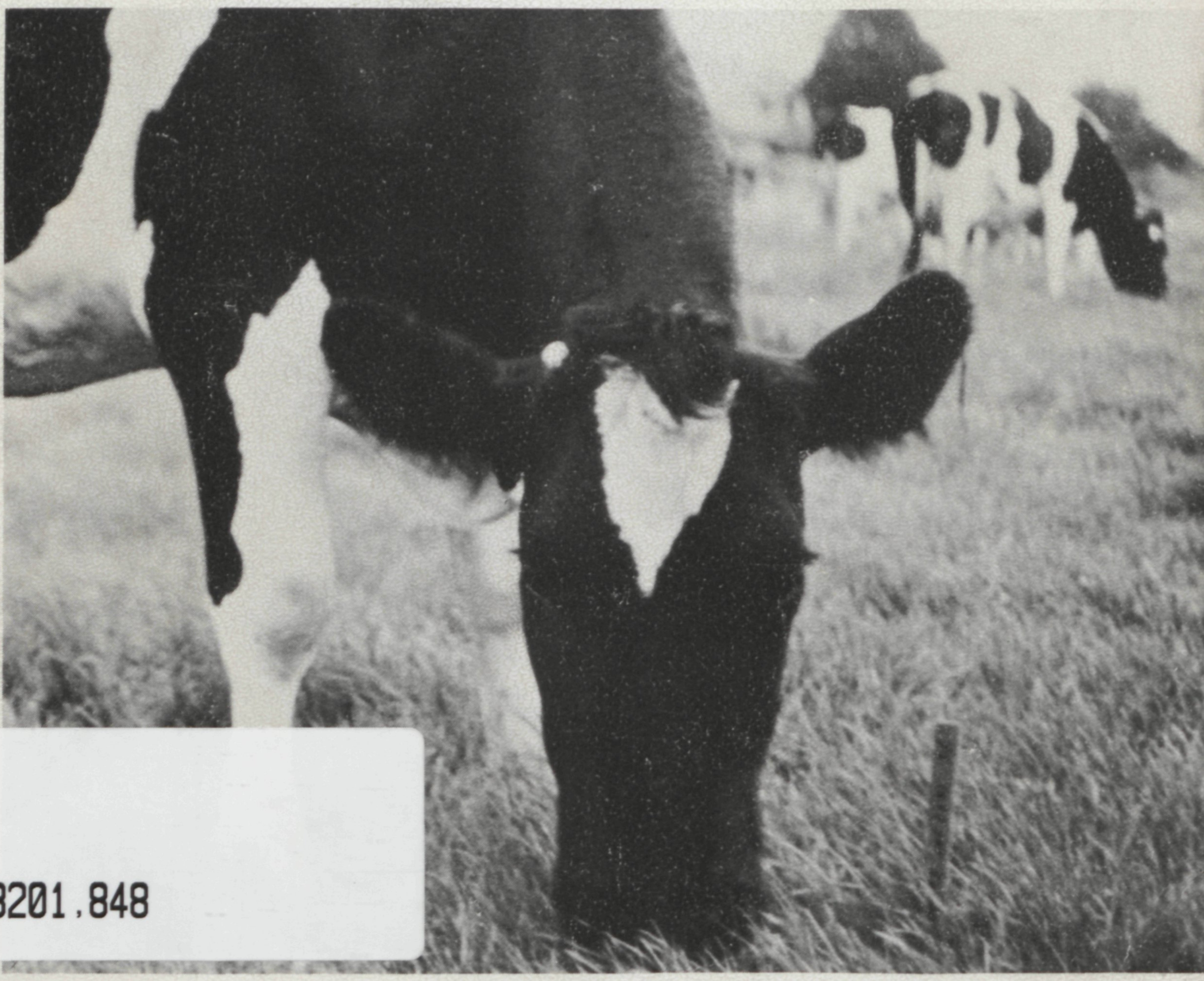
nn 8201 07840 C

Herbage intake by grazing dairy cows

J.A.C. Meijs



Abstract

Meijs, J.A.C. (1981). Herbage intake by grazing dairy cows. Agric. Res. Rep. (Versl. landbouwk. Onderz.) 909. Pudoc, Wageningen. ISBN 90 220 0764 2, (xvi) + 264 p., 78 tbs, 11 figs, 481 refs, Eng. and Dutch summaries, 15 appendices.
Also: Doctoral thesis, Wageningen.

An extensive review of the literature is given of
- nine possible methods for estimating herbage intake by grazing ruminants, with special attention to the sward-cutting and indirect animal methods
- the factors determining the herbage intake by grazing ruminants.

The herbage intake of lactating cows was determined in 151 trials at Lelystad from 1976 to 1979. The pre-cut swards consisted predominantly of perennial ryegrass. A sward-sampling technique was used for estimating herbage intake by cows grazing swards for 3 or 4 days (with corrections for herbage accumulation during grazing). If herbage samples were cut both with a motor scythe and a lawn-mower accurate intake figures could be obtained.

It was shown that there were no significant effects of higher levels of areic mass of herbage (by taking longer rest periods) on daily organic matter intake of herbage neither by grazing nor by stall-fed cows. However in early summer daily intake of nutrients and milk production decreased at increasing maturity; in late summer these effects were not significant. Higher levels of daily herbage allowance had significant positive effects on daily intake of organic matter of nutrients from herbage and on daily milk production per grazing animal. High amounts of residual herbage (achieved by higher levels of daily herbage allowance) increased net regrowth of herbage, especially in early summer.

At a mean allowance level of 23 kg d^{-1} above 4.5 cm our grazing cows consumed 13.6-14.8 kg d^{-1} of organic matter if no concentrates were fed. This was sufficient, at the quality of herbage as in our trials, for a daily 4%-fat corrected milk production of 22-23 kg.

Free descriptors: herbage consumption, efficiency of grazing, herbage accumulation, herbage allowance, stage of maturity, herbage mass, rest period, regrowth, perennial ryegrass, sward cutting, sward sampling, zero grazing, digestibility, milk production, nutrient balance.

foto-omslag: J. Keuning - M. Mulder

This thesis will also be published as Agricultural Research Reports 909.

Stellingen

1. Bij een hoger grasaanbod per dier per dag neemt bij afwisselend weiden en maaien van een perceel grasland zowel de dagelijkse grasopname per koe als de grasopname per oppervlakte toe.

Dit proefschrift.

2. In tegenstelling tot de conclusie van Hodgson hebben hogere grasopbrengsten bij een verouderend, voorafgaand gemaaid gewas geen duidelijk negatief effect op de organische-stofopname per koe per dag, indien de verteerbaarheid van de organische stof van het opgenomen gras hoger is dan 70%.

Hodgson, J., 1977. Factors limiting herbage intake by the grazing animal. Proc. Int. Meeting on Anim. Prod. from Temp. Grassl., Dublin p. 70.
Dit proefschrift.

3. Bij de weidende melkkoe, gehouden onder de huidige Nederlandse bedrijfsomstandigheden, kan niet van ad libitum opname van gras worden gesproken.

Dit proefschrift.

4. De term voederwaarde zou slechts gebruikt moeten worden voor het gehalte aan nutriënten in een voedermiddel en niet voor de opname aan nutriënten van dat voedermiddel.

Zemmelink, G., 1980. Effect of selective consumption on voluntary intake and digestibility of tropical forages. Agric. Res. Rep. 896. Pudoc, Wageningen.
Rijpkema, Y.S., B. Smits & A. Steg, 1975. Onderzoekingen aan neven- en afvalprodukten bij herkauwers en varkens. Bedrijfsontw. 6:143.

5. Bij studies naar de rentabiliteit van het voeren van krachtvoer bij beweiding dient er rekening mee te worden gehouden, dat de verdringing van gras door krachtvoer waarschijnlijk toeneemt bij een hoger grasaanbod per dier per dag.

Young, N.E., G.E. Newton & R.J. Orr, 1980. The effect of a cereal supplement during early lactation on the performance and intake of ewes grazing perennial ryegrass at three stocking rates. Grass & Forage Sci. 35:197.

6. Het voornemen van de Europese Gemeenschap om declaratie van de energiewaarde van mengvoeders te verlangen, controleerbaar met eenvoudige analytische methoden, is voor Nederland ongewenst.

Härtel, H., W. Schneider, R. Seibold & H.J. Lantzsch, 1977. Beziehungen zwischen der N-korrigierten umsetzbaren Energie und den nährstoffgehalten des Futters beim Huhn. Arch. Geflügelk. 41:152.
Donselaar, B. van & A. Steg, 1980. Voederwaardebepaling en voederwaardeberekening van mengvoer voor melkvee. Rapport nr. 132 I.V.V.O.

7. Bij herhaalde beweiding van percelen grasland onderschatten Harkess et al. de efficiëntie van de grasopname sterk door de grasopname per oppervlakte te delen door de bruto grasopbrengst in plaats van door de bruto grasproduktie per oppervlakte.

Harkess, R.D., J. de Bassita & I.A. Dickson, 1972. A portable corral technique for measuring the effect of grazing intensity on yield, quality and intake of herbage. J. Br. Grassld. Soc. 27:145.

8. Het ad libitum voeren van mestvarkens heeft tegenover arbeidstechnische voordelen niet te onderschatten nadelen voor de kwaliteit van het dierlijk produkt en voor de efficiëntie waarmee voer in vlees wordt omgezet.

Metz, S.H.M., P.L. Bergström, N.P. Lenis, M. de Wijs & R.A. Dekker, 1980. The effect of daily energy intake on growth rate and composition of weight gain in pigs. Livestock Prod. Sci. 7:79.

9. Bij de interpretatie van de grasopname en dierlijke produktie op verschillende graslanden, dient meer rekening te worden gehouden met de gestratificeerde grasopbrengsten (kg ha^{-1} cm^{-1}).

Chacon, E.A., T.H. Stobbs & M.B. Dale, 1978. Influence of sward characteristics on grazing behaviour and growth of Hereford steers grazing tropical grass pastures. Austr. J. Agric. Res. 29:89.

10. Tegen de achtergrond van de volksspreuk 'Elk pondje gaat door het mondje' is het verbazingwekkend dat er energiebalansproeven met mensen nodig zijn om de consument ervan te overtuigen dat minder eten de beste manier is om af te vallen.

11. De mogelijkheid om de grasopname door weidend rundvee met behulp van een telemetrische diergewichtsregistratie nauwkeurig te meten is door Horn & Miller overschat.

Horn, F.P. & G.E. Miller, 1979. Bovine boots - a new research tool. Animal Science Research Report, Oklahoma State University and USDA. p. 44.

12. Tijdens het verblijf van jonge kinderen in een ziekenhuis dienen ouders onbeperkt toegang tot hen te krijgen.

Robertson, J., 1979. Jonge kinderen in het ziekenhuis. Kooyker, Rotterdam.

13. Het dierlijk welzijn moet niet zo vereenzelvigd worden met het menselijk welzijn dat proefdieren beter gehuisvest worden dan proefnemers.

14. Ten behoeve van een meer gevarieerd modebeeld is het wenselijk om de confectieindustrie op een kleinschaliger leest te schoeien.

Proefschrift van J.A.C. Meijs
Herbage intake by grazing dairy cows
Wageningen, 3 juni 1981.

Aan Angelie, Bas en Koen

Voorwoord

Bij het gereedkomen van dit proefschrift realiseer ik mij dat velen, direct of indirect, hebben bijgedragen tot het uiteindelijke resultaat. Het zou te ver voeren allen hier persoonlijk te bedanken, maar een aantal wil ik graag met name noemen.

Het onderzoek werd uitgevoerd op het Instituut voor Veevoedingsonderzoek te Lelystad. De directeur, ir. F. de Boer, ben ik zeer erkentelijk voor de outillage en mankracht die ik voor dit onderzoek mocht gebruiken en voor de mij geboden gelegenheid om aan dit proefschrift te werken binnen het kader van een onderzoekproject van het instituut.

Prof. ir. M.L. 't Hart en prof. dr. ir. A.J.H. van Es, mijn promotoren dank ik in het bijzonder voor de stimulerende begeleiding bij het grasopname onderzoek. Voor de discussies omtrent opzet van proeven en de interpretatie van de resultaten, alsmede de waardevolle kritiek en suggesties bij het samenstellen van het proefschrift ben ik hen zeer erkentelijk.

De warme belangstelling voor mijn onderzoek en de betrokkenheid bij de voorbereiding van dit proefschrift van mijn afdelingshoofd dr. ir. Y.S. Rijpkema heb ik zeer gewaardeerd. Ir. A. Steg en dr. Y.L.P. Le Du ben ik veel dank verschuldigd voor hun waardevolle commentaar op het manuscript. Mijn erkentelijkheid gaat verder in het bijzonder uit naar ir. A. Keen, voor zijn uitstekende statistische begeleiding van het gehele onderzoek en zijn waardevolle suggesties bij het samenstellen van het manuscript.

Grasopname onderzoek met weidende koeien is slechts mogelijk in teamverband. Voor een goede uitvoering van de proeven zorgden ing. L. van Reeuwijk, H.J. Wentink en een grote groep studenten van Hogere Agrarische Scholen en de Landbouwhogeschool; hartelijk dank voor jullie enorme inzet, zelfs onder extreme weersomstandigheden. De bedrijfsleiders, achtereenvolgens de heren ing. N. Kingma en ing. R. Radersma, en alle medewerkers van de proefboerderij stonden met hun inzet borg voor een goede verzorging van de proefdieren en het tijdig beschikbaar zijn van het proefvoer. De samenwerking met de andere medewerkers aan de proeven was zeer goed en heeft bijgedragen tot een plezierige werksfeer. De medewerkers van de afdeling monstervoorbereiding en van het Weende laboratorium onder leiding van A. Nijenhuis slaagden erin om de talrijke grasmonsters goed te bewerken en te analyseren.

Het concept manuscript werd nauwgezet getypt door mevr. B. de Bruin-Marsh, mevr. H.J.W. Jezuit-Lohmeyer, mevr. C.J. Rijpert-de Jongh en mej. S. Vink. Het typewerk voor het definitieve manuscript werd in korte tijd op uitstekende wijze verzorgd door mej. S. Vink. De duidelijke grafieken werden getekend door ing. B. van Donselaar.

De publikatie van dit verslag werd verzorgd door de heer J. Castelein (Pudoc). De Engelse tekst werd in korte tijd gecorrigeerd door de heer I.R.C. Cressie (Pudoc).

Veel dank ben ik verschuldigd aan mijn ouders, die mij tot verdere studie stimuleerden.

In het bijzonder bewonder ik mijn vrouw en kinderen die het zovele uren als het ware zonder man en vader moesten stellen. De liefde en de morele steun van mijn vrouw zijn voor dit werk onontbeerlijk geweest.

Tenslotte betuig ik gaarne mijn dank aan allen die door hun hulp of belangstelling een bijdrage hebben geleverd aan het tot stand komen van dit proefschrift.

Curriculum vitae

De auteur van dit proefschrift werd op 12 november 1952 geboren te Raamsdonk. Na het behalen van het einddiploma H.B.S.-B aan de John F. Kennedy H.B.S. te Dongen in 1970, werd in september van dat jaar begonnen met een studie aan de Landbouwhogeschool in Wageningen. Hij studeerde af in juni 1975 in de studierichting Zoötechniek, met als hoofdvak Veevoeding en als keuzevakken Fysiologie der huisdieren, de Leer van het grasland en de Pluimveeteelt. Vanaf 18 augustus 1975 is hij als wetenschappelijk ambtenaar werkzaam bij het Instituut voor Veevoedingsonderzoek te Lelystad met als opdracht het onderzoek naar de opname en benutting van gras door herkauwers.

Contents

Symbols, abbreviations and names of quantities

General symbols and abbreviations

n	= number of sample units
x	= value of a sample unit
$\bar{x}$	= sample mean (sample = totality of sampling units under consideration)
s_x	= standard deviation of x = $\sqrt{\Sigma(x - \bar{x})^2/(n-1)}$
$s_{\bar{x}}$	= standard deviation of $\bar{x}$ = $s_x/\sqrt{n}$
CV_x	= coefficient of variation of x = $s_x/\bar{x}$
$CV_{\bar{x}}$	= coefficient of variation of $\bar{x}$ = $s_{\bar{x}}/\bar{x}$
df	= degrees of freedom
P	= probability (* $0.025 < P \leq 0.05$ ** $0.01 < P \leq 0.025$ *** $P \leq 0.01$)
n.s.	= not significant ($P > 0.05$)
r	= correlation coefficient
a,b,c,	= estimates of regression coefficients (with a the estimate of the intercept)
RSD	= residual standard deviation from regression
PP	= preliminary period
EP	= experimental period
Se	= season
es	= early summer
ls	= late summer
lm	= lawn-mower
ms	= motor scythe
W	= live weight, mass of animal
FCM	= fat corrected milk [mass fraction of fat 4% = (0.4 + 0.15 fat %)L]
VEM	= Dutch feed unit (net energy for lactation)
G	= group (of animals)

Principal symbols for quantities

The nomenclature for quantities is based on proposals made for grazing, energy metabolism and chemical studies (Hodgson, 1979; Blaxter et al., 1973 and Rigg & Visser, 1979, respectively).

Symbols without subscript represent the total mass; symbols can also be used with any subscript to represent a component. The first term is that usually used in the text and then after a colon the complete strict term is given. Indications of cutting height (necessary when herbage masses and allowances are reported) are given in the text.

In the tables quantities are all expressed in the units mentioned here.

Symbol	Name of quantity	units[1]
S	area grazed, surface area	ha
N	number of animals	1
m	mass	kg
t	time, length of (grazing or growing) period	d (= day)
h	height of the sward at start of a grazing period	cm
h^f	height of the sward at finish of a grazing period	cm
H	height of the stubble at start of a grazing period	cm
H^f	height of the stubble at finish of a grazing period	cm
ΔH	difference in stubble height between start and finish of a grazing period = $H - H^f$	cm
M	areic[2] mass of herbage or herbage mass, total mass of herbage divided by area of ground at start of a grazing period = m/S	kg ha^{-1}
M^e	areic mass of herbage in exclosure (in an area not grazed)	kg ha^{-1}
M^f	(areic mass of) residual herbage, total mass of herbage divided by area of ground at finish of a grazing period = m/S	kg ha^{-1}
$M^{f,e}$	(areic mass of) residual herbage in exclosure (in an area not grazed)	kg ha^{-1}
ΔM^e	herbage accumulation in exclosure, change in total areic mass of herbage during a grazing period in exclosure (= difference between growth of new plant material and losses due to senescence and decomposition) = $M^{f,e} - M^e$	kg ha^{-1}
$\Delta_t M^e$	rate of herbage accumulation in exclosure = $\Delta M^e/t$	kg ha^{-1} d^{-1}
ΔM	change in total areic mass of herbage during a grazing period = $M - M^f$ (not corrected for herbage accumulation during the grazing period)	kg ha^{-1}
C	areic consumption of herbage, the total areic mass of herbage removed by animals during a grazing period = $\Delta M + g\ \Delta M^e$	kg ha^{-1}
ΔM_i^r	herbage accumulation during regrowth after period i, change in total areic mass of herbage, during rest period between grazings = $M_{i+1} - M_i^f$	kg ha^{-1}
$\Delta_t M^r$	rate of herbage accumulation during regrowth = $\Delta M^r/t$	kg ha^{-1} d^{-1}
A	daily herbage allowance, rate of offering total herbage mass per animal = $(M + g\ \Delta M^e)\ S/N\ t$	kg d^{-1}
R	daily herbage residue, rate of refusal of total herbage mass per animal	kg d^{-1}
I	daily herbage intake, rate of consumption of total herbage mass per animal = C S/N t = A - R	kg d^{-1}
F	daily faecal production, rate of excretion of faeces per animal	kg d^{-1}
D	daily intake of digestible herbage, rate of digestion of herbage per animal = I - F	kg d^{-1}
L	daily milk production, rate of excretion of milk per animal	kg d^{-1}

K	daily nutrient requirement, rate of requirement of nutrients for maintenance and production per animal	$kg\ d^{-1}$

1. When the subscripts E, ME or NE are used the units are $J\ ha^{-1}$ or $J\ d^{-1}$.
2. Areic = divided by area.

Subscripts

i = indication of period

B = general indicator of a component e.g. T, O, N

T = dry matter

O = organic matter

N = nitrogen

XP = crude protein (usually 6.25N)

XL = crude lipid

XF = crude fibre

NDF = neutral detergent fibre

E = combustible energy

ME = metabolizable energy

NE = net energy

dO = digestible organic matter

dXP = digestible crude protein

Dimensionless ratios

g = mass fraction of accumulated herbage in exclosure that was accumulated in the grazed area

c = degree of consumption (grazing or cutting), fraction of (areic) mass of herbage that was consumed (for a single defoliation) = $C/(M + g\ \Delta M^e) = I/A$

u = efficiency of consumption (grazing or cutting), fraction of total accumulated herbage mass that was consumed (for a series of n defoliations) =

$$\sum_{i=1}^{n} C / \sum_{i=1}^{n} (\Delta M^r + g\ \Delta M^e)$$

d = (apparent) digestibility, mass fraction of consumed herbage that was apparently digested = D/I

k = degree of nutrient balance, fraction of nutrient requirement that was consumed = I/K

Expression of contents

$w_B/$ = mass fraction or content of a component (dimensionless), for example: w_N/T content of nitrogen in dry matter

e/ = energy content, specific energy ($J\ kg^{-1}$ or $VEM\ kg^{-1}$) for example: e_{NE}/O = content of net energy in organic matter

1 VEM = 1.650 kcal = 6.904 kJ

Introduction

It has been estimated that 65% of the agricultural land in the world consists of temporary and permanent pastures, most of which are grazed by animals (FAO, 1978). In the Netherlands this percentage is about 60 (Landbouwcijfers, 1978). Herbage i.e. the total vegetation of herbaceous plants (grasses, legumes and herbs) in pastures, cannot be consumed directly by humans since little of it can be digested by man. Herbage cell walls, especially in warmer climates, contain much cellulose and hemicellulose. The digestive system of man lacks cellulase and hemicellulase, essential enzymes for the digestion of cellulose and hemicellulose. The micro organisms in the fore-stomach of ruminants, however, produce cellulase and hemicellulase, which can convert a part of the herbage cell walls into substances which are valuable for the ruminant and also make the herbage cell contents more accessible for the digestive enzymes of the host. So, ruminants can convert herbage of little direct value to man into animal products of a high nutritive quality for human consumption.

To meet the rising demands for human food it seems useful to give priority to trying to increase the productivity of grassland because its area is so large. Production of human food per unit area from arable crops (of which a much larger part is directly consumable for humans) is superior in terms of efficiency to any form of animal production (Holmes, 1970; Van Es, 1979). However arable crops are often no alternative to grassland because the soil condition (unploughable land, high water level e.g. on peaty soils) or climatic conditions limit the production of arable crops or because economic reasons make it more profitable for the farmer to use grassland rather than arable crops.

The importance of grassland in ruminant livestock production in the Netherlands is clearly shown in a report (Landbouwcijfers, 1978) which indicates that herbage and grassland products (hay, silage) supply approximately 63% of the annual net energy requirements of cattle and sheep. Grazing remains the major method of utilization of grassland although its precise contribution is difficult to quantify. From figures of Landbouwcijfers (1978) it can be estimated that 38% of the net energy requirements of cattle and sheep were supplied by fresh herbage (= 60% of energy supply by all grassland products). Other possible ways of utilization of grassland are harvesting the herbage and feeding it in the stall as such (zero grazing) or after preservation (as hay or silage). The main purpose of grassland research is to find the optimal combination of ways of grassland utilization for maximal animal production per area.

Figure 1 shows the various losses of energy which occur during the conversion of the accumulated herbage into animal product when a pasture is grazed by dairy cows. Herbage accumulation is the difference between the growth of new plant material and

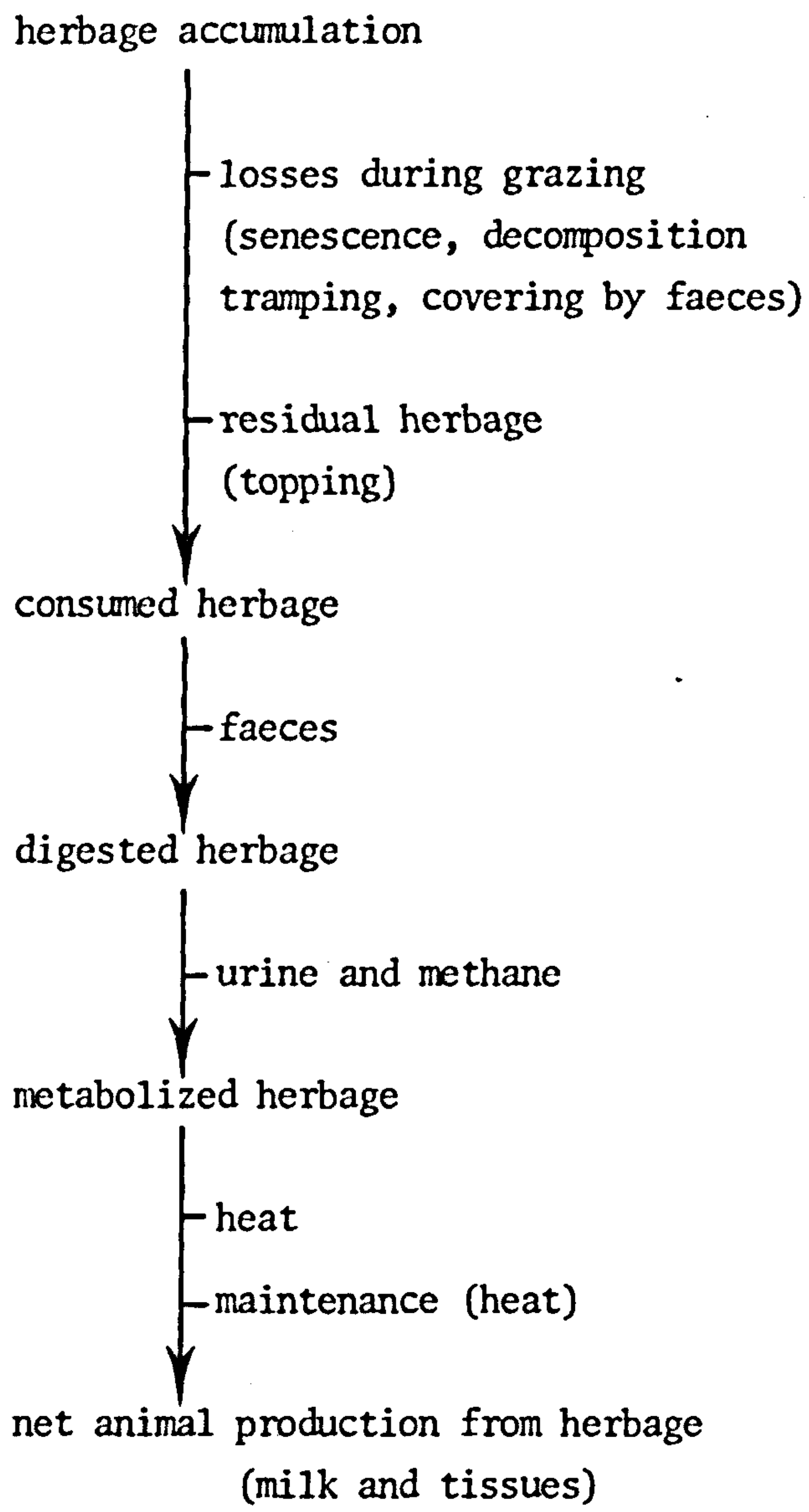


Figure 1. Sources of energy loss in the utilization of grazed pasture by dairy cows.

losses due to senescence and decomposition and to removal by non-agricultural consumers. These losses which occur during sward development are also effective during the grazing period. Animal effects such as trampling and contamination by faeces during the grazing period make a part of the consumable herbage unavailable to the animal; this part possibly decays. The residual herbage (herbage mass at the end of grazing) can partly be used in succeeding grazing periods. Part of the residual herbage can be considered as lost when it is topped by mechanical harvesting and thrown away.

Part of the energy in the herbage ingested by the animal is lost as energy in faeces, urine and methane. Subtraction of these losses from the ingested herbage gives the metabolizable energy (ME) which is converted in heat and energy in animal products. Of the various energy losses the most important one within the animal is heat. Part of this represents energy that is needed for maintenance. The remainder arises from inefficiency in the use of ME for either maintenance or production of milk and tissues. The efficiency of utilization of ME for maintenance and for production of milk appears not to vary much (Blaxter, 1974; Van Es, 1975).

Losses of energy with urine and methane are relatively small. Losses with faeces are greater and also more variable as they are related to digestibility and this can vary considerably in relation to intake, herbage species, climate and stage of maturity. When the composition and the digestibility of herbage are known the gross efficiency of conversion of ingested herbage into animal product can be predicted with a reasonable accuracy as is done in several energetic feeding systems for dairy cows. Highest efficiencies were obtained at a high level of milk production because so the inevitable maintenance costs are diluted most. To sustain such levels of milk production over long periods a high intake of digestible nutrients is necessary. Therefore, herbage consumption per animal per day and herbage quality (chemical composition and digestibility) are the most important links between herbage accumulation and animal production. Knowledge of basic pasture data such as accumulation, consumption and digestion are necessary in order to understand pathways of herbage use and to improve efficiency of utilization of herbage for animal production.

Apart from digestibility, the efficiency of consumption of accumulated herbage into consumed herbage seems very important when comparing different ways of grassland utilization. When herbage is preserved losses occur in the field, during preservation and during the feeding to animals (mechanical losses, leaching, respiration, fermentation and residues). If herbage is supplied fresh, losses in the stall (residues) are the most important. For a single defoliation the fraction of areic mass of herbage that was consumed by grazing animals may be comparable to that of stall-fed animals fed with conserved herbage while this fraction may be higher when fresh herbage is fed as such to stall-fed animals (Greenhalgh, 1978). However the need to commit men and machinery daily and the energetic cost for harvesting the herbage and for returning the excreta of animals have been arguments against zero grazing. For a series of defoliations the comparison between ways of grassland utilization is more difficult to make because the residual herbage after grazing possibly influences herbage accumulation in the regrowth period and because part of the residues can be utilized in succeeding grazing periods while an other part of it decays. For this thesis some of the factors, influencing the efficiency of consumption of accumulated herbage into consumed herbage for a single defoliation of pastures by grazing, were studied.

The aim of a high efficiency of grazing (herbage consumed as a proportion of the herbage accumulated) does not always correspond with the aim of an optimal nutrition of the individual animal. The number of animal-days per unit area and thus the herbage allowance play an important role in the relationships between herbage consumption per unit area and herbage consumption per animal. The aim of grazing management should be to find the optimum between production of milk and tissues per animal and production per unit area. Because animal production is largely dependant on intake of digestible nutrients an optimum between consumption of digestible herbage per animal and consumption of digestible herbage per unit area should be achieved in grazing management.

Little information is available on the factors affecting the herbage intake of grazing animals, particularly for the grazing systems which do not involve daily change of animals to a new pasture. It is therefore difficult to make rational decisions about potential improvements in methods of grazing management. The paucity of information appears to be due largely to the laborious nature and doubtful accuracy of the methods used to measure herbage intake under grazing conditions; another reason probably is the complexity of factors regulating herbage intake. The work described in this thesis was therefore undertaken with two purposes in mind:

- To study some of the factors influencing herbage intake of grazing animals
- To study the potential errors in the existing techniques for measuring herbage intake of grazing animals with a view to establishing a method which was acceptable as to accuracy and simplicity.

I Review of the literature

1 Techniques for estimating herbage intake of grazing ruminants

1.1 INTRODUCTION

Several types of technique have been used to measure the herbage intake of grazing animals.

In sward methods the quantity of herbage present on a pasture is measured. The difference between herbage at the start of a grazing period and at the end of it is taken to represent the total intake of the animals. The quantity of herbage present on a pasture can be measured by mechanical (destructive) means or by electronic or visual (non-destructive) means, or by a combination of these. The non-destructive techniques have been described by 't Mannetje (1978) and will not be considered here. The destructive sward methods will be discussed in Section 1.2.

In indirect animal methods the quantity of organic matter in the faeces in a given period and the apparent digestibility (d) of the organic matter of the herbage consumed is determined. The intake is calculated by dividing the faecal production by the indigestibility (1-d). These indirect techniques are described in Section 1.3 and can be divided in:

- marker-ratio techniques: calculation of digestibility from the relative contents of a naturally-occurring indigestible marker in samples of herbage grazed and in samples of faeces.
- faecal-index techniques: prediction of digestibility from the composition of the faeces.
- techniques using fistulated animals: estimation of digestibility with in-vivo or in-vitro methods in samples actually being selected by the animals.

Most information in the literature on techniques for measuring herbage intake deals with the sward cutting and indirect animal techniques. In Section 1.4 some alternative procedures of estimating intake will be described that have received little attention yet because they were developed only recently, or due to their low precision:

- grazing-behaviour methods: measurement of the number of eating bites during the grazing period and the average size of each bite.
- live-weight methods: determination of short-term changes in live weight during grazing periods with corrections for changes in live weight not due to herbage consumption.
- water-intake method: estimation of the water requirements of the animals, the liquid water drunk and the water content of the herbage consumed.
- animal-production methods: estimation of the energy requirements of the animal (which are derived from measurements of animal production) and the energy content of the consumed herbage.

- isotope techniques: measurement of the rate of depletion of an isotope in the body of an animal when it does not receive that isotope in its feed or water.

1.2 SWARD-CUTTING TECHNIQUES

1.2.1 Introduction

The sward-cutting technique is based on the same principle of the difference trial as most intake experiments indoors:

herbage intake = herbage offered - herbage left.

A measured proportion of the area of pasture allotted to the animal is harvested and the total weights of various constituents offered for grazing can be calculated. The residues after grazing are determined in a similar manner. The difference between these two herbage masses gives an estimate of the quantity and quality of the herbage consumed in the area grazed. As the herbage may also grow during the grazing period some correction has to be applied. The total intake in the grazed pasture can be transformed to the rate of consumption of herbage mass per animal when the number of grazing days and the number of animals are known.

Pasture sampling methods can provide intake data on an individual-animal basis. However to obtain a normal (group)-grazing behaviour and to reduce the labour requirement such intake studies are usually done with groups of animals. One of the advantages of the technique is the possible combination of information on herbage mass, herbage allowance, herbage quality, herbage intake and efficiency of herbage utilization without extra labour investment.

The potential for the sward-cutting technique to provide reliable intake estimates depends on:
- the ability to cut to a reproducible height: the material left after sample cutting at the start and at the end of the grazing period should be comparable. These heights of cutting should be deep enough to avoid eating below cutting height by the grazing animals and to collect all trampled herbage during grazing (1.2.2)
- the accuracy of the estimation of herbage accumulation during the grazing period (1.2.3)
- the precision of the intake estimate (1.2.5) depending on the variability of the pasture, on the way the samples before and after grazing are taken and on their number and size (1.2.4).

1.2.2 Cutting machinery, in relation to cutting height

Many methods have been suggested for estimating areic mass of herbage. The equipment used for cutting herbage samples is reviewed by Brown (1954), Davison (1959), C.A.B. (1961), Carter (1962) and 't Mannetje (1978). The choice of machinery is related to the height of cutting, which has to be controllable.

1.2.2.1 Cutting close to ground level

The total biomass above ground can be estimated with hand-held equipment. The simplest harvesting devices are hand-operated tools, such as shears, scissors and knives. These require a high labour input but have the advantage, that height of cutting (zero level) can be accurately controlled especially when rough or trampled areas are harvested ('t Mannetje, 1978). However differences can exist in the choice of ground level between persons, so pre- and post-grazing strips should be cut by the same person.

Hand-held power-driven tools can be used, for example hedge trimmers and sheep-shearing hand pieces. The disadvantage of hedge trimmers is that they cannot be equipped with collecting trays ('t Mannetje, 1978). Tarpen hedge trimmers (cutting width 30 cm) cut at a height of about 1.2 cm and possibly over estimate areic mass of residual herbage (Alder & Minson, 1963). The hedge trimmer requires very frequent overhaul and replacement of cutter-bar assemblies (C.A.B., 1961).

It appears to be less difficult to maintain the sheep-shearer head in good cutting order, and because of the smaller scale of its components it is capable of cutting closer to ground level than the hedge trimmer. These cutting tools have a minimum width of 8 cm, giving more problems to achieve the zero level than the hand-powdered equipment. On rough or trampled areas this zero level will not be reached, but herbage will be cut as close to ground level as possible (Walters & Evans, 1979). Hardy et al. (1978) reached a cutting height of 1-3 cm with a sheep-shearer, showing the variable cutting conditions.

With this technique no herbage can be consumed below the cutting level. It seems possible to reach a comparable cutting height and stubble mass (approximately zero) at the start and at the end of the grazing period when hand-powered equipment is used requiring a lot of labour. However in grazed rough or trampled areas it is difficult to cut to a reproducible height with the sheep-shearing head and in short, dense swards losses can occur in recovering post-grazing samples if herbage with a prostrate habit of growth was used (Walters & Evans, 1979).

The disadvantages of this cutting level are:

- damage to the grass sward
- high contamination of the samples with soil
- comparison with the herbage mass cut at a stubble level for winter feed (about 5 cm) is difficult; such herbage masses may be needed when whole season yields are to be calculated.

1.2.2.2 Cutting above ground level

The major reason for the development of machinery for sampling above ground level has been to reduce the labour requirement involved in sward sampling. Power-driven equipment, except sheep-shearing hand pieces, cannot cut to ground level.

A motor scythe is often used for measuring crops at stubble heights used in practice. Such machines usually cut at a height of 4-5 cm and vary in finger bar width from 60 to 120 cm. The advantages of this method are:

- the large area sampled in a relatively short time
- minimal damage to the grass sward
- minimal contamination with soil
- comparability of herbage mass with herbage cut for conservation.

Possible disadvantages of this technique are:

- uptake of herbage below the cutting height by the animals (especially sheep) during the grazing period
- difficulty of keeping the stubble height and stubble mass precisely at the intended height and comparable between the start and the end of the grazing period due to the influence of weather, faecal contamination or trampling of herbage into the stubble.

Holmes et al. (1950) and Castle (1953) used a motor scythe with a stubble height of approximately 5 cm; Davison (1959) reached a stubble height of 2.5-4 cm with the same machine. Details of measurement of stubble height are not given by these authors. Kleter (1975) cut at an average height of 4 cm with a motor mower. The stubble height after cutting in one direction was 4.5 cm; to reduce this height he mowed each strip a second time in the opposite direction and reached the 4 cm level. A problem with this technique, especially when grazing residues are cut, is to mow the second time exactly the same area. At the end of grazing Holmes et al. (1950) combined the herbage mass cut with a motor mower at 5 cm in strips of 13.9 m^2 with the herbage mass of 3 hand-cut samples in each strip of 0.89 m^2 with a cutting height of 1.2 cm.

