de stikstofconcentratie in het resterende gewas relatief hoog zal zijn waardoor de kans op urineverbranding weer toeneemt.

### **Benutting van stikstof**

Terwijl een groot deel van de toegediende stikstof door het gewas kan worden opgenomen, wordt de door de herkauwer opgenomen stikstof slechts zeer ten dele benut en omgezet in dierlijk eiwit (melk en vlees). Bij een bemestingsniveau van  $250 \text{ kg N ha}^{-1}\text{jr}^{-1}$  werd 23% van de door het dier opgenomen stikstof benut (Hoofdstuk 2). Theoretisch kan de benutting van de door het dier opgenomen stikstof maximaal 40% zijn. Wanneer de stikstofbemesting werd verhoogd van 250 naar  $400 \text{ kg N ha}^{-1}\text{jr}^{-1}$  dan nam de stikstofoutput slechts met 16 kg N toe. Zelfs bij een bemestingsniveau van slechts  $250 \text{ kg N ha}^{-1}\text{jr}^{-1}$  gaat ten minste 70% van alle toegediende stikstof verloren. In een beweidingssysteem met vleesvee zal dit verlies tenminste 90% zijn. Oorzaken van deze lage stikstofbenutting zijn een lage benutting van stikstof door herkauwers en een relatief geringe opname van stikstof uit mest en urine.

### **De stikstofhuishouding van beweid grasland**

De stikstofvoorziening in beweid grasland wordt pleksgewijze vergroot door de uitscheiding van mest en urine. Dit leidt tot zeer hoge lokale stikstofconcentraties: in urineplekken  $500 \text{ kg N ha}^{-1}$  en in mestplekken ongeveer  $2000 \text{ kg N ha}^{-1}$ . Een deel van deze stikstof vervluchtigt in de vorm van ammoniak. Uit metingen in de omweideproef op de kleigrond bleek bij een bemesting van  $250 \text{ kg N ha}^{-1}\text{jr}^{-1}$  ongeveer  $8 \text{ kg N ha}^{-1}$  te vervluchtigen en bij een bemesting van  $550 \text{ kg N ha}^{-1}\text{jr}^{-1}$  ongeveer  $40 \text{ kg N ha}^{-1}$ . Deze hoeveelheden komen overeen met respectievelijk ongeveer 3% en 8% van de totale hoeveelheid stikstof die in de vorm van mest en urine werd uitgescheiden door het weidende vee.

De urine trekt snel in de grond, zodat de ammoniakvervluchtiging relatief gering is. Er mag derhalve worden verwacht dat de produktiviteit van de zode toeneemt door de stikstof die wordt aangevoerd in de urine en mest. Wanneer de stikstofvoorraad in de bodem niet toereikend is voor maximale drogestofproduktie kan uitscheiding de grasgroei stimuleren (Hoofdstuk 5). Dit positief effect werd gevonden bij het laagste bemestingsniveau ( $250 \text{ kg N ha}^{-1}\text{jr}^{-1}$ ; Hoofdstukken 2, 3 en 5). In Hoofdstuk 5 wordt beschreven dat stikstof die in de vorm van mest en urine in juli op zandgrond werd toegediend een opbrengstverhoging gaf van  $440 \text{ kg drogestof per ha}$  bij een bemestingsniveau van  $250 \text{ kg N ha}^{-1}\text{jr}^{-1}$ . Bij een bemestingsniveau van  $400 \text{ kg N ha}^{-1}\text{jr}^{-1}$  was het effect van de mest en urine echter negatief ten gevolge van urineverbranding ( $-360 \text{ kg drogestof ha}^{-1}$ ). De urinebrandplekken waren aan het einde van het experiment, in het daarop volgende voorjaar, nog steeds zichtbaar. Hierdoor zal het stikstofeffect onder beweiding beduidend lager zijn dan onder maaien. Dit blijkt uit Hoofdstuk 3 waar op de zandgrond bij maaien een stikstofeffect werd gevonden tot een bemestingsniveau van  $550 \text{ kg N ha}^{-1}$  terwijl er bij beweiding nauwelijks sprake was van een effect bij een bemesting hoger dan  $250 \text{ kg N ha}^{-1}$ .

Anorganische stikstof uit urine wordt genitrificeerd, dit kan hoge lokale concentraties van nitraatstikstof tot gevolg hebben. Op de zandgrond werd in de beweidde percelen een stikstofuitspoeling gemeten die ongeveer het tweevoudige was van de uitspoeling onder gemaaide percelen. Op de kleigrond was de uitspoeling geringer. Om aan de kwaliteitseis van  $11,3 \text{ mg nitraat-N l}^{-1}$  te kunnen voldoen zal op de zandgrond de stikstofbemesting bij beweiding niet hoger mogen zijn dan maximaal  $250 \text{ kg N ha}^{-1}\text{jr}^{-1}$ . Op de kleigrond zal de input maximaal  $400 \text{ kg N ha}^{-1}\text{jr}^{-1}$  mogen zijn. De geringere uitspoeling op de kleigrond bij een vergelijkbaar stikstofniveau gaat samen met een hogere recovery, denitrificatie en immobilisatie van stikstof dan op de zandgrond. Bovendien gaat gedurende de winter minder stikstof uit het kleiprofiel verloren.