There is very little quantitative information regarding the possible disadvantages when using cutting heights above ground level. The cutting level at the end of the grazing period was higher than at the start of it when a motor scythe was used; however when a lawn-mower was used to cut the total material these cutting heights were comparable (Hardy et al., 1978). Losses of herbage during cutting the total herbage mass was the biggest problem when lawn-mowers were used (Hardy et al., 1978). There is no quantitative information on comparability of stubble masses at the start and the end of grazing periods when motor scythes or lawn-mowers are used.

1.2.3 Herbage accumulation during the grazing period

The sward-cutting technique is most satisfactory when the grazing period is short and relatively large amounts of material are eaten per unit area during the period. In this case herbage accumulation during the period of grazing is negligible in relation to the amount of herbage eaten. These conditions are met where pastures are grazed for one day. When the animals enter the field in the afternoon and much grass is eaten soon after entry, the herbage growth during grazing is often neglected for the strip grazing system (Holmes et al., 1950; Castle, 1953; Davison, 1959; Corbett & Greenhalgh, 1960; Kleter, 1975). To reduce the herbage growth during grazing Kirchgessner & Roth (1972) and Stehr & Kirchgessner (1976) used a new area twice a day.

Most authors agree that any bias introduced by excluding accumulation during grazing over short grazing periods of 2 to 3 days is likely to be minimal and can be ignored for practical purposes (Carter, 1961; C.A.B., 1961; Linehan et al., 1952; Walters & Evans, 1979). 't Hart & Kleter (1974) neglected accumulation of herbage during grazing in trials with grazing periods of 1.5-5 days. Kleter (1975) corrected for herbage accumulation using 3-4 day grazing periods. Holmes et al. (1950) and Linehan et al. (1947, 1952) made corrections when using 5-14 days periods.

The importance of the herbage accumulation during grazing as a fraction of herbage intake depends on:

- the length of the grazing period
- the level of herbage accumulation in ungrazed areas (depending on season and weather, fertilizer and water supply etc.)
- the intensity of grazing (herbage allowance, herbage contamination).

When the absolute level of herbage intake has to be estimated precisely and normal herbage allowances are supplied under favourable growing conditions it is usually desirable to obtain an estimate of herbage accumulation during the grazing period if this period is longer than one day.

The 'disturbed' accumulation cannot be measured in the grazed pasture where the animal influences the herbage. Therefore the accumulation of herbage during the grazing period is measured in undisturbed pasture (in exclosures) and then the disturbed accumulation is estimated based on a model for the relation between disturbed and undisturbed accumulation.

The undisturbed accumulation can be measured by estimating herbage mass at the start and at the end of the grazing period

- Under cages (one sample in each cage). Cages are commonly 4.20 m long and 1.20 m wide. A bias may arise if herbage is protected by a cage for a long time due to an abnormal microclimate within the cage resulting in a herbage accumulation not typical for the rest of the sward (Jagtenberg & De Boer, 1958). But if the grazing period is not longer than one week then this influence of a different microclimate is very small (Klapp, 1963). A disadvantage of cages is their fixed size, especially if long strips should be cut mechanically.
- In fenced areas (more samples from each fenced area). A part of the area to be grazed is fenced. Often one or two areas are fenced in the pasture and in each exclosure a number of samples are cut. Advantages of the use of large fenced areas are the free choice of the surface of each sample site (especially important when cutting is mechanized) and the lack of bias due to a different microclimate between the disturbed and undisturbed pasture. Due to the fencing of one or a few large parts of the grazed area there is a possibility of choosing parts that are not representative. However, not the level of herbage mass has to be estimated, but the difference in herbage mass between start and end of the grazing period; when the sward has reached a certain level of leaf area, herbage accumulation is almost independent of level of herbage mass, so it is less likely that there will be a bias.

The disturbed herbage accumulation will be lower than the undisturbed accumulation due to defoliation (reduction of leaf area per unit area), treading, trampling and faeces contamination:

disturbed accumulation = g x undisturbed accumulation.

The areic consumption of herbage (C) when a correction is applied for the disturbed herbage accumulation can then be calculated:

$$C = M - M^f + g \ \Delta M^e$$

Linehan et al. (1947, 1952) assumed that the rate of consumption of herbage and the rate of herbage accumulation are each proportional to the quantity of herbage remaining uneaten at that time and derived the following equation:

$$C = (M - M^f) \frac{\log(M + \Delta M^e) - \log M^f}{\log M - \log M^f}$$

When cages are used the herbage mass at the end of the grazing period under cages is equal to $M + \Delta M^e$.

Linehan et al. (1947) compared their estimate of intake with the consumption that in growing bullocks, according to the requirement standard, would have been needed for the live weight gain. The averaged results showed reasonable similarity between the two methods if taken over a two-year period, but in fact the difference in the first year was -27% and in the second year +18%, with even greater differences in individual grazing periods.

Bosch (1956) simplified the equation to

$$C = M - M^f + 0.5 \ \Delta M^e.$$

He compared Linehan's formula and the simple one drawn up by himself in a series of observations made by Linehan. He found that both equations gave practically the same result when the residual herbage was 20-30% of the herbage mass at the start of the grazing period (at a cutting level of approximately 4 cm). Bosch (1956) used a constant factor of 0.5, independent of the residual herbage. Especially when the herbage allowance is varied in experiments, this results in a variation in the herbage mass at the end of the grazing period which causes a variation in the relation between undisturbed accumulation and accumulation during grazing due to the varying amount of leafy material.

The size of the accumulation fraction as part of the total intake amounted on average to 31% (Linehan et al., 1952) and 39% (Iwasaki, 1972) at grazing periods varying from 5 to 14 days. These data demonstrate the importance of the accumulation fraction under certain conditions. Walters & Evans (1979) found a small and not significant accumulation fraction in total intake varying from 1 to 4% for grazing periods of 3 or 4 days. It is notable, however, that accumulation rates of 0 calculated for ungrazed swards were relatively low (between 10 and 30 kg ha^{-1} d^{-1}).

No recent check has been made on the reliability of Linehan's formula; experiments are in progress to estimate herbage accumulation under grazing conditions using photosynthesis measurements and physiological studies (Deinum, personal communication, 1979).

1.2.4 The estimation of herbage mass

Precision of the estimation of herbage mass depends on the manner and intensity of sampling (number and size of samples) and on the variability of the pasture (Waddington & Cooke, 1971).

1.2.4.1 Distribution, number and size of sampling areas

Several sampling systems have been applied in studies of estimating herbage mass (Carter, 1962; Klapp, 1963). Recently McIntyre (1978) has reviewed these systems, therefore distribution of sample sites will not be considered here. Simple random sampling, stratified random sampling and systematic sampling are the most appropriate systems of sample site distribution.

The variance of the difference of the estimate of herbage mass at the start and end of the grazing period contains the variance of two estimates. But if pre- and post-grazing sampling units are paired, the correlation between neighbouring units may reduce the variance of this difference considerably (Green et al., 1952). When cages are used for the estimation of herbage accumulation during the grazing period pairing should not be too proximate to avoid excessive trampling and soiling in the vicinity of the cage (Green et al., 1952).

The shape of sample units in use are square, rectangular and circular. To reduce edge effects the perimeter of the sample unit should be as small as possible in relation to its area. For this reason Van Dyne et al. (1963) recommended the use of circular sample units. However circular frames may be difficult to place in tall or very dense vegetation; under these conditions open-ended rectangular or square frames can better be used ('t Mannetje, 1978). Of course the choice of shape of sampling units is also influenced by the method of harvesting. Because of inaccuracies in starting and stopping cutting machinery, errors caused by this will be minimized using sample units with a large length: width ratio (strips). Sample units using a long and narrow shape were less variable than sample units from square frames of equal area (McIntyre, 1978). In areas of 4, 9 and 16 m^2 the CV_x of herbage mass of rectangular sample units was a little lower than that of herbage mass in square sample units (Iwasaki, 1976).

With an increase in the size of the sample units the number of sample units can be reduced without a change in the precision of the herbage mass estimate (Green, 1949). Also Bosch (1956) and Iwasaki (1976) found that number and size of the strips could be substituted one another within certain limits without influencing precision. Sixteen samples with a strip size of 0.7 m^2 would achieve the same $CV_{\bar{x}}$ of 5% of residual herbage estimate as 9 samples with a strip size of 2.8 m^2 (Green, 1949).

Davison (1959) concluded that the herbage mass could be estimated as accurately with 20 samples of 0.09 m^2 as with 20 samples of 0.42 m^2. In 1957 he used the small samples, and in 1958 in another place and at other levels of herbage mass the bigger ones, so also other factors may have been responsible for the same accuracy being found.

Green et al. (1952) preferred a sample area of 0.3-0.6 m^2, because with the hand-cutting they used the total cut area has to be as small as possible to reduce the labour requirement. When motor mowers are used it is less important to keep the cut area small and strip sizes bigger than 5 m^2 can be used for a relatively small number of samples. Recently Walters & Evans (1979) compared short (0.08 m^2) and long (1.90 m^2) strips. To reach the same level of accuracy in herbage intake estimation as with 6 long strips ($CV_{\bar{x}}$ = 6.2%), the number of short strips should be increased to 45, with a total cut area of 3.6 m^2.

If the area per strip is decreased, the number of samples that have to be taken to reach the same precision increases only slowly, resulting in a smaller total area to be cut (Green, 1949; Iwasaki, 1976). When the technique of cutting is labour intensive it may be preferable to use many small strips. If the labour involved in cutting is not limiting it may be preferable to use large strips and to reduce the number of samples. The choice made depends both on experimental circumstances such as cutting machinery and labour supply in field and laboratory, and on statistical aspects.

1.2.4.2 The variability in the estimate of herbage mass

The level of herbage mass Green (1949) related the CV_x of herbage mass estimates to the level of herbage mass. The CV_x was the highest at the lowest levels of herbage mass while there was no difference in this relation between herbage mass before or after grazing. So Green (1949) stated that the high CV_x of the residual herbage cannot be attributed to selective grazing, but is partly a function of herbage mass. An increasing CV_x at lower levels of herbage mass was also found by Castle (1953).

Kleter (1973) and 't Hart & Kleter (1974) studied the factors influencing the variability in the estimate of herbage mass and herbage intake. The absolute variation (s_x) of the herbage mass estimate was significantly positively correlated with the level of herbage mass, both at the start and at the end of the grazing period. The relative variation (CV_x) of the herbage mass estimate was significantly negatively correlated with the level of herbage mass. The CV_x of herbage intake was negatively correlated with herbage mass at start of grazing and was positively correlated with residual herbage. They concluded that the variability in the estimate of herbage intake can be reduced with a relatively high level of herbage mass at start of grazing and a low level of residual herbage. This conclusion can be applied in practice only within certain limits of herbage mass because other experimental reasons may be more important than a high precision of intake estimate.

Number of preceding grazing periods At the end of a grazing period the variation in areic mass of herbage in the pasture will be higher as a result of selective grazing and local defaecation than when the area would have been cut. This variation in residual herbage and in fertilization level by excretion of local urine and faeces will influence the CV_x of the next herbage mass estimation. 't Hart & Kleter (1974) compared the precision of the herbage mass and herbage intake estimates after the pastures had been used in different ways in the preceding period (grazing or cutting). Grazing in successive periods, without intervening cuts increased the variation of herbage mass and herbage intake estimates; this effect was strongest on CV_x of residual herbage. When the herbage mass of T was 2 500 kg ha^{-1} (above 4.5 cm) at the start of grazing and 300 kg ha^{-1} at the end of grazing the CV_x of the estimation of herbage intake on aftermath herbage was 13%, on pastures once grazed during the preceding period 17% and on pastures grazed 2-4 times in the preceding periods 23.5%.

The effect of grazing in one period on the accuracy of the figures in the next can be minimized when the residual herbage at the end of the first grazing period is cut (topped). Kleter (1973) mowed the residual herbage and calculated that the average CV_x of the intake estimate from this topped herbage was only 1% higher than that of the aftermath herbage.

These results indicate that the error in the estimation of herbage intake can be reduced when aftermath herbage or topped pre-grazed pastures can be used.

Other factors The precision of the estimate of herbage mass and herbage intake will be negatively influenced by heterogeneity of the sward. This heterogeneity of the pasture can be caused by variation in factors which influence herbage accumulation, such as:

- supply of water
- supply of fertilizers (edge effects)
- soil composition
- soil structure (treading and over-riding effects)
- botanical composition
- weather
- plant-disease levels (e.g. parasites).

1.2.5 *Precision*

The precision of some intake experiments with the sward-cutting technique is summarized in Table 1.

- Aftermath herbage (cut in the preceding period). When aftermath was used the CV_x of herbage mass varied between 8 and 14%. In several experiments a $CV_{\bar{x}}$ of herbage intake of 6% could be achieved ('t Hart & Kleter, 1974; Kleter & Hof, 1975; Kleter, 1975; Hijink, 1978; Walters & Evans, 1979). The high $CV_{\bar{x}}$ of 10% as found by Kleter (1975) using grazing periods of 3-4 days can partly be attributed to the relatively high level of residual herbage in comparison with the strip grazing results.
- Pre-grazed herbage. The number of preceding grazing periods varied from 0-4 times. The CV_x of herbage mass varied around 20% (Linehan et al., 1947; Castle, 1953; Davison, 1959; 't Hart & Kleter, 1974). In these experiments the CV_x of herbage intake varied from 23 to 42%, resulting in a $CV_{\bar{x}}$ of herbage intake varying from 10.4 to 13.5%. $CV_{\bar{x}}$ of herbage intake varying from 10.4 to 13.5%.

The average group intake can be estimated with a coefficient of variation of about 6%, provided that aftermath (or topped pre-grazed) herbage can be used.

1.2.6 *Conclusions*

Cutting techniques can provide reliable estimates of intake when short grazing periods are applied and the rate of areic consumption of herbage is high relative to

Table 1. The precision of the sward-cutting technique.

Author	Year	Number of grazing days	Number of preceding grazing periods	Number of sample units	Area per sample unit (m^2)	Cutting height (cm)	Pairing in/out[1]	Accumulation correction[2]	Number of intake determinations	T/O	M $\bar{x}$	M CV_x	M^f $\bar{x}$	M^f CV_x	I $\bar{x}$	I CV_x	I $CV_{\bar{x}}$[3]
Linehan et al.	(1947)	6-14	0-4	10-40	3.07	5?	-	L	15	T	1970	25.6	580	48.3	17.2	42.4	13.4
Holmes et al.	(1950)	5-14	0-2	6	0.89	1.2[4]	-	L	10	T	2297	10.3	1098	-	12.6	-	-
Holmes et al.	(1950)	1	0-2	8-10	0.89	1.2	-	-	20	T	2799	7.0	995	-	10.9	-	-
Castle	(1953)	1	0-3	8	2.51	5?	+	-	?	T	-	22.5	-	50.5	13.9	38.2	13.5
Davison	(1959)	1	0-1	20	0.09	0	-	-	13	T	3802	17.8	1294	29.6	9.4	38.5	8.6
Kirchgessner & Roth	(1972a)	1	0-1	6	1.90	2-3	?	-	10	T	-	19.1	-	25.6	-	-	-
't Hart & Kleter	(1974)	1.5-5	2-4	6	4.35	4	+	-	?	T	2200	22.7	350	62.6	6.2	26.4	10.8
Corbett & Greenhalgh	(1960)	1	0?	5	1.67	0?	-	-	320	T	4425	8.0	2177	16.2	-	23.2	10.4
't Hart & Kleter	(1974)	1.5-5	0	6	4.35	4	+	-	?	T	2200	14.2	350	37.4	6.7	16.1	6.6
Kleter	(1975)	3-4	0	10	4.35	4	+	B	20	T	1950	12.5	1080	27.5	12.8	-	10.5
Kleter	(1975)	1	0	8	4.35	4	+	-	17	T	2382	9.1	693	29.5	14.4	15.6	5.5
Kleter & Hof	(1975)	1	0	8	4.35	4	+	-	46	T	2388	9.0	797	22.4	14.2	16.4	5.8
Hijink	(1978)	2-8	0	10	5.21	4.5	+	B	33	T	2197	14.5	769	29.9	13.7	19.6	6.2
Walters & Evans	(1979)	3	0	6	1.91	0	+	-	2	0	1980	8.5	1030	14.8	66.2[5]	15.2	6.2
Walters & Evans	(1979)	4	0	6	1.91	0	+	-	4	0	3040	9.3	1380	13.1	64.8	21.8	8.9

1. Pairing of pre-grazing and post-grazing strips.
2. L = Linehan, B = Bosch.
3. CV of the mean intake of n strips.
4. Two-step method with the cut area at the lowest cutting height (see 1.2.2.1).
5. Intake in g per kg live weight$^{0.75}$.

the rate of herbage accumulation in the grazed area.

Cutting long and narrow strips to ground level with hand shears is one of the possibilities for the sward-cutting technique. The use of motor mowers for cutting a larger area at stubble heights of 3-5 cm is a possible alternative but too little information is available on the comparability of the stubble masses at the start and end of the grazing period. The corrections for herbage accumulation during grazing when pastures are used for several days are unreliable; more research on the disturbed herbage accumulation is needed.

With regard to precision, within certain limits the number and size of the strips are interchangeable; the best combination of the two depends on such factors as labour required for cutting, sampling and analysis. It seems preferable to cut rectangular sample units and to pair the strips cut at the start with those cut at the end of the grazing period.

The precision of herbage intake measured with the sward-cutting technique can be increased when using aftermath or topped pre-grazed herbage with a high level of herbage mass at the start and a low level of herbage mass at the end of the grazing period; but for other experimental reasons these levels can only be chosen within certain limits.

With the sward-cutting technique the herbage intake can be estimated with a coefficient of variation of 6% if aftermath or topped pre-grazed pastures are used.

1.3 INDIRECT ANIMAL TECHNIQUES

1.3.1 Introduction

The apparent digestibility of a component of the herbage consumed can be calculated from the amount of the component ingested and the quantity of the component excreted in the faeces by the animal:

$$d_B = \left(\frac{I_B - F_B}{I_B}\right) \quad \text{or} \quad d_B = \left(1 - \frac{F_B}{I_B}\right) \tag{1}$$

By reversing Equation (1) the intake of a component can be calculated from estimates of faecal output of the component and the digestibility of the component:

$$I_B = \frac{F_B}{(1 - d_B)} = F_B\left(\frac{1}{1 - d_B}\right) \tag{2}$$

Some investigators use the term feed to faeces ratio (Y):

$$Y_B = \frac{I_B}{F_B} = \frac{1}{1-d_B} \quad \text{thus } I_B = F_B\, Y_B \tag{3}$$

Therefore to estimate herbage intake measurements of faecal output and the digestibility (or feed to faeces ratio) of the diet consumed are required.

It will be seen from Equation (2) that estimation of intakes from faeces measurements actually involves determination of the indigestibility (1-d). In consequence, a small error in the digestibility (for example, one percent) results in errors in the estimated indigestibility 3 times so high (for example, three percent) at a digestibility of 0.75.

1.3.2 The estimation of faecal production

1.3.2.1 Total collection of faeces

Faecal output may be measured directly by the use of harnesses and collecting bags. But in field experiments this direct collection of faeces has disadvantages:
- significant reduction in animal performance (Corbett, 1960; Milne, 1974; Meyer et al., 1956) possibly due to a lower intake (Milne, 1974) and a higher energy expenditure (Reid, 1962) caused by the stress of the equipment
- incomplete collection of faeces due to losses (Hodgson, 1974a)
- distortion of hind legs due to weight of faeces bags (Baker, 1974)
- high labour requirement (e.g. with cows it is necessary to change the collection bags 4 times daily (Greenhalgh, 1974))
- difficulties in collecting faeces free of urine with female animals (Raymond & Minson, 1955)
- influence on grazing behaviour (Hutchinson, 1956; Reid, 1962)
- lack of return of faeces to the sward may interfere with long-term soil fertility experiments (C.A.B., 1961).

Part of the problems of separating urine and faeces may be solved by using bladder catheters, and bags may also be used successfully with females (Morgan et al., 1976). Possibly some of the losses of faeces when the animals lie down can be diminished with an other type of bag and harness (Morgan et al., 1976). Marchi et al. (1973) found no influence on intake of grazing cattle when the bags were emptied at 8-hour intervals. Perhaps in this way it is possible to avoid some of the disadvantages of the method with more intensive collection of the faeces when labour supply is not limiting.

Collection bags have the advantage that they give rapid results, requiring only simple laboratory analysis (T, ash), and that they can provide determinations of faeces production over short periods.

1.3.2.2 Indirect estimation of faecal production

Introduction

Due to the mentioned disadvantages of the total collection technique, an indirect method was developed to measure the faeces production of grazing animals. This technique is based on the use of indigestible external indicators (markers) that are not a natural component of the feed. When markers are used the labour requirement for the sampling of faeces may be lower than when the total collection method is used, but the preparation, administration and analyses of the marker also require a considerable amount of work. A known weight of a marker is fed daily to each animal and it is then assumed that this marker is quantitatively excreted in the faeces or that a constant proportion of the marker fed is excreted. If a representative sample of the faecal excretion is obtained and analysed for its content of marker (M), total faecal production of a component can then be calculated (C.A.B., 1961):

$$F_B\ (g) = \frac{\text{weight of ingested M (g)}}{\text{weight of M (g) per gram of a component in the faeces}}$$

The most important criteria for effective markers are described by Kotb & Luckey (1972). The marker should:
- be inert and non-toxic
- be quantitatively recovered in the faeces (i.e. neither absorbed nor retained in the digestive tract)
- have no appreciable bulk
- mix completely with the food and distribute uniformly during digestion
- have no influence on alimentary secretion, digestion, absorption or motility nor on the microflora of the alimentary tract
- be easily to analyse and cheap.

Some external faecal markers

Kotb & Luckey (1972) have reviewed the markers available to estimate the faecal output of grazing animals. The dye anthraquinone violet was absorbed from the rumen (Flatt et al., 1957) and the rate of absorption was too variable for the dye to be of value as an indicator. Kotb & Luckey (1972) concluded that contradictions in literature on the intensity of variation in the rate of passage of ferric oxide in the digestive tract caution against further use of this compound as an inert indicator.

The variation of polyethylene glycol (PEG) concentration in the faeces is rather high compared with the variation in chromic oxide (Cr_2O_3) percentage because of the higher rate of passage of PEG (Corbett et al., 1958a, 1959). Another disadvantage of PEG is the lack of a specific, sensitive and accurate method for analysis (Kotb & Luckey, 1972) which may partly explain the occasional failure to achieve complete recovery or reproducible results.

Results of Dijkstra (1971) with polyethylene powder were encouraging: the powder did not affect the digestibility of the ration and was completely recovered; however the analysis is very difficult. The information on polyethylene powder as a faecal marker is still limited. Further experimental evaluation is needed before final judgement on its usefulness can be made.

The use of chromic oxide as a marker to determine faecal production has become widely accepted (Kotb & Luckey, 1972; C.A.B., 1961; Morgan et al., 1976; Reid, 1962; Milne, 1974; Le Du & Penning, 1979). Various aspects of the use of chromic oxide that have been studied are considered in the following sections.

Methods of administering chromic oxide in relation to diurnal variation

The main forms in which chromic oxide is being used today are as an impregnation in paper (Corbett et al., 1958b), as an oil suspension in gelatine capsules (Cowlishaw & Alder, 1963) and as a concentrate cube (Curran et al., 1967). If the oxide is fed in capsules a considerable variation in the chromic oxide concentration of faeces sampled at different times of the day is found (Raymond & Minson, 1955; Kotb & Luckey, 1972). In spite of the occurrence of diurnal variations in the excretion of markers many workers used rectal grab-sampling. However, to minimize errors some workers have devised special sampling schedules with exact times or periods of sampling (Kotb & Luckey, 1972). The technique has been criticised by Raymond & Minson (1955) because the diurnal pattern of chromic oxide excretion is not stable and varies with any change in feeding level, digestibility, grazing management and climatic conditions. Recently Hopper et al. (1978) found a considerable diurnal variation in the faeces when chromic oxide was incorporated in a pelleted feed.

Variability in chromic oxide concentration during the day was much less for paper strips than for the oil suspension (Corbett et al., 1960; Langlands et al., 1963a), due to quick release of the fine powder in the capsule in comparison with the sustained release of the chromium oxide in the paper.

The daily variation of marker content in the faeces is significantly less with two daily doses than with one (Langlands et al., 1963a; Kotb & Luckey, 1972). Brisson et al. (1957) showed that when chromic oxide was given six times daily it was excreted at a constant rate which could be determined from a faecal grab sample taken at any time during the day. But such a schedule of administration is impractical, as they pointed out.

Recovery of the chromic oxide

Recovery is defined as the weight of marker excreted (measured with total faeces collections) expressed as a percentage of the weight of marker given during a comparable period (Curran et al., 1967). There are clear indications in the literature that absolute recovery cannot be assumed for all methods of administration of chromic oxide. The recovery of chromic oxide with sheep when used in the form of impregnated paper was higher than when used as an oil suspension in gelatine capsules (Gibb & Penning, 1976). Curran et al. (1967) reported that only 88.8% of chromic oxide was recovered when used as an oil suspension, but recovery was 98.5% when the chromic oxide was incorporated in the concentrate. For chromic oxide incorporated in the concentrate Corbett et al. (1958a) attributed the incomplete recovery of 97.2% to variations of the marker in the cubes fed; Curran et al. (1967), who achieved a recovery of 98.5%, mentioned retention of the marker in the digestive tract as a possible explanation. With chromic oxide paper complete (Corbett et al., 1960; Morgan et al., 1976; Thill et al., 1978; Van 't Klooster et al., 1972) and incomplete (Deinum et al., 1962; Langlands et al., 1963a; Kemmink & Dijkstra, 1968; Le Du & Penning, 1979) recoveries have been reported.

Incomplete recovery of chromic oxide may possibly be explained by:

- absorption of soluble chromium compounds (Deinum et al., 1962; Le Du & Penning, 1979)

- retention of the marker in the digestive tract (Kemmink & Dijkstra, 1968) when length of dosing period and of sampling period are insufficient (Curran et al., 1967)
- losses of chromic oxide during grinding of the faeces (Stevenson, 1962; Curran et al., 1967)
- losses of chromic oxide with rumen liquor sampling or rumen liquor leakages (Morgan et al., 1976) when using rumen fistulated animals
- regurgitation of the marker (Curran et al., 1967)
- methods of analysing chromic oxide in the faeces (Curran et al., 1967)
- failure to collect all the faeces (Langlands et al., 1963a; Raymond & Minson, 1955)

Le Du & Penning (1979) advised to make a correction for the solubility of commercial grade chromic oxide. Regurgitation usually occurs immediately after dosing (Baker, 1974) and a correction can be made. There was no indication that recovery increased as the preliminary dosing period was extended beyond 7 days (Le Du & Penning, 1979). The apparent recovery rates must be examined in the circumstances in which the technique is used, then the calculated faecal outputs should be corrected for the percentage recovery of chromic oxide.

Sampling of the faeces

With grab sampling, individual faeces samples can easily be taken. The disadvantages of grab sampling are:
- the possibility of getting marker concentrations not representative for the average of the day due to diurnal variation of marker excretion (Kotb & Luckey, 1972)
-stress reactions during sampling of certain animals (Rijpkema, 1974).

Some errors of grab sampling may be diminished by more frequent dosing with chromic oxide or by taking more frequent rectal samples, but the increased handling of the animals then reduces the advantages in the use of the marker. It is generally suggested that a seven-day preliminary dosing period is sufficient to achieve acceptable variations in the concentration of chromic oxide in the faeces with the paper form (Gibb & Penning, 1976; Hodgson & Rodriguez, 1970) to apply twice daily grab sampling.

Sward sampling has been suggested as an alternative since it is a more random procedure (Raymond & Minson, 1955). To identify the defaecations of each animal, when a group is grazing together, each can be given particles of differently coloured polysterene (Minson et al., 1960; Rijpkema, 1974). Langlands et al. (1963b) compared sward and grab sampling. They concluded that the random error was appreciably less in the estimates of faecal output from the sward samples. The disadvantage of sward sampling as practised by Langlands et al. is the higher labour requirement compared with the grab sampling. But when the faeces sampling can be restricted to predetermined areas of the pasture (ring sampling) the labour could be reduced without seriously increasing the total error of estimation of faeces output (Raymond & Minson, 1955; Langlands et al., 1963b). An error which may arise in the sward sampling method is the possible change in composition of the faeces on the sward due to insect damage and leaching during heavy rain (Raymond & Minson, 1955). In very wet weather it may be necessary for the faeces on the sward to be sampled more than once daily to avoid rain effects. Greenhalgh (1974) mentioned sedimentation of chromic oxide in faeces at pasture as a possible disadvantage. Systems of sward sampling for sheep and cattle are described by C.A.B. (1961).

Precision of the indirect faecal production estimation

The faecal chromic oxide concentration when the marker is administered in oil suspension in capsules is more variable than with the paper form (Corbett et al., 1960; Langlands et al., 1963a, b). Chromic oxide paper is to be preferred to capsules when grab sampling is practised, but the advantage of the paper may be slight with sward sampling (Langlands et al., 1963b). There are two main sources of inaccuracy with the indicator technique:

- The random variation and bias involved in the assumption that all the marker fed is excreted in the measurement period (long-term component).

The bias involved in the assumption of complete recovery can be tested in trials with both total faecal collection and use of indicators (see Recovery of the chromic oxide). However the collection equipment may influence the behaviour or performance of the animals (especially for dairy cows); so under these conditions total faecal collection is no ideal control. When the chromic oxide paper was administrated twice a day recovery rates varied between 88 and 101% (Le Du & Penning, 1979). When the technique is applied under new circumstances the recovery rate should be checked.

The coefficient of variation (CV_x) of the rate of recovery is approximately 7.2% for a three-day faeces sampling period and for periods of t days $7.2 \sqrt{\frac{3}{t}}$ % (Langlands et al., 1963a, b).

- The random variation and bias in the marker concentration (short-term component).

. Grab sampling. The bias due to differences between estimates of faecal output from chromic oxide percentage in representative (total collection) samples and in corresponding bulked grab samples taken twice a day varied from 3 to 5% (Langlands et al., 1963a) when the paper was supplied twice a day. When the paper was supplied once a day Langlands et al. (1963a) found a bias of on average 12%, while Corbett et al. (1960) found a bias of only 2% then.

When grab sampling is employed in grazing trials it would be advisable to determine the average bias of estimates of faeces output by harnessing some animals for the total collection of faeces, and collect the faeces intensively. However, as already pointed out, due to stress reactions of the animals total collection is no ideal control for high producing animals.

The CV_x of marker concentration in faeces varied from 4 to 5% (Langlands et al., 1963a) when paper was given twice a day.

. Sward sampling. No direct check can be made for bias in estimates from sward sampling since the technique, unlike that of grab sampling, is obviously incompatible with the total collection of faeces (Langlands et al., 1963b). Coefficients of variation of estimates of faeces output calculated from the mean concentration of chromic oxide in faeces samples from the sward averaged 11% (Langlands et al., 1963b). When the ring sampling technique is applied (C.A.B., 1961) a certain fraction (f) of all defaecations will be sampled. The random error associated with the sampling process may be described according to Langlands et al. (1963b) as:

$$CV_{\bar{x}}\ (\%) = 11 \sqrt{\frac{1}{n}(1 - f)} \qquad f = \frac{\text{number of samples (n)}}{\text{total number of defaecations}}$$

With a three-day sampling period the $CV_{\bar{x}}$ of faeces output of a cow was 1.14% at a sample fraction of 0.7; with a sampling period of t days the $CV_{\bar{x}}$ was 1.1 $\sqrt{\frac{3}{t}}$ % (Langlands et al., 1963b).

- Total random variation. The total random variation at grab sampling is considerably less than might be expected from the standard deviations of the two components (% recovery and % marker) due to the negative correlation of these on a within animal basis. The CV_x of total error varied from 7 (sheep) to 8.5 (steers) % with a three-day sampling period (Langlands et al., 1963a); in another experiment with a five-day sampling period (Langlands et al., 1963b) a total random error of 9.6% could be calculated with cows.

With sward sampling the total random variation could be reduced to 6.3% and 7.3% for sampling periods of 5 and 3 days respectively and a sampling fraction of 0.7 with heifers (Langlands et al., 1963b).

1.3.2.3 Conclusions

When labour supply in the field is not limiting, total collection of faeces by bags can be applied with grazing sheep and steers with a rather low risk of bias. The indirect marker technique requires less labour for the sampling of the faeces but more work in the laboratory while the risk for bias is great. When grab sampling is employed in grazing trials, together with the use of an external indicator, it would be advisable to determine the average bias of estimates of faeces output by harnessing some animals for the total collection of faeces, and collect the faeces intensively. However, total collection is no reliable check when high-producing animals are used, due to stress reactions.

When chromic oxide is used in grazing trials it should be supplied as an impregnation in paper; this gives the best qualities in relation to diurnal variation and recovery rate. The recovery rate must be examined with total collection in the circumstances in which the technique is used. The faecal outputs should be corrected for percentage recovery of chromic oxide. The total random variation of sward sampling can be diminished to a coefficient of variation of about 7%; the random variation of grab sampling is higher than the random variation which can be obtained with sward sampling.

1.3.3 The estimation of the digestibility of herbage consumed

1.3.3.1 Introduction

The digestibility of herbage harvested can be determined directly by the 'conventional method'. Confined animals are fed the forage for several days and measurements are made of feed consumption and faecal production. Digestibility is calculated using Equation (1) (see 1.3.1). When using Equation (2) (see 1.3.1) to calculate intake of grazing animals the digestibility of the diet selected is required. Because feed consumption is not known the conventional method to determine digestibility cannot be carried out in the pasture with grazing animals.

Direct measurements of the digestibility of herbage harvested mechanically from pastures and hand fed to confined animals does not necessarily evaluate the forage consumed by animals grazing the same pasture correctly because:

- differences in the rate, pattern and quantity of feed consumption may result in differences in the rate of feed passage which may in turn influence digestibility
- differences in selection of specific plant species or plant parts may influence digestibility.

When oesophageal fistulated animals (see 1.3.3.4) can be used the selection problem may be solved as shown by Wallace & Van Dyne (1970). They sampled herbage with oesophageally fistulated steers and fed the samples later to sheep in conventional digestion trials. The second problem may be solved 1) if the animals in the two environments are comparable and if the production levels (and the unknown intake levels) of both groups of animals are similar, or 2) if information is available on the influence of level of feeding on digestibility; then corrections could be made.

Before the use of fistulated animals the procedures most commonly used for estimating digestibility of the diet selected by grazing animals, were the marker-ratio methods (1.3.3.2) and the faecal-index methods (1.3.3.3). These two techniques will be described first, together with their historical developments. The techniques using in-vitro or in-vivo digestibility estimation of the selected herbage are described in 1.3.3.4.

1.3.3.2 Marker-ratio techniques

Introduction

In the ratio techniques, digestibility is calculated from the relative contents of a naturally occurring indigestible marker in samples of herbage grazed and in samples of faeces (Reid, 1962; Kotb & Luckey, 1972). If

$w_{M,I}/B$ = content of marker in a component of herbage consumed
$w_{M,F}/B$ = content of marker in a component of faeces produced

and if the indicator is completely indigestible, then the amount of marker excreted must equal the amount of marker ingested:

$$I_B \, w_{M,I}/B = F_B \, w_{M,F}/B \qquad (4)$$

thus

$$\frac{F_B}{I_B} = \frac{w_{M,I}/B}{w_{M,F}/B} \qquad (5)$$

Substituting Equation (5) into Equation (1) (see 1.3.1) gives the formula for apparent digestibility:

$$d_B = (1 - \frac{w_{M,I}/B}{w_{M,F}/B}) \qquad (6)$$

When only intakes has to be determined Equation (4) can directly be applied:

$$I_B = F_B \frac{w_{M,F}/B}{w_{M,I}/B} \qquad (7)$$

The ratio technique may only be used if a representative sample of the herbage consumed and of the faeces produced can be obtained and if the indicator is completely indigestible. The most important internal markers will be described with special attention to digestibility; afterwards, sample collection of herbage and of faeces are described.

Some internal indicators

The term 'internal' indicator is used for markers naturally occurring in the herbage, while the term 'external' marker is applied when the marker is added to the feed (e.g. chromic oxide as a faecal marker).

Lignin Lignin is an ill-defined group of substances found in plant cell wall material which is insoluble in a solution of 72% sulphuric acid. This fraction of the plant is thought to be completely undigestible by the ruminants (Crampton & Maynard, 1938). Ellis et al. (1946) suggested an improved method for estimating lignin using 72% H_2SO_4 and removal of contaminating proteins with pepsin dissolved in a hydrochloric acid solution. Interfering proteins and hemicellulose can be effectively removed by treatment of the forage with an acid detergent solution (Van Soest, 1963). Van Soest & Wine (1968) have proposed an indirect method for determining lignin, involving potassium permanganate. Morrison (1973) introduced a spectrophotic method of lignin analysis. The incomplete knowledge of lignin structure limits the specificity of all lignin methods.

The situation is further complicated by evidence that 1) faecal and dietary lignin differ in their chemical characteristics (Elam & Davis, 1961), 2) lignin varies in chemical nature among plant groups and among parts of the same plant (Wallace & Van Dyne, 1970), 3) certain substances such as cutins, waxes and tannins are included as artifacts in most methods to isolate lignin (Lesperance et al., 1967), giving considerable variation in faecal recovery of lignin when acid detergent lignin values fall below 5% of the dry matter, 4) heating forage samples at temperatures above 50 °C increases the lignin content by condensation of carbohydrate degradation products with proteins via the non-enzymatic browning reaction (Van Soest, 1964, 1965b). This temperature effect may differ between faeces and herbage samples (Smith et al., 1967).

If the analytical herbage sample is not representative for the diet selected (e.g. a hand-cut sample) lignin recovery may be influenced. Thus method of lignin analysis, stage of maturity (lignin level), sample drying temperature and method of sample collection have to be considered when interpreting lignin recovery results. The recovery of lignin can be tested in experiments where the herbage is fed and is totally consumed indoors in combination with total collection of faeces. With this technique an incomplete recovery of lignin varying from 87 to 96% has been found by Kane et al. (1953), Ely et al. (1953), Sullivan (1955), Elam & Davis (1961) and Elam et al. (1962). These low recoveries may be attributed to differences in the lignin content of dietary and faecal samples resulting from drying the samples at excessively high temperatures (Van Soest, 1964). This drying temperature effect may also be responsible for the low lignin recoveries found by Waite et al. (1964) and Van Dyne & Meyer (1964). The former lignin analyses were all made using the method of Ellis et al. (1946), sometimes with slight modifications.

Using the lignin analysis according to Van Soest (1963) at drying temperatures below 55 ^{o}C or by freeze drying, Kellaway (1969) and Scales et al. (1974a) obtained good results with the lignin-ratio technique. But when the lignin levels are too low, forming of artifacts gives unreliable results (Lesperance et al., 1967; Colburn et al., 1968).

Scales et al. (1974a) compared the H_2SO_4-lignin method (Van Soest, 1963) with $KMnO_4$-lignin (Van Soest & Wine, 1968). $KMnO_4$-lignin proved unsatisfactory as a predictor of digestibility, better results being obtained with H_2SO_4-lignin. The $KMnO_4$-lignin ratio method gave invalid digestibility results with apparent lignin digestion coefficients from 4 to 46% (Wallace & Van Dyne, 1970) but good results were obtained by correcting faecal lignin values for apparent digestibility of lignin as found in conventional digestibility trials.

When the lignin-ratio method is applied with grazing animals, lignin digestibility should be checked indoors with conventional digestibility trials feeding the herbage as consumed outdoors using fistulated animals to sample the outdoor diet (Wallace & Denham, 1970; Scales et al., 1974a). However, when fistulated animals can be used it is better to use in-vitro digestibility techniques with a regularly control of in-vivo trials (1.3.3.4) than the lignin-ratio method especially when the lignin content of the herbage is low due to the mentioned problems in the lignin analyses.

Chromogens Reid et al. (1950) proposed the use of chromogens (plant pigments) as an internal indicator for digestion studies. The chromogen content of feed and faeces was measured colorimetrically in an acetone extract at a wavelength of 406 µm. The pigments have been identified as mostly chlorophylls and their degradation products, chiefly phaeophytins (Deijs & Bosman, 1953). The addition of oxalic acid to acetone extracts of feed and faeces was found by Deijs & Bosman (1953) and Kane & Jacobson (1954) to yield a chromogen displaying a light absorption maximum at the maximum absorption of phaeophytin (415 µm). By steaming of the fresh herbage, the pigments of the feed changed as in the digestive tract and gave a chromogen displaying a light absorption maximum at about 413 µm (Steger et al., 1962).

The recovery of chromogen has been tested in indoor trials with total collection of faeces. A complete or almost complete recovery of the chromogens has been found by

Reid et al. (1950), Irvin et al. (1953) and Kemmink & Dijkstra (1968). An incomplete recovery of 92% has been observed by Steger et al. (1962); however Kane et al. (1953) and Greenhalgh & Corbett (1960) have found more chromogen in the faeces than in the consumed feed. These differences in chromogen input and output have been attributed to analytical errors, either to the incomplete extraction of herbage pigments or to the increase in optical density on standing for extracts from faeces (Lancaster & Bartrum, 1954) even when the faeces extracts were prepared in minimum light (Greenhalgh & Corbett, 1960).

Until chromogen in faeces can be excreted in a stable condition this indicator must be used with caution (Greenhalgh & Corbett, 1960).

Silica Determining silica as acid-insoluble ash gives variable results because variable amounts of alkalis, alkaline earths and water are retained by the silica (Jones & Handreck, 1965). The determination of silica in biological materials has been made accurate by the use of an improved colorimetric silicon-molybdate method (Jones & Handreck, 1965).

For a pelleted ration, Jones & Handreck (1965) suggested that reliable estimates of digestibility could be obtained with silica if precautions are taken to prevent contamination. It was shown that urinary silica was less than 1.8% of the ingested silica even though the silica content of the diet was abnormally high. The recoveries of silica in the faeces were close to 100%.

Van Dyne & Lofgreen (1964) concluded that silica temporarily accumulated in the digestive tract of grazing animals. However this error may have arisen from contamination with soil silica (Streeter, 1969) and the crude silica analysis (Jones & Handreck, 1965). McManus et al. (1967) used a colorimetric silica determination and found silica recoveries varying from 63 to 137% with green forages indoors. They attributed these variable recoveries to excretion of silica in the urine or to movable depositions of silica in the gastrointestinal tract or in the body tissue and concluded that silicon is not a satisfactory indicator.

Le Du & Penning (1979) estimated the element silicon directly using atomic absorption spectrometry. The influence of the variable soil or dust contamination (Jones & Handreck, 1965) can possibly be eliminated with determination of titanium concentrations in the samples (Le Du & Penning, 1979).

Sample collection of herbage

The validity of the use of the ratio technique in grazing studies depends among others upon the ability to obtain representative samples of forage consumed and of faeces produced. Collecting samples of forage representative of eaten by the grazing animal is a complicated problem since animals often select plants and plant parts from a mixture of species (Cook, 1964). Three methods have been used in the ratio technique in obtaining representative forage samples a) cutting or clipping, b) hand-plucking, c) using fistulated animals (see 1.3.3.4).

Selective grazing was studied by comparing the chemical composition and digestibility of forage samples obtained by hand-clipping or cutting and those from oesophageal fistulated animals. Grazing sheep selected forage higher in protein and lower in crude fibre than that obtained by hand-clipping (Weir & Torrel, 1959). Grazing steers selected herbage of higher digestibility than the average of that available (Tayler & Deriaz, 1963; Alder, 1969). This selection effect depended on the level of utilization of the herbage (Alder, 1969), the season of the year (Tayler & Deriaz, 1963), the moment of sampling in the grazing period (Alder, 1969) and the cutting height (Tayler & Deriaz, 1963). Barth & Kazzal (1972) tried to measure selectivity of steers by passing both the selected forage and the ground-cut available forage via the mouth through a fistula avoiding different saliva or leaching effects. They found no difference in in-vitro digestibility between selected and ground-cut samples, only the crude protein content was higher in the selected forages. When samples are clipped to grazing height the comparison with the selected herbage by steers is better than when cut to ground level (Tayler & Deriaz, 1963). When short grazing periods are applied determination of herbage mass and quality before and after grazing can give reliable information on the selected herbage (see 1.2).

Hand-plucking can be accomplished by observing grazed plants or grazed portions of plants and selecting ungrazed material comparable to that already removed by grazing (Cook, 1964; Edlefsen et al., 1960). Hand-plucking overestimated in-vitro digestibility and nitrogen content at high levels of digestibility and underestimated nutritive value when this was low; moreover the differences between fistula and hand-plucked samples varied between pastures when sheep were used (Langlands, 1974).

When the ratio technique is applied it seems advisable to use fistulated animals for getting representative samples of the selected herbage.

Sample collection of faeces

Total faecal collections can be made with harnesses and bags (see 1.3.2.1). Faecal samples can also be obtained from the rectum at various times of the day (grab sampling) or from the sward (see 1.3.2.2). Kane et al. (1952) reported a significant difference between the a.m. and p.m. concentrations of lignin in grab samples of faeces of dairy cows fed long hay, silage and grain. However, Elam & Davis (1961) found a coefficient of variation in lignin percentage of only 2% among grab samples taken periodically throughout the day when a complete pelleted ration was fed to heifers indoors. Information concerning variation in lignin percentage in faeces samples of grazing animals is not available.

The diurnal variation in the chromogen content of faeces of grazing sheep is large and without special pattern (Soni et al., 1954; Bradley et al., 1956). A more-or-less random variation in the chromogen content of faeces samples of grazing cows during the day has been reported by Steger et al. (1962). When grab samples were taken from grazing cows at a specific time each day the coefficient of variation for the concentration of chromogen between days was 9.1% (Brisson, 1960). Even when the faeces was sampled every six hours there was a significant between day variation in the average daily chromogen concentration of stall-fed cows (Steger et al., 1962). But with this sampling system for four days the digestibility determination with the chromogen ratio method was equal to the determination with the conventional digestibility trial (Steger et al., 1962).

1.3.3.3 Faecal-index techniques

Introduction

The faecal-index technique was developed by workers who questioned the ability to obtain representative dietary samples by hand-clipping for use in the ratio methods (Raymond et al., 1954). This technique involves the prediction of digestibility from the composition of the faeces. A series of conventional digestion trials are conducted in which forages of varying digestibilities are fed to animals indoors. After measuring the content of an internal marker in the faeces (w_M) an equation is developed which shows the best relationship between the content of the marker in the faeces and the digestibility

$$d_B = a + b\, w_M \tag{8}$$

Some investigators relate the concentration of the marker in the faeces to the feed/faeces ratio Y (see 1.3.1). Measuring the concentration of the marker in the faeces produced by grazing animals and substituting this in Equation (8) an estimation of the digestibility of herbage grazed can be obtained.

The reliability of the faecal-index techniques depends on:

- the accuracy of the regression equations
- the errors involved in applying the relationship as found indoors to grazing animals
- the possibility of getting representative faeces samples.

Some faecal indicators

Nitrogen Lancaster (1949) showed that faecal nitrogen concentration was related to the digestibility of herbage. A linear regression between digestibility and faecal nitrogen was found by Raymond et al. (1954), Greenhalgh & Corbett (1960), Minson & Kemp (1961), Langlands et al. (1963c) and Greenhalgh et al. (1966b); however Greenhalgh et al. (1960) reported a curvilinear relationship. A linear regression between the feed to faeces ratio and faecal nitrogen has been shown by Lancaster (1954), Lambourne & Reardon (1962, 1963b), Vercoe & Pearce (1962), Arnold & Dudzinski (1963), Hutton & Jury (1964) and Langlands (1967b). Kennedy et al. (1959) stated a logarithmic relationship between the feed to faeces ratio and faecal nitrogen. The quantity of faecal N excreted (Arnold & Dudzinski, 1963) and the month of the year (Minson & Kemp, 1961; Langlands, 1969b) have been included with N percentage in faeces in equations for predicting digestibility. Langlands (1967b, 1969b) also included dietary N percentage in the equations.

Chromogens Reid et al. (1952) found that the digestibility of pasture forage by steers could be predicted from the concentration of chromogens in the faeces. A linear regression between digestibility and faecal chromogen was found by Raymond et al. (1954), Greenhalgh & Corbett (1960) and Lambourne & Reardon (1962). Kennedy et al. (1959) developed a logarithmic relationship between the feed to faeces ratio and faecal chromogen. Reliable results with the chromogen technique may be obtained when fresh faeces was used, when light was excluded from the extraction process and when the absorption was determined within six hours after the preparation of the extract (Streeter, 1969).

Raymond et al. (1954) and Kennedy et al. (1959) obtained slightly smaller prediction errors for the faecal nitrogen than for the faecal chromogen index technique. Greenhalgh & Corbett (1960) found a comparable prediction error with both techniques but preferred the faecal nitrogen technique because 1) the determination of the chromogen was much more difficult and inaccurate than the nitrogen determination, 2) the chromogen-faeces extracts were unstable, 3) the difference in regression equations when first growth herbage was compared to aftermath herbage was greater with the faecal chromogen than with the faecal nitrogen.

The faecal indicator-digestibility relationship

The original aim was to develop faecal-index relationships based on a wide range of forages, to obtain a wide applicability, yet with low errors of prediction (Raymond et al., 1954). These regressions formulated from more or less random digestibility investigations involving widely differing types of pasture over an extended period of time have been called 'general' regressions. Streeter (1969) reviewed the digestibility-faecal nitrogen regressions. General relationships of Raymond et al. (1954) and Minson & Kemp (1961) had residual standard deviations (R.S.D.) from regression of 5.7 and 4.0 digestibility units respectively and were rather inprecise certainly for the purpose of predicting the intake of grazing animals. General feed to faeces ratio-faecal nitrogen regressions were calculated by Kennedy et al. (1959) and Hutton & Jury (1964).

The variation around the regression line can be diminished by basing it on a restricted range of herbages. The 'local' regression method is based on digestibility/faecal nitrogen data from indoor digestion trials carried out on herbage cut from areas similar to those on which herbage intake is being measured (Minson & Raymond, 1958; Greenhalgh et al., 1960). The estimates of digestibility were much more precise than if a general prediction equation was used, but labour requirement for the continuous digestibility trials are considerable (Greenhalgh et al., 1960).

Faecal nitrogen regressions have been found to vary significantly with the season of the year (Minson & Raymond, 1958; Greenhalgh & Corbett, 1960; Minson & Kemp, 1961; Vercoe & Pearce, 1962; Langlands et al., 1963c). Greenhalgh et al. (1960) showed small differences in these relationships at different levels of nitrogen fertilization. Langlands (1969b) derived significant differences between faecal nitrogen-digestibility relationships for various stocking rates, levels of herbage mass and levels of digestibility with grazing fistulated sheep. He concluded that techniques based on faecal nitrogen content do not appear to be reliable for estimating the digestibility of the diet selected by grazing sheep when intake, pasture availability or digestibility vary markedly.

Application of the faecal-index relationship for grazing animals

The faecal index-digestibility relationship is obtained with herbages fed indoors and can later be used for grazing animals when this regression equation is the same for the two environments. Lambourne & Reardon (1962) reported significant differences between faecal nitrogen-digestibility relationships established with leaf and stem fractions of a single herbage. As a result, these relationships might differ between cut herbages for the digestibility trial and the selected herbage in the field. Pearce et al. (1962) found different relationships for the top and bottom fractions of a sward harvested and fed separately in digestibility experiments. However Greenhalgh et al. (1966b) found little difference between the prediction equation derived from top and bottom cut herbage. This discrepancy can possibly be attributed to the fact that Greenhalgh et al. (1966b) used cattle and Pearce et al. (1962) the more selective sheep, and to the larger difference between the digestibility of the top and bottom fractions of the herbage fed to the sheep.

Langlands (1967b) concluded that faecal index relationships must be derived with material similar to that selected by sheep when grazing. The relationship between the feed to faeces ratio and faecal nitrogen derived in the digestibility trial indoors differed significantly from the relationship established at pasture when the samples were obtained through fistulas. These differences may have arisen from selective grazing or from bias in estimating digestibility from fistula samples (Langlands, 1967b).

Wallace & Van Dyne (1970) sampled forage from the range with oesophageally fistulated steers and fed it to sheep in conventional digestion trials. They related the in-vivo sheep digestibility of the selected herbage to the nitrogen content of faeces of steers. Digestibility values estimated by the faecal nitrogen method were in close agreement with those found in the conventional trials. A similar conclusion was drawn by Scales et al. (1974a) using the same technique.

When level of feed intake has an influence on the faecal index-digestibility relationships and when level of feed intake differs between in- and outdoors another application error may arise. Minson & Raymond (1958) and Corbett (1960) concluded that the level of feed intake had an effect on the faecal nitrogen regression equation with hand-fed sheep and steers, respectively. Hutton & Jury (1964) however found no effect of level of feeding on the regression equation using non-lactating cattle indoors. They also concluded that the statistical errors of faecal index relationships based on forages fed under ad lib. conditions are greater than under restricted intake conditions. Langlands (1969) derived significant differences between faecal nitrogen-digestibility relationships for various levels of intake when using fistulated grazing sheep.

Another application error may arise when the derivation of the regression equation indoors and the use of it outdoors is done with different species of animals. Regression equations relating faecal nitrogen to digestibility were not significantly different between sheep and steers (Corbett, 1960; Langlands et al., 1963c) nor between sheep and non-lactating cows (Thomas & Campling, 1976). No direct comparisons have been made of these relationships between sheep and lactating dairy cows.

Sample collection of faeces

There is little information on the diurnal pattern of nitrogen concentration in faeces of grazing animals. Soni et al. (1954) showed a small variation in nitrogen concentration of faeces of grazing sheep. In experiments with stall-fed sheep Lambourne & Reardon (1963a) found only small diurnal variations in faecal nitrogen concentration.

When grab samples were taken at a specified time each day from grazing cows the coefficient of variation for the concentration of nitrogen in faeces between days was 7.5% (Brisson, 1960) corresponding with a 7% level for grazing sheep (Lambourne & Reardon, 1963b). This large variation in faecal nitrogen concentration between days will result in a high variation in the estimation of intake, so grab sampling at a specified time each day is no advisable way of faeces collection.

1.3.3.4 Techniques using fistulated animals

Introduction

Fistulated animals can be used for obtaining samples of the herbage actually being selected. Animals may be fitted with either an oesophageal or a rumen fistula. The samples of the grazed herbage which have been masticated and ensalivated are called extrusa. The digestibility of the extrusa samples can be determined

- in-vivo with the conventional method (Wallace & Van Dyne, 1970; Scales et al., 1974a)
- in-vitro which involves incubation of the herbage sample with rumen fluid and pepsin (Tilley & Terry, 1963) or with rumen fluid and a neutral detergent (Van Soest et al., 1966) or with cellulase (Jones & Hayward, 1973)
- with the ratio technique (see 1.3.3.2).

Rumen fistulated animals have been used to sample the sward (Lesperance et al., 1960; Tayler & Deriaz, 1963). Boluses of ingested herbage are collected by hand through the orifice of a rumen fistula (Tayler & Deriaz, 1963). The free movement of the animal may be hampered and only cattle can be used (Raymond, 1969). The rumen evacuation technique involving forage sampling from an empty rumen is labour intensive and can have an effect upon digestibility and animal performance (Van Dyne & Torrell, 1964).

The establishment of oesophageal fistulas in ruminants was first described by Torrell (1954). The more general application of the technique was advanced by the development of the split plug closure technique, which simplifies the handling of the animals in the field (McManus et al., 1962).

The accuracy of the fistulate techniques for obtaining estimates of the digestibility of the herbage selected depends on

- the similarity of the diet selected by oesophageal fistulates and non-fistulated animals
- the similarity of the extrusa sample collected through the fistula and the herbage eaten
- the possibility of getting representative extrusa samples
- the validity of the digestibility estimate of the extrusa sample.

The similarity of the diet selected by oesophageal fistulates and non-fistulated animals

Samples of extrusa collected from fistulae will not be representative of the diet of normal animals grazing in the same conditions if there are differences between the non-fistulated and fistulated animals in the selection of sward components. It is not possible to check this directly but there is no evidence that the grazing behaviour or herbage intake of fistulates differs significantly from that of normal animals (Arnold et al., 1964). Lambourne (1965) has shown that the main difference between fistulated and non-fistulated animals is the loss of saliva that gives the fistulated animals a marked appetite for salt; if salt licks are available to the animals a possible difference in grazing behaviour between the two groups can be avoided.

Selection of animals for fistulation not representative of the main group with regard to eating behaviour may give bias. Age, breed or sex differences of sheep do not appear to be important sources of variation in extrusa composition (Langlands, 1969a). Differences may be observed between the nitrogen content of extrusa samples collected from cattle and sheep grazing the same sward due to differences in the nitrogen content of the saliva (Hodgson & Rodriguez, 1970).

The similarity of the extrusa sample collected through the fistula and the herbage eaten

Samples collected from oesophageal fistulated animals vary in the degree of mastication and addition of saliva. For this reason collecting bags with mesh bottoms that allow the saliva to drain away have been used (Van Dyne & Torrell, 1964). The composition of the extrusa sample will depend on the part of the added saliva that has drained out and on the possible leaching effects due to saliva addition and mastication.

The saliva added to the herbage appears to be responsible for the higher concentration of ash in the extrusa sample (Lesperance et al., 1960; Hoehne et al., 1967; Barth et al., 1970; Scales et al., 1974b). Ash contamination of extrusa samples can be corrected for by expression of data on an organic matter basis. Increases in extrusa crude-protein content due to saliva addition (Campbell et al., 1968; Scales et al., 1974b), as well as decreases in extrusa crude-protein content (Hoehne et al., 1967) and non-significant effects (Barth et al., 1970) have been reported. In low protein forages contamination by salivary nitrogen is possibly greater than the loss of soluble crude protein by leaching hence resulting in elevated crude protein values of extrusa samples while in high protein forages contamination and loss are of similar magnitude (Scales et al., 1974b). Losses of soluble carbohydrates due to leaching in the collection bags has been reported by Hoehne et al. (1967) in correspondence with losses of non-structural carbohydrates as found by Acosta & Kothmann (1978). The loss of cell solubles can result in an increase in ADF and lignin contents (Barth et al., 1970; Scales et al., 1974b).

Decreases in in-vitro digestibility of alfalfa samples collected via an oesophageal fistula were reported by Barth et al. (1970) and Scales et al. (1974b). The in-vitro digestibility of grass extrusa samples was 1-5% higher than that of herbage fed (Barth & Kazzal, 1972; Scales et al., 1974b), increases being dependent upon the species examined. It is conceivable that mastication liberated plant enzymes, which in the draining and drying stages of sample preparation might have caused partial breakdown of grass (Barth et al., 1970). It is not advisable to use the screen-bottom bags because the variable influence of leaching due to level of saliva addition, time and speed of draining of saliva and herbage species.

Hoehne et al. (1967) squeezed the oesophageal samples while Alder (1969) collected the feed boluses from the pasture as they were extruded through the fistula both in an attempt to remove salivary contamination. When saliva is squeezed out of the extrusa samples as much as 16% of the herbage organic matter may be transferred to the liquid fraction (Grimes et al., 1966).

Langlands (1966) has shown that the most precise means of determining the in-vivo and in-vitro digestibility relationship of extrusa samples is when both the liquid and solid fraction are used, therefore it appears that total collection of extrusa samples should be carried out. This may be accomplished by using total collection bags (Hodgson, 1969; Grimes et al., 1966; Acosta & Kothmann, 1978). To avoid the non-enzymic browning reaction (Van Dyne & Torrell, 1954) Grimes et al. (1966) and Langlands (1966) squeezed the liquid through muslin and sampled both fractions. Attempts have been made (Langlands & Bowles, 1973) to estimate saliva in the liquid using tritiated water, but these were unsuccessful. Salivary organic matter has been related to the volume of the liquid fraction (Grimes et al., 1965) and to the weight of 0 in the squeezed solid fraction (Langlands, 1975) while non-salivary 0 in the liquid was assumed to be complete digestible.

When freeze drying is applied the non-enzymic browning reaction can be avoided. The best procedure is to determine with penned animals the digestibilities in-vivo of the feeds and establish by regression analysis the relationship with the in-vitro values determined on extrusa samples obtained during the same study.

Sample collection of extrusa

Arnold et al. (1964) showed that overnight fasting resulted in a significant reduction in the nitrogen content of the diet consumed. However Langlands (1967a) and Hodgson (1969) found no difference between the nitrogen content of the diets selected by fasted and unfasted sheep. The in-vitro digestibility of the diet was equal in overnight fasted and unfasted sheep (Hodgson, 1969). But with increasing length of the fasting period, it appears that fasted sheep tend to be less selective than unfasted sheep (Sidahmed et al., 1977). However very little difficulty is experienced in obtaining satisfactory samples of extrusa from unfasted sheep at all times of the day, so there seems to be little benefit in preliminary fasting (Hodgson, 1969).

Arnold et al. (1964) and Langlands (1967a) have shown that the diet selected by animals newly introduced to a sward differs in both the botanical composition and the nitrogen content from the diet selected by animals that had been grazing the sward for some time. Hodgson (1969) compared the composition of extrusa samples of sheep grazing a monoculture. Two days after start of grazing both the nitrogen content and the in-vitro digestibility of the extrusa samples were lower in inexperienced animals than in experienced animals, but no significant differences were observed in the next 14 days following introduction. Fistulated calves can give representative samples of extrusa as soon as they start grazing a sward to which they are not accustomed (Hodgson &

Rodriguez, 1970). Cattle have been shown to be less selective grazers than sheep (Meyer et al., 1957); this may explain in part the difference observed between the results of Hodgson (1969) with sheep and the experiments with calves (Rodriguez, 1973).

The stronger 'experience of a sward' effect found in Australia can be attributed to the great opportunity for within-sward selection and to between-animal variations (Hodgson & Rodriguez, 1970).

Langlands (1965, 1967a) showed significant diurnal variations in the nitrogen concentration and in-vitro digestibility of the extrusa samples from free-grazing sheep. Hodgson (1969) also observed marked diurnal changes in both nitrogen and ash content of extrusa samples, but not in the in-vitro digestibility. The type of sward (mixed species) used by Langlands (1967a) in comparison with the monoculture used by Hodgson (1969) may have allowed a greater opportunity for selection.

Rodriguez (1973) found no significant diurnal variation in the digestibility of extrusa samples of grazing calves while the nitrogen percentage and ash percentage varied significantly during the day. There is strong evidence from indoor trials of a direct relationship between the nitrogen content of extrusa and the weight of saliva added per unit of extrusa OM collected which may explain the diurnal variation in nitrogen content of extrusa samples (Hodgson & Rodriguez, 1970).

The digestibility estimate of the extrusa sample

The digestibility of the extrusa sample can be estimated with the in-vivo, in-vitro and ratio techniques (The problems related to the ratio technique have already been described (1.3.3.2)). Wallace & Denham (1970) collected forage from oesophageal fistulated steers with screen-bottomed bags and fed the forage to sheep in digestion trials. The drained saliva might contain leached components of the herbage. When watertight bags are used, the extrusa can be completely collected. The excess saliva can be removed by drying at low temperatures (Wallace & Denham, 1970) or the fresh extrusa can be fed in the indoor trial when the saliva has no effect on the digestibility or intake of the forage (Wallace, 1969, cited by Wallace & Denham, 1970).

The errors involved in the determination of the in-vitro and in-vivo digestibility relationships have been discussed by Raymond (1969) and Osbourn & Terry (1977). In general, some of the errors in estimating in-vivo digestibility from in-vitro digestibility may be reduced if standard preparations of known in-vivo digestibility are included in each group of analyses, and estimates of the unknown samples are made from regression equations derived from the standards (McDonald, 1968).

The in-vitro digestibility of extrusa may be 1.5-3.0% higher than that of the corresponding feed, due to saliva contamination and mastication (Langlands, 1975; Le Du & Penning, 1979). Therefore extrusa samples should be used as standards in the in-vitro digestibility determination (Corbett, 1979). Both the in-vivo and in-vitro digestibility values of extrusa may be influenced by the drying temperature and the level of feeding. The in-vitro T digestibility of extrusa samples dried at 65 °C was 1.5% (not significant) lower than the digestibility of samples dried at 45 °C (Barth et al., 1970). The in-vitro 0 digestibility of extrusa samples oven-dried at 80 °C was on average 1.7% lower than the digestibility of freeze-dried samples (Rodriguez, 1973). However Scales et al. (1974b) showed that the in-vitro T digestibility of extrusa samples oven-dried at 55 ^{o}C was 2.1% higher than that of freeze-dried samples in the first experimental year but in the second year the difference was 1.1% in the opposite direction. Although the differences in in-vitro digestibility of extrusa samples dried at the different mentioned temperatures were not significant, freeze drying is preferred because small differences in digestibility have a strong influence on the calculated intake (see 1.3.1). When the temperature is below 55 ^{o}C the oven-drying technique can be used with relative confidence for dry-matter digestibility analyses (Scales et al., 1974b).

Digestive efficiency may be affected by the level of feed intake. If the level of feed intake of the grazing animals is different from indoors (where the digestibility is determined in-vivo or in-vitro) this may cause another bias in the estimation of digestibility. Experiments with sheep have shown that the feeding level influences fresh herbage digestibility (Raymond et al., 1959; Penning & Valderrabano, 1979). Information for non-lactating cattle is available from Hutton (1962) and Harkess (1963) who showed that herbage O digestibility decreased 1.4 to 1.6% when intake was increased from maintenance level to twice maintenance, but ranges of intake were small.

No information is available on the influence of the level of fresh herbage feeding on the digestibility of producing dairy cows but several experiments are in progress to assemble this information.

1.3.3.5 Precision of the estimation of digestibility and intake

In this section the random variation in the estimation of digestibility and intake will be considered; the possible bias have been already discussed in the earlier sections.

Marker-ratio techniques

There are three sources of inaccuracy with marker-ratio techniques:

- The random variation involved in the assumption that 100% of the feed marker is recovered in the faeces.
- The random variation in the marker concentration in the feed.
- The random variation in the marker concentration in the faeces.

Most reports of variation associated with the ratio technique are in terms of percent recovery of the indicator. Streeter (1969) reviewed the standard errors in the recoveries of several indicators. The results showed a large variation in standard error especially with lignin (CV_x of recovery 0.6-7.7%). Variation in predicted digestibility cannot be calculated directly from variation in percent recovery of the marker (Streeter, 1969).

No information is available on the random variation in the lignin concentration in the feed or faeces of grazing animals. Some information on the random variation in the chromogen concentration in the faeces of grazing animals is given by Steger et al. (1962). The literature is too incomplete to make conclusions on total random variation of the ratio technique.

Faecal-index techniques

The accuracy of the faecal-index technique depends on:

- the error of prediction by using the regression equation
- the random variation in the marker concentration in the faeces.

Objective comparisons of errors associated with different faecal indices are difficult to make because different investigators have reported their results in terms of different parameters. Variability in estimating the feed to faeces ratio cannot be converted directly into variability involved in estimating digestibility because one is a function of the reciprocal of the other. Streeter (1969) reviewed the standard errors of estimate of both the digestibility and of the feed to faeces-ratio. The residual standard deviations of the regression equation (RSD) when using the restricted 'local' regression method vary mostly around 0.015 when digestibility is expressed as a mass fraction (Greenhalgh & Corbett, 1960; Langlands et al., 1963; Greenhalgh et al., 1966b); only Greenhalgh et al. (1960) reached a RSD below 0.01.

The RSD is a measure of the amount of variability in the data not accounted for by regression. The standard errors of digestibilities predicted from these equations can be given by the term

$$\text{RSD}\sqrt{(c_1 + c_2 + {}^1/n)}$$

where

n = number of observations on which the regression equation is based

c_1 = a constant depending upon the number of animals and length of period contributing to the faeces sample

c_2 = a constant which allows for the fact that prediction at the extremes of a regression line is less accurate than prediction near the mean (Corbett & Greenhalgh, 1960).

If digestibilities were being predicted for three animals over three days c_1 was unity in these experiments. c_2 was found to have a value of approximately 0.2; however details on the derivation of these values were not given by Corbett & Greenhalgh (1960).

When n = 15 then $\text{RSD}_{\text{prediction}} = 1.13\ \text{RSD}_{\text{regression}}$

A standard error of 1.7 units for a digestibility value of about 0.70 predicted for three animals over three days represents a CV of about 2.4%. But as shown in Equation 2 (1.3.1) the calculation of herbage consumption requires estimation of indigestibility (1-d) and on this basis the coefficient of variation becomes 5.7% (Raymond et al., 1954; Greenhalgh et al., 1960).

The diurnal variation in faecal nitrogen concentration is small (1.3.3.3). The variation in the marker concentration in the faeces then mostly depends on between-day and between-animal variation corresponding with the constant c_1 in the formula of Corbett & Greenhalgh (1960).

With sward sampling the total random variation of faeces production was about 7.3%

at a sampling period of 3 days (1.3.2.2). The total random variation of intake estimation will amount to $\sqrt{7.3^2 + 5.7^2} = 9.3\%$ when variation of digestibility and of faeces production are independent and when the average digestibility of the herbage is 0.70; at a digestibility level of 0.80 the total random variation of intake estimation is about 11.2%.

Techniques using fistulated animals

The precision of the techniques using fistulated animals depends on:
- the error of prediction by using the regression equation between in-vivo digestibility of feed and in-vitro digestibility of extrusa samples
- the random variation in the feed sampling

Errors introduced in collecting and processing extrusa can be estimated by giving forage to fistulated animals in pens and relating digestibility of the forage to the digestibility of the extrusa. These equations, in which the independent variable was estimated from both solid and liquid fractions, showed RSD's of 0.021 (Langlands, 1975). The RSD of the best regression equation relating in-vivo 0 digestibility of the feed to the in-vitro 0 digestibility of the extrusa samples was 0.034 units (Langlands, 1966), in agreement with a RSD of 0.03 as found by Le Du & Penning (1979). The standard errors of digestibilities predicted from these regression equations can be derived with the formula mentioned in the preceding subsection; however quantitative information on the constants c_1 and c_2 is missing in the literature.

Langlands (1967b) calculated indirectly a total random error of 0.027; corresponding with a coefficient of variation of 3.4% at a digestibility of 0.80 and 13.5% for estimating the 'indigestibility'. The total error of the digestibility estimate found by Hodgson (1969) varied from 2.9 to 5.4%. The average CV of 3.9% for the digestibility estimate corresponded with a CV of 15.6% for the 'indigestibility' estimate at a digestibility of 0.80.

The total random error of faeces production was about 7.3% when sward sampling was applied. The total random error of intake estimation will at least amount to 15% at a digestibility level of 0.80.

The digestibility of the extrusa sample can also be estimated in-vivo (Wallace & Denham, 1970). The problems of this method are the saliva contamination, which possibly influences digestibility or intake in the digestibility trials and the large amount of labour involved in the collecting of enough material for the digestibility trial. The coefficient of variation of the in-vivo digestibility estimate is at least 1.3% when 3 wether sheep are used (Steg, 1980, personal communication). The total random error of intake estimation will at least amount to 9% at a digestibility of 0.80.

The in-vitro digestibility determinations on extrusa samples gave less precise estimates of digestibility than faecal nitrogen-digestibility relationships restricted to a single growth of herbage (Langlands, 1966). Arnold & Dudzinki (1967a) found that under feeding conditions in pens the faecal nitrogen technique was more precise than the in-vitro methods but they indicated that while most of the errors associated with the use of the in-vitro digestibility determinations on extrusa samples from the field can be predicted from measured effects under pen-feeding conditions, those for faecal-nitrogen methods cannot. Scales et al. (1974a) also found a better prediction of in-vivo digestibility with faecal nitrogen than with the in-vitro techniques. In general, estimates of the digestibility of grazed herbage obtained by the oesophageal fistula technique are less precise than those that can be obtained by prediction from faecal nitrogen percentage. However the latter technique carries a greater risk of bias (see 1.3.3.3); this bias can be very large and, unlike inaccuracies in results obtained from extrusa, the main causes do not arise from faulty laboratory procedures that can be detected and corrected.

1.3.3.6 Conclusions

The digestibility of the herbage consumed can be estimated with marker-ratio techniques, faecal-index methods and in-vivo or in-vitro methods combined with the use of fistulated animals.

The ratio technique can only be applied when the selected diet can be sampled with fistulated animals. Lignin may be used as an internal indicator when the faecal lignin values are corrected for apparent digestibility derived with in-vivo digestibility trials indoors and when the lignin levels in feed are above 5%. The varying recoveries of chromogen, mostly due to analytical errors, caution against use of this indicator. New methods of silicon determination together with efforts to reduce the influence of soil contamination are at present being examined. The incomplete nature of the available information prevents drawing of conclusions on total random variation of the ratio technique.

The best results of the faecal-index technique have been obtained with the internal marker nitrogen, rather than chromogen. The error of the regression equation can be diminished by basing it on a restricted range of local herbages cut from areas similar to those on which herbage intake is being measured. Particularly with selective grazing sheep, the regression equations indoors and outdoors may be different. Therefore it is preferable to derive the faecal-index relationship with material similar to that being selected by the animal which can be achieved by using fistulated animals.

Faecal-index equations can be influenced by season of the year and by level of intake; there is some information in the literature that level of herbage mass, stocking rate and level of N-fertilizer application may also be important. These factors may cause bias in the predicted digestibility values. The random variation of digestibility estimation (at a digestibility of 0.80) with the faecal-index technique is about 2% if restricted local regressions are used.

Total collection bags should be used with oesophageal fistulated animals rather than screen-bottomed bags. It is advisable to freeze-dry the extrusa samples. The best procedure is to determine with penned animals the digestibility in-vivo of the feeds and establish by regression analysis the relationship with the in-vitro values determined on extrusa samples obtained during the same study. These extrusa samples of which the in-vivo digestibility has been determined should be taken as standards in each in-vitro digestibility series. When the opportunity for within sward selection is small diurnal variation in digestibility of extrusa samples is small. The feeding level may influence fresh-herbage digestibility of sheep. Digestibility should be corrected then when the level of feeding of the grazing sheep is higher than that of the sheep in the indoor digestibility trial. There is no information on this effect of level of feeding with dairy cows. The random variation of the digestibility estimation (d = 0.80) with in-vitro techniques using fistulated animals is 3.5 to 4%.

The total random variation of intake estimation at a digestibility of 0.80 is at least 11 and 15% when faecal-index techniques and techniques using fistulated animals (with in-vitro digestibility analysis), respectively, are combined with sward sampling for the estimation of faeces production.

1.4 OTHER TECHNIQUES

1.4.1 Grazing-behaviour methods

Feed intake (I) by grazing animals is a function of time spent eating (T), the number of bites per unit of time (R) and the average size of each bite (S) (Spedding et al., 1966):

$$I = T\ R\ S$$

Few attempts have been made to estimate herbage consumption in this way because of the difficulty in measuring each of these components. Methods of recording the number of bites during grazing over extended periods and techniques to measure bite size have been developed recently (Stobbs & Cowper, 1972; Stobbs, 1973a).

Bite size can be measured with oesophageally fistulated animals when the material eaten is quantitatively recovered at the fistula. With an open oesophagus the recovery can be low and variable. However when the lower oesophagus of cattle was blocked with a foam rubber plug the mean recovery of organic matter was 95% (Stobbs, 1973a). The use of a plug in wether sheep greatly improved the mean recovery rate (84 versus 41%) and reduced the percentage variation, but recovery remained significantly below 100% (Le Du & Penning, 1979).

The eating-behaviour technique, which allowed for mastication bites and diurnal variation in feeding behaviour, compared favourably with a cutting technique for measuring herbage consumption of groups of animals strip-grazed on an oat-crop (Chacon et al., 1976). Estimation of herbage consumption by grazing cattle using eating behaviour has considerable merit because it is reasonably precise (10.1% CV), could be applicable to a wide range of pasture conditions, measurements are easily taken and laboratory analyses are kept to a minimum (Chacon et al., 1976). This technique merits more investigation in future.

1.4.2 *Live-weight methods*

The technique used by Allden (1969) depends on observations of short-term changes in live weight:

$$I = (W_{t_2} - W_{t_1}) - L + F + U + R$$

W_{t_2} and W_{t_1} = live weight respectively after and before a period of grazing
L = weight of water drunk
F = weight of faeces production
U = weight of urine production
R = loss of weight by respiration and transpiration (CO_2, CH_4 and H_2O)

The weight of voided faeces and urine was measured with harnessed sheep (Allden, 1969), a procedure probably also possible with grazing steers when faeces is collected intensively (see 1.3.2.1). However when dairy cows are used total faecal collection cannot be applied and indirect methods are often used with a high risk of bias and a high random variation (see 1.3.2.2).

Allden (1969) weighed the sheep on a balance in the field. With an electronic system it is possible to weigh the animals accurately with minimum disturbance and at frequent intervals (Horn, 1979, personal communication). With very frequent weighing intervals it is not necessary to measure urine or faeces weights separately but these figures can be derived from the changes in animal weight.

It is very difficult and inaccurate to measure changes in animal weight due to evaporation in the field. Therefore Allden (1969) made also observations on the live weight changes of similar fully harnessed sheep without access to grazing during the same periods. However due to the less intensive movement and lower metabolism the evaporation of these animals will not be comparable with that of the grazing animals. Ernst (1978) measured a decrease in animal weight of about 8 kg during a 5-hour resting period due to respiration and perspiration. He concluded that because these losses occurred also during the grazing period (which were not measured) he could not use the animal weights to estimate herbage intake.