Het stikstofbemestingadvies voor grasland is nog steeds gebaseerd op economische overwegingen. De economische optimumgift is de gift waarbij de marginale opbrengst  $7,5 \text{ kg drogestof per kg stikstof}$  is. Tot voor kort waren de geadviseerde jaargiften  $400 \text{ kg N ha}^{-1}\text{jr}^{-1}$  voor zand-, klei- en natte veengronden en  $250 \text{ kg N ha}^{-1}\text{jr}^{-1}$  voor goed ontwaterde veengronden. Het verfijnde stikstofadviesstelsel dat in 1994 operationeel is geworden biedt mogelijkheden voor de nodige nuancering doch is nog primair gericht op

landbouwkundige doelstellingen.

In de nabije toekomst zullen veehouders echter in toenemende mate de bemesting zodanig moeten toedienen dat onacceptabele verliezen worden voorkomen door te streven naar zo weinig mogelijk anorganische stikstof in het profiel aan het einde van het groeiseizoen. Het vaststellen van de juiste hoeveelheid is echter niet eenvoudig en onder andere afhankelijk van het bodemtype en de weersomstandigheden. Op basis van deze milieukundige benadering bleek op de zandgrond (Hoofdstuk 3) de optimale stikstofgift bij beweiden ongeveer 200 kg lager te liggen dan de economisch optimale gift van 420 kg N ha<sup>-1</sup>jr<sup>-1</sup> bij maaien.

## DANKWOORD

Dit proefschrift is het resultaat van een onderzoek dat werd uitgevoerd op de Vakgroep Agronomie van de Landbouwniversiteit in Wageningen. Graag wil ik allen die op enigerlei wijze, zowel in woord als daad, hebben bijgedragen aan de totstandkoming ervan bedanken.

Mijn promotor, prof. dr. ir. L. 't Mannetje, dank ik voor zijn begeleiding, waardevolle suggesties en commentaren bij het samenstellen van dit proefschrift.

Naar mijn co-promotor, dr. ir. E.A. Lantinga, gaat erg veel dank uit. Zijn begeleiding was intensief, uiterst kritisch en stimulerend en verliep altijd in een goede sfeer.

Veel dank gaat ook naar drs. J.H. Neuteboom. Zijn commentaren en bijdragen aan dit proefschrift zijn erg waardevol.

H. Schlepers bedank ik voor de uiterst plezierige samenwerking en voor zijn niet aflatende inzet bij de vele waarnemingen en bepalingen gedurende het gehele onderzoek. Ook dank ik H. Halm voor het uitvoeren van de chemische bepalingen en K. Wind voor het tekenwerk en het omslagontwerp.

Ing. L. Mol en zijn personeel van de proefaccommodatie van de Vakgroep Agronomie en ing. J. Overvest en zijn personeel van de ir. A.P. Minderhoudhoeve te Swifterbant dank ik voor de hulp bij het aanleggen en het uitvoeren van de veldproeven. Een bijzonder woord van dank gaat naar T. Bleijenberg, bedrijfsleider van 'De Meenthoeve' te Achterberg.

Dank gaat naar de volgende studenten en stagiair(e)s die een bijdrage aan het onderzoek hebben geleverd: J. Heeres, A. Seignette, M. Hagg, C. de Groot, L. van den Broek, G. Ruitenbergh, R. Heida, J. Panman, G. Schaaf, P. van Dinther, M. Helmus, D. Lennips, J. Kroeze, M. Weenink, L. Lufting, P. de Groot, S. Kooistra H. Stegenga, M. Geelen, N. Middelkoop, K. Bouwknecht.

I am grateful to dr. Rimanthas Dapkus (Lituania) for his invaluable help.

Tot slot dank ik mijn ouders die mij de kans hebben geboden om aan de landbouwniversiteit te studeren. En als laatste maar zeker niet in het minste, gaat bijzonder veel dank uit naar Lea, Ingmar, Cristian en Harald die jaren hebben moeten samenleven met een echtgenoot en vader die zijn proefschrift bijna afhad.

## Curriculum vitae

Piet Deenen werd geboren op 30 juli 1956 op de ouderlijke boerderij in het Noordbrabantse Vierlingsbeek. Hij volgde de VWO-opleiding aan het Elzendaalcollege te Boxmeer en haalde in 1975 het eindexamen. In datzelfde jaar begon hij met de studie Landbouwplantenteelt aan de toenmalige Landbouwhogeschool te Wageningen. In 1981 was hij gedurende een jaar aangesteld als wetenschappelijk assistent aan de Zweedse Landbouwuniversiteit in Uppsala. Vanaf augustus 1982 werkte hij voor een periode van drie en een half jaar als leraar aan de Middelbaar Agrarische Scholen in Oss, Cuijk en Helmond. Het ingenieursdiploma met als doctoraalvakken Graslandkunde, Bodemkunde en Bemestingsleer, en Algemene Agrarische Economie werd in 1984 behaald. Gedurende de periode 1986-1990 was hij werkzaam als promotie-assistent bij de Vakgroep Landbouwplantenteelt en Graslandkunde van de Landbouwuniversiteit in Wageningen waar het onderzoek voor dit proefschrift werd uitgevoerd. Vanaf 1990 is hij projectleider van de Stuurgroep Landbouw en Milieu (LAMI) in Noord-Brabant. LAMI is een privaatspublieke organisatie waarin overheid en bedrijfsleven samenwerken aan oplossingen voor de milieuproblematiek in de landbouw.