These animal weights provide only an estimate of the intake of fresh herbage of unknown T content. In experiments on pasture productivity or animal nutrition information is needed on T or O intake. Therefore it is necessary to gather a sample representative of the selected herbage during the period of animal weighing (see 1.3.3.2). Under most conditions the use of oesophageal fistulated animals will be needed to provide a representative sample. Then one of the biggest problems will be the separation of the added saliva from the herbage eaten without altering chemical composition of the herbage (see 1.3.3.4).

1.4.3 Water-intake methods

The water requirement per kilogram of dry matter consumption of animals is related to the ambient temperature. Hyder et al. (1966) used this relationship to predict the water requirement of cattle, corrected for body size. The assumption is made that if the amount of water drunk can be measured then the remaining water that is required must come from the herbage that is grazed. If the content of water in the herbage consumed can be determined then the total amount of herbage consumed can directly be calculated when the metabolic fraction of water is assumed to be zero (Hyder et al., 1966).

The relationships between water requirement per kilogram T intake and air temperature have been derived indoors and are applied outdoors. A possible bias may arise if variation in other climatic factors such as relative humidity and solar radiation in the grazing situation influence the ratio of water intake to T intake.

When the water in the feed exceeds the water requirement of animals the water-intake method cannot be used to estimate the amount of food eaten (Hyder et al., 1966). At a temperature of 16 ^{o}C the water intake method cannot be used when the dry-matter content of the herbage is below 21% (Hyder et al., 1966); an example of the limitations of this technique when herbage with a low T content is to be used.

Fistulated animals can best be used to sample the selected diet. However the separation of the added saliva without altering dry matter content of the sample is not possible yet.

Benjamin et al. (1977) derived a constant ratio between water drunk and the consumption of dry matter when food and water were offered ad lib. to sheep caged outdoors. The very low moisture content of the feed (10%) was almost constant, furthermore there was little variation in ambient temperature or in relative humidity, so corrections of water consumption for climatic conditions were not applied. The authors themselves questioned if the ratio of water drunk to T intake by grazing sheep remains the same as for caged sheep.

1.4.4 Animal-production methods

Energy requirements for maintenance and production have been derived with stall--fed animals. These feeding standards are usually given in ME or NE. When the live weight and the production of animals are measured over a long period these feeding standards can be used to estimate feed intake.

When the live weight and the composition of the live weight are constant then the energy requirement is equal to the energy consumption. Dividing the energy requirement by the energy content of the consumed herbage gives an estimate of the T or O intake of herbage.

The maintenance requirement of grazing animals is higher than that of stall-fed animals, estimates of the quantitative difference vary in the literature. Possibly the effects of the level of feeding on the digestibility of herbage of dairy cows differ from these effects as derived on winter rations for the feeding standards. For the calculation of T or O intake the energy content of the consumed herbage is necessary, requiring fistulated animals or sward-cutting methods to provide estimates of the selection effect of grazing animals.

When the energy requirement is not equal to the energy intake feeding standards for the changes in live weight are necessary. Application of standards for live weight gain is inaccurate because determination of live weight is difficult (due to variable rumen contents) and because the composition of live weight gain is not known.

1.4.5 Isotope techniques

Benjamin et al. (1975) dosed grazing sheep with tritiated water and determined periodically the concentration of it in the blood. The water turnover was estimated by following the decrease in radio activity. While the sheep were not consuming liquid water the water turnover was assumed to represent water intake obtained from the herbage. The water turnover was divided by the water content of the pasture grazed to calculate fresh matter intake.

However the water obtained from the herbage consists of preformed free water and metabolic water. The metabolic water was omitted when calculating intake in the trials of Benjamin et al. (1975). Another source of bias in these trials was the determination of the content of dry matter which was not done in the consumed herbage (barley) but in the ungrazed control plot.

Benjamin et al. (1977) again estimated water turnover by the tritium-dilution technique. It was assumed that total water turnover was equal to the water drunk plus the water obtained from the herbage consumed (food water) both preformed and metabolic. Because the fraction of metabolic water is not known, a relationship between herbage T intake and food water was established with caged animals. The caged animals should obtain the same feed with the same water content as the grazing animals upon which the relationship is applied.

In the trials of Benjamin et al. (1977) a monoculture legume with a very low water content of 10% was used. Under these conditions the food consumed by the grazing animals and the caged animals was equal and the food water obtained from herbage eaten by the caged sheep was similar to that in herbage consumed by the grazing sheep. However problems arise when grazing animals select between herbage species and between material with different water content. It is questionable if under such conditions a relationship between herbage T intake and food water can be derived that is representative for the grazing situation. Fistulated animals can be used to assemble the selected diet of the grazing animals; these samples should be fed to the caged animals to derive the mentioned relationship. However the problem of the added saliva in the extrusa samples is not solved yet.

2 Factors affecting the herbage intake of grazing cattle

2.1 INTRODUCTION

The control of feed intake has been studied mainly under indoor feeding conditions, but as Arnold (1970) has pointed out, it is reasonable to assume that the principles developed from indoor experiments will apply to grazing animals. In the first part of this review a general description of the mechanisms involved in the regulation of feed intake will be given. As a consequence of the complexity of these mechanisms more simple approaches have been introduced to bring into perspective the factors influencing voluntary feed intake. The usual approach with housed ruminants has been to partition the factors into physical and metabolic ones (Conrad, 1966; Campling, 1970; Bines, 1971, 1976). In the complexity of the grazing situation an ad lib. supply of feed does not always exist and other approaches have been used (Raymond, 1969; Arnold, 1970; Combellas, 1977).

The factors determining the herbage intake of grazing animals will be considered under three headings:

- factors of animal origin: animal age and weight, (stage of) pregnancy, (stage of) lactation, milk production level and animal condition
- factors of sward origin: digestibility, chemical composition, herbage species, herbage mass and maturity
- factors of management origin: herbage allowance, concentrate supplementation, herbage contamination, nitrogen fertilization, climate, season and grazing system.

It has to be realized that many of these factors are interrelated under most experimental and practical conditions. For example, changes in the maturity of the herbage result both in variations in herbage mass and herbage quality (Green et al., 1971) and both factors might influence herbage intake. Variations in herbage mass can also be achieved by varying nitrogen fertilizer application rates or by variation in density of the sward. For convenience the effects of the mentioned factors upon herbage intake will be dealt with separately, although interactions between them might exist.

2.2 REGULATION OF FEED INTAKE IN RUMINANTS

Extensive reviews have analysed the factors affecting regulation of intake by ruminants (Balch & Campling, 1969; Campling, 1970; Baumgardt, 1970; Rohr, 1977) and recent reviews have described the mechanisms (Bines, 1971; Jones, 1972; Baile & Forbes, 1974; Bines, 1976; Journet & Remond, 1976; Forbes, 1979). The assumption was made that the principles developed in indoor experiments will apply to grazing animals (Arnold, 1970).

It is generally accepted that ruminants try to adjust voluntary feed intake to their energy requirement (Baile & Forbes, 1974; Rohr, 1977). So over longer periods the adult animal can keep net energy intake almost in balance with energy output, if the amount of feed consumed and its energy content are no limiting factors (Baumgardt, 1970). The hypothalamus plays an important role in the central control of feed intake in the brain (Balch & Campling, 1969; Baile & Forbes, 1974). Electrical and chemical stimulation of the lateral hypothalamus increased intake in sheep and goats; stimulation of the ventromedial region caused hypophagia (Rohr, 1977). In addition the hypothalamus may be sensitive to changes in hormone levels (Balch & Campling, 1969; Rohr, 1977).

Considerable work has been carried out on the origin of the (neural, endocrine or other) feedback signals to the central control system, which determines food intake. It is generally acknowledged that there are two groups of intrinsic stimuli that may provide feedback to the central control system to limit food intake in ruminants. These are stimuli arising from the process of absorbing and metabolising nutrients from the ingested food (metabolic control) and stimuli arising from distension of the alimentary tract by the physical presence of food (physical control).

2.2.1 Metabolic control

Chemostatic mechanisms Ruminants offered mixed forage/concentrate or pure concentrate diets of high nutrient concentration do not eat to a limiting level of rumen fill at the end of the meal (Bines, 1971). It has been demonstrated that the average daily intake of digestible energy remains remarkably constant, regardless of variations in food composition (Baumgardt, 1970). Thus as digestible energy concentration of a diet increases above a certain level, food intake will decrease such that digestible energy intake is maintained at the level determined by the energy requirements of the animal. The digestible energy concentration at which this occurs depends on the energy requirement and hence on the physiological state of the animal (Bines, 1971).

Baile & Mayer (1970) and Baile & Forbes (1974) did not consider small changes in blood glucose level to be important determinants of intake for ruminants. Because volatile fatty acids rather than glucose are the main products of energy digestion in ruminants these compounds have received considerable attention as possible components of a food intake regulation system. However the experiments with infusion of volatile fatty acids, which are described below, have often been done at non-physiological levels and with forms, in which the acids were supplied, which could affect intake by other mechanisms (De Jong, 1979, personal communication). Food intake decreased as the result of infusion of acetate into the rumen of cattle and sheep (Bines, 1971; Rohr, 1977). Baile & Mayer (1968) have shown that intraruminal addition of acetate was more effective than the same amount of acetate administered intravenously, indicating that acetate receptors are probably on the lumen side of the rumen wall.

Intraruminal addition of propionate and lactate also influenced feed intake negatively, whereas results with butyrate addition were more variable (Bines, 1971; Baile & Forbes, 1974; Rohr, 1977). Propionate receptors may be present in veins draining the rumen and on the lumen side of the rumen wall (Bines, 1971; Rohr, 1977). Forbes (1979) supports the view that the liver is the primary site of action of infused propionate. The mechanism of the response to acetate and propionate is not a compensation for the added energy, nor is it due to the increase in osmolarity (Bines, 1971). The decrease in food intake by intraruminal acetate infusion is less when the rumen is locally anaesthetized, an indication of a neural transport of the signal to the central control system (Martin & Baile, 1972). The information regarding the influence of volatile fatty acids on intake regulation needs to be increased, with special attention paid to the levels (physiological) and forms in which the acids are supplied.

Thermostatic mechanisms The theory of a thermostatic regulation of food intake is based on the existence of temperature sensitive centres in the hypothalamus. It has not been shown in experiments that a thermostatic regulation operates under normal physiological conditions in ruminants (Balch & Campling, 1969; Rohr, 1977). The temperature of the hypothalamus did not raise after the intake of grains or intraruminal infusion of acetate (Rohr, 1977).

Changes in environmental temperature however may have an effect on food intake, peripheral receptors which also regulate the heat loss may play a role in the regulation of intake (Rohr, 1977). The interplay of heat production and environmental heat load is well recognized as affecting feed intake. In a cold environment the feed intake of ruminants increased; in a warm or hot environment the intake decreased (Jones, 1972; Baile & Forbes, 1974; Bines, 1976).

Lipostatic mechanisms The importance of lipostatic mechanisms for long-term regulation of energy balance is indicated by the negative correlation between body fat and feed intake (Rohr, 1977). Animals strife for a certain condition, so when they are too thin they will try to increase feed intake and build up some fat reserves. Recently a relationship between post-partum fat mobilization of dairy cows and the low intake at this time has been postulated (Journet & Remond, 1976). After calving a high level of plasma free fatty acids from adipose tissue corresponded to low intake. However the mobilization of fat probably does not cause the low intake but is an effect of the low intake. The doubtful role of free fatty acids also follows from short-term studies of Thye et al. (1970), who found a positive correlation between the level of free fatty acids in the blood after feeding and the feed intake during subsequent feeding.

Several possibilities of feed-back mechanisms involved in lipostatic control are given in the literature: 1) a direct effect of free fatty acids on the central control in the hypothalamus (Journet & Remond, 1976), 2) the size of the adipose tissue cells may initiate a signal (Baumgardt, 1970), 3) hormones (Baumgardt, 1970; Baile & Forbes, 1974) may connect the fat depots with the control centre of feed intake in the hypothalamus. Clear evidence for one or more of these mechanisms has not yet been found.

2.2.2 Physical control

There is considerable evidence now suggesting that ruminants being fed bulky forages may stop eating before they have consumed sufficient nutrients to achieve their genetic potential for production (Balch & Campling, 1969; Bines, 1971). In this situation food intake is determined by two major factors:

- The capacity of the alimentary tract and especially of the reticulo rumen. Intra-ruminal additions of food caused an immediate decrease in oral food intake while animals could be encouraged to eat far much longer than normal by removing the swallowed feed from the rumen (Campling, 1970). Further evidence confirming the importance of the amount of contents in the rumen has come from experiments in which it was shown that ruminants eat to a similar fill of the reticulo rumen at the end of a meal, when offered roughages such as hay and artificially dried grass varying in digestibility between 50 and 70% (Balch & Campling, 1969).

A direct association between the voluntary intake of food and the size or weight of the empty reticulo rumen has been found (Campling, 1970). The principal determinant of rumen capacity is the size of the animal; thus when food of a relatively low digestibility is given to a number of animals intake is broadly related to live weight (Bines, 1971; Rohr, 1977). The size of the rumen is partly determined by the size of the abdominal cavity, which appears to be limited in the extent to which it can stretch. Physical regulation of food intake presumably involves stretch receptors in the wall of the rumen or abdomen, but the exact nature and location of these is not yet known (Bines, 1971).

Foetal enlargement and deposition of fat within the abdominal cavity apparently reduces the capacity of the reticulo rumen and this is associated with a reduced intake by these animals (Campling, 1970; Bines, 1970; Forbes, 1977). In the lactating cow it is possible that the increased demand for nutrients can be met in part by what has been termed a hypertrophy of the alimentary canal, thus permitting an increased food intake (Bines, 1971). The effects of animal species, animal weight, fatness, pregnancy stage and lactation on feed intake will be reviewed in chapter 2.3.

- The rate of disappearance of digesta from the reticulo rumen, which depends on the rate at which the food is broken down chemically by the processes of digestion and on the rate at which the undigested residues of the food are broken down physically before they can be moved of from the rumen. Balch & Campling (1969) considered the rate of disappearance of digesta from the reticulo rumen to be a function of rate of breakdown by combined action of microbial fermentation and mechanical activity of the gut, including chewing during eating and rumination and muscular contractions of the gut. The soluble products of digestion are absorbed or, if gaseous, removed by eructation, and the undigested residues are transferred through the reticulo-omasal orifice to the abomasum and intestine. The rate of enzymic digestion by rumen microbes is closely related to the chemical composition of the feed (Bines, 1971). When inferior roughage was supplied, addition of nitrogen to the rumen increased microbial activity, rate of breakdown and voluntary intake (Campling, 1970; Bines, 1971).

The relationship between feed intake and rate of disappearance of digesta is reflected in the relationship between voluntary intake and digestibility of various roughages. These relationships will be discussed in Section 2.4. From information in this section the conclusion can be drawn that there is a strong relationship between digestibility and feed intake over variable ranges of digestibilities, these ranges depend on the type of food. The point at which there is no influence of digestibility on intake and at which regulation of food intake moves from physical to metabolic factors depends on the type of feed, on the physiological demand of the animal and on the energy concentration per unit of diet volume.

Apart from digestibility rate of passage depends on saliva production, on rumen pH and on the physical structure of the feed (long against ground roughages) (Rohr, 1977). A decrease in saliva production reduces rumen pH and buffer capacity and thus delays microbial breakdown of cellulose. Large amounts of concentrates intensify acid production in the rumen and reduce saliva flow; the resulting decrease in rumen pH affects cellulolytic activity, rate of passage and intake of roughages (Balch & Campling, 1969; Baile & Forbes, 1974; Rohr, 1977). Presenting the ruminant with ground roughage, that is in a physical form in which the roughage can readily pass the reticulo-omasal orifice generally leads to a higher voluntary intake than when the same roughage is offered in the long form (Campling, 1970; Rohr, 1977). The rate of passage of the small particles is increased resulting in higher intake but lower digestibility (Van der Honing, 1975). This finding provides support for the concept of the physical limitation of roughage intake imposed by the small size of the reticulo-omasal orifice.

Although it is convenient to separate physical from metabolic factors regulating intake, they are not necessarily independant and it is unlikely that any one factor or group of factors will be universally responsible for regulating intake (Forbes, 1979).

2.3 FACTORS OF ANIMAL ORIGIN

2.3.1 *Animal age and weight*

Live weight and size of a growing animal are highly correlated. Because of the close relationship between body size and the capacity of the alimentary tract food consumption increases with live weight at comparable fatness (Rohr, 1977). The relation between intake of feed (hay or silage and concentrates) indoors and live weight of dairy cows was positive but weak (r = 0.44); the total amount of dry matter increased broadly by 0.8 to 1.0 kg for each increase of 100 kg live weight (Journet et al., 1965) Hyppöla & Hasunen (1970) cited by Bines (1976) found a correlation of 0.79 between roughage dry matter intake and the live weight of dairy cows; when live weight changed by 100 kg the roughage T intake changed 1.7 kg in the same direction. Live weight had an important effect on total feed intake when complete diets (forages plus concentrates) were fed to a large group of lactating cows; for each 100 kg increase in body weight, the increase of T intake was 1.07 kg (Brown et al., 1977).

2.2.2 *Physical control*

There is considerable evidence now suggesting that ruminants being fed bulky forages may stop eating before they have consumed sufficient nutrients to achieve their genetic potential for production (Balch & Campling, 1969; Bines, 1971). In this situation food intake is determined by two major factors:

- The capacity of the alimentary tract and especially of the reticulo rumen. Intra-ruminal additions of food caused an immediate decrease in oral food intake while animals could be encouraged to eat far much longer than normal by removing the swallowed feed from the rumen (Campling, 1970). Further evidence confirming the importance of the amount of contents in the rumen has come from experiments in which it was shown that ruminants eat to a similar fill of the reticulo rumen at the end of a meal, when offered roughages such as hay and artificially dried grass varying in digestibility between 50 and 70% (Balch & Campling, 1969).

A direct association between the voluntary intake of food and the size or weight of the empty reticulo rumen has been found (Campling, 1970). The principal determinant of rumen capacity is the size of the animal; thus when food of a relatively low digestibility is given to a number of animals intake is broadly related to live weight (Bines, 1971; Rohr, 1977). The size of the rumen is partly determined by the size of the abdominal cavity, which appears to be limited in the extent to which it can stretch. Physical regulation of food intake presumably involves stretch receptors in the wall of the rumen or abdomen, but the exact nature and location of these is not yet known (Bines, 1971).

Foetal enlargement and deposition of fat within the abdominal cavity apparently reduces the capacity of the reticulo rumen and this is associated with a reduced intake by these animals (Campling, 1970; Bines, 1970; Forbes, 1977). In the lactating cow it is possible that the increased demand for nutrients can be met in part by what has been termed a hypertrophy of the alimentary canal, thus permitting an increased food intake (Bines, 1971). The effects of animal species, animal weight, fatness, pregnancy stage and lactation on feed intake will be reviewed in chapter 2.3.

- The rate of disappearance of digesta from the reticulo rumen, which depends on the rate at which the food is broken down chemically by the processes of digestion and on the rate at which the undigested residues of the food are broken down physically before they can be moved of from the rumen. Balch & Campling (1969) considered the rate of disappearance of digesta from the reticulo rumen to be a function of rate of breakdown by combined action of microbial fermentation and mechanical activity of the gut, including chewing during eating and rumination and muscular contractions of the gut. The soluble products of digestion are absorbed or, if gaseous, removed by eructation, and the undigested residues are transferred through the reticulo-omasal orifice to the abomasum and intestine. The rate of enzymic digestion by rumen microbes is closely related to the chemical composition of the feed (Bines, 1971). When inferior roughage was supplied, addition of nitrogen to the rumen increased microbial activity, rate of breakdown and voluntary intake (Campling, 1970; Bines, 1971).

The relationship between feed intake and rate of disappearance of digesta is reflected in the relationship between voluntary intake and digestibility of various roughages. These relationships will be discussed in Section 2.4. From information in this section the conclusion can be drawn that there is a strong relationship between digestibility and feed intake over variable ranges of digestibilities, these ranges depend on the type of food. The point at which there is no influence of digestibility on intake and at which regulation of food intake moves from physical to metabolic factors depends on the type of feed, on the physiological demand of the animal and on the energy concentration per unit of diet volume.

Apart from digestibility rate of passage depends on saliva production, on rumen pH and on the physical structure of the feed (long against ground roughages) (Rohr, 1977). A decrease in saliva production reduces rumen pH and buffer capacity and thus delays microbial breakdown of cellulose. Large amounts of concentrates intensify acid production in the rumen and reduce saliva flow; the resulting decrease in rumen pH affects cellulolytic activity, rate of passage and intake of roughages (Balch & Campling, 1969; Baile & Forbes, 1974; Rohr, 1977). Presenting the ruminant with ground roughage, that is in a physical form in which the roughage can readily pass the reticulo-omasal orifice generally leads to a higher voluntary intake than when the same roughage is offered in the long form (Campling, 1970; Rohr, 1977). The rate of passage of the small particles is increased resulting in higher intake but lower digestibility (Van der Honing, 1975). This finding provides support for the concept of the physical limitation of roughage intake imposed by the small size of the reticulo-omasal orifice.

Although it is convenient to separate physical from metabolic factors regulating intake, they are not necessarily independant and it is unlikely that any one factor or group of factors will be universally responsible for regulating intake (Forbes, 1979).

2.3 FACTORS OF ANIMAL ORIGIN

2.3.1 Animal age and weight

Live weight and size of a growing animal are highly correlated. Because of the close relationship between body size and the capacity of the alimentary tract food consumption increases with live weight at comparable fatness (Rohr, 1977). The relation between intake of feed (hay or silage and concentrates) indoors and live weight of dairy cows was positive but weak ($r = 0.44$); the total amount of dry matter increased broadly by 0.8 to 1.0 kg for each increase of 100 kg live weight (Journet et al., 1965) Hyppöla & Hasunen (1970) cited by Bines (1976) found a correlation of 0.79 between roughage dry matter intake and the live weight of dairy cows; when live weight changed by 100 kg the roughage T intake changed 1.7 kg in the same direction. Live weight had an important effect on total feed intake when complete diets (forages plus concentrates) were fed to a large group of lactating cows; for each 100 kg increase in body weight, the increase of T intake was 1.07 kg (Brown et al., 1977).

Conrad et al. (1964) found that the food intake of lactating cows, eating forage or mixed diets in 114 different trials, varied in direct proportion to live weight when the digestibility of the dry matter was below 66%; with diets of higher digestibility food intake varied with the 0.73 power of live weight.

The effect of live weight in relation to age on the feed intake of grazing animals has been determined. Five-year-old wethers, weighing about 98 kg, consumed 1.2 to 1.4 times the digestible organic matter ingested by four-month-old lambs, weighing about 39 kg (Hadjipieres et al., 1965). Holmes et al. (1961) reported that adult dry cows consumed about 1.6 times more digestible organic matter than growing calves of eleven months of age. There were high simple correlations between live weight and organic matter intake when grazing dry cows, heifers and calves were compared (Hodgson & Wilkinson, 1967).

Brody (1945) reasoned that maximal relative food capacity was related approximately to basal metabolism. A linear correlation between the logarithm of basal metabolism and the logarithm of body weight showed that basal metabolism is proportional to a given power function of body weight (= metabolic weight)(Kleiber, 1961). Brody showed that the exponent 0.73 was the most appropriate factor relating basal metabolism to live weight in mature animals, he also suggested that the relationship in animals at different stages of growth after puberty was better expressed on the basis of live weight raised to the power 0.6. Kleiber (1961) recommended a power of three-quarters of live weight (W) as representative of metabolic weight and stated that there was no significant difference between Brody's factor and his; thus $I = a\ W^{\frac{3}{4}}$.

The exponent relating feed intake to live weight can be derived by regression analysis of log I on log W. When this was done with stall-fed cows the exponent was the same as the generally accepted value of 0.73 (Conrad et al., 1964; Blaxter et al., 1961). The calculated exponent of live weight (nearly 1) suggested that intake of actively growing grazing sheep was directly proportional to live weight (Hadjipieres et al., 1965; Langlands et al., 1963c). Other workers calculated the exponents which gave the best fit to their experimental results with grazing cattle; both Holmes et al. (1961) and Hodgson & Wilkinson (1967) obtained good results with the exponents 0.61 when growing and mature animals were used. In most of the above mentioned experiments the number of data was too low to derive an accurate exponent; therefore most workers prefer the exponent 0.75 or 0.73 (Curran & Holmes, 1970; Greenhalgh & McDonald, 1978).

The influence of animal weight on herbage intake of lactating grazing cows has been tested by regression analysis relating intake of digestible organic matter (D_O) to metabolic live weight, live weight change and FCM yield. The partial regression coefficients of D_O on $W^{0.73}$ varied between 0.08 and 0.12 (Corbett, 1960; Wallace, 1961; Hutton, 1962; Holmes & Jones, 1964; Jones et al., 1965; Greenhalgh et al., 1966a; Curran & Holmes, 1970). The variation in the regression coefficient can be attributed to inappropriate application of multiple regression analysis by using correlated variables, not completely randomized variables, a small range in the variables or a small number of observations (Curran & Holmes, 1970).

2.3.2 Pregnancy

In many experiments the effect of pregnancy is confounded with effects of lactation (cows) or animal growth (heifers). Most reports on the voluntary intake of pregnant ruminants are confined to the last two months of pregnancy.

The results of some experiments with non-lactating ewes have shown that an increase in food intake occurs in early and mid-pregnancy (Forbes, 1970). In non-lactating heifers pregnancy produces a measurable increase in absolute intake (Penzhorn & Meintjes, 1972; Bines, 1976), however this increase is partly due to the growth of the animals (corrected for foetal development). Gestational effects did not contribute to differences in weekly intake observations for individual·lactating cows (Johnson et al., 1966). Bines (1971, 1976) attributed the higher intake in early and mid gestation to a possible increase in the rate of passage of the food, to the energy requirement of the developing foetus or to elevated progesterone levels in the blood. However, Lamberth (1969) could find no differences between pregnant and non-pregnant twin heifers in rate of passage while the energy demands for the foetus are important only in the last months of gestation. More information is needed before conclusions can be made about the intake in early and mid-pregnancy of non-lactating, non-growing cattle.

The foetus and associated tissues occupy a considerable part of the total volume of the abdominal cavity in later pregnancy. During the last 6 weeks of pregnancy intake of ewes declined although the time of onset and the rate of decline have been variable (Forbes, 1970); this decline can be attributed to a reduction in the volume of the rumen. Cows ate 13% less hay in the last 6 weeks of pregnancy than did their non-pregnant monozygotic twins (Campling, 1966). Comparable results (12-15% depression of intake in the last 6 weeks of pregnancy) were obtained by Johnson et al. (1966), Curran et al. (1967) and Marsh et al. (1971b) with roughage rich diets.

The few experiments in which concentrate rich diets have been offered ad lib. to pregnant cattle in the last months of pregnancy show that a decline in intake does occur (Aitken & Preston, 1964; Owen et al., 1968). Under some circumstances this depression in food intake possibly occurs as a result of the change in endocrine balance at this time (Forbes, 1970).

All the above mentioned experiments are done with stall-fed animals; there is no information on the pregnancy effect on herbage intake of grazing animals.

2.3.3 Lactation

Where comparisons have been made between the intakes of lactating and dry animals it has been found that more food was always consumed by the lactating animals. The intake of stalled (Hadjipieres & Holmes, 1966) or grazing (Arnold & Dudzinski, 1967b) lactating ewes was higher than that of dry ewes. Lactating cows also eat more than their non-lactating controls. This has been shown by comparisons of monozygotic twins fed hay or concentrates (Campling, 1966), long dried grass (Leaver et al., 1969a) and fresh grass indoors (Hutton, 1963).

Estimates of the food intake of grazing cows suggested that lactating cows ate

28% more food than non-lactating cows grazing the same pasture (Elliot et al., 1961). Lactation of grazing cows increased I_T by 25% compared with non-lactating identical twin cattle (Field, 1966). Similar results were achieved by Jones et al. (1965) and Dijkstra (1971) giving differences of 35% in I_O and of 30% in I_T, respectively.

The weight of digesta in the rumen is greater in lactating than in dry cows (Tulloh, 1966). The hypertrophy of the alimentary tract which occurs in the lactating cow enables it to eat larger amounts of food than a non-lactating cow without altering to a great extent the mean retention time of food in the gut (Leaver et al., 1969a). The weight of the empty rumen of a lactating cow was on average 20% higher than that of a non-lactating cow (Smith & Baldwin, 1974). The primary cause of the change in rumen capacity presumably arises from endocrine changes associated with the onset of lactation, but the mechanism is not understood (Campling, 1970).

The greater physiological requirement of the lactating relative to the non-lactating cow results in a higher long-term intake by the former. The increase in level of food intake after parturition indoors usually continues for several weeks after the peak yield has been reached and then either remains steady as milk yield declines or declines slowly (Forbes, 1970; Bines, 1976). A review of published work by Bines (1976, 1979) shows that the maximum milk yield is reached in five to eight weeks, whereas the time of occurrence of maximum intake is more variable ranging from 5 to 36 weeks with a mean value of 16 weeks; this length is largely dependent on the diet composition.

The regulation of food intake in high producing lactating cows is characterized by a temporary failure to regulate the energy balance to maintain body weight in early lactation (Baile & Forbes, 1974). After calving the energy requirement for maintenance and production is higher than the energy intake and therefore a loss of body weight occurs at this stage (early lactation); this is recovered later (mid and late lactation) when the milk yield declines.

Stage of lactation

Early lactation It is not clear why food intake in early lactation increases slowly in relation to the energy output in milk. A physical limitation overcome by slow hypertrophy of the alimentary tract was suggested by Tulloh (1966). This theory would partly explain why the lag between peak yield and peak intake is shorter when indoor diets rich in concentrates were fed, as observed by Journet & Remond (1976). Another possibility is that the rate of metabolism in both rumen and tissues takes time to adapt after calving to the increased demand for nutrients (Bines, 1976). It is possible that fat deposited within the abdomen before calving must be mobilized before rumen fill can be maximized (Bines, 1976, 1979). Both free fatty acids released from adipose tissue (Journet & Remond, 1976) and endocrinical factors associated with lactation (Forbes, 1970) could affect the intake.

It appears that the lag between peak milk yield and peak food intake is greater in the first than in subsequent lactations (Bines, 1976). Feeding high levels of concentrates ad lib. in early lactation increases total energy intake but complete equilibration of intake and output of energy was not possible (Bines, 1976). This failure may be partly due to the accumulation in the rumen of the acid end products of fermentation (Baile & Forbes, 1974), but attempts to neutralize these by use of buffers have been only partly successful (Bines, 1976). With higher levels of structural carbohydrates in the concentrates the production of acids is more regular in time and total intake of cows is increased due to a better environment for fermentation. The reaction of the very high yielding cows to the higher intake is a higher peak production and a comparable deficit between energy intake and output (De Visser, 1980). The use of higher contents of (protected) fat in the concentrates is being researched (Bines, 1979).

Recent information concerning the influence of lactation stage on dry matter intake of stall-fed high producing cows is given by Brown et al. (1977). The maximum dry matter intake was achieved 100 days after calving; at 50 days after calving the T intake was 1 kg lower than the maximum. At lower production levels the maximum intake may be reached earlier (Curran et al., 1970).

Mid and late lactation Once the peak of lactation is past the cow is soon able to consume enough energy to meet production requirements. After the maximum intake is reached intake either remains steady as milk yield declines (Forbes, 1970) or declines slowly (Hutton, 1963). The intake of dry matter decreased with about 1 kg from 100 to 200 days post partum and again about 2 kg from 200 to 300 days post partum when cows were fed a 70% concentrate diet (Brown et al., 1977); the dry matter intake varied only 1 kg between 50 and 200 days post partum. Those studies which have included drying off and the end of lactation have shown that intake declines at that time (Johnson et al., 1966; Hadjipieres & Holmes, 1966; Journet & Remond, 1976).

There is little information concerning the influence of lactation stage on intake of grazing cows. Jones et al. (1965) compared the intake of grazing cows 2 months post partum with that of cows 6-7 months post partum. In a first experiment the O intake of the high-yielding cows was 1.3 kg lower than that of the low-yielding cows, but the difference in FCM yield was only 2.4 kg d^{-1}. In a second experiment the difference in FCM yield was greater (7 kg d^{-1}) and the high yielding cows ate 2.4 kg O more than the low-yielding cows. At a decrease in milk production of 3.7 kg, between 46 and 130 days after calving, no effect could be derived on I_T of herbage ('t Hart, 1979a). From about 125 to about 210 days post partum the milk yield declined 2.1 (exp. 1) to 4.3 (exp. 2) kg; in the first experiment there was no influence on herbage intake but I_T decreased 1.3 kg in the second experiment. When cows 4 and 14 months in lactation were compared both milk production and I_T of the 'late-lactation' group was less (11.4 and 1.4 kg respectively), leading to the conclusion that during the lactation herbage consumption is not closely related with milk production ('t Hart, 1979a).

2.3.4 Level of milk production

The effect of the level of milk production during the lactation period on intake has already been discussed (lactation stage). Differences in milk production at the same stage of lactation exist between animals (genetic production level) and may normally be related with intake. In this section the effects of differences in milk yield over the whole lactation on feed intake will be discussed.

It is difficult to establish the true relationship between daily milk yield and intake at a given lactation stage since the common commercial and experimental practice is to feed cows (especially indoors) according to yield. Concentrates fed in a ratio to milk produced was combined with ad lib. forage feeding in several experiments. Journet et al. (1965) compared individual intakes from the fifth to the ninth week of lactation and found a linear increase of total dry matter intake with daily level of milk production (0.28 kg I_T per kg FCM). A significant correlation ($r = 0.59$) was obtained between forage I_T and FCM yield averaged over the total lactation period (Johnson et al., 1966). At given levels of concentrates daily milk yield was positively associated with roughage intake in week 1 to 4 and in week 9 to 16 of lactation (Curran et al., 1970). At comparable stages of lactation Brown et al. (1977) derived a strong relationship between daily milk yield and total I_T.

In several grazing experiments a strong positive relationship between herbage intake and daily milk production has been shown (Hutton, 1962; Holmes & Jones, 1964; Greenhalgh et al., 1966a; Curran & Holmes, 1970). However the effects of milk production due to lactation stage and the effects of milk production due to genetical factors are often confounded or details are not given.

The herbage consumption of two groups of dairy cows with different production capacities were compared by 't Hart (1979a). At comparable stages of lactation the milk production difference between the groups was 4.4 kg per day (average of 3 experiments); the dry matter intake differed on average 1.9 kg.

2.3.5 Animal condition

In fat animals fed indoors extensive deposition of fat within the abdominal cavity apparently reduces the effective capacity of the rumen and this is associated with a reduced roughage intake by these animals (Bines et al., 1969; McGraham, 1969; Forbes, 1969). The combined effects of pregnancy and fatness on the depression of rumen volume of ewes were confirmed by Forbes (1969). This reduction in intake is not necessarily an effect of a physical regulatory mechanism (see 2.2.2), since concentrate intake is also reduced in fat animals without the rumen being filled to capacity (Bines et al., 1969). Also cows which were fat at the time of calving have shown depressed intake during the critical early part of lactation (Bines, 1976).

There is little information available about the condition effect on intake of grazing animals. As thin grazing sheep became fat intake decreased (Arnold, 1970). The amount of abdominal fat was found by Tayler (1959) to be important in restricting the voluntary intake of herbage by grazing steers.

2.3.6 *Other animal characteristics*

Relative to body weight cattle eat more than sheep on diets fed indoors (Leaver et al., 1969a; Greenhalgh & Reid, 1973). There are few data on intakes of sheep and cattle grazing together; results of Van Dyne & Meyer (1964), Arnold (1970) and Jamieson (1975) indicate that the two species may not obtain similar nutrient intakes per unit live weight.

Differences in absolute intake between animal breeds fed herbage indoors have been shown. These differences can partly be attributed to variation in animal size; by expressing intake in relation to live weight the smaller cows eat the most (Greenhalgh & Runcie, 1962; Künzi, 1969; Rohr, 1972). Differences in intake between breeds of grazing sheep have been found by Langlands (1968). There is very little information on the breed effect at grazing dairy cows: Greenhalgh & Runcie (1962) found the same intake (relative to live weight) of Ayrshires and Friesian cows.

The social behaviour may influence intake of grazing animals but there are very few quantitative data (Arnold, 1970; Jamieson, 1975). Infectious and parasitic diseases are consistently associated with decreased feed intakes (Baile & Forbes, 1974; Jamieson, 1975). Psychic stress associated with strange environments results in depressed feed intake (Weston & Hogan, 1973).

2.3.7 *Conclusions*

In several grazing experiments a linear relationship between metabolic live weight and herbage intake has been observed. During the last 6 weeks of pregnancy intake of stall-fed animals declines, the time of onset and the rate of decline in intake have been variable. More information is needed to allow conclusions to be drawn about herbage intake in early and mid pregnancy of non-lactating, non-growing cattle.

The herbage intake of lactating cows is much higher than that of those not lactating. When differences in lactation stages were associated with small differences in milk yield per cow per day (< 3 kg) no influence on herbage intake could be derived. When the differences in milk yield per cow per day due to lactation stage were great (> 3 kg), then the herbage intake was affected but much less than could be expected from the declining milk yield.

In several grazing experiments a positive relationship between herbage intake and daily milk production has been shown, however the effects of milk production due to lactation stage and of milk production due to genetical factors are often confounded. There is some information showing an effect of milk production per animal (at comparable lactation stage) on herbage intake; however more experiments are needed to make quantitative conclusions.

Too little information is available from which to draw conclusions on the effects of animal species, animal breed and animal condition on herbage intake of grazing animals.

2.4 FACTORS OF SWARD ORIGIN

2.4.1 Digestibility

Forages fed indoors In stall-fed sheep offered only hay, it appears that intake of dry matter (I_T) is directly related to dry matter digestibility (d_T) up to levels of d_T = 0.75 (Blaxter et al., 1961; Wilson & McGarrick, 1966; Troelsen & Campbell, 1969). However, when chopped hay with a range of d_T = 0.51-0.69 was fed to sheep the correlation between I_T and d_T was not significant (Reid & Jung, 1966). Differences in the intake between herbage species at the same level of digestibility may be responsible for this. When dried grass was fed to sheep some 70% of the observed variation in dry matter intake could be attributed to differences in in-vitro digestibility (range d_O: 0.50-0.76) between the grasses and between the growth stages. This higher figure could be obtained in spite of established differences in intake between species and between varieties at similar levels of d_O (Walters, 1971; Jones & Bailey, 1974).

Blaxter & Wilson (1962) found a curvilinear relationship between digestibility and intake of roughages by steers. They achieved the ranges in digestibility by using several feeds (straw, hay, dried grass), possibly causing variation in other intake--regulating factors. With growing heifers, fed hay, the relationship between d_T and I_T was positive but rather variable (McCullough, 1963) while this relationship was linear when hay of varying digestibility was fed to dairy cattle (Spahr et al., 1961). With mixed rations of forages and concentrates the voluntary intake of dairy cattle was directly related to d_T within the range of d_T of 0.52 to 0.67, above a digestibility of 0.67 intake appeared to fall as digestibility increased (Conrad et al., 1964). Physical factors limited food intake up to a d_T of 0.67 on mixed diets; above this level metabolic factors were the primary determinants of intake (Conrad et al., 1964; Baumgardt, 1970). The range where the intake of mixed diets is directly related to digestibility depends on the physiological demand of the animal and the energy concentration per unit of diet volume (Baumgardt, 1970).

Fresh herbage offered to stall-fed animals The experiments of Minson et al. (1964) have shown a linear relationship between I_T and d_O over a wide range of digestibilities (0.58-0.83) when fresh herbage was fed to wethers, but with indications of divergencies between herbage species. Osbourn et al. (1966), Demarquilly & Jarrige (1971) and Jarrige et al. (1974) also concluded that intake and digestibility were linearly related up to levels of d_O >0.80 when fresh herbage was fed to sheep, but it also appeared that there was no general relationship for all herbage species.

When fresh herbage was fed to dry cows indoors there was a relationship between digestibility of energy and I_T for herbages with a digestibility below 0.70, above this level the association was poor (Hutton, 1962). Lomba et al. (1970) also concluded that the dry matter intake of dry cows is not influenced by a reduction of d_T from about 0.80 to 0.70.

Hutton et al. (1964) found no relationship between I_T of lactating cows and the digestibility of energy (d_E) when the d_E varied between 0.65 and 0.77 during the season. In agreement with these results Demarquilly (1966) concluded that the digestibility of offered herbage indoors has little influence on herbage intake of dairy cattle when the d_O varied between 0.65 and 0.83. Witt & Huth (1966) found an increase (!) in herbage intake of dairy cows fed fresh herbage indoors with advancing maturity and decreasing digestibility of the herbage and explained the higher intake at lower d_T values with a positive effect of structural carbohydrates on rumen function due to stimulation of saliva excretion. Rohr (1972) fed herbage of a permanent pasture or Italian ryegrass indoors to dairy cattle and found that changes in in-vitro digestibility had no significant influence on herbage intake; only when red clover was fed a significant relationship could be derived.

Fresh herbage consumed at pasture There was a close relationship between the in-vitro digestibility of the herbage and the amount eaten by grazing steer calves when d_O of samples cut at grazing height varied between 0.68 and 0.82 (Hodgson, 1968). However the effect of declining digestibility during the grazing season on intake may have been exaggerated by the progressive effects of fouling following repeated grazings. The digestibility of the herbage ingested exerted a dominant influence on herbage intake of grazing calves, which increased at a constant rate as d_O increased throughout the range 0.55-0.81 (Hodgson et al., 1977).

Corbett et al. (1963) calculated the digestibility of the herbage grazed by dairy cows from faecal N values and showed that a fall in d_O from 80 to 68% was accompanied by a fall of about 5% in I_O. Data on faecal output indicated that the decrease in intake per unit fall in digestibility was less at higher than at lower levels of digestibility. Allowance levels were not reported by Corbett et al. (1963). Stehr & Kirchgessner (1976) found a positive linear relationship between the intake of dairy cows on pasture and the d_O of offered herbage over the range 0.64-0.82. However the effect of declining digestibility during the growing season on intake can probably partly be attributed to the progressive effects of faeces contamination following repeated grazings. The partial correlation coefficient between I_O and d_O was only 0.29 so the relationship was not so strong as the authors indicated. The very large variation in herbage supply and concentrate supplementation in these trials are other reasons for some doubt on the conclusions of the authors.

In experiments of Holmes & Jones (1965) the herbage intake of dairy cows increased when the d_O of consumed herbage decreased from 0.83 to 0.74. However the daily herbage allowance also increased very strongly during these periods and the concentrate supplementation differed between periods so other factors may have been responsible for the increase in herbage intake. Rohr & Kaufmann (1967) and Curran & Holmes (1970) found no significant effect of herbage digestibility on herbage intake of grazing cows using a small range in digestibility data (about 5%). Holmes et al. (1972) found a rather strong negative effect of digestibility of the selected herbage during the 1969 grazing season on herbage intake, in 1970 however this effect was positive during a shorter period of measurement. Greenhalgh & Runcie (1962) concluded that there was no obvious causative relationship between digestibility and intake of dairy cows using a d_O range of 0.72-0.79.

Most experiments with sheep and steers indicate that there is a strong positive relationship between digestibility and intake up to levels of d_0 = 0.80 with both stall-fed and grazing animals. However when dairy cattle were used there are indications that this relationship does not exist above d_0 levels of 0.70, for both grazing and stall-fed animals. Possibly differences in the role of the metabolic regulation of feed intake between species and between levels of production may explain these different relationships.

In most grazing experiments in which the relationship d-I has been studied the digestibility of the consumed herbage has been determined. When the role of selection depends on the level of digestibility, relationships between I and d of the consumed herbage may differ from these between I and d of the offered herbage. However in all described experiments only one digestibility value (offered or consumed) has been determined, so the influence of the selection effect cannot be examined.

Another complicating factor in the grazing trials is the influence of the daily herbage allowance on the relationship d-I. As already pointed out in a lot of the described trials with dairy cattle the allowance levels were not measured or were variable, probably influencing conclusions.

2.4.2 *Herbage mass (at the start of the grazing period)*

Variation in areic mass of herbage due to maturity Variation in herbage mass and variation in digestibility of a sward result in part from changes in the maturity of the herbage and are therefore inter-related. In experiments with variation in the stage of growth of the herbage the responses of herbage intake on herbage mass are confounded with changes in digestibility. The relationship between digestibility and herbage intake has already been described (2.4.1) and was positive in several experiments with dairy cattle up to levels of d of 0.70 of the consumed herbage. In some of these trials variation in digestibility could be attributed to variation in the maturity of the herbage (Corbett et al., 1963; Greenhalgh & Runcie, 1962; Greenhalgh et al., 1967); however details on herbage mass are not given by these authors.

Van der Kley (1956) observed a curvilinear relationship between herbage mass and intake. However the intake figures were inaccurate (the sward cutting technique was applied without measuring the residual herbage and growth during grazing) and the herbage allowance was not kept constant. Reardon (1977) found in a grazing experiment with steers that I_T decreased by 0.5 kg per day when the herbage mass increased by 1 000 kg ha^{-1} at a given level of herbage allowance. This experiment was conducted with a rapidly maturing pasture but herbage digestibilities were not measured. Berngruber (1977) compared young and short pastures (areic mass of T above about 4 cm of 1 820 and 1 400 kg ha^{-1}) with old and long pastures (areic mass of 3 510 and 3 290 kg ha^{-1}) in the years 1972 and 1973 respectively. At comparable levels of herbage allowance the herbage intake of the steers was not different between the groups in both years. The digestibility of the supplied herbage, estimated from chemical composition, was about 0.79 (young) and 0.75 (old pasture). In experiments of Hodgson & Wilkinson (1968) calves, heifers and dry cows grazing a mature sward (M_T = 7 950 kg ha^{-1} above

0 cm, d_0 = 0.67) consumed significantly less at a 14% higher allowance level than when grazing a leafy aftermath (M_T = 2 180 kg ha^{-1}, d_0 = 0.79).

Jamieson (1975) varied herbage mass and digestibility values by lengthening the period of growth before grazing. The results of these strip grazing experiments are summarized in Table 2. In all periods the daily herbage allowance was the same. The depression of intake in Period III was attributed to the low digestibility of the ingested herbage. The rather low herbage intake in the first period could possibly be explained by metabolic factors controlling digestible energy intakes at low levels of herbage mass and at digestibility values over 0.80 (Jamieson, 1975) or bite size may have been limiting at these low levels of herbage mass (Stobbs, 1973b).

Variation in herbage mass due to varying nitrogen fertilization Hodgson (1968) applied different nitro-chalk levels in a rotational grazing experiment with calves. In most experimental periods the herbage mass increased at higher levels of nitrogen fertilization, which had no effect on the digestibility of the hand-plucked 'grazed' herbage. There was a close linear relationship between I_0 and d_0, which can partly be attributed to fouling effects (see 2.4.1); the regression of I_0 on M_0 was not significant. The length of the period of growth before grazing and the amount of nitrogenous fertilizer applied were both varied in trials with strip grazed calves (Hodgson et al., 1977). Simple linear regression on the digestibility of the diet selected explained 79% of the variation in I_0; intake was not significantly affected by the level of herbage mass. Hodgson et al. (1977) concluded that under strip grazing conditions intake of calves is not likely to be markedly affected by the herbage mass, independent of any associated variation in herbage allowance.

Jamieson (1975) achieved several combinations of digestibility and herbage mass by varying the level of nitrogen application and period of grazing in a strip grazing experiment with calves. He concluded that the absence of any effect of herbage mass on intake reflects partly the variability in the herbage intake responses of calves in different periods and partly the herbage mass-digestibility inter-correlations which confused interpretation.

Table 2. The influence of herbage mass and herbage digestibility upon herbage intake of dairy cows at constant levels of daily herbage allowance.

Reference: Jamieson (1975)		Period		
		I	II	III
herbage mass (M_0)	kg ha^{-1} above 0 cm	2880	6340	8240
digestibility of M	d_0 in-vitro(offered)	0.78	0.82	0.65
digestibility of I	d_0 in-vitro(selected)	0.83	0.81	0.67
herbage intake (I_0)	g W^{-1} d^{-1}	30.2	36.2	24.8
Reference: Combellas & Hodgson (1979)		Treatment		
		L	H	
herbage mass (M_0)	kg ha^{-1} above 0 cm	4281	4979	
digestibility of I	d_0 in-vitro(selected)	0.80	0.80	
herbage intake (I_0)	g W^{-1} d^{-1}	26.3	24.6	

In a strip grazing experiment with dairy cows contrasting herbage masses were achieved by applying different nitrogen fertilizer levels (Combellas & Hodgson, 1979). The results of this experiment are summarized in Table 2. The digestibility of the diet selected did not differ between the levels of herbage mass. Also the levels of daily allowance were comparable. Intake of organic matter was lower at high than at low levels of herbage mass (12.6 against 11.9 kg d^{-1}). There was no indication of a negative relationship between herbage intake and herbage mass between periods, intake being highest in Period II when herbage mass was highest; these differences could partly be attributed to digestibility levels in the periods. Combellas (1977) concluded that more information is needed to establish the relationship between herbage mass and herbage intake and to examine the causes of the fall observed in intake at high levels of herbage mass.

Variation in the spatial distribution of herbage mass It is possible that at the same level of areic mass of herbage the distribution of the mass influences herbage intake. Several criteria have been used to characterize spatial distribution: sward height (Tayler, 1966; Arnold & Dudzinski, 1967b; Hodgson et al., 1971), tiller length (Allden & Whittaker, 1970), number of tillers or leaves per unit area (Arnold & Dudzinski, 1967b) and sward density as herbage T in kg ha^{-1} cm^{-1} (Stobbs, 1973b).

Arnold & Dudzinski (1967b) and Rodriguez & Hodgson (1974) using multiple regression techniques to determine the influence of sward characteristics on herbage intake both found that after herbage digestibility and herbage mass, sward height was the next important character in accounting for variations in herbage intake. The rate of intake over hourly periods of pastures by continuously grazing sheep was closely associated with tiller length, there being little relation between herbage mass and intake; the variation in herbage mass was achieved within several height levels by mechanical cultivation of parts of the grazed area (Allden & Whittaker, 1970). However the rate of intake is only a component of the total intake, measurement of the grazing time is also needed to estimate effects of tiller length on herbage intake.

There have been few reports studying the influence of sward density on herbage intake although the probable importance of sward density in relation to the grazing animal has been acknowledged (Allden & Whittaker, 1970). Arnold & Dudzinski (1967b) found that sward density accounted for a significant proportion of the variation in herbage intake of sheep for three of the seven species studied. Stobbs' (1973a, b) work on the bite size of cows has demonstrated that sward density is the most important quantitative sward characteristic determining bite size in tropical pastures.

2.4.3 *Herbage species*

The relationship between digestibility and intake may differ for different herbage species (see 2.4.1). Thus when species are compared at the same level of digestibility the intakes are not necessarily the same. When dried forages were compared at the same level of digestibility sheep ate more of a legume than of grass (Reid & Jung, 1965; Troelsen & Campbell, 1969). Within legumes the intake of red clover was higher than of lucerne (Osbourn et al., 1966) and within grasses the intake of Italian ryegrass was higher than that of perennial ryegrass (Walters, 1971). The intake of dried herbage at the same digestibility will differ between species, and between varieties within the same species (Walters, 1971, 1973; Baker, 1975).

When fresh herbage was fed indoors, large differences in intake were found at the same level of digestibility between grasses and legumes, between species within a family and also between varieties within a species (Jarrige et al., 1974). Indoors, at the same digestibility, legumes are eaten in larger amounts than fresh-fed grasses (Van Soest, 1965a; Reid & Jung, 1965). Differences in intake between grass species at the same level of digestibility have been shown by Minson et al. (1964), Demarquilly & Weiss (1970) and Luten (1976). The influence of variety has been shown by Osbourn et al. (1966) and Wilson (1966). Possible explanations for these differences in intake will be given in the next chapter. In all these experiments the herbage species have been fed to housed animals, mostly sheep. Baker (1975) pointed out that due to possible differences in the spatial distribution of the plant and in the digestibility of the selected forage between grazing and stall-feeding the influence of herbage species on intake may not be comparable in the two environments.

There are reports that grazing sheep eat greater amounts of red (Hodgson, 1975b; Gibb & Treacher, 1976) and white clover (Ulyat, 1971) than of perennial ryegrass. Greenhalgh (1966), Greenhalgh & Reid (1969a) and Alder & Cooper (1967) compared the herbage consumption of cattle on perennial ryegrass and cocksfoot; however the effect of herbage species was confounded with differences in digestibility and herbage allowance. Levels of herbage intake by grazing calves tend to be similar on perennial ryegrass, meadow fescue and timothy at comparable digestibility levels (Alder, 1970). Experiments with grazing beef cattle have shown that the herbage intake on Italian ryegrass was greater than on perennial ryegrass (Jackson, 1975).

Few measurements have been made on the intake of different temperate plant species and varieties under grazing conditions; especially with dairy cows. More work in this area is needed if conclusions are to be drawn.

2.4.4 *Chemical composition*

Organic elements All forages can be considered to consist of two major fractions: the almost completely digestible cell contents and the cell walls, which are less readily available to the animal (Donaldson, 1979), The proportion of cell wall components increases with maturity and at the same time their digestibility decreases. Therefore levels of structural material (cell wall constituents or crude fibre) are often correlated with digestibility, especially when considered within a species (Donaldson, 1979; Osbourn, 1978; Rohr, 1976). While studying these factors, care should be taken that the effects on intake are not confounded with the effects of digestibility.

Kaufmann & Orth (1966) found an increase in saliva secretion with an increase in crude fibre content due to maturation. The saliva addition possibly improved the cellulolytic activity in the rumen (Rohr, 1977). In trials with grazing cattle Rohr & Kaufmann (1967) and Roth & Kirchgessner (1972) explained the positive relationship between crude fibre content (<0.25) and herbage intake with this saliva effect. However the range of crude fibre content and intake in the trials of Rohr & Kaufmann (1967) was small, while the relationship between these variables was not corrected for differences in digestibility in the figures of Roth & Kirchgessner (1972). In zero grazing trials Rohr (1972) found however a negative relationship between intake and crude fibre content from 21 to 26% crude fibre.

When different herbage species were fed indoors the correlation between cell wall content and intake was higher than between digestibility and intake (Van Soest, 1965a; Osbourn et al., 1974). Differences in herbage intake between species have been attributed to the proportions of cell walls in the plants at comparable digestibility levels (Baker, 1975). The variation in intake between varieties within a species at comparable digestibility was mainly attributed to the contents of lignin within the cell walls (Walters, 1973).

No relationship could be found between the crude protein content of the herbage and the intake of stall-fed (Rohr, 1972) or grazing (Kirchgessner & Roth, 1972b) cows. The effect of sugar content on herbage intake of indoor-fed cows depended on the herbage species (Rohr, 1972). No relationship was found between the crude fat content and the herbage intake of grazing cows (Kirchgessner & Roth, 1972b).

The influence of the dry matter content of the herbage on the intake will be described in Subsection 2.5.5.

Inorganic elements The role of minerals in the nutrition of the grazing animal has been reviewed by McDonald (1968) and Kemp & Geurink (1978). There is very little information on the influence of inorganic nutrients on herbage intake of animals without a deficiency of minerals. In experiments with grazing dairy cattle calcium, magnesium, sodium and potassium had no influence on herbage consumption, but phosphorus content had a significantly positive effect on intake (Kirchgessner & Roth, 1972b). Finger & Werk (1973) increased the sodium and magnesium content of the herbage by using a K-Mg-Na fertilizer and found a positive effect on herbage intake. Comparable results were obtained by Ernst (1978), who concluded that there was a strong influence of sodium content of the herbage on intake of dairy cows. The latter two trials were carried out with free choice of the animals between the treatments (cafetaria system); it is possible that the effects of sodium content on intake would be different when the animals were treated separately and had no choice (Rohr, 1976; Raymond, 1969).

2.4.5 *Palatability and smell*

Balch & Campling (1969) concluded that while taste and smell are important in influencing the grazing behaviour of ruminants they exercise little overall control on intake of food. The direct effects of odour of different chemicals were measured by Arnold (1970) using grazing sheep. Four of the six odours that affected feed intake when sheep has a choice between odours, altered feed intake, even when there was no choice. The direction of effect of an odour was not necessarily the same in the two feeding situations. The reason for rejection of faeces-contaminated herbage by cattle seems to be smell (Subsection 2.5.3).

Large depressions of intake occurred when various chemical contaminants known to give taste responses were added to a feed (Arnold, 1970). Some of the additives were applied in non-physiological doses, while in other cases the depressions in intake were associated with altered feed digestibility due to the additive.

2.4.6 *Conclusions*

Most experiments with dairy cattle fed fresh herbage indicate that above a level of digestibility of the consumed herbage of 0.70 there is no strong relationship between herbage intake and digestibility. Below the level of 0.70 the relationship between digestibility and intake was positive. However interactions with the daily herbage allowance may have occurred in a lot of trials.

When variation in digestibility is achieved by use of swards with a different maturity, then herbage mass is also influenced. With changing maturity of the herbage, variation in intake of growing and lactating cattle can mainly be attributed to changes in digestibility. The additional effects of herbage mass are small; but no data for really low levels of herbage mass are available. There is only one experiment with strip grazing lactating cows in which herbage intake declined at high levels of herbage mass. There is too little information available to make conclusions concerning the influence of spatial distribution of herbage mass on intake of cows.

When fresh herbage was fed indoors large differences in intake have been found at the same level of digestibility between grasses and legumes, between species within a family and also between varieties within a species. Few measurements have been made of the intake of different temperate plant species and varieties under grazing conditions. Differences in herbage intake indoors between species have been attributed to the proportions of cell walls in the plants (at comparable levels of digestibility).

2.5 FACTORS OF MANAGEMENT ORIGIN

2.5.1 *Herbage allowance*

The amount of herbage on offer per animal has been widely recognized as a major factor affecting food intake and several terms have been used to describe it. Mott (1960) used the term grazing pressure, the number of animals per unit of available herbage. Greenhalgh et al. (1966a) added the time dimension to the relationship and defined herbage allowance as the quantity of herbage allotted to the animal per unit of time.

Unfortunately the cutting height above ground level used for the estimation of standing crop weight, from which herbage allowance is derived, varies in the literature. The best cutting height is the one below which animals cannot graze - not even on a low allowance - because only material above this level can be eaten by the animal. Some workers have suggested that animals are able to graze below a cutting height of 3 to 5 cm at low herbage allowances (Greenhalgh et al., 1966a; Greenhalgh, 1970; Gordon, 1973).

Therefore Hodgson (1975a) and Gibb & Treacher (1976) have chosen the ground level as cutting height in their definition of herbage allowance. The definition can be extended to incorporate a measure of animal weight to take account of the differences in animal species or type.

When the allowance is determined at ground level grazing below the height of cutting is avoided. However the proportion of the total herbage situated close to ground level, and therefore difficult or impossible for the animal to graze, will be greater on short light sward canopies than on tall, heavy ones (Combellas & Hodgson, 1979). It is possible that at comparable levels of herbage allowance up to which animals can eat (e.g. 3 cm), the allowance measured to ground level can differ. These are grounds for believing that the intake-allowance relationships may be affected by the cutting level at which the allowance is determined and may vary between different swards (or periods) when ground level is applied (Combellas & Hodgson, 1979).

Sheep Gibb & Treacher (1976) varied herbage T allowances (>0 cm) in the range 20-160 g W^{-1} d^{-1} in a trial with weaned lambs. Asymptotic curves were fitted to describe the relationship between herbage allowance and daily intake of herbage. They concluded that if the herbage present to ground level is not more than three times the daily maximal intake of the animals intake of herbage may be less than maximal. By offering one third of that quantity the intake was reduced by about 15% (Gibb & Treacher, 1976; Hodgson, 1975a). In an experiment with ewes and twin lambs the range of 0-allowances (>0 cm) used (26-116 g W^{-1} d^{-1}) gave a linear response in intake suggesting that even at the highest allowance ewes may not have achieved maximum intakes (Gibb & Treacher, 1978). The in-vitro digestibility values, which were used to calculate intake in these trials were not adjusted for increases in intake above maintenance. However, Penning & Valderrabano (1979) concluded that level of feed intake influences the digestibility of herbage-fed sheep. Probably the intakes at the highest allowance levels were overestimated.

Harkess et al. (1972) showed a strong relationship between 0 allowance (>0 cm) and intake over the range 23-96 g W^{-1} d^{-1} using grazing sheep. They used a sward method to determine herbage intake. The grazing periods varied from 1.5 to 3 days, nevertheless herbage accumulation during the grazing period was not accounted for. Due to the high rates of herbage accumulation in the rest periods between grazing, due to differences in herbage mass between treatments, and due to differences in the length of the grazing period between treatments the relative intake figures probably change when a correction is made for herbage accumulation during grazing.

Growing cattle Jamieson & Hodgson (1979) varied A_0 (>0 cm) between 30 and 90 g W^{-1} d^{-1} in a strip grazing trial with calves. In the spring the relationship between herbage allowance and intake was curvilinear; reductions in 0 allowance from 90 to 50 g W^{-1} d^{-1} had little effect on intake, but further restriction to 30 g W^{-1} d^{-1} resulted in a decrease in I_0 of 19%. In the autumn the overall results indicated a linear relationship between intake and allowance. A higher daily herbage allowance measured to ground level may be required to achieve maximum intake on autumn swards than on spring swards. The reason for this seemed to be partly attributable to differences in the vertical distribution of material within the sward (Jamieson, 1975).

The equation given by Hull et al. (1961) for grazing steers was curvilinear with a range of T allowances from 13 to 94 g W^{-1} d^{-1} (cutting height 5 cm). Curvilinear relationships for grazing steers were also obtained by Marsh & Murdoch (1974) with a range in T allowance (>0 cm) of 10 to 85 g W^{-1} d^{-1} and by 't Hart & Kleter (1974) applying a range in T allowance per animal of 6 to 17 kg d^{-1} (cutting height about 4 cm). Reardon (1977) derived a linear relationship with steers at T allowances varying from 31 to 105 g W^{-1} d^{-1} above ground level. That was in agreement with results of Davison (1959), who applied a much smaller range in allowances.

The effect of allowance on herbage intake of grazing steers varied between periods in an experiment of Wilkinson & Prescot (1970). However in these trials the intake was always higher than the amount on offer in the group with the low allowance, which was attributed to grazing of the animals at the wrong side of the fences; but it seems doubtful that such high amounts of herbage (up to 59% of allowance) can be consumed there. Hodgson & Wilkinson (1968) found that a 50% increase in herbage allowance to groups of cows, heifers and calves increased their herbage intake even though the lower allowance was well in excess of the quantity consumed.

Broster et al. (1963) found a linear relationship with growing dairy heifers over a narrow range of herbage T allowances from 27 to 39 g W^{-1} d^{-1} (the cutting height was not stated). Berngruber (1977) compared swards of different maturities; in the combined data he found an asymptotic relationship between T allowance (varying from 20 to 80 g W^{-1} d^{-1} at a cutting height of about 4 cm) and intake of growing heifers. When the young and old swards were considered separately the relationships differed. Berngruber (1977) concluded that the relationship between allowance and intake depends on the maturity (and areic mass) of the herbage: in older herbage the allowance to reach maximum intake is higher than in younger herbage, due to differences in selection during grazing.

Lactating cattle With lactating dairy cows a marked effect of herbage allowance upon intake was observed when two distinct levels were applied (Holmes et al., 1966; Holmes & Curran, 1967; Leaver et al., 1969b; Gordon, 1973). A true quantification of the effect of this factor is not possible from these results because several factors contributed to a low precision of allowance and intake estimates: eating of the cows below cutting height (Holmes et al., 1966; Holmes & Curran, 1967; Leaver et al., 1969b; Gordon, 1973); the feeding of mixed herbage/concentrate diets in combination with indirect techniques of intake estimation (Holmes et al., 1966; Holmes & Curran, 1967); variation in pre-treatment, e.g. cutting, trimming or grazing of the experimental swards (Leaver et al., 1969b); and estimation of the digestibility (and intake) of the offered herbage instead of the selected herbage (Gordon, 1973).

Kirchgessner & Roth (1972a) and Stehr & Kirchgessner (1976) found that intake increased linearly with herbage T allowance up to daily allowances of 35 kg per cow (above 3 cm). The quantitative effects varied from 0.27 to 0.65 kg T intake/kg T allowance. However the treatments were not applied simultaneously and the effect of allowance could have been confounded with variations in sward conditions (fouling) and

Table 3. The influence of herbage allowance upon herbage intake of dairy cows in strip grazing experiments.

Reference	Variable	Units	Treatment A	B	C	D
Greenhalgh et al. (1966a)	A_O (>4 cm)	kg d^{-1}	10.4	14.6	18.8	23.0
	d_O		0.75	0.75	0.76	0.76
	I_O	kg d^{-1}	10.9	11.9	12.6	12.6
Greenhalgh et al. (1967)	A_O (>4 cm)	kg d^{-1}	10.4	14.6	18.8	
	d_O		0.75	0.75	0.75	
	I_O	kg d^{-1}	10.9	11.6	12.0	
Greenhalgh (1970)	A_O (>4 cm)	kg d^{-1}	10.4	14.6	18.8	
	d_O		0.78	0.78	0.76	
	I_O	kg d^{-1}	9.9	11.9	10.8	
Mott (1974)	A_T (>4 cm)		12.6	17.0	21.1	24.5
	I_T		10.3	13.3	14.7	14.1
Le Du et al. (1979b) Exp. 1 (= Combellas, 1977)	A_O (>0 cm)	kg d^{-1}	10.8	22.9	33.9	
		g W^{-1} d^{-1}	23	45	68	
	d_O		0.79	0.81	0.81	
	I_O	kg d^{-1}	10.7	13.3	14.1	
		g W^{-1} d^{-1}	22.3	26.3	28.0	
Le Du et al. (1979b) Exp. 2	A_O (>0 cm)	kg d^{-1}	12.8	21.2	31.6	
		g W^{-1} d^{-1}	26	43	60	
	d_O		0.78	0.78	0.79	
	I_O	kg d^{-1}	11.5	12.1	12.5	
		g W^{-1} d^{-1}	23.0	24.4	23.9	
Combellas & Hodgson (1979)	A_O (>0 cm)	kg d^{-1}	13.1	26.0	38.6	
		g W^{-1} d^{-1}	27	54	81	
	d_O		0.79	0.80	0.80	
	I_O	kg d^{-1}	11.0	12.8	12.8	
		g W^{-1} d^{-1}	22.9	26.6	26.9	

level of milk production of the cows. The strong linear allowance effect was attributed to an increase in the digestibility of the selected herbage at higher allowance levels in the rather old mixed swards (Stehr & Kirchgessner, 1975).

In most strip grazing experiments with dairy cattle a curvilinear relationship between herbage allowance and intake was established, which is shown in Table 3 (Greenhalgh et al., 1966a, 1967; Greenhalgh, 1970; Mott, 1974; Le Du et al., 1979b). In some trials, cows on treatment A appeared to eat more herbage than was offered them. This is due to grazing below the height of cutting, grazing outside the fences (Greenhalgh et al., 1966a, 1967) or neglecting herbage accumulation during grazing. There was no indication of effects of herbage allowance on the digestibility of the selected herbage (Table 3). This can possibly be attributed to the small differences that existed between the digestibilities of the different fractions (bottom-top) of the sward (Greenhalgh et al., 1966a).

The pastures used by Greenhalgh et al. (1966a, 1967) and Combellas & Hodgson (1979) were not previously grazed. The pastures used by Le Du et al. (1979b) and Combellas (1977) were rotationally grazed and the refusals were topped after grazing. Greenhalgh & Reid (1969b) showed that fouling reduced herbage intake to a similar degree at low and high herbage allowances, so in these experiments an interaction between pre-treatment of the swards and the allowance seems unlikely. Repeated grazing on the same sward (without topping) was applied by Mott (1974) and Greenhalgh (1970, topping once). Only the results of Greenhalgh (1970) at the high allowance level differ from the other experimental results on clean or topped swards.

Although there was some evidence that the effect of herbage allowance on intake was stronger at high levels of herbage mass than at low levels of herbage mass, the interaction was not significant (Combellas & Hodgson, 1979). However, in view of the relatively small differences in herbage mass for all treatments the possibility of a herbage mass and allowance interaction cannot be discounted.

The results of studies by Combellas (1977) emphasize the influence of the level of milk yield on the relationship between herbage allowance and intake. Herbage intake of high-yielding cows is more sensitive to restrictions in herbage allowance and is higher at a certain level of this factor than of low-yielding cows. The average daily FCM production in all the experiments mentioned in Table 3 was close to 15 kg.

In all the cited experiments strip grazing was applied where animals moved to new strips or paddocks of grass each day. Results of experiments with varying allowances at longer grazing periods are scarce. Results from Hijink (1978) indicate a curvilinear relationship between allowance and intake when the 'daily' T allowance (>4 cm) varied between 12 and 30 kg d^{-1}. In this trial the grazing period per paddock was on average 4 days.

2.5.2 *Concentrate supplementation*

In most trials, with concentrate supplementation at pasture only the production of the animals has been measured; relative little information is available on the influence of supplementation on herbage intake (Leaver et al., 1968; Boxem, 1972).

In experiments with indoor-housed steers fed herbage ad lib., varying in age from 6 to 12 months, there was an increase in total intake as the proportion of concentrate in the diet increased, and the relationship between herbage intake and concentrate intake was negative and rectilinear (Forbes et al., 1966, 1967; Tayler & Wilkinson, 1972). The rate at which barley or concentrate replaced grass in these diets varied from 0.38 to 0.95 kg T from herbage per kg T from supplement (Tayler & Wilkinson, 1972; Marsh & Chestnutt, 1977).

The zero grazing trials on supplementation of dairy cows are summarized in Table 4. Except in the first trial of Le Du et al. (1979a) concentrate supplementation varying from 2.7 to 6.9 kg T of stall-fed cows always reduced herbage intake; the decrease in herbage T intake in kg per kg concentrate T (= substitution rate) varied from 0.07 to 0.93. The low substitution rate of Masubuchi et al. (1976) can probably be attributed to the low levels of d_0 (0.50-0.65) and the resulting low herbage intake; in all other trials the d_0 values were much higher (0.70-0.80). Holmes & Jones (1964) showed a positive relationship between roughage digestibility and the depression in its intake by the concentrate.

In several experiments there was an indication that the substitution rate was higher at higher levels of concentrate supply (Masubuchi et al., 1976; Boxem, 1976;

Table 4. The influence of concentrate supplementation upon herbage intake of dairy cows in zero grazing and grazing experiments.

Reference	Trial	I_T concentrates[1]			I_T herbage[1]			Substitution rate		FCM[1]
		A	B	C	A	B	C	A-B	B-C	A/B/C
zero grazing										
Taparia & Davey (1970)	1	0	2.7	4.0	4.1[2]	4.3	4.3	0.63	0.66	16.9
Masubuchi et al. (1976)	1	0	3.5	6.9	11.1	10.8	9.6	0.07	0.37	14.2
Boxem (1976)	1	0	2.7	5.4	15.1	13.8	12.0	0.45	0.68	23.5
"	2	0	2.7	5.4	13.8	12.0	9.9	0.67	0.80	17.7
"	3	0	2.7	5.4	15.5	14.5	13.3	0.38	0.44	22.8
Hijink (1978)	1	0	3.9		14.2	11.2		0.77		17.7
"	2	0	3.9		13.6	10.4		0.80		14.9
"	3	0	4.0		13.3	11.0		0.59		19.5
"	4	0	4.0		15.0	11.2		0.93		17.2
"	5	0	4.0		13.5	11.5		0.50		-
"	6	0	4.0		13.7	11.1		0.66		-
Boxem (1979)	1	0.5	3.2	5.9	13.6	12.1	10.5	0.54	0.58	17.2
"	2	0.5	3.2	5.9	13.4	12.2	10.4	0.42	0.70	17.1
Le Du et al. (1979a)	1	0	5.2		13.4	13.4		0		23.1
"	2	0	5.2		13.1	11.8		0.25		18.3
"	3	0	5.2		14.9	11.7		0.62		18.3
Meijer (1979)	1	0.5	3.2	5.9	15.1	14.2	12.1	0.34	0.78	-
"	2	0.5	3.2	5.9	16.1	14.5	12.7	0.57	0.67	-
"	3	0.5	3.2	5.9	14.4	13.7	12.0	0.26	0.43	-
"	4	0.5	3.2	5.9	14.2	13.1	11.9	0.66	0.44	-
grazing										
McLusky (1955)	1	0	3.3		10.6	9.3		0.39		13.5
Corbett & Boyne (1958)	1	0	3.1		16.4	14.6		0.58		16.6
"	2	0	3.9		13.9	12.3		0.42		12.1
Frederiksen (1976)	1	0	2.3		12.4	11.2		0.49		16.4
Otsokovic & Velotch-kovic (1977)	1	1.7	4.9	7.4	9.9	8.2	6.6	0.56	0.64	18.8

1. Kg per day per animal.
2. Kg per day per 100 kg live weight.

Boxem, 1979; Meijer, 1979). Boxem (1979) found a linear relationship between the herbage substitution rate and the intake of herbage (without concentrates) when he compared intake data averaged over a week; supplementation of 3 kg concentrates T at herbage T intake levels of 11 and 16 kg d^{-1} resulted in a total T intake of 13.7 and 16.3 kg d^{-1} respectively. The variation in herbage intake between weeks may be caused by sward or environmental factors.

Boxem assumed that the substitution rate was lower in the first part of the lactation of the cow than in the latter part; this phenomenon possibly also caused the variable substitution rates in the trials of Le Du et al. (1979a). In the Trials 1, 2 and 3 of Hijink (1978), the herbage was offered for only 8.5 hours to the supplemented cows, while Treatment A was available for 19 hours, which possibly caused the high substitution rates in these experiments. The high substitution rate of 0.93 in the fourth experiment of Hijink (1978) was attributed to the high level of herbage intake of the animals without concentrates. Meijer (1979) again showed the importance of the level of herbage intake of the Treatment A cows on the substitution rates obtained. In his first and second experiment the herbage for all treatments was supplied day and night; however in the trials 3 and 4 the herbage of all treatments was only supplied on the day (8.5 hours) giving lower herbage intakes and lower substitution rates.

Marsh & Chestnutt (1977) reviewed the results of supplementation trials with grazing sheep. The substitution rate varied from 0.48 to 0.58 when grazing lambs were used; in experiments with grazing wethers the substitution rate varied from 0.36 to 0.84. Hodgson & Tayler (1972) calculated indirectly a replacement rate of approximately 0.5 kg herbage O per kg barley O eaten in a grazing trial with steer calves. Comparable results were achieved by Umoh & Holmes (1974) with grazing beef cattle supplemented with sugar beet pulp (substitution rate 0.52) and by Sarker & Holmes (1974) using dry cows supplemented with concentrates (substitution rate 0.54). In autumn the response to sugar beet pulp fed to grazing beef cattle was even smaller and a substitution rate of 0.72 was calculated (Umoh & Holmes, 1974); these results were in agreement with later results of Gomez & Holmes (1976) with grazing beef cattle.

The limited information on the effect of supplementation of grazing dairy cows when the quantity of available herbage (allowance) was not restricted is summarized in Table 4. The average substitution effect as derived in the experiments of McLusky (1955) varied strongly between periods; probably due to variations in daily herbage allowance. The herbage substitution rate in the other grazing trials varied between 0.42 and 0.56 at a supply of 2.3-4.9 kg T from concentrates. There is a small indication that the substitution rate increased at higher levels of concentrate feeding, as in the zero grazing trials (Otsokovic & Velotchkovic, 1977).

Holmes & Jones (1964) and Leaver (1976) have pointed out that the digestibility of the herbage may influence the substitution rate. Also the quantity of available herbage per animal may be important (Leaver et al., 1968). However in the trials summarized in Table 4, neither d_O nor A_O were measured. The substitution effect may also depend on the type of supplement (Boxem, 1972; Umoh & Holmes, 1974) and on the season of the year (Corbett & Boyne, 1958; Leaver et al., 1968).

A lot of the effects of the observed factors influencing the substitution rate may possibly be explained with the difference between the intake of nutrients and the nutrient requirement. When this difference is negative the substitution of herbage is low (e.g. when herbage intake is relatively low due to a low allowance, or when the requirement is relatively high in the first part of the lactation); when the balance is positive the substitution of herbage is high.

Holmes et al.(1966) and Holmes & Curran (1967) restricted the herbage allowance to the supplemented groups and found comparable total intakes of these cows and the unsupplemented cows at higher allowances; in these trials the concentrate supply was not varied at given allowance levels. Leaver et al. (1969b) found a substitution rate of 0.55 kg O herbage/kg O concentrates at restricted grazing, the cows being allotted a fixed area each day without cutting after grazing. However in this trial the herbage allowance varied greatly between the treatments and during the season and so confounded the supplementation effect. No data are available of experiments where different levels of supplementation were combined with different levels of allowance.

2.5.3 *Contamination of herbage*

The acceptability of herbage to grazing animals may be affected by contamination with dung pats, urine or by slurry applied to the pasture. Cattle may initially refuse urine-contaminated herbage but graze it preferentially on entering the paddock at the next grazing (Norman & Green, 1958). Urine does not normally lead to major rejection of herbage (McLusky, 1960). However in hot weather urine may occasionally scorch and kill small patches of pasture ('urine burn'), the cause of which is not fully understood (Keuning, 1979).

The fouling of pastures by dung has been reviewed by Marsh & Campling (1970). When a clean pasture is grazed only once the area of the produced dung pats depends on the food intake, on the consistency of the faeces and on the weather (Marsh & Campling, 1970). The area of the pasture rejected by the grazing animal is greater than the area of the dung pats, the difference depending on the grazing intensity (Brockington, 1972). After grazing, the pasture can be topped to remove uneaten herbage around the pats (Mott et al., 1972). With topping, the faeces may be spread over a greater area which may improve the decomposition of the faeces (Mott et al., 1972; Voigtländer & Kuhbauch, 1978). Without topping the previously neglected herbage around the pats matures and possibly affects intake in the next grazing cycle (Brockington, 1972). A positive influence of topping residues on the herbage intake per hectare has been shown by Mott & Müller (1971).

The herbage intake of grazing steers on a clean pasture was 8-13% higher than on a pasture which was grazed once before without topping residues (Kleter, 1972). Greenhalgh & Reid (1969b) created a fouled area by grazing a sward 3 times combined with regularly topping the ungrazed herbage. The herbage intake of the dung-fouled pasture was 9% lower than the intake of the clean pasture; there was no difference in effect between high and low grazing intensity (Greenhalgh & Reid, 1969b). In a mathematical model of pasture contamination by grazing cattle Brockington (1972) calculated that the potential intake was 4-8% reduced due to faeces (with topping of residues);

this reduction increased at low herbage allowances (more animals/ha). The low figure of 4% at the high allowance could be attributed to imposing the allowance level throughout the season while Greenhalgh & Reid (1969b) imposed the high allowance only after the first three grazing periods (Brockington, 1972). The reason for rejection of the fouled herbage by cattle appears to be smell (Marten & Donker, 1966; MacDiarmid & Watkins, 1972).

The use of organic manure (slurry) on pastures possibly influences feed intake, in correspondence with the faeces-pats effect.

Manuring in spring caused considerable forage refusal of first crop by heifers (Marten & Donker, 1966). Pain et al. (1974) showed that when given no choice dairy heifers ate pasture that had been dressed 6 weeks before with slurry at rates up to 100 tonnes/ha. No significant differences were obtained between herbage intakes of the animals on clean or slurry dressed swards at any time from 6 to 30 weeks after spreading the slurry. However in these trials at relatively low stocking rates, the amount of herbage available at the beginning of the grazing periods increased with the level of slurry application (Pain et al., 1974). When given a choice of herbage with or without applied slurry cattle show a distinct preference for clean herbage. This effect is most marked at the first grazing after slurry application (Broom et al., 1975).

Reid et al. (1972) demonstrated that the intake of dairy cows on pasture dressed with slurry 3 weeks prior to grazing was significantly lower (12%) than that of animals on untreated pasture. Dairy cattle on pasture spread with slurry 9 weeks previously consumed 30% less herbage T than those on clean pastures. This difference may decrease to 25% when a correction is made for differences in herbage allowance between treatments (Pain & Broom, 1978). Injection of slurry into the soil had no effect on herbage intake of dairy cows (Pain & Broom, 1978).

2.5.4 Nitrogen fertilization

The effect of nitrogen supply on grassland productivity and quality has been reviewed by Holmes (1968) and Minderhoud et al. (1974), but in these reviews little attention is given to the effect of nitrogen fertilization on herbage intake.

In experiments with dried herbage fed indoors to sheep it was generally agreed that intake is not affected by nitrogen fertilization (Reid & Jung, 1965; Hight et al., 1968). Variable results when fresh herbage was fed indoors to sheep were reported by Demarquilly (1970). However in some of these experiments the botanical composition was possibly also influenced by nitrogen fertilization; the effect of nitrogen on d_0 was small and variable. Holmes & Lang (1963) have shown that the T intake of stall-fed cattle offered herbages which received 130 and 460 kg of nitrogen per ha were practically identical although the digestibility of the high N herbage was slightly higher.

In a grazing trial with sheep, Reid et al. (1966) found higher consumptions of herbage at increasing levels of applied nitrogen. However in this trial sheep were given free access to plots having all nitrogen treatments and apparent differences in preference do not necessarily imply differences in intake in the conventional trial without choice between feeds (Reid & Jung, 1965; Rodriguez, 1973). The mean daily intake of digestible organic matter of grazing steers was not significantly affected by fertilizer application rate (Marsh & Murdoch, 1974); this conclusion is in agreement with results of Alder et al. (1967) in trials with growing cattle. Gordon (1973) has shown that the T intake of grazing dairy cows offered herbage that received 400 and 700 kg N/ha was not significantly different; the digestibilities were not reported.

Several studies show no evidence of differences associated with level of nitrogen application on the digestibility of grass dominant swards of similar age (Holmes, 1968; Deinum, 1974). In the experiments described earlier the nitrogen effect was also studied in swards of similar age. However Deinum (1974) pointed out that at comparable levels of herbage mass the digestibility may increase at higher levels of nitrogen fertilization. Under these conditions the nitrogen fertilizer effect on herbage intake possibly also differs from the effect as found when swards of comparable age are used, however information is not available in literature.

2.5.5 *Climate*

Temperature The effect of warm climates upon the food intake has been reviewed by Bianca (1965), Payne (1966) and Thompson (1973). The experimental data on stall-fed cattle suggest that high ambient temperatures depress the feed intake of all types; the temperature at which the feed intake starts dropping depends on the breed and on the production level. The temperature thresholds for a decline in food consumption are not the same in the field as in the climatic room because of the modifying effects of other climatic factors that operate outdoors (Bianca, 1965), and because adaptative behaviour and management can alter the critical temperature (Combellas, 1977).

In a lot of trials under tropical conditions it has been shown that high temperatures reduced the total grazing time and that daylight grazing is radically curtailed and confined almost entirely to early morning and late afternoon (Payne, 1966). However in temperate regions no relationship has been found between air temperature and grazing time, even over wide temperature ranges (Jamieson, 1975). Grazing time is only one component of the herbage intake (see 1.4.1). Information on herbage intake of grazing animals at variable temperatures is scarce. The temperature does not only possibly affect herbage intake but influences also the quality of the feed (Deinum, 1966; Deinum et al., 1968; Deinum & Dirven, 1974).

Rainfall There is some information on the effect of rainfall, and the resulting lower dry matter content, on the herbage intake of stall-fed animals. When freshly cut herbage is fed to cattle a positive correlation between dry matter content and herbage intake has been shown (Halley & Dougall, 1962; Demarquilly, 1966; Vérité & Journet, 1970; Rohr, 1972). However, when an insufficient amount of grass was offered on wet days, to compensate for the amount of water in the grass, a relationship between the amount of dry matter offered and the dry matter content was noted (Holmes & Lang, 1963). The question arises whether the fluctuations in dry matter intake were due to the changes in the dry matter content or to the changes in the amount of dry matter offered. Sonneveld (1965a) also showed a negative influence of rainfall on herbage intake. The effect of the dry matter content however also depended on the water content within the plant, with special attention to the maturity of the herbage (Sonneveld, 1965a, b).

In grazing experiments with dairy cows Roth & Kirchgessner (1972) found a negative correlation between dry matter content and herbage intake, but as the authors pointed out the influence of dry matter content was possibly confounded with herbage allowance or herbage quality. With grazing dairy cows Rohr & Kaufmann (1967) found a positive correlation between dry matter content and herbage intake. Kurohiji et al. (1973) have implied that the intake of pasture by cattle is partly influenced by rainfall. However the intake of beef cattle in a dry and a wet autumn was comparable (Marsh, 1975). More information is needed before conclusions on the effect of rainfall on herbage intake of grazing animals can be drawn.

Other climatic factors The temperature at which heat stress affects feed intake can be extended by an increase in air velocity or reduced by rises in the level of solar radiation or relative humidity (Combellas, 1977). Quantitative information on these factors in temperate regions with dairy cattle is not known. The influence of day length on voluntary intake of lambs kept indoors was shown by Forbes et al. (1975). Reed (1978) suggested from limited observations that day length may modify grazing behaviour and intake.

2.5.6 *Season*

The effect of season of growth on the feeding value of pasture has been reviewed by Reed (1978). When artificially dried grass was fed to sheep (Michell, 1973; Greenhalgh, 1976) or steers (Lonsdale & Tayler, 1971) indoors, the herbage intake of autumn herbage was about 10% lower than that of spring herbage at comparable digestibilities. The herbage intake of spring and autumn herbage was compared in zero grazing trials with steers (Greenhalgh, 1976). The intake results were very variable, so Greenhalgh (1976) concluded the major problem in investigating possible causes of seasonal differences in intake has been to reproduce the differences consistently.

Marsh (1975) has reported very large differences in intake between spring and autumn herbage using grazing beef cattle. These intake levels were associated with (and estimated from) differences in the digestibility of the herbage. In grazing trials with steers the herbage intake in the autumn was about 14% lower than in the spring at comparable levels of digestibility. For grazing cows Corbett et al. (1963) reported a 10% lower intake from autumn herbage than from spring herbage of the same digestibility.

Possible causes of these differences in intake can be found in the intake-regulating factors, which vary during the grazing season: animal factors (Greenhalgh, 1976); composition of the herbage, e.g. dead material and dry matter content (Burstedt, 1979); fouling by excreta (Greenhalgh, 1976); climatic conditions, e.g. day length (Burstedt, 1979); herbage availability (Reed, 1978); and composition of the carbohydrates (Reed, 1978).

2.5.7 *Grazing system*

There have been several comparisons of systems of grazing management for dairy cattle, but in most of these experiments the animal production and not the herbage intake was measured (Campling, 1975; Davies, 1976; Carlier et al., 1977; Castle & Watson, 1978; Ernst & Mott, 1978; 't Hart, 1979b; Journet & Demarquilly, 1979). Hodgson (1979) defined the three main grazing systems as continuous stocking, paddock grazing and strip grazing. Within a grazing system a large variation in grazing management can exist, therefore it is impossible to make conclusions on herbage intake of different grazing systems and only certain variants of grazing systems can be compared.

The herbage intake at certain variants of continuous grazing and strip grazing has been compared and a higher intake at the continuous grazing system in most of the experimental periods has been shown (Holmes & Osman, 1960; Adamson & Garstang, 1979). Waite et al. (1952) found a 16% higher herbage intake by paddock grazed cows in comparison with strip grazed animals, but the authors themselves doubted the precision of their technique of intake estimation in the paddock grazing.

Within the strip grazing system several variants have been compared with measurement of herbage intake:

- a length of the rest period between grazing periods of 21 or 28 days (Marsh et al., 1971a; Adamson & Garstang, 1979)
- a similar quantity of herbage available each day or a fixed area of the paddock each day (Leaver et al., 1969b)
- a system in which grazing alternated with cutting or repeated grazing on the same paddock (Holmes et al., 1972)
- a leader and follower grazing system or a conventional strip grazing system (Archibald et al., 1975).

In these strip grazing experiments comparable herbage intakes were recorded between treatments. A problem with these comparisons of grazing systems is the involvement of a lot of variable factors such as herbage quality, herbage allowance, herbage mass, faeces contamination etc.

2.5.8 *Conclusions*

A positive influence of daily herbage allowance on herbage intake has been shown in many grazing experiments with several types of animals. Both linear and asymptotic relationships have been established between allowance and intake; these different forms of the relationship could partly be attributed to the ranges of allowances applied. There are indications that the relationship between allowance and intake can be influenced by the levels of herbage mass, the structure of the sward (season), the contamination with faeces and the milk production level of the cows.

Supplementation with concentrates decreased the herbage intake both in- and outdoors. The substitution effect depended on the quantity and quality of the available herbage, on the quantity and the type (quality) of the supplement fed and on the season of the year. When the quantity of available herbage is not limiting the herbage substitution rate is about 0.4 to 0.6 kg T/kg concentrate T, at a supply of 2-4 kg concentrate. There is too little information on the effect of supplementation on herbage intake at low levels of allowance.

There is strong evidence from the literature that faeces contamination or the application of slurry to the sward influences herbage intake negatively. When the effects of nitrogen fertilization were studied at comparable age of the herbage several trials showed no effect of nitrogen supply on herbage intake; however the nitrogen supply effect can be different when compared at similar levels of herbage mass.

There is little information available on the effects of climate on herbage intake of grazing animals in temperate conditions. When the herbage intake is compared at different periods within the grazing season or on different grazing systems, the results can differ between experiments, because so many of the factors involved (e.g. herbage quality and quantity, faeces contamination) may vary with the season or with the system.

II Experiments

Introduction

The most important factors influencing the herbage intake of grazing animals as described in Chapter 2 are shown in Figure 2. In this Figure herbage intake can be seen to be the result of the balance between the requirement for nutrients as determined by factors of animal origin, and the supply of nutrients (quality and quantity) as determined by factors of sward, management and environmental origin. Of course interactions between several factors may occur.

Most intake experiments with grazing cows have been done within a strip grazing system. However in the Netherlands most farmers use a rotational grazing system with grazing periods of 2-6 days per pasture. Both the absolute level of intake and the effects of factors affecting intake may be different for 'one day'-grazing and 'more days'-grazing so that extrapolation may lead to errors.

In grazing management the most important questions are when to start and when to finish each grazing period, in view of the available herbage. To make rational decisions information on the relation between herbage mass, herbage quality and herbage consumption is required. One way of influencing herbage mass at the start of the grazing period is to vary the maturity of the herbage, a way which is applied often in practice. Herbage mass at the end of grazing can be influenced largely by the level of herbage allowance, i.e. the estimated amount of herbage available per animal during the 3-4 day grazing period.

Therefore experiments were done to estimate the effects of areic mass of herbage (by varying the length of the rest period) and of herbage allowance on the herbage intake of dairy cows using 3-4 day grazing periods.

By changing maturity of herbage both herbage mass and digestibility can be influenced. Therefore an attempt was made to measure the effect of digestibility (due to variation in maturity) on herbage intake with stall-fed animals and the combined effects of digestibility and spatial distribution of herbage mass with grazing animals. The intention was to compare different levels of herbage mass due to maturity at the same level of herbage allowance. This can be achieved by varying the grazed area at the same number of animal-days for the different levels of mass.

Research on the factor herbage allowance was not only necessary because information of this factor was gathered only with the strip grazing system, but also because this factor is the most essential link between herbage intake per unit area and herbage intake per animal. Information on the effects of herbage allowance should be gathered at a constant level of herbage mass; variation in herbage allowance can be achieved by variation in the area grazed at the same number of animal days for the treatments.

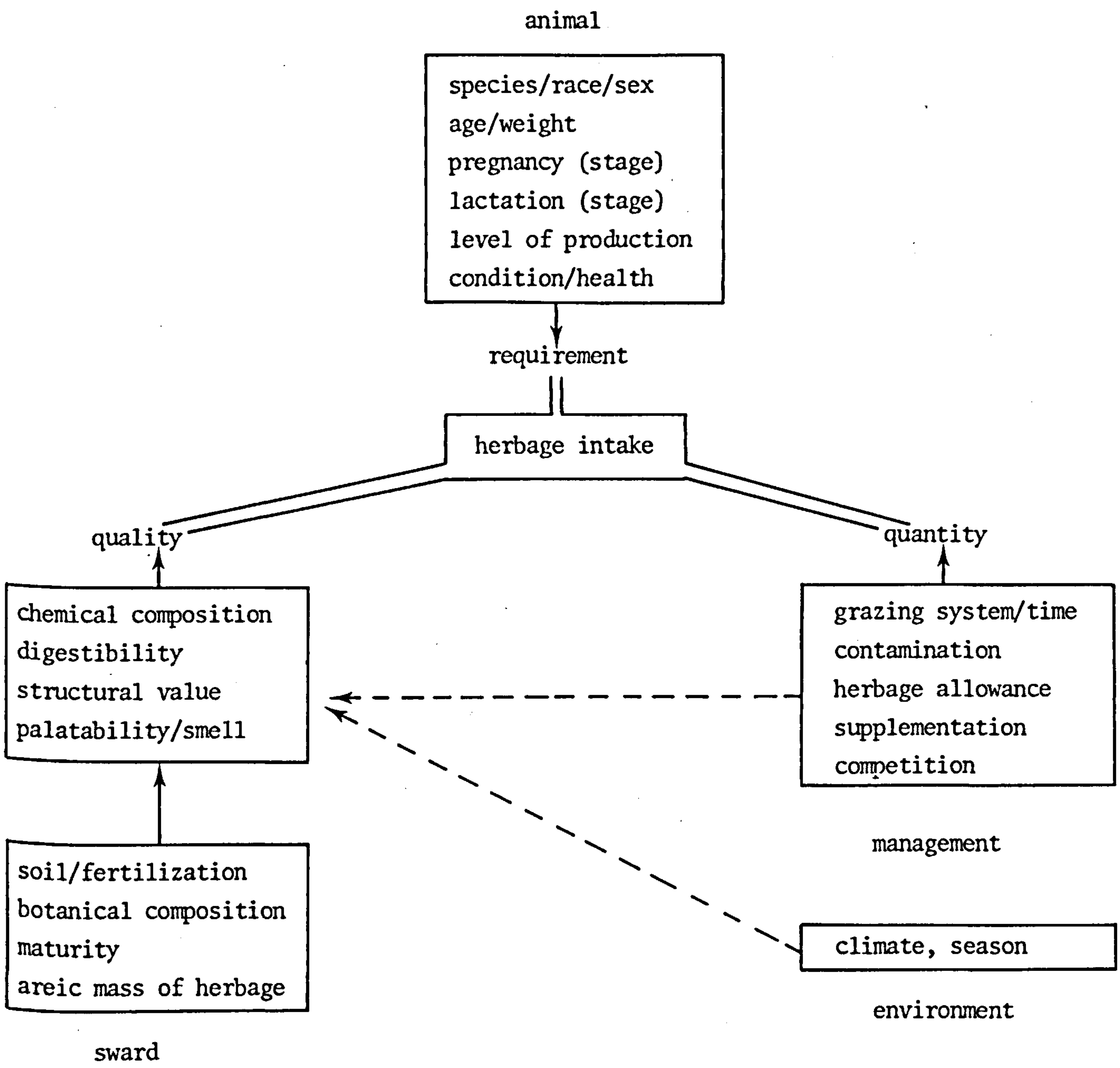


Figure 2. Factors influencing herbage intake of grazing animals.

METHOD OF MEASURING INTAKE

To establish a method which was acceptable in terms of accuracy and simplicity for estimation of the herbage intake of grazing animals was one of the aims of the experiments. At the start of the investigations a choice had to be made between a sward-cutting technique and the method based on estimation of digestibility and faeces production. The sward-cutting technique was preferred because:

- Information was needed on the herbage intake in a rotational grazing system with grazing periods of 2-6 days, which is mostly practised in the Netherlands. Under these conditions the variation in herbage intake between days can be large which makes the 'indirect' technique less attractive (high variation in faecal marker content in faeces between days, variable recovery of the faecal marker, large variation in the digestibility of the extrusa sample between days; Section 1.3)

- The digestibility of young well fertilized grassland is high under most Dutch conditions resulting in a high random variation of the intake estimate based on estimation of digestibility and faeces production (Section 1.3). Because homogeneous swards were available, the random variation to be expected with the sward-cutting technique would be of acceptable size (Subsection 1.2.5)
- With the sward-cutting technique information on both herbage mass, allowance, consumption and efficiency of grazing is gathered at the same time. When the indirect techniques are used only intake and digestibility are measured; but in most grazing experiments information on herbage mass and allowance is also necessary resulting in a high labour requirement when all these data should be measured
- During these investigations it might be possible to obtain a more precise insight in the limitations and possibilities of the sward-cutting technique than available at present (Section 1.2).

EXPERIMENTS ON THE INFLUENCE OF HERBAGE MASS AND ALLOWANCE ON INTAKE

The trials with variation in herbage mass (due to difference in the maturity of the herbage) were done both with grazing cows (digestibility and spatial distribution effects) and with stall-fed cows (mainly digestibility effects). With the zero grazing technique herbage intake can be measured precisely and information can be assembled on the variation in herbage intake between animals, but effects of the spatial distribution of the herbage of course cannot be taken into account.

The trials in which the factor length of rest period was studied both with grazing and stall-fed dairy cows were carried out in 1976 (Experiment 1) and 1977 (Experiment 2). The trials in which the factor daily herbage allowance was studied with grazing dairy cows were carried out in 1978 (Experiment 3) and 1979 (Experiment 4).

The methods used in all experiments will be described together in Chapter 3 because differences in experimental techniques between years were small. Results with the sward-cutting technique in the four experiments together will be given in Chapter 4. Design, materials, results and discussion of Experiments 3 and 4 will be given in Chapter 5. In Chapter 6 the same subdivision will be used for the Experiments 1 and 2; these experiments although carried out earlier than the allowance trials are presented here because some of the results of the Experiments 3 and 4 are necessary when interpreting the results of the Experiments 1 and 2. In Chapter 7 a general discussion and conclusions finish the experimental section.

3 Experimental methods

3.1 AREIC MASS, ALLOWANCE AND CONSUMPTION OF HERBAGE OF THE GRAZING ANIMALS

Estimation of areic mass of herbage

- In exclosures (areas not grazed). Exclosures were used to estimate the 'undisturbed' herbage accumulation during the grazing period. An area of 10 x 100 m was fenced. Both at the beginning and end of the grazing period strips were cut with a motor scythe. In 1976 eight strips were cut, in the other years ten. Post-grazing strips were located alongside the pre-grazing strips at a distance of about 0.5 m. The length of pre- and post-grazing strips was about 15 m. After raking the cut material was collected in plastic bags, the length of the strips was measured and the samples were immediately brought indoors and weighed.

Pre-grazing strips were cut on Monday morning, post-grazing strips on Friday morning. The accumulation periods in exclosures corresponded with the grazing periods in Experiments 1 and 2; in Experiments 3 and 4 two groups of animals grazed from Monday to Thursday and two other groups from Tuesday to Friday so accumulation in exclosures (measured during 4 days) was multiplied by 0.75 to correspond to the actual 3-day grazing period.

- In the grazed areas. Samples of the standing crop were cut by mowing machines. Pre-grazing strips for estimating herbage mass were sited systematically over the pasture. The distribution of the sample sites is illustrated in Figure 3.

Post-grazing strips for estimating residual herbage were located alongside the pre-grazing strips at a distance of about 0.5 m. Before cutting the post-grazing strips the faeces on the strips was removed with a shovel. Pre-grazing strips were cut on Monday afternoon, post-grazing strips on Friday afternoon in the first and second experiment. In Experiments 3 and 4 the pre-grazing strips of two groups of animals were cut on Monday, those of the other two groups were cut on Tuesday; corresponding cutting-days of post-grazing strips were Thursday and Friday respectively (all cut in the afternoon).

Post-regrowth strips (Experiments 3 and 4) for estimating 19-day regrowth of residual herbage were located alongside the post-grazing strips at a distance of about 0.5 m. At the start of the regrowth period faeces was removed from the sample sites. Post-regrowth strips were cut on Tuesday and Wednesday morning.

The pastures were drained by pipes at a distance of 12 m. The land was ploughed on ridges between the pipes. To avoid bias due to differences in the humidity of the soil between 'valleys' and 'hills' all strips were located perpendicular to the direction of the drain-pipes.

In the first experiment pre- and post-grazing samples were cut with a reciproca-

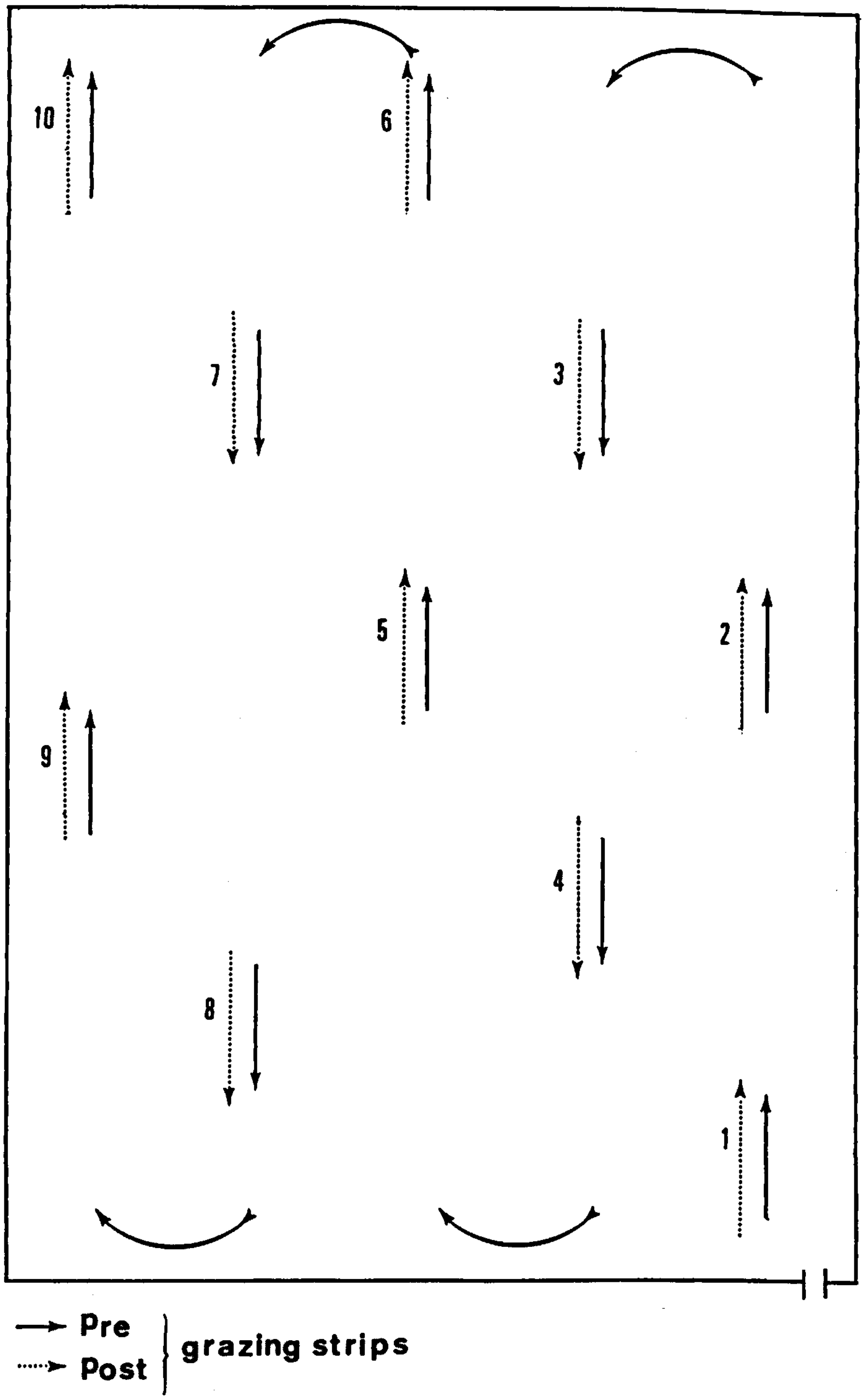


Figure 3. Distribution of the sample sites over the grazed area.

ting motor mower, leaving a stubble height of about 4.5 cm. In Experiments 2, 3 and 4 a two-step cutting system was used to estimate herbage mass. The herbage samples were first cut with a reciprocating motor mower. After removing the cut material a second cut was made with a lawn-mower, with a smaller mowing width, mowing at a stubble height of 3-3.5 cm.

The reciprocating motor mower used in all experiments was an Agria motor scythe with a fingerbar width of 0.60 m. In the second and third Experiment a Husqvarna lawn-mower was used with a cutting width of 0.48 m and a cutting height of 3.5-3.6 cm. In Experiment 4 a Honda lawn-mower was used with a cutting width of 0.51 m and a cutting height of 3.1-3.2 cm.

In the first and second experimental year the length of the strips was varied to get information on the influence of the cut area on the variation in the estimate of herbage mass. In Experiment 1 the length of the pre-grazing strips varied between 10 and 17 m; the post-grazing strips varied from 12 to 19 m. In Experiment 2 the length of the pre-grazing strips varied from 7 to 17 m; the post-grazing strips varied from 7 to 18 m. In the other years the length of the pre-grazing strips and post-regrowth strips was about 12 m; the post-grazing strips were about 14 m long. The motor scythe and lawn-mower cut the same length of strip.

The material cut with the motor scythe was raked and assembled in plastic bags. The raking was without a special pattern in the first three experimental years; in 1979 the raking was done in the direction opposite to the cutting of the motor scythe. The lawn-mower assembled the cut material in a box behind the machine. At the end of each strip the box was emptied and the cut material was transferred to bags. The length of the strips was measured with a tape. Immediately after cutting both the motor scythe and lawn-mower samples were weighed and subsampled indoors.

Estimation of the area to be fenced and the (net) area grazed The area allocated to grazing animals can be calculated from estimations of herbage mass and the intended herbage allowance. The pre-grazing strips in the exclosures were cut at 8.30 a.m. with a motor scythe. The dry matter content of two representative core samples of the 8-10 strips was estimated using a 'Knolpot' instrument (a kind of hair-dryer), requiring 10 minutes per sample. Each core sample was at least analysed in duplo.

The areic herbage mass of dry matter in the exclosure (M_T^e) was calculated as follows:

$$M_T^e = \frac{\text{mass of cut herbage} \cdot \text{dry matter content of the herbage}}{\text{cut area}}$$

The grazing period was 3-4 days in the experiments. Therefore the area to be fenced was corrected for the expected herbage accumulation during the grazing period. The expected rate of herbage accumulation in the exclosures (est $\Delta_t M_T^e$) during May, June, July, August and September was 140, 120, 100, 80 and 60 kg $ha^{-1} d^{-1}$. When the area to be fenced was calculated it was assumed that the herbage accumulation in the grazed area was 50% (Bosch, 1956) of the expected accumulation in the exclosures.

The total requirement of herbage dry matter in a grazing period of t days can be calculated from daily herbage dry matter allowance and number of animals (N). By dividing total requirement by the available quantity of herbage the area to be fenced can be calculated:

$$\text{fenced area} = \frac{A_T\ N\ t}{M_T^e + 0.5t\ (\text{est}\ \Delta_t\ M_T^e)}$$

The calculated area was corrected for the area to be cut for the estimation of herbage mass in the grazed plot. At 10:30 the assigned areas were fenced.

At the end of the grazing period the area grazed outside the fences (under the wires) was estimated. The (net) area grazed (S) = area fenced - area of cut pre-grazing strips + area of grazing under the wires.

Estimation of changes in areic mass of herbage The pre-grazing and the (paired) post--grazing strips in the exclosures were cut at 8:30 on the first and last day of the grazing period respectively with a motor scythe. The herbage accumulation of a component in the exclosure during the grazing period (ΔM_B^e) is the change in areic herbage mass of a component between start (M_B^e) and end ($M_B^{f,e}$) of grazing:

$$\Delta M_B^e = M_B^{f,e} - M_B^e$$

Just before the start of grazing, pre-grazing strips in the grazing areas were cut at 13:00. The paired post-grazing strips in the grazed areas were cut at 14:30, after removing the cows. The change in areic herbage mass of a component during the grazing period (ΔM_B) is:

$$\Delta M_B = M_B - M_B^f$$

When the accumulation of herbage during the grazing period can be neglected the change in areic herbage mass is the same as the herbage consumed. However in the experiments grazing periods of 3-4 days were used and the accumulation of herbage in the exclosures of the well-fertilized pastures was relatively high. Therefore herbage consumed (and herbage allowance) were corrected for the accumulation of herbage during the grazing period (see 3.1.4).

In Experiments 3 and 4 the areic mass of herbage (M_B) was again estimated 19 days after the animals had left the plots. The herbage accumulation of a component during the regrowth period (ΔM_B^r) is the change in areic herbage mass of a component between the end of grazing period i and the start of grazing period i+1:

$$\Delta M_{i,B}^r = M_{i+1,B} - M_{i,B}^f$$

The pre-grazing, post-grazing and post-regrowth strips were all cut with motor scythe (ms) and lawn-mower (lm), so levels of areic herbage mass were determined both above 4.5 cm (ms) and above 3.5 or 3.0 cm depending on type of lawn-mower (ms + lm).

The equations given for changes in areic herbage mass can be converted into equations for rates of change in areic herbage mass by dividing through the length of the grazing or growing period (in days).

Estimation of daily herbage consumption and allowance The areic consumption of a component was calculated from the change in areic herbage mass of a component with a correction for the herbage accumulation in the pasture during the grazing period:

$$C_B = \Delta M_B + g\,\Delta M_B^e = M_B - M_B^f + g\,\Delta M_B^e \qquad (1)$$

g = mass fraction of accumulated herbage in exclosure that was accumulated in the grazed area.

Linehan et al. (1947) assumed that the rate of herbage accumulation and the rate of consumption of herbage were each proportional to the quantity of herbage remaining at that time and derived the following equation:

$$C_B = (M_B - M_B^f) \frac{\log (M_B + \Delta M_B^e) - \log M_B^f}{\log M_B - \log M_B^f} \qquad (2)$$

The formula of Linehan was used for calculating of herbage accumulation during the grazing period in the experiments. When the Formulas (1) and (2) are combined, the accumulation factor g (Linehan) can be calculated:

$$g = \frac{\log\left(\frac{M_B + \Delta M_B^e}{M_B}\right) (M_B - M_B^f)}{\log\left(\frac{M_B}{M_B^f}\right) \Delta M_B^e}$$

The areic consumption of a component was converted to the average rate of consumption of a component of herbage per animal with the formula:

$$I_B = \frac{C_B\ S}{N\ t}$$

The same conversion factor was used for the calculation of daily herbage allowance A (rate of offering a component of herbage mass to an animal) from the available herbage mass. The available herbage mass included the accumulation of herbage in the pasture during the grazing period:

$$A_B = \frac{(M_B + g\ \Delta M_B^e)\ S}{N\ t}$$

Herbage consumption and allowance were both calculated above 4.5 cm (ms) and above 3.5 or 3.0 cm (ms + lm); in the text the cutting level referred to will be reported.

3.2 AREIC MASS AND CONSUMPTION OF HERBAGE OF THE STALL-FED ANIMALS

Areic mass of herbage Herbage was cut with a drum mower twice daily at 9:00 and 13:30 and collected immediately with a pick-up waggon (without chopping knives). The cutting height of the drum mower was about 5 cm.

The long strips were 1.63 m wide and a small strip of 20-40 cm was left between them so there was no overlap. The length of the cut area was measured. The pick-up waggon was weighed when full and empty on a weighing bridge. The areic herbage mass was calculated from the weight and area of the cut grass.

Daily herbage intake The cut herbage was sampled and weighed into plastic bins. After weighing the herbage was spread in front of each animal or group of animals to prevent heating. The herbage which was cut at 9:00 was fed at 11:00 and 13:30 (25-30% of the daily ration). The herbage which was cut at 13:30 was fed at 17:00 and 21:00 and at 6:00 and 8:30 the next day (70-75% of the daily ration). Herbage was offered ad lib. allowing a 15% residue.

Refusals were removed twice a day (10:30 and 16:30) before each fresh batch of grass was introduced. The residues were weighed and sampled. Intake was calculated by subtracting the residues from the offered herbage.

In 1976 the animals were housed in a cubicle shed and were fed in groups of 3 animals. In 1977 the animals were housed in a cowshed and were fed individually.

3.3 SWARD HEIGHT, STUBBLE HEIGHT AND STUBBLE MASS

Sward height The sward height was measured at the start of grazing (Experiments 2, 3 and 4) and at the end of the grazing period (Experiments 3 and 4). A modified tempex disk of Jagtenberg (1974) was used with a diameter of 50 cm and a thickness of 5 cm. The height of the disk from the ground was recorded with a vertical graduated shaft. Forty height measurements were taken diagonally over the grazed area.

Stubble height In Experiments 2, 3 and 4 a lot of measurements of stubble height have been made. The stubble height after cutting the pre-grazing strips with a motor scythe (Experiments 2, 3, 4) and lawn-mower (Experiments 2, 3 early summer, 4) as well as the stubble height after cutting the post-grazing strips with a motor scythe (Experiments 2, 3 late summer, 4) and lawn-mower (Experiments 2, 3 early summer, 4) have been measured. In Experiment 2 a ruler was used. In Experiments 3 and 4 a small tempex or polythene disk was used. The diameter of the disk was 4 cm.

In most experiments 5 stubble heights were recorded per strip, giving a total of 50 measurements per grazed area. In the early summer of 1978 (Experiment 3) 3 heights were measured per mowed pre-grazing strip.

Stubble mass In Experiments 3 and 4 the stubble mass after cutting with motor scythe and lawn-mower was estimated both in the pre- and post-grazing strips. All the material above ground level was removed by cutting with a knife. In Experiment 3 an area of 60 x 40 cm was cut in each strip (10 strips). In Experiment 4 two samples areas of 30 x 40 cm each were cut per strip. Iron frames were used to mark the sample sites.

The sample sites were chosen at random; the post-grazing sample area was placed alongside the pre-grazing area. All the cut material was collected in polythene bags, totally dried immediately and weighed.

3.4 MILK PRODUCTION AND LIVE WEIGHT

Milk yield and composition Immediately after milking milk yield was recorded for individual animals using measuring glasses (a volumetric determination). In Experiment 1 the milk yield was recorded from Tuesday evening until Thursday morning; the two morning samples were mixed together and analysed for fat and protein; the same was done with the evening samples.

In Experiments 2, 3 and 4 the milk yield was recorded from Monday evening until Thursday morning; the six samples per animal were all analysed separately. When the grazing period started on Tuesday evening then the milk yield was recorded from Tuesday evening until Friday morning (Experiments 3 and 4).

Live weight In all the grazing trials the animals were weighed on two successive days every week: the first time (after milking) just before the start of the experimental grazing period, the second time 24 hours later. In 1976 the stall-fed cows were weighed on Monday and Tuesday evening; in 1977 the stall-fed cows were weighed on Wednesday and Thursday morning.

3.5 ANIMAL BEHAVIOUR

Grazing time The grazing time was measured in Experiments 2 and 4 during the whole grazing period. A Kienzle vibrarecorder was attached to the head of a cow (Zeeb, 1972). In a preliminary investigation in the first experiment on a group of dairy cows grazing times recorded with the vibrarecorder did not differ from visual records.

Rate of biting In Experiment 4 the rate of biting was recorded during a grazing period in the morning (between 10:00 and 12:00) on the second or third day grazing. A stopwatch was used to measure the time taken for animals to make 50 bites and from these records biting rates (bites per min.) were calculated (Jamieson & Hodgson, 1979). Three measurements per animal were made. It was not intended to provide a representative estimate of biting rate over the whole day, but only to compare the biting rates of the treatments.

3.6 WEIGHING AND SAMPLING

The herbage offered to and the residues from the stall-fed cows were weighed in plastic bins on a 50 kg balance with an imprecision of less than 0.2%. The same balance was used for all the herbage samples cut with the motor scythe. The herbage samples cut with the lawn-mower were weighed on a 2 kg balance with an imprecision of less than 0.2%. The small balance was also used to weigh concentrates for the early-summer trials of Experiment 2, 3 and 4 when a mixture of magnesium-rich and normal concentrates was fed. In the other experimental periods the small amount of concentrates (1 kg) was measured volumetrically in the milking parlour.

During the weighing of the concentrate mixture a composite sample was taken in duplicate. When the concentrates were weighed in the milking parlour a duplicate sample was gathered during the experimental period. During the filling of every single bin with a half-day's ration of herbage for the stall-fed cows, a handful of material was put into a 30 litre sample container to obtain a composite sample of the herbage. This sampling was done in triplicate. The herbage samples in the containers were each subsampled with a herbage core (bore 5 cm); a constant proportion of the supplied mass was subsampled.

The feed residues of the stall-fed cows were individually sampled in duplicate. A constant proportion of the total amount of residues per animal was put into 2 containers. The combined sample of all the animals in the containers were each subsampled with a core; a constant proportion of the total residues was subsampled.

Each herbage sample cut with the motor scythe was individually subsampled with a core. The samples of short herbage cut with the lawn-mower were mixed and subsampled by hand.

From the samples of concentrate and herbage about 300 g were weighed, dried for one day at about 65 °C and weighed again after three hours of cooling.

At the end of the experimental period of 4 days each group of eight herbage samples of the stall-fed cows were bulked and a representative subsample was taken (ISO/DP 6498); the same procedure was followed with the residues. The 8 or 10 samples gathered with motor scythe or lawn-mower were bulked after drying, mixed and subsampled in duplicate in the first and second experiment. In Experiments 3 and 4 the total sample of 8 or 10 strips was ground and subsampled by taking small amounts with a spoon from many places of the homogenized sample (ISO 34/SC10 N 181). All samples were ground with a small hammer mill through a 1.00 mm sieve. All the components were analysed on ground air-dry material.

After mixing the milk a singe sample was put into a bottle, preserved with $HgCl_2$ and stored at 2-4 °C. Taking a proportional sample was not necessary because the individual samples from each milking time were analysed separately.

3.7 ANALYTICAL METHODS

The moisture and ash content of feed samples was determined using the standard methods of the CEC (CEC 14L279/8-11 and CEC 14L155/20 respectively). The nitrogen content of feed samples was estimated with the Dumas method (Merz, 1979). Diethyl ether was used for the determination of the fat content of the concentrate samples from Experiments 1, 2 and 3 (CEC 14L279/17-18). In Experiment 4 hexane was used in the analyses of fat (ISO/DP 6492).

The crude fibre analyses in the feed samples of 1976 were done with the Holdefleiss method (1864) modified by Van Kampen (1936). In the other experiments crude fibre was analysed with the national NEN 3326 method; this method is equal to CEC 16 L83/24-26.

The neutral detergent fibre content of herbages was determined by the modified method of Van Soest & Robertson (1977).

The fat content of the milk samples was determined by means of a Milcotester automatic machine which was standardized with the Gerber method. The protein content tests of the milk were done with a colour-binding method which was standardized with the Kjeldahl-method. The milk analyses were done by the Central Milk Recording Service.

3.8 DIGESTIBILITY

In-vitro digestibility The in-vitro digestibility of the herbage samples was carried out according to the Tilley & Terry (1963) method. The modification of Van der Koelen & Dijkstra (1971) was applied.

In each series of in-vitro analyses 3-4 standard herbage samples of known in-vivo digestibility were included. The in-vitro digestibility of these standard samples was determined with wether sheep at the maintenance feeding level. So the predicted in--vivo digestibilities using the in-vitro methods apply to this feeding level.

In-vivo digestibility In 1976 four digestibility trials with herbage were carried out both with wether sheep and lactating cows. The cows were fed in the same way as the stall-fed cows of the intake experiments (see 3.2), the wether sheep were offered 900-1 000 g T per animal per day. The herbage was cut twice daily and fed fresh. After a preliminary period of 7 days the faeces was quantitatively collected during a 7-day experimental period. Details of these digestibility experiments have been described by Van der Honing (1977).

In 1979 five digestibility trials with herbage were performed with wether sheep. After collecting the herbage in the field all the daily rations of one experimental period were weighed out on the same day. After weighing and sampling the herbage was frozen. Each wether sheep received 900-1 000 g T per day. After a preliminary period of 11 days the faeces was collected during an experimental period of 10 days.

3.9 NUTRITIVE VALUE AND NUTRIENT REQUIREMENT

Nutritive value The term nutritive value is used here for the relative contents of nutrients in the feed and not to refer to the combined effects of intake and nutrient contents of forages. The new feed evaluation system applied in the Netherlands (Van Es, 1975, 1978) starts with the measurement or prediction of contents of digestible nutrients obtained with sheep fed around maintenance level for energy.

The content of crude protein (w_{XP}) of the herbage samples was determined in the laboratory; afterwards the content of digestible crude protein (w_{dXP}) was calculated from regression equations given in the manual for the calculation of the nutritive value of roughages (C.V.B., 1977a):

$$w_{dXP}/O = 0.959\ w_{XP}/O - a,$$

in which
a = 0.04 from 1 May to 15 July
a = 0.042 from 16 July to 15 August
a = 0.044 from 16 August to 15 September
a = 0.046 after 15 September

The digestibility of the organic matter of the herbage was estimated from in-vitro determinations (see 3.8); the content of digestible organic matter when expressed in organic matter is equal to d_O:

$$w_{dO}/O = d_O$$

The content of metabolizable energy (ME) of fresh herbage for cattle was predicted from w_{dXP}/O and w_{dO}/O values obtained with sheep at maintenance level by using the equation:

$$e_{ME}/O \text{ (kJ/kg)} = (3.4\ w_{dO}/O + 1.4\ w_{dXP}/O)\ 4\ 184$$

The gross energy content (^{e}GE) of forages was assumed to be 20 083 (4 800 · 4.184) kJ per kg organic matter.
For all forages the content (q) of ME in the gross energy was computed by division:

$$q = \frac{e_{ME}/O}{e_{GE}/O} = \frac{e_{ME}/O}{20\ 083}$$

The obtained ME content was converted into a net energy content for lactation ($^{e}NE_1$) with the equation:

$$e_{NE_1}/O \text{ (kJ/kg)} = 0.6 \left[1 + 0.4(q - 0.57) \right] e_{ME}/O$$

Due to the influence of level of feeding on the ME content (1.8% per feeding level) also the e_{NE_1} values would vary with the feeding level. By multiplying the NE content at maintenance level by 0.9752 (1 - 1.38 · 1.8%) the NE content at the standardized feeding level 2.38 · maintenance was obtained. There are some indications from respiration trials that the influence of the level of feeding on the ME content of the herbage is smaller than on winter diets, this aspect will be treated further in the discussion.

One Dutch feed unit for lactation (voedereenheid melk = VEM) contains 6.904 kJ net energy lactation. Together this led to the following equation to calculate the VEM of herbages from their ME contents:

$$e_{NE_1}/O \text{ (VEM kg}^{-1}\text{)} = \frac{0.6 \left[1 + 0.4 \left(\frac{e_{ME}/O}{20\ 083} - 0.57 \right) \right] 0.9752\ e_{ME}/O}{6.904}$$

$$= (1\ 688 \cdot 10^{-9}\ e_{ME}/O + 6\ 543 \cdot 10^{-5})\ e_{ME}/O$$

The nutritive value of the small amounts of concentrates fed has been calculated from the nutritive value of the components of the mixture by use of the Veevoedertabel (C.V.B., 1977b).

Nutrient requirements The energetic requirements are expressed in net energy for lactation. The requirements at maintenance level are 3 054 kJ (442 VEM) NE_1 for each kg 4% fat-corrected milk and 293 $W^{0.75}$ kJ (42.4 $W^{0.75}$ VEM) NE_1 for maintenance.

This maintenance requirement has been derived for stall-fed animals. Four factors increase the energy required by the grazing cow: it grazes, walks, eats a ration with a high protein content and has periods of food excess and food shortage when the grazing period is long (Van Es, 1974). Assuming a grazing period of 9 hours and an indoor eating period of 2 hours the extra 7 hours grazing for a 550 kg cow require 420 VEM d^{-1} when the additional requirement of NE due to eating is 30% above maintenance. The requirement for walking during grazing is included in this eating-activity surplus. If walking to and from the milkshed and walking in the pasture without grazing is assumed to be in total 2.5 km per day the maintenance requirement is increased with 250 VEM d^{-1} for a 550 kg cow.

Herbage consumed by grazing cows contain far more protein than the cows need. The consumption of digestible crude protein above estimated needs at a production level of 24 kg FCM/day and an intake of 13 kg O with a w_{dXP}/O of 0.20 is 720 g. Excretion of the excess digested nitrogen in the urine requires about 18 VEM/100 g dXP, giving a requirement of 130 VEM d^{-1}.

When the cows graze the same pasture during three days they probably eat more than they need during the first part of the grazing period and less during the last days. That means deposition of reserve tissue and utilization of this tissue afterwards with a loss of about 15% compared with immediate utilization. If an excess consumption of 25% in the first third part of the grazing period is assumed the total loss of a cow consuming 15 kVEM per day would be 190 VEM.

The total additional maintenance requirement of the grazing cow would amount to 990 VEM, equal to 20% of the requirement for a 550 kg cow. The surplus of 20% was used when calculating net energy requirement of the grazing animals; however it should be realized that due to the assumptions made and due to the low precision of the estimation of the energy requirements for the separate components the surplus may range between 15 and 30%. The surplus of 20% for the net energy requirement for maintenance of grazing dairy cows in comparison with stall-fed cows is not in agreement with the actual Dutch feeding standards where no surplus is accounted for due to the expected lower depression of digestibility at high feeding levels of grazing cows than of cows fed on winter diets.

The energy requirements given for maintenance and for milk are correct only for feeding level 2.38, i.e. at a yield of 15 kg milk because the energetic value applies to this level. For higher and lower feeding levels the requirement for NE_1 is higher and smaller, in fact + and -1.8% per level, respectively. The total energy requirement for stall-fed animals corrected for feeding level was calculated with the equation (Benedictus, 1977):

$$K_{NE_1}\ (\text{VEM d}^{-1}) = (442\ \text{FCM} + 42.4\ W^{0.75})(0.9752 + 0.00165\ \text{FCM})$$

The total energy requirement for grazing animals with the 20% surplus for maintenance was:

$$K_{NE_1}\ (\text{VEM d}^{-1}) = (442\ \text{FCM} + 50.9\ W^{0.75})(0.9752 + 0.00165\ \text{FCM})$$

The Dutch protein requirements are expressed in digestible crude protein. The requirements for dXP are 0.43 W + 130 g for maintenance and 63 g for each kg fat-corrected milk. The total protein requirement was calculated with the equation (C.V.B., 1975):

$$K_{dXP}\ (\text{g d}^{-1}) = 63\ \text{FCM} + 0.43\ W + 130$$

By multiplying the nutritive value of each component of the ration with the O intake the intake of nutrients from the component was calculated, e.g.

$$I_{NE_1}\ (\text{VEM d}^{-1}) = I_O\ (\text{kg d}^{-1})\ e_{NE_1}/O\ (\text{VEM kg}^{-1})$$

In all trials the two ration components fed were fresh herbage and a small amount of concentrates.

The degree of nutrient balance b shows if the intake of nutrients of the total ration is sufficient for the estimated nutrient requirement of the cow or not, e.g.:

$$k_{NE_1} = I_{NE_1}/K_{NE_1}\ ;\ k_{dXP} = D_{XP}/K_{dXP}$$

3.10 STATISTICAL ANALYSIS

Most of the data collected were subjected to inorthogonal analysis of variance, carried out by means of regression technique. The dependent and independent variables in the regression analyses and other details of statistical analyses will be given in Chapter 5 and 6. Analyses were carried out with the statistical package GENSTAT.

The backgrounds of the statistical analysis performed can be found in two reports of Keen. In the first report (Keen, 1979) statistical considerations regarding the technique of estimating herbage intake (both sward cutting as well as zero grazing) are given and the mathematical models used in the analysis of variance, especially of the zero grazing trials, are presented in relation to possible designs of experiments. In the second report (Keen, 1981) the models and techniques used for the grazing experiments are discussed.

4 The sward-cutting technique

In all experiments performed a sward-cutting technique was used to estimate the herbage intake of grazing cows. The reasons for choosing a sward method for the estimation of herbage intake are described in the introduction to the experimental section. A description of the sward method used is given in Chapter 3. In this chapter results of the cutting technique will be presented and special attention will be paid to the systematic error as well as to the random error of the estimate.

The potential for the sward cutting technique to provide reliable intake estimates depends on minimising or eliminating:

- the random error of the estimates of herbage mass before and after grazing
- possible systematic errors in estimating the difference between the herbage mass before and after grazing. The same amount of material should be left after cutting pre- and post-grazing samples. The cutting heights should be below the height at which animals graze and low enough to ensure the collection of all trampled herbage during grazing.
- possible systematic errors in estimating the herbage accumulation during grazing.

Possible systematic errors will de bescribed first in the Sections 4.1 and 4.2. Results on cutting height, herbage mass and stubble mass in relation to cutting height will be shown in Section 4.1. The influence of herbage accumulation during grazing on the estimation of herbage intake in the experiments is given in Section 4.2. Equations used to calculate random errors of the estimates of herbage mass and of herbage intake and some of the precision results obtained will be described in Section 4.3. Also some of the factors affecting experimental precision will be examined in Section 4.3. A discussion in Section 4.4 on the results obtained with the sward-cutting technique will end this section.

4.1 DETERMINING THE DIFFERENCE IN HERBAGE MASS BETWEEN START AND FINISH OF GRAZING - THE PROBLEM OF CUTTING TO THE SAME RESIDUAL STUBBLE -

4.1.1 Stubble height

In 1976 an Agria motor scythe was used to cut the sward. After cutting, raking and collecting the herbage the stubble height was measured with a rule. During 6 grazing periods stubble heights were measured before and after grazing under dry weather conditions (30 measurements each time). The average stubble height before and after grazing was 4.22 (s_x = 0.30) and 4.40 (s_x = 0.31) cm respectively. From this limited number of measurements Student t-test provided an indication for a higher stubble at the end of grazing than at the beginning of grazing ($P < 0.10$).

The same motor scythe has been used in the other experiments. After cutting, raking and collecting the herbage the stubble height was measured. The average stubble height (H) after cutting by motor scythe in Experiments 2, 3 and 4, in grazing periods with dry weather conditions during cutting (see 5.3.2.1 and 6.3.2.1), are presented in Table 5. The variation of the stubble heights between grazing periods is given as standard deviation (s_x) in brackets; N = the number of grazing periods.

In 1977 the stubble heights were measured with a rule, but in 1978 and 1979 a small disk was used which provides an integrated measure of height and density. The relatively high stubble left after cutting by motor scythe both before (H) and after (H^f) grazing in 1977 may be partly explained by the use of a rule, which avoids bending of herbage when measuring stubble height. The values in the table show that the stubble height after cutting by motor scythe varies considerably between periods and between years.

The difference in stubble height after cutting by motor scythe between start and finish of grazing (ΔH) was negative in all periods and varied from -0.29 to -0.68 cm. Except in the early summer of 1977, in all other periods Student t-test showed a significantly ($P < 0.01$) higher stubble at the end compared to start of grazing after cutting by ms.

From 1977 to 1979 a lawn-mower was used to cut the strips at a lower height, after they were first cut by the motor scythe. The reasons for the use of the lawn-mower were that:
- quantitative data on the comparability of the material left after cutting by motor scythe before and after grazing would become available
- the cutting height could be more reproducible than could be achieved by motor scythe
- grazing by the animals below cutting height would be impossible and that herbage trampled during grazing could be collected.

In 1977 and 1978 a Husqvarna lawn-mower was used for cutting at a stubble height of 3.5 to 3.6 cm. The variation in stubble height after cutting by lm was rather small both between periods (s_x in brackets) and between years (Table 5). In 1979 an other type of lm was used (Honda), to cut at a stubble height of 3.1-3.2 cm. The differences in stubble height after cutting by lm between start and finish of grazing were small and not significant. So it was possible to cut to a height reproducible both between and within grazing periods using a lawn-mower after cutting with a motor scythe.

4.1.2 Herbage mass

The areic mass of herbage above cutting height at start (M) and finish (M^f) of grazing both cut with ms and with lm is given in Table 6. M_0 (ms) and M_0^f (ms) varied considerably between grazing periods (s_x in brackets), between seasons and between years due to the aim of the experiments (see Chapters 5 and 6). The M_0 (lm) and M_0^f (lm) in 1978 were higher than those in 1977. This may be explained by differences in the density of the swards used. M_0 (lm) and M_0^f (lm) were highest in 1979 when the lm with the lowest cutting height was used. This can be explained with the observation that the

Table 5. Stubble height after cutting by motor scythe and lawn-mower.

		1977		1978		1979		1977 + 1979
		es	ls	es	ls	es	ls	es + ls
	N	9	9	27	24	11	11	40
ms	H	5.05(0.70)[1]	4.58(0.41)	4.64(0.39)	4.60(0.25)	4.18(0.28)	4.33(0.31)	4.51(0.54)
	H^f	5.49(0.74)	5.25(0.52)	-	4.99(0.33)	4.53(0.61)	4.62(0.38)	4.93(0.69)
	ΔH	-0.44(0.78)	-0.68***(0.62)	-	-0.40***(0.26)	-0.35**(0.47)	-0.29***(0.32)	-0.43***(0.56)
lm	H	3.61(0.20)	3.52(0.29)	3.54(0.15)	-	3.09(0.16)	3.18(0.24)	3.33(0.31)
	H^f	3.62(0.29)	3.71(0.14)	3.51(0.19)	-	3.18(0.26)	3.12(0.22)	3.38(0.35)
	ΔH	-0.02(0.31)	-0.19(0.34)	0.02(0.25)	-	-0.08(0.31)	0.06(0.22)	-0.05(0.30)
ms-lm	H_f	1.44(0.68)	1.06(0.31)	1.11(0.33)	-	1.09(0.34)	1.15(0.21)	1.18(0.42)
	H	1.88(0.76)	1.54(0.49)	-	-	1.35(0.48)	1.50(0.31)	1.55(0.54)
	ΔH	-0.44(0.79)	-0.48*(0.66)	-	-	-0.26**(0.35)	-0.35***(0.39)	-0.38***(0.54)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

Table 6. Estimation of herbage mass by motor scythe and lawn-mower.

		1977		1978		1979		Mean
		es	ls	es	ls	es	ls	es + ls
	N	9	9	27	24	22	22	113
ms	M_0	2970(889)[1]	2146(400)	2662(838)	1965(294)	1867(516)	1617(311)	2139(716)
	M_0^f	1019(417)	643(161)	1037(548)	550(241)	719(379)	602(236)	754(416)
	ΔM_0	1950***(613)	1503***(356)	1625***(611)	1415***(308)	1148***(434)	1015***(372)	1385***(531)
lm	M_0	319(101)	328(91)	370(114)	486(98)	423(120)	672(108)	457(159)
	M_0^f	434(116)	495(62)	510(119)	668(100)	565(129)	843(116)	612(173)
	ΔM_0	-115***(`74)	-167***(101)	-140***(80)	-182***(85)	-142***(63)	-171***(109)	-155***(87)
ms + lm	M_0	3289(954)	2474(343)	3032(893)	2451(293)	2290(469)	2289(232)	2596(674)
	M_0^f	1453(490)	1138(190)	1547(586)	1218(268)	1284(410)	1445(187)	1366(415)
	ΔM_0	1836***(604)	1335***(293)	1485***(639)	1233***(298)	1006***(417)	844***(304)	1229***(529)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

areic mass of herbage per cm stubble height increased with decreasing distance to ground level (Tayler & Rudman, 1966). In 1978 and 1979 M_0 (lm) and M_0^f (lm) differed significantly (P <0.01) between seasons.

The average ΔM_0 (lm) per season varied from -115 to -182 kg ha^{-1} and was significant (P <0.01) in all seasons. So at finish of grazing the areic mass of herbage cut by the lawn-mower was higher than at start of grazing; the reasons for this difference will be examined in the discussion. In all years there was a tendency for ΔM_0 (lm) to be higher in ls than in es but only in 1978 was this effect significant (P <0.05).

The combined areic masses of ms and lm are shown also in Table 6. Averaged over all years ΔM_0 (ms + lm) was 1 229 kg ha^{-1}, while ΔM_0 (ms) was 1 385 kg ha^{-1}. When the motor scythe alone was used the difference in herbage mass between start and finish of grazing was overestimated by 13%.

The areic consumption (C) of herbage (corrected for herbage accumulation during the grazing period) as calculated with ms and with ms + lm is given in Table 7. The absolute effect of the lawn-mower on the change in herbage mass during grazing when calculating C_0 was of course the same as when calculating ΔM_0. However due to the herbage accumulation during grazing, the lawn-mower effect on C_0 was relatively smaller than on ΔM_0. When the motor scythe alone was used the areic consumption of herbage averaged over all years was overestimated by 10% (Table 7). Due to the higher M_0 (ms) in es and the lower ΔM_0 (lm) in es the correction of the estimate of C_0 by cutting with a lawn-mower in es was much lower than in ls. The daily herbage intake (I_0) averaged over all years was 15.0 kg per animal when estimated with ms alone, and 13.4 kg per animal when estimated with ms + lm (Table 7).

4.1.3 Stubble mass

The cutting results with the lawn-mower proved that the material left after cutting by motor scythe at start and at finish of grazing was not comparable. The question arose whether the lawn-mower cut deep enough to correct the motor scythe satisfactorily. The herbage mass in the stubble (stubble mass) that remains following the two-stage cutting operation was sampled by hand-cutting at ground level to check whether this stubble mass was of equal size for pre- and post-grazing strips. This labour-intensive hand-cutting could only be performed during 5 experimental periods (EPs) in 1978, in which the plot for one group of animals was cut by one person, and during 5 EPs in 1979, in which the plots for two groups of animals within the same pasture were cut on the same day by two persons. The results of Group a in EP 11 1979 were not reliable due to the tearing of sods by animals during grazing. Cutting conditions and stubble masses are presented in Table 8.

When the material left after cutting by motor scythe was wet (due to rainfall in the preceding period or during cutting) not all the herbage cut by lawn-mower was transported to the collecting box behind the machine but part of the material stuck to the underside of the machine. Under wet conditions the underside of the machine had to be cleaned after cutting each strip. Table 8 shows that adhesion of herbage to the lawn-mower coincides with low fractions of organic matter (w_0) in the fresh herbage

Table 7. Estimation of herbage consumption by cutting with motor scythe and lawn-mower.

		1977		1978		1979		Mean
		es	ls	es	ls	es	ls	es + ls
	N	9	9	27	24	22	22	113
ms	C_0	2318(677)[1]	1687(327)	1940(597)	1613(340)	1458(416)	1211(387)	1645(556)
	I_0	14.9(1.3)	16.4(1.1)	13.5(1.5)	15.0(2.2)	15.7(2.6)	15.6(2.1)	15.0(2.2)
ms + lm	C_0	2203(647)	1520(249)	1801(620)	1431(331)	1316(396)	1040(315)	1489(552)
	I_0	14.1(1.1)	14.9(0.9)	12.4(1.2)	13.3(2.0)	14.1(2.0)	13.4(1.9)	13.4(1.8)
$\frac{C_0(ms)-C_0(ms+lm)}{C_0(ms+lm)}$		0.05	0.11	0.08	0.13	0.11	0.16	0.10

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

Table 8. Stubble mass after cutting by motor scythe and lawn-mower.

	EP	Cutting conditions (1m)		w_0 (1m)		Adhesion of herbage to 1m		Stubble mass (SM)		
		M	M^f	M	M^f	M	M^f	SM_0	SM_0^f	ΔSM_0
1978	5	dry	dry	0.35	0.39	-	-	1994(94)[1]	2137(77)	-143
	6	dry	rain	0.46	0.15	-	+	1792(58)	2150(82)	-358***
	9	rain	dry	0.17	0.30	+	-	1657(70)	1320(45)	+337***
	11	dry	dry	0.43	0.45	-	-	1205(48)	1201(47)	+ 4
	13	dry	dry	0.25	0.31	-	-	1389(79)	1288(69)	+101
1979	1 a	rain	wet ms	0.18	0.16	+	+	2749(95)	2653(91)	+ 96
	b	dry	stubble	0.19	0.15	-	+	2650(111)	2772(78)	-122
	2 a	dry	puddles,	0.18	0.15	-	+	1900(82)	1692(88)	+208***
	b		wet ms stubble	0.19	0.16	-	+	1881(98)	1915(76)	- 34
	3 a	wet ms	wet ms	0.13	0.14	+	+	1092(46)	1171(118)	- 79
	b	stubble	stubble	0.15	0.16	+	+	1036(55)	1010(63)	+ 26
	9 a	dry	rain	0.37	0.14	-	+	1486(47)	1849(97)	-363**
	b			0.37	0.12	-	+	1601(57)	1829(120)	-228*
	11 b	dry	dry	0.38	0.33	-	-	1531(54)	1517(56)	+ 14

1. The figure in brackets is the standard deviation of the mean ($s_{\bar{x}}$) as calculated from the measurements on different strips within experimental periods.

cut by this mower. This organic matter fraction in fresh herbage may be affected by rainfall during cutting (as indicated by "rain") or by rainfall in the preceding period (as indicated by "wet ms stubble").

When no sticking of herbage to lm occurred, either at start or at finish of grazing (1978: EP 5, 11, 13; 1979: EP 11b), no difference could be demonstrated in stubble mass between start (SM_0) and finish (SM_0^f) of grazing. When the cutting conditions were dry at start of grazing and wet at finish of grazing with sticking of herbage (1978: EP 6; 1979: EP 1b, 9a, 9b), SM_0^f was significantly higher than SM_0 ($P < 0.01$; $P < 0.10$; $P < 0.025$ and $P < 0.05$ respectively). SM_0 was significantly ($P < 0.01$) higher than SM_0^f when the reversed cutting conditions existed (1978: EP 9). Wet cutting conditions both at start and at finish of grazing was attended with the lack of a significant difference between SM_0 and SM_0^f (1979: EP 1a, 3a, 3b). Only the figures of EP 2 in 1979 did not correspond with these of the other weeks. However, due to the formation of puddles during the grazing period some of the pre- and post-grazing sample sites could not be paired and increase in random error may have been introduced in this week.

These results indicate that under comparable cutting conditions the stubble masses were equal for pre- and post-grazing strips. However, if the hand-cutting results were indeed reliable, under very wet conditions the efficiency of mowing of both machines was reduced and the stubble mass increased. This effect was independent of the moment of cutting.

4.2 HERBAGE ACCUMULATION DURING THE GRAZING PERIOD

The undisturbed accumulation of herbage during the grazing period was measured by estimating herbage mass at the beginning and at the end of grazing in a fenced area. The accumulation factor g (Section 3.1) was used to estimate the disturbed herbage accumulation from the undisturbed accumulation during grazing; this factor was based on an equation for the calculation of herbage consumption given by Linehan et al. (1952). They assumed that the rate of herbage accumulation and the rate of consumption of herbage were each proportional to the quantity of herbage remaining at any time during a grazing period.

Some important figures concerning the accumulation of herbage during grazing are shown in Table 9. The daily rates of herbage O accumulation in the exclosure averaged over the season were high and ranged from 135 to 169 kg ha^{-1} d^{-1} in es and from 55 to 98 kg ha^{-1} d^{-1} in ls. The length of the grazing- (and accumulation-) period was either 3 (part of 1977, 1978 and 1979) or 4 (1976, part of 1977) days.

When the areic masses of herbage cut by the ms were used to calculate the accumulation factor, g was on average 0.57. However in Section 4.1 it was shown that M^f was underestimated when cut by ms only. Therefore g will also be underestimated by using ms-cutting results only. In 1976 only a motor scythe was used in the experiments; so the herbage consumption was calculated then with an accumulation factor derived from estimates of M and M^f by ms. Due to an underestimation of the residual herbage by ms, herbage consumption was probably overestimated in 1976; this was only partly corrected by an underestimation of the accumulation factor g, which was affected in the opposite

Table 9. Accumulation of herbage during grazing.

		1976[1]		1977		1978		1979		Mean
		es	ls	es	ls	es	ls	es	ls	es + ls
	N	6	3	9	9	27	24	22	22	113
ms	$\Delta_t M_0^e$	135	55	169	81	156	98	150	87	124
	ΔM_0^e	539	218	582	277	468	293	450	260	381
	g	0.54	0.58	0.56	0.55	0.60	0.53	0.58	0.59	0.57
ms + lm	g	0.54	0.58	0.62	0.65	0.67	0.67	0.68	0.76	0.68
	$g\ \Delta M_0^e$	288	127	367	185	316	198	310	196	260
	ΔM_0	1621	1224	1836	1335	1485	1233	1006	844	1229
	C_0	1909	1351	2203	1520	1801	1431	1316	1040	1489
	$\frac{g\ \Delta M_0^e}{C_0}$	0.15	0.09	0.17	0.12	0.18	0.14	0.24	0.19	0.17

1. In 1976 all data were determined with a ms only.

direction.

The accumulation factor g was also calculated by using the areic masses of herbage cut by ms and lm from 1977 to 1979 (Table 9); g was on average 0.68. The much higher value of g when calculated with areic masses cut by ms + lm than when only cut by ms can be attributed to two effects a) M^f (lm) was higher than M (lm); b) if the equation of Linehan et al. is used for the data determined with ms + lm it is assumed that the material in the region of the sward cut by the lm has the same effects on herbage accumulation as the herbage above the ms cutting height i.e. the photosynthetic activity of the material in both regions of the sward is assumed to be about equal. The factor g was also calculated with the assumption that the region of the sward cut by the lm at start of grazing does not contribute to the herbage accumulation during grazing, thus the ms level was chosen, however with correction for the underestimation of M^f by ms. This can be performed by using M (ms) at start of grazing and $[M^f\ (ms) + \Delta M\ (lm)]$ at finish of grazing in the equation of Linehan et al. The accumulation factor g calculated with corrected ms data was on average 0.59, 0.60, 0.63, 0.59, 0.62 and 0.66 in the es and ls of 1977, 1978 and 1979 respectively. The 3-year mean was 0.62. So the average difference in g between calculations with ms + lm data and corrected ms data was 0.07 or 9%.

For the estimations of herbage consumption from 1977 to 1979 the g factor was calculated with ms + lm data; this choice will be discussed in Subsection 4.4.2. The factor g depends on M, M^f and ΔM^e. Differences in g between years or seasons can therefore be attributed to the treatments applied. For example, in ls 1979 M was low and the average daily herbage allowance was high, resulting in a relatively high M^f and a small ΔM giving a high accumulation factor.

In grazing periods of 3-4 days the fraction of disturbed herbage accumulation in total intake was on average 0.17 when Linehan's equation was used with the ms and lm data (Table 9). When the corrected ms data were used for calculating g the fraction of disturbed herbage accumulation in total intake was on average 0.155. The 9% difference in g between ms + lm data and corrected ms data resulted in a 1.7% difference in C_0 between both estimates.

In es high accumulation rates occurred and the accumulation fraction of total intake was larger than in ls. At a given grazing period and daily herbage allowance a lower level of M will increase the disturbed accumulation fraction of intake due to the larger area grazed (e.g. compare es of 1978 with es of 1979). At a comparable level of M a high level of daily herbage allowance gives a high M^f, resulting in an increased accumulation factor and an increased fraction of disturbed herbage accumulation in total intake (e.g. compare ls of 1978 with ls of 1979).

4.3 THE PRECISION OF THE ESTIMATE OF HERBAGE MASS AND OF HERBAGE CONSUMPTION

The estimate of the intake applying a sward method is a function of the estimates of the herbage mass of the pasture concerned, obtained by cutting parts of the pasture. The precision of the estimate of the herbage mass is completely determined by the spatial distribution of the herbage mass, by the sampling procedure and by the way the estimate is calculated from the observations on the sampling units.

4.3.1 Calculation of precision

The variance of the estimate of the areic mass of herbage was estimated with the general equation for simple random sampling:

$$s_x^2 = \frac{\sum_{i=1}^{n} x^2 - \frac{\left(\sum_{i=1}^{n} x\right)^2}{n}}{n-1}$$

This equation was applied when estimating the variance of M, M^e, M^f and $M^{f,e}$, where n is the number of strips and x is the value at a strip.

The sample units for the estimation of the differences ΔM, ΔM^e and ΔM^r were paired, so the general variance equation can be applied with use of the n values of differences in herbage mass per paired strip.

The areic consumption of herbage was calculated with the equation:

$$\bar{C} = \overline{\Delta M} + g\ \overline{\Delta M^e}$$

Because the exclosure was a separate plot the correlation between M^e and M as well as between $M^{f,e}$ and M^f was zero. For a given value of g the estimate of the variance of the consumption then is:

$$s_{\bar{C}}^2 = s_{\overline{\Delta M}}^2 + g^2\ s_{\overline{\Delta M^e}}^2$$

However g is not a constant when applying Linehan's estimate (Section 3.1). And in all experiments the equation of Linehan et al. (1952) was used to calculate herbage consumption. The variance of the consumption can be approximated using Taylor's Series expansion:

$$s^2_{\bar{C}} \approx \bar{C}^2 \{(\frac{1}{\Delta M} + \frac{1}{x \log z} - \frac{1}{M \log y})^2 s^2_{\bar{M}} +$$

$$+ (\frac{-1}{\Delta M} - \frac{M}{M^f}\frac{1}{\log z} + \frac{M}{M^f}\frac{1}{\log y})^2 s^2_{\bar{M}^f} + \frac{s^2_{\overline{\Delta M}^e}}{x^2(\log z)^2} +$$

$$+ 2 \text{ cov } (M,M^f) (\frac{1}{\Delta M} + \frac{1}{x \log z} - \frac{1}{M \log y})(\frac{-1}{\Delta M} - \frac{M}{M^f}\frac{1}{\log z} + \frac{M}{M^f}\frac{1}{\log y})\}$$

where

$x = M + \Delta M^e$, $y = \frac{M}{M^f}$, $z = \frac{M + \Delta M^e}{M^f}$

$$\text{cov } (M, M^f) = \frac{s^2_{\bar{M}} + s^2_{\bar{M}^f} - s^2_{\overline{\Delta M}}}{2}$$

4.3.2 Precision obtained

Results on precision of the estimation of the herbage mass and of the herbage consumption are summarized in Table 10. The preceding utilization of all swards was cutting. Pre- and post-grazing strips were paired. The estimation of herbage accumulation during grazing in 1976 was based on the cutting of 8 strips; for all other measurements of areic mass of herbage 10 strips were cut each time. Differences in precision between seasons and years due to sample size, to levels of M and of M^f and to the spatial distribution of herbage mass will be discussed in 4.3.3.

Students t-tests showed that s_{M^f} was significantly lower than s_M in all years when cut by ms ($P < 0.025$ in 1977, $P < 0.05$ in 1978, $P < 0.01$ in 1979). Due to the lower level of M^f than of M, the coefficient of variation of M (ms) was higher at finish of grazing than at start ($P < 0.01$ in all years). The differences between s_M and s_{M^f} were small and not significant when cut by ms + lm due to a higher s_{M^f} (ms + lm) than s_{M^f} (ms) especially in late summer. Cutting by motor scythe alone does not only underestimate M^f but also underestimates s_{M^f} (Table 10). However the CV_{M^f} (ms + lm) was in all years significantly ($P < 0.01$) lower than the CV_{M^f} (ms). As by ms alone CV_{M^f} (ms + lm) was higher ($P < 0.01$) than CV_M (ms + lm). $s_{\Delta\bar{M}_0}$ was on average 68 kg ha^{-1} corresponding with a $CV_{\Delta\bar{M}}$ of 6.29%. Due to the inclusion of the imprecision of the estimate of herbage accumulation during grazing $s_{\bar{C}}$ was higher than the $s_{\Delta\bar{M}}$ in 1977 and 1978 ($P < 0.01$); however when $s_{\Delta\bar{M}^e}$ was low relative to $s_{\Delta\bar{M}}$ then $s_{\bar{C}}$ was lower than $s_{\Delta\bar{M}}$ (e.g. in 1979). The $CV_{\bar{C}}$ depended on the fraction of disturbed herbage accumulation in C, on the precision of ΔM and on the precision of ΔM^e and was on average 5.55%.

Table 10. Precision of the estimate of herbage mass and of herbage consumption.

			1976[1]		1977		1978		1979		Mean
			es	ls	es	ls	es	ls	es	ls	es + ls
		N	6	3	9	9	27	24	22	22	113
ms	M_0	$\bar{x}$	2367	1851	2970	2146	2662	1965	1867	1617	2139
		$s_{\bar{x}}$	87	75	85	53	56	43	53	51	54
		$CV_{\bar{x}}$	3.66	4.03	2.86	2.48	2.19	2.19	3.01	3.18	2.62
	M_0^f	$\bar{x}$	746	627	1019	643	1037	550	719	602	754
		$s_{\bar{x}}$	52	30	72	40	53	35	34	36	43
		$CV_{\bar{x}}$	7.00	4.76	6.99	6.22	6.11	6.62	5.66	5.97	6.18
	ΔM_0^e	$\bar{x}$	539	218	582	277	468	293	450	260	381
		$s_{\bar{x}}$	99	59	90	62	57	44	37	36	51
		$CV_{\bar{x}}$	18.40	27.09	15.51	22.51	12.13	14.90	8.27	14.02	13.43
ms + lm	M_0	$\bar{x}$	-	-	3289	2474	3032	2451	2290	2289	2596
		$s_{\bar{x}}$			84	53	57	46	54	56	56
		$CV_{\bar{x}}$			2.62	2.15	1.94	1.84	2.40	2.45	2.18
	M_0^f	$\bar{x}$	-	-	1453	1138	1547	1218	1284	1445	1366
		$s_{\bar{x}}$			78	50	60	49	41	53	53
		$CV_{\bar{x}}$			5.37	4.46	4.23	3.99	3.46	3.64	4.02
	ΔM_0	$\bar{x}$	1621	1224	1836	1335	1485	1233	1006	844	1229
		$s_{\bar{x}}$	83	65	93	57	73	60	63	68	68
		$CV_{\bar{x}}$	5.64	5.26	5.57	4.43	5.34	5.09	7.48	8.61	6.29
	C_0	$\bar{x}$	1909	1351	2203	1520	1801	1431	1316	1040	1489
		$s_{\bar{x}}$	115	88	118	92	84	78	59	66	78
		$CV_{\bar{x}}$	6.34	5.80	5.48	6.22	4.97	5.58	4.91	6.65	5.55

1. In 1976 all data were determined with a ms only.

4.3.3 Some factors affecting precision

4.3.3.1 The sampling procedure

The sampling procedure is the way the sampling units are selected and the choice of the number, size and shape of these units. Systematic sampling was applied for the estimation of herbage mass, i.e. the sampling units were selected at regular positions in the pasture (Section 3.1). Selecting the samples was easily organised, an efficient cutting scheme could be applied with minimum treading of the pasture and the risks for mistakes in the numbering of the sample sites were low (Figure 3). All strips were located perpendicular to the direction of the drain pipes to avoid bias due to differences in the humidity of the soil at variable distances to the drain pipes. There is no guaranteed reasonable estimate of the standard deviation of the estimate when using systematic sampling. A common estimate of precision is the s of simple random sampling as was used when calculating precision in the experiments. When estimating s from a systematic sample, acting as if it were a simple random sample, usually this s is overestimated (Cochran, 1969). So the precision of the estimates might be higher than the figures shown in 4.3.2.

It is generally advisable to take the units for the estimation of the differences

ΔM and ΔM^e, when estimated on a separate pasture, paired, because the correlation between neighbouring units will be positive. How much the pairing reduces the variances of C depends on g, on the correlation between paired sampling units and on the areic mass of herbage. Calculations of Keen (1979) on the experimental results of 1976 and 1977 have shown that pairing reduced the number of samples needed to achieve the same precision by a factor of 2. Even where the variance in the population of sampling units after grazing is smaller than in the population of sampling units before grazing, as found in the experiments of 1976 and 1977, the advantage of adopting different numbers of sample units for estimating M and M^f was usually not as large as the disadvantage of not pairing (Keen, 1979).

The shape of the sampling units was restricted to a rectangle due to the use of mechanized cutting. The shape of a rectangle ranges from a square to a very long and narrow strip. The long and narrow strip shape was chosen for two reasons:

- Due to a possible trend in the level of herbage mass perpendicular to the direction of the drainpipes (because the land was ploughed on ridges between the pipes) strips of the same length as the distance between the pipes (about 12 m) would cover the whole range in herbage mass.
- When choosing the optimum combination of number and size of strips preference was given to a small number of large strips due to the small increase in labour requirement when making mechanically cut strips longer, in comparison with the large labour requirement in the laboratory when cutting more small samples due to the production of two samples per strip.

The average size of the strips cut by ms at the start of grazing during Experiments 1, 2, 3 and 4 was 7.34(s_x = 1.56), 7.29(s_x = 1.65), 7.28(s_x = 0.70) and 7.76(s_x = 0.95) m^2 respectively, corresponding with an average strip length of about 12 m. The average size of the strips cut by ms at the end of grazing during Experiments 1, 2, 3 and 4 was 9.28(s_x = 1.03), 8.05(s_x = 1.82), 8.19(s_x = 0.68) and 8.55(s_x = 0.83) m^2, corresponding with a strip length of about 14 m (except in 1976). In the first and second experiment the length of the strips was varied to get information about the influence of the size of the cut area on the precision of the estimate of M and M^f. The sample size of the pre-grazing strips ranged from 5.7 to 10.0 m^2 in 1976 and from 4.3 to 10.5 m^2 in 1977. The sample size of the post-grazing strips ranged from 8.0 to 11.3 m^2 in 1976 and from 4.3 to 11.1 m^2 in 1977. In some periods in all experiments the strips had to be shortened due to very high levels of M (and a limiting capacity of the plastic bags) or to a limited grazed area.

Due to the small range in strip length in Experiments 3 and 4 no effect of sample size on the precision of the estimate of M or M^f could be shown in these trials. The effect on precision of the size of the area cut in 1976 and 1977 was examined with multiple regression analysis where influences of variation in M or M^f on precision could first be eliminated. The regression equations, based on estimates of M and M^f by ms in 1976 and by ms + lm in 1977, are presented in Table 11. The effects of level of M and M^f on precision will be discussed later. In both years no effect could be shown of sample size on precision at start of grazing. However in both years a significant effect of sample size of post-grazing strips on s_{M^f} could be shown.

Table 11. Regression coefficients in the multiple regression of the standard deviation of the estimate of areic herbage mass on areic herbage mass and sample size.

	$s_M = a + b\,M + c\,Z$[1]					
	b	s_b	P(b)	c	s_c	P(c)
1976	0.0077	0.0105	n.s.	-2.099	4.475	n.s.
1977	0.0230	0.0872	**	-3.705	4.278	n.s.
	$s_{M^f} = a + b\,M^f + c\,Z^f$[1]					
	b	s_b	P(b)	c	s_c	P(c)
1976	0.0708	0.0229	**	-6.085	2.651	*
1977	0.0537	0.0095	***	-5.081	.2.041	**

1. Z and Z^f: sample size (m^2) at start and finish of grazing respectively.

4.3.3.2 The spatial distribution of herbage mass

The precision of the estimate of herbage mass will be negatively influenced by heterogeneity of the sward. This heterogeneity is caused by variation within the pasture of factors which influence herbage accumulation such as botanical composition, sward density, soil structure and composition, supply of fertilizers and water. An example of the effect of water supply on precision could be found in the results of the dry summer of 1976. Comparable swards were cut with the same number and size of samples in May (normal humidity) and June (dry). In the very dry June period $CV_{\bar{M}}$ was 4.05% and higher than in May ($CV_{\bar{M}}$ = 2.65) due to differences in the effect of drought above and between drainpipes in June.

At the end of the grazing period the variation in herbage mass will be higher as a result of selective grazing (selection between species, between plant parts, between clean and contaminated herbage) than when the area would have been cut. This variation in residual herbage and in fertilization level by local urine- and faeces excretion will increase variation in herbage mass of the regrowth. This effect could be tested in the results of the experiments of 1978 and 1979 in which the regrowth of herbage was estimated after an accumulation period of 19 days. These regrowth measurements were done in es during EP 1 to EP 5 and in ls during EP 9 to EP 13, so over 5 weeks each season. The precision of the estimate of herbage mass in the grazing periods (M_i) averaged over 5 weeks, were comparable to those averaged over 8 weeks which were presented in Table 10; the exact averages will be given below in the text. The precision of the estimation of herbage mass after regrowth (M_{i+1}) is presented in Table 12.

Combined over all seasons, Students t-tests showed that $s_{M_{i+1}}$ was significantly ($P < 0.01$) higher than s_{M_i} both when measured with ms (90 and 55 kg ha^{-1} respectively) and when measured with ms + lm (98 and 57 kg ha^{-1}, respectively). Due to comparable levels of herbage mass in the periods i and i+1 also the $CV_{\bar{M}_{i+1}}$ was significantly ($P < 0.01$) higher than the $CV_{\bar{M}_i}$ both when measured with ms (3.82 and 2.43%, respectively) and when estimated with ms + lm (3.25 and 2.08% respectively).

Table 12. Precision of the estimate of herbage mass and of herbage accumulation after regrowth.

			1978		1979		Mean
			es	ls	es	ls	es + ls
		N	16	12	12	10	50
ms	$M_{i+1,0}$	$\bar{x}$	3195	1474	3101	1625	2445
		$s_{\bar{x}}$	116	63	96	73	90
		$CV_{\bar{x}}$	3.64	4.25	3.10	4.48	3.82
	$\Delta M^{r}_{i,0}$	$\bar{x}$	2105	842	2254	911	1599
		$s_{\bar{x}}$	103	55	84	60	78
		$CV_{\bar{x}}$	5.42	7.09	3.80	6.89	5.73
ms + lm	$M_{i+1,0}$	$\bar{x}$	3696	2139	3442	2476	3017
		$s_{\bar{x}}$	125	71	99	84	98
		$CV_{\bar{x}}$	3.38	3.31	2.88	3.41	3.25
	$\Delta M^{r}_{i,0}$	$\bar{x}$	2102	797	2168	883	1561
		$s_{\bar{x}}$	108	68	88	79	88
		$CV_{\bar{x}}$	5.69	9.13	4.24	9.63	6.96

Table 12 also shows the precision results of the estimates of herbage accumulation during regrowth ($\Delta M^{r}_{i} = M_{i+1} - M^{f}_{i}$). Averaged over all seasons $s_{\Delta M^{r}_{0}}$ was 78 kg ha^{-1} (ms) and 88 kg ha^{-1} (ms + lm). This standard deviation is high in comparison with the $s_{\Delta M^{e}_{0}}$ of 53 kg ha^{-1} measured on aftermath herbage during the corresponding grazing periods. So the precision of the estimates of herbage mass and of herbage accumulation on aftermath, pre-cut pastures was higher than on pastures which were grazed once before.

4.3.3.3 The level of herbage mass and of residual herbage

The effects of level of herbage mass and of residual herbage on precision of estimates of herbage mass and of herbage consumption were examined with regression analysis. The results of this analysis on the total data from 1977 to 1979 (n = 113) are presented in Table 13. All levels of herbage mass and consumption were determined with ms + lm. The s_M and s_{M^f} significantly ($P < 0.01$) increased at higher levels of M and M^f respectively. The increase of the standard deviation however was smaller than that of the areic mass resulting in a significant ($P < 0.025$ for M and $P < 0.01$ for M^f) reduction of the coefficient of variation at higher levels of areic mass.

There was a significant positive effect ($P < 0.01$) of levels of M and of M^f on $s_{\bar{C}}$; when the effects of M and M^f are combined in a multiple regression analysis only the effects of mass at start of grazing was important probably due to a high correlation between M and M^f within pastures.

The coefficient of variation of the intake estimate was reduced at high levels of areic mass at start of grazing and at low levels of areic mass at finish of grazing. Due to the high correlation between daily herbage allowance (A) and level of residual herbage (Chapter 5) $CV_{\bar{C}}$ also was reduced at decreasing A. So a high precision of intake estimate can be achieved when the difference between M and M^f is large. An example

Table 13. Regression coefficients in the linear and multiple regression of the precision of the estimates of areic herbage mass and consumption on areic herbage mass and on daily herbage allowance.

y	x_1	x_2	a	b	s_b	P(b)	c	s_c	P(c)
			y = a + b x_1 + c x_2						
s_M	M	-	16.2	0.0152	0.0028	***	-	-	-
s_{M^f}	M^f	-	17.3	0.0263	0.0047	***	-	-	-
s_C	M	-	10.7	0.0259	0.0033	***	-	-	-
	M^f	-	43.3	0.0252	0.0062	***	-	-	-
	A	-	88.6	-0.3921	0.3312	n.s.	-	-	-
	M	M^f	11.2	0.0263	0.0042	***	-0.0013	0.0064	n.s.
	M	A	10.1	0.0259	0.0033	***	0.0172	0.0995	n.s.
CV_M	M	-	2.8	-0.0003	0.0001	**	-	-	-
CV_{M^f}	M^f	-	5.6	-0.0011	0.0004	***	-	-	-
CV_C	M	-	7.3	-0.0007	0.0003	**	-	-	-
	M^f	-	4.1	0.0011	0.0004	**	-	-	-
	A	-	2.0	0.1285	0.0194	***	-	-	-
	M	M^f	6.2	-0.0018	0.0003	***	0.0029	0.0005	***
	M	A	3.1	-0.0004	0.0002	*	0.1225	0.0194	***

showing the effects of M and M^f on precision of C based on the regression equations of Table 13:

M	1500	1500	2500	2500
M^f	500	1000	500	1000
$s_{\bar{C}}$	50.0	49.3	77.5	75.6
$CV_{\bar{C}}$	5.00	6.44	3.25	4.69

4.4 DISCUSSION

4.4.1 The difference in herbage mass between start and finish of grazing - the problem of cutting to the same residual stubble-

The stubble height after cutting by ms could only be measured after raking the cut herbage. Therefore this stubble height was not necessarily equal to the cutting height of the ms. The variation in stubble height after cutting by ms between years and periods was large. Reasons for this high variation might have been:

- Variation in sward conditions: bending and smoothing of herbage when the areic mass of herbage was low (density, height) or when the herbage was wet
- Variation in soil conditions: due to ploughing of the land on ridges between the drainpipes and to a cutting direction perpendicular to the direction of the "hills and valleys" and due to some distance between wheels and cutterbar of the ms it was sometimes difficult to follow soil level precisely; also other irregularities in the soil may have affected the position of the ms.
- Variation in machine conditions: although every effort was made to keep the ms in optimal cutting condition by regular control, cleaning and changing of the knife some

variation in the sharpness of the knives may have affected cutting efficiency.
- Variation in the upward force applied in the handling of the machine: because the same person handled the ms in all experiments this risk seems low; however in general the necessary raising of the serving part of the ms (with two wheels) is a disadvantage for a reproducible cutting height.
- Differences in the method of measuring stubble height: within years the stubble heights were measured by the same person; between years the measuring persons differed but it is unlikely that large differences existed in this easy method of height measuring with a disk.

Using the cutting results by the lawn-mower to check the cutting efficiency of the ms it was shown that the areic mass of the material left after cutting post-grazing strips by ms was much higher than after cutting pre-grazing strips. The reasons for this difference in stubble mass between start and finish of grazing after cutting by ms might have been:
- Displacement of herbage originally above cutting height into the layer below during grazing by trampling, lying down of animals and contamination with faeces.
- Displacement of herbage originally above cutting height into the layer below during cutting by ms or during raking: the areic mass of residual herbage might be such that the resistance for the cutting knife of ms became too low and the herbage bended and smoothed. This more horizontal disposition of tillers after cutting residual herbage compared with herbage at start of grazing occurred more especially when the T content of herbage was low. Especially under dry conditions, some of the short herbage parts may have been so small that they were lost in the stubble.
- A higher cutting height by ms at the end of grazing than at the start of grazing; due to the effect of raking on stubble height this effect cannot be examined.

The stubble height was more regular after cutting by lm than after cutting by ms. The lm cutting height depends on the position of the wheels, so the attitude of the cutting person has minimal influence. When flat fields can be used the variation in stubble height after cutting by lm would probably be even smaller than that observed on the "hill and valley" type pastures used in these experiments. The areic mass of herbage cut by lm in late summer was higher than that in early summer, the higher density of the sward (especially the content of dead material) in ls may be responsible for this. The average seasonal difference in herbage mass between start and finish of grazing cut by lm was of the same order each year; however, these differences varied considerably between experimental periods due to variation in sward and cutting conditions.

It is not possible to make a general correction of the residual herbage mass estimates by ms due to these variable conditions, so cutting the same strips each time by both ms and lm is necessary if the absolute difference in herbage mass between start and finish of grazing should be estimated.

Quantitative information on the comparability of stubble mass after cutting by ms between start and finish of grazing is lacking in the literature. The supposed over-estimation of intake when estimated with a sward method in comparison with that when estimated with a faecal indicator/digestibility technique was attributed to a lower cutting efficiency at the end of grazing due to trampling and faeces contamination (Petersen et al., 1966; Dijkstra & Kemmink, 1970). The combined use of ms and lm is not known from literature, so comparisons of areic mass of herbage cut by lm cannot be made with that found in the literature.

Another possible source of bias in the use of motor scythes was the risk of grazing by the animals below cutting height. In Experiments 3 and 4 the sward height was measured with a tempex disk with a diameter of 50 cm. The sward height at the end of the grazing period of treatment X (the lowest daily herbage allowance level) was on average 9.5 and 8.1 cm in es and ls 1978 respectively (Lantinga, 1979) and 7.8 and 7.1 cm in es and ls 1979 respectively (Flikweert, 1980). The lowest sward heights achieved in individual grazing periods in 1978 and 1979 were 7.2 (s_x = 0.17) and 6.2 (s_x = 0.16) respectively (Lantinga, 1979; Flikweert, 1980). These results show that even at very low levels of herbage allowance the risk of eating by animals below the cutting height (about 4.5 cm) of the ms was very low.

The disadvantage of the large disk used to measure the height of residual herbage was that this height was determined by the height of the most stemmy tillers. In the late summer of 1977 the sward height was measured with a very small tempex disk with a diameter of 2 cm. At moderate levels of daily herbage allowance (comparable to treatment Y of Experiments 3 and 4) the average sward height at the end of the grazing period was 7.9 cm. A stubble height lower than 4.5 cm was recorded only in 0.9% of the individual measurements. These results also show the small risk of consumption by these dairy cows below the cutting height of the ms. Another indication of this small risk can be found in the Experiments 3 and 4. When the animals with the low allowance had consumed herbage below the cutting height of the ms then the M_0 (lm) of these animals should have been lower than that of the animals with the high allowance. However, no differences could be found in the M_0 (lm) between the treatments. With the two-step cutting system (ms + lm) the chance of grazing by dairy cows below the cutting height of 3.1-3.2 cm (Honda) is much smaller than when cutting by ms only and therefore seems negligible.

The herbage mass in the stubble from 0-3 cm after cutting with ms + lm was estimated by hand-cutting. The influence of the cutting person on the results could be checked in 1979 when each person cut a strip (2 samples of 0.12 m^2 per strip). Analysis of variance per period showed that the absolute level of stubble mass differed significantly (P <0.025) between persons in one out of 5 periods; while in two other periods the difference, although not significant, was in the same direction. In Table 8 the strips cut by two persons per group were combined to get a total cut area comparable to that of 1978 (0.24 m^2). When the analysis of variance on the difference in stubble mass between start and finish of grazing was done with the combined results of 2 animal groups per person, the conclusions between persons differed in two (period 2 with the puddles and period 9) out of 5 periods. A layer of dead organic material just above ground-level had built up on the new polder soils. The amount of this dead material in the ground-level sample (and even in the lawn-mower sample) may have depended on the weather conditions: when the stubble was wet these very small particles stuck to the cut part of the sample. However when the stubble was dry it was very difficult to collect all small very light particles. Part of the between person difference in cutting results possibly may also be attributed to the dead material.

The hand-cutting results indicated that 1) the stubble mass did not differ between pre- and post-grazing strips under comparable wetness of the stubble of these strips 2) when the dry matter fraction of fresh herbage was low the efficiency of cutting of ms and lm was reduced and the stubble mass increased 3) the effect of a wet stubble on stubble mass was independent of time (start or finish) in the grazing period.

When the herbage was wet the stubble height after cutting by ms increased due to smoothing and bending of the herbage. The lm tried to correct this but due to the large amount of material, to the high weight of the wet material and to the sticking of herbage to the underside of the machine this was not completely achieved, as was indicated by the levels of stubble mass. So when the wetness of the herbage differed strongly between start and finish of the grazing period a bias in the intake estimate might have been introduced.

Some of the possible ways to reduce the problems of wet stubble are:

- Cutting the total material to ground level in one operation, assuming that this method is not affected by wetness of stubble. There is no critical evaluation of ground-level cutting results under variable weather conditions in the literature.
- Combining the two-step cutting system with hand-cutting of the 0-3 cm stubble; however the labour requirement involved with this three-step cutting system is very large.
- Making corrections of the areic mass of herbage based on the content of organic matter of the fresh mass cut by the lm; the limited number of stubble mass measurements in the experiments showed a reasonable correlation (r^2 = 0.7) between $\{w_O$ of M (lm) - w_O of M^f (lm)$\}$ and (SM - SM^f). However more measurements over a wider range of O content are necessary before a regression procedure can be applied.
- Postponing cutting by lawn-mower until the stubble is dry: when this can be achieved within a few hours it possibly can be done when labour and equipment at other moments of the day are available; however when the period of delay becomes longer the stubble may change.
- Cutting all treatments under the same stubble conditions when there is mainly interest in differences between treatments and not in the absolute levels of intake.
- Cleaning the underside of the lm during the cutting of a strip if the adhesion of herbage to the lm was the reason of the lower cutting efficiency. However the labour involved in cleaning the lm once at the end of each strip under wet stubble conditions was already large. It will also be very difficult to cut exactly the same area with intermittant stopping and cleaning.
- Making experimental designs that are not sensitive to missing observations; in fact, this was done in the Experiments 3 and 4.
- Avoiding abundant rainfall on the pastures to be cut by the use of a large shed or tilt; the large areas grazed in the experiment prevented this application. However when shorter grazing periods, a smaller number of cows per group, or smaller animals (sheep, steers) are used it seems possible to use movable sheds. The sheds should also be used on the sites where the undisturbed herbage accumulation is measured, due to possible effects of these on light transmission.

The estimates of herbage consumption in 1976 were only done by means of ms and are systematically too high. In the other years the estimation of herbage consumption was based on ms + lm; these results will be examined in Chapters 5 and 6. In the Appendices 4 and 8, data from all experimental periods are presented. The tables with average results and the data for statistical analysis are only based on 'reliable' data. When the stubble was dry at the beginning and at the end of the grazing period the estimates of consumption are considered reliable, also when the stubble was wet at both times the systematic errors may compensate each other (Table 8). In the periods where the stubble mass was estimated, it was shown that there was a high correlation between stubble mass from 0-3 cm and the sticking of herbage to the lm. The estimates of herbage consumption were classified as unreliable when there was adhesion of herbage to the lm at start and/or at the end of grazing. However when the w_0 of M (lm) was equal to w_0 of M^f (lm) and when there was sticking of herbage to lm at both moments of cutting the observations were classified as reliable because the possible systematic errors at both moments probably compensated one another.

4.4.2 Herbage accumulation during the grazing period

The consequences of a bias in the estimate of the accumulation factor g for the calculation of herbage consumption can be estimated from the fraction of g ΔM^e in total consumption. A bias of 20% in the estimation of g (0.68 $\pm$ 0.14) corresponds with a bias of 3.4% in herbage consumption when averaged data over 1977-1979 are used. Of course in individual grazing periods the effects of a bias in g on C may be much higher than 20% (e.g. at low levels of M or at high levels of A or M^e). In the trials reported, a choice had to be made between the use of the ms + lm data (average g = 0.68) and the corrected ms data (average g = 0.62) when calculating g (Section 4.2). The 9% maximal difference in g between both estimates corresponded with a maximal difference of 1.7% in herbage consumption.

The ms and lm data were chosen for calculating g because

- Extrapolation of photosynthesis measurements during grazing periods showed that the herbage in the lm fraction was also photosynthetic active during several periods of the year (Lantinga, 1980); this effect was the strongest in May when the sward is leafy and highly digestible in the lower regions, but also in some periods of June and August there was a tendency of this effect. This is in agreement with results of Ernst & Mott (1980) who assumed that a lower seasonal accumulation of herbage when estimated above 5 cm compared to an estimation above 3 cm, could be possibly attributed to accumulation of herbage in the 3-5 cm region of the sward.
- A curvilinear relationship between the rate of areic herbage consumption and the areic mass of herbage during a grazing period will result in a higher accumulation factor than is derived with the equation of Linehan et al., who assumed a linear relationship. Curvilinear relationships have been found by Van der Kleij & Van der Ploeg (1955) and Arnold & Dudzinski (1967).

However, both considerations are based on very limited information, so more information on both aspects is needed if a definite choice between ms + lm data or corrected ms data for calculating g has to be made. The small effects of the choice of the method of calculating g on the ultimate herbage consumption has already been pointed out. The question arises as to whether differences in herbage consumption between treatments are affected by the choice of the method of calculating g. In the next example the effects of way of calculating g on the herbage consumption and herbage allowance at the most extreme treatments of Experiments 3 and 4 (Chapter 5) is shown. The 1s of 1979 was chosen because the differences in both calculation methods of g were the most extreme then (due to a low level of M (ms) and a high level of M (1m) in this period).

Example of average results in the 1s of 1979:

calculation of g	ms + 1m		corrected ms	
treatment	X	Z	X	Z
g	0.70	0.80	0.57	0.72
A_0	16.0	30.9	15.7	30.6
I_0	11.0	14.6	10.7	14.3
b	0.24		0.24	

The greater difference in g between both calculation methods at treatment X was compensated by the smaller area grazed and resulted in a comparable difference in herbage consumption between treatments at both ways of calculating g. The allowance levels were affected in the same direction and of course with the same magnitude. Therefore the relationship between allowance and intake was not affected by the way of calculating g; which is shown in the equal regression coefficient (b) of A_0 on I_0. In the 1s of 1979 the difference in I_0 between both calculations of g was 0.33 (2.5%); in the other periods this effect was smaller: 0.14 (1%), 0.16 (1.3%), 0.24 (1.8%) and 0.34 (2.4%) in the es and 1s of 1977, the es and 1s of 1978 and the es of 1979 respectively. These results indicate that the way of calculating g had no effect on the differences in herbage consumption between treatments. Compared at the same allowance level the daily herbage O intake would be 0.1-0.2 kg d^{-1} lower calculated with corrected ms data than with ms + 1m data.

The average level of the estimate of the accumulation factor g (0.68) was much higher than the few figures in the literature which vary around 0.50 (Linehan et al., 1952; Iwasaki, 1972). The reasons for the higher g in the experiments appear to be the use of the two-step cutting system as pointed out before and the high levels of residual herbage in the trials reported. The fraction of herbage accumulation in total consumption was on average 0.17. This value was low in comparison with levels varying between 0.30 and 0.40 in literature (Linehan et al., 1952; Iwasaki, 1972). The length of the grazing period (3-4 days in our experiments; 5-14 days in the quoted literature) may explain the difference in the accumulation fraction of total intake.

The equation of Linehan et al. (1947, 1952) is based on the assumptions that the rate of herbage accumulation and the rate of consumption of herbage at any time during the grazing period are each proportional to the quantity of herbage remaining uneaten at that time. The first hypothesis has been tested in grazing trials with steers in Wageningen (Lantinga, 1980). Intermittent periods of grazing and photosynthesis measurement showed that the relationship between sward height (which was highly correlated with areic mass of herbage) and the rate of net photosynthesis was linear during the grazing period. If the ratio between net photosynthesis and herbage accumulation does not change markedly during the grazing period, these results indicate that the first assumption of Linehan et al. (1947) was a very reasonable one.

The second hypothesis was tested in our experiment of 1977 when during 5 grazing periods of 4 days the areic herbage mass was determined just before grazing, after 2 days grazing and after 4 days grazing (Benedictus, 1978). At levels of daily herbage O allowance around 22 kg d^{-1} the herbage O intake in the first part of the grazing period was on average 16.3 kg d^{-1} and in the second part on average 12.5 kg d^{-1}. These results show that daily herbage intake declines during the grazing period at decreasing levels of herbage mass; in agreement with results of Van der Kleij & Van der Ploeg (1955).

Another way to test the second hypothesis of Linehan et al. (1947) is to use the results of Experiments 3 and 4. In these trials different levels of daily herbage allowance were achieved by varying the area grazed with comparable number of animals and days of grazing. It is possible to achieve the same allowance treatments by varying the length of the grazing period at equally grazed area for the treatment (e.g. average O allowance levels of 15 and 30 kg d^{-1} were given in 3 days, both at grazed areas of 1.5 S and 3 S m^2 respectively; the same allowances could have been achieved at grazed areas of S m^2 both, with grazing periods of 2 and 1 days respectively). In early summer the average effect of levels of daily herbage O allowance (A) on herbage O consumption per ha (C) was 40 kg ha^{-1}/kg d^{-1} (see Chapter 5). The levels of herbage mass and herbage consumption predicted with this regression coefficient at different levels of A are shown in Table 14. When the assumption is made that the highest allowance level was comparable to grazing area S for one day, than the length of the grazing periods of the other treatments, grazing the same area, can be derived from the ratios of allowances applied.

In this way the maximum grazing period of 3 days can be split up in periods of 0.5 day and the O consumption per 0.5 day can be calculated (on the first day the con-

Table 14. Effect of decrease in herbage mass during the grazing period on the rate of herbage consumption (M_0 + g ΔM_0^e = 2 000 and M_0^f = 400 kg ha^{-1} at A_0 = 15 kg d^{-1}).

Area grazed	Experiments 3 and 4			Simulation to variable length of grazing period			
	A_0	C_0	M_0^f	area grazed	grazing days	C_0/0.5d	C_0/d
3 S	30	1000	1000	S	1.0		
2 S	20	1400	600	S	1.5	400	600
1.5 S	15	1600	400	S	2.0	200	
1.2 S	12	1720	280	S	2.5	120	200
S	10	1800	200	S	3.0	80	

sumption was 1 000 kg ha^{-1}). The results of Table 14 show that there was a strong relationship between the herbage mass available at a given time during the grazing period and the rate of herbage consumption on the next 0.5 day. This conclusion could only be drawn in this example below a level of herbage mass of 1 000 kg ha^{-1} (>4.5 cm). At very high allowance levels however, the maximum intake of the animals will be reached and the herbage mass is not limiting herbage consumption. This effect can already be observed in the relationship between A and C which was taken as linear in this example. The shape of this relationship will be discussed further in Chapter 5. The consequences of reaching maximum C at non-limiting levels of M during grazing are an increase of the accumulation factor g because accumulation of herbage is assumed to be proportional to the quantity of herbage available at that time. So a curvilinear A-C relationship will result in a higher accumulation factor than is derived with the equation of Linehan.

Although simulation of herbage intake during several parts of a grazing period seems possible from the allowance experiments more research is needed on this aspect by use of grazing trials measuring intake during grazing periods with very short intervals.

4.4.3 The precision of the estimate of herbage mass and of herbage consumption

The variance of ΔM and of C was reduced considerably by pairing the pre- and post-grazing sample units, in agreement with results of Green et al. (1952). The positive effect of pairing on precision of intake can also be found in the trials of 't Hart & Kleter (1974), Hijink (1978) and Walters & Evans (1979). The choice of the shape of the sampling units (strips) was largely determined by the method of harvesting using cutting machines and was also based on the information from the literature that sample units using a long and narrow strip were less variable than sample units from square frames of equal area (Iwasaki, 1976; McIntyre, 1978).

The area per sample unit was large when compared to experiments reported in literature (Table 1). In 1976 and 1977 the area of the strips at start of grazing was varied between 4.3 and 10.5 m^2 and no significant influence of sample area on precision of M could be shown. From this point of view the length of the pre-grazing strips could have been shorter than 12 m without a major effect on precision of M. However, at the end of grazing variation in strip size between 4.3 and 11.3 m^2 significantly affected precision of M^f, so long post-grazing strips reduced variability of estimates of residual herbage. The difference in length between pre- and post-grazing strips cannot be too large, otherwise the correlation between M and M^f decreases and the positive effect of pairing M and M^f will be reduced. The choice made in Experiments 3 and 4 of strip lengths of 12 (M) and 14 (M^f) m was based on the following considerations:

- the distance between drain pipes was 12 m
- the labour requirement for cutting is only to a small extent related to sample size, however labour for collecting and sampling the herbage increases with larger sample size; therefore a longer strip may be more profitable at the end of grazing when areic mass of herbage is low

- the correlation between M and M^f should be as high as possible
- the precision of the estimate of M^f and of C increases at larger sample sizes at the end of grazing

The higher s_M and CV_M when the pasture was grazed once than those on aftermath herbage, which was shown in the herbage allowance trials, was in agreement with the results of 't Hart & Kleter (1974). The effect of grazing on the precision of the intake estimates in a second subsequent period can be minimized when the residual herbage at the end of the first grazing period is cut (Kleter, 1973). When this is not possible due to the aim of the experiments, the number and/or size of the strips cut on the pasture after regrowth should be larger if the same precision is to be achieved.

The $s_M f$ was lower than or equal to the s_M, however due to the low level of M^f, $CV_M f$ was much higher than CV_M. These results are in agreement with figures of Green (1949) and Castle (1953). The s_M and $s_M f$ increased, while the CV_M and $CV_M f$ decreased at higher levels of herbage mass; comparable results were found by Kleter (1973). The CV_C was significantly negatively affected by M and significantly positively by M^f or A. The conclusion that the precision of the estimate of C can be reduced with a relatively high level of herbage mass at start of grazing and a low level of residual herbage is in agreement with results of Kleter (1973) and 't Hart & Kleter (1974). This conclusion can be applied in practice only within certain limits of herbage mass because other experimental reasons may be more important than a high precision of intake estimate.

The CV_C was on average 5.55%, obtained on pre-cut pastures which were grazed for 3 or 4 days. 't Hart & Kleter (1974) and Hijink (1978) found comparable CV_C's (6.6 and 6.2% respectively) on aftermath herbage at grazing periods varying from 1.5 to 8 days. Kleter (1975) and Walters & Evans (1979) also used aftermath herbage with grazing periods of 3-4 days as in the experiments described here. The high CV_C of 10.5% found by Kleter (1975) can probably be attributed to the high levels of residual herbage in these trials. From the results of Walters & Evans (1979) who cut 6 strips each time, an average CV_C of 8% can be calculated; if 10 strips would have been cut the CV_C would have become 6.2%.

Due to the aim of the experiments in several of the grazing periods levels of herbage mass or of herbage allowance were chosen which were not optimal for a high precision. Nevertheless a high precision of intake estimate has been achieved by using homogeneous swards and sampling large parts of the grazed area.

4.5 CONCLUSIONS

After cutting by motor scythe and raking the cut material, the stubble height of post-grazing strips was higher than that of pre-grazing strips. The areic mass of O of herbage of the post-grazing strips cut again by a lawn-mower was on average 155 kg ha^{-1} higher than that of the pre-grazing strips. Without correction for this difference in stubble mass between pre- and post-grazing strips the herbage consumption would have been overestimated by 10%. The reasons for the higher stubble left after cutting by ms at the end of grazing may be displacement of herbage originally above cutting height into the layer below during the grazing period (trampling, lying of animals, faeces contamination), or during the cutting and raking activities (bending and smoothing of tillers, losses of small herbage parts).

The stubble mass above ground level after cutting with both machines was estimated by hand-cutting, however, the determination of ground level was sometimes affected by the operator and possibly by the weather conditions due to disturbance of a layer of dead organic material on the new polder soils. Despite these complications the conclusion could be drawn that under comparable cutting conditions (i.e. comparable wetness of the 1m stubble) the stubble masses did not differ between pre- and post-grazing strips. However, assuming the ground-level cutting results are to be reliable, under very wet conditions the efficiency of mowing of both machines was reduced and the stubble mass increased (independent of time of cutting). So when weather conditions during cutting differ strongly between start and finish of grazing bias in the intake estimate will probably be introduced.

The consumption of herbage as calculated with Linehan's equation using grazing periods of 3-4 days consisted on average of a fraction of disturbed herbage accumulation of 0.17. There are indications that the assumptions made by Linehan when deriving the intake equation are in agreement with results from experiments, however more research is needed before quantitative conclusions can be made.

The precision of the intake estimate can be increased when using aftermath herbage with a high level of herbage mass at start of grazing and a low level of residual herbage; but for other experimental reasons these levels can only be chosen within certain limits. Pairing of pre- and post-grazing strips reduced the number of samples required by a factor 2. Enlargement of the size of the post-grazing strips (ranging from 4 to 11 m^2 in Experiments 1 and 2) increased precision of intake estimate. On average the herbage consumption could be estimated with a coefficient of variation of 5.5%.

The two-step cutting technique provided intake estimates with a high precision and a low risk of bias under most conditions. Two aspects need more research in future:
1) how can bad cutting results in very wet pastures be avoided or corrected and
2) is the relationship between the rate of consumption of herbage and the quantity of herbage remaining at any time during the grazing period as Linehan et al. (1952) assumed?

5 The influence of daily herbage allowance on herbage intake of dairy cows and on herbage accumulation during regrowth (Experiments 3 and 4)

5.1 TREATMENTS AND DESIGN

The experiments of 1978 and 1979 were both carried out at the Institute for Livestock Feeding and Nutrition Research in Lelystad. The treatments were different levels of daily herbage allowance (A), established by varying the area grazed for comparable groups of cows at the same number of animal-days and the same areic mass of herbage. The levels of herbage allowance were compared between groups of animals during the same period.

After an adaptation period of 14 days at a level of daily herbage 0 allowance per animal of 20 kg d^{-1} (>4.5 cm, see below) the grazing cows were split up in 4 groups of animals for a 8-week experiment both in early summer and in late summer. Each week trial consisted of a 4-day preliminary period (including the weekend) in which the same allowance treatments were applied on the same sward as in the experimental period but without any other measurements, followed by a 3-day experimental period during which the measurements were taken.

The allowance levels used in the experiments applied to the herbage mass present above the cutting height of the motor scythe (about 4.5 cm) with a correction for herbage accumulation during the grazing period. With the two-step cutting system while sampling used (Chapter 4) it was also possible afterwards to calculate levels of A above the lawn-mower cutting heights. This was done when the results were analysed. The areic mass of herbage cut by the ms was the variable at choice for the treatments, not the mass cut by ms and lm.

Three levels of A_0 were compared: in 1978 (Experiment 3) 15 (X), 20 (Y) and 30 (Z) kg d^{-1} per animal, in 1979 (Experiment 4) 15 (X), 23 (Y) and 30 (Z) kg d^{-1} per animal, all measured above 4.5 cm inclusive of disturbed accumulation. Because grazing periods of 3 days were used the total supply for the whole experimental grazing period in fact was 3 times the daily allowance. Four groups of animals were used, giving the possibility to apply one of the three treatments to two groups of animals.

In both years the experiments were performed in a joint period of 8 weeks in early as well as in late summer. The designs of Experiments 3 and 4 are shown in Table 15. The design of Experiment 3 allowed some examination of the longer term effects of the continuation of treatments for more than one week during parts of the experiment. In most periods treatment Y was supplied to two groups instead of one because a possible curvilinear allowance-intake relationship could be best proved statistically when a lot of measurements were done near the expected point where there is a maximum deviation from linearity in the A - I curve. In Experiment 4 treatment Z was also applied to two groups of animals, alternating with Y, because the variation in intake

Table 15. Designs of Experiments 3 and 4.

	Animal group	Experimental period (EP)															
		es								ls							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1978	1	X[1]	Y	Z	Z	Z	X	Y	Y	Y	X	Y	Y	Y	Z	Z	X
	2	Y	Z	X	X	X	Y	Y	Z	Z	Y	X	Y	Y	Z	X	Y
	3	Y	X	Y	Y	Y	Z	Z	X	X	Y	Z	Z	Z	X	Y	Y
	4	Z	Y	X	Y	Z	Z	X	Y	Y	Z	Y	X	X	Y	Y	Z
1979	1	X	Z	Y	Y	Z	Y	X	Z	Z	Y	X	Z	Y	Z	X	Y
	2	Z	Y	X	Z	Y	Z	Y	X	Y	X	Z	Z	X	Y	Y	Z
	3	Y	Z	Y	X	Y	X	Z	Z	X	Y	Z	Y	Z	X	Z	Y
	4	Y	X	Z	Z	X	Z	Y	Y	Y	Z	Y	X	Y	Z	Z	X

1. X, Y, Z, levels of daily herbage allowance (Section 5.1).

in Experiment 3 was found to be highest at high levels of herbage allowance.

It was impossible to do all the measurements for the four groups of animals on the same day; therefore animal groups 1 + 2 changed from pasture on Monday and Thursday and animal groups 3 + 4 changed from pasture on Tuesday and Friday. The change from winter feed to herbage in spring was made gradually during a two-week period; in the first week the roughage part was steadily diminished to zero and replaced by herbage, in the second week the concentrates were reduced to the summer level. In the early summer 2.0 (Experiment 3) - 2.4 (Experiment 4) kg of a mixture (1:1) consisting of Mg-rich and normal concentrates, was supplied per animal per day. The consumption of Mg-rich concentrates alone was low, thus to ensure sufficient Mg intake it was mixed with the normal form of concentrates. In late summer each animal was offered 1 kg of normal concentrates per day.

5.2 MATERIALS

5.2.1 Animals

In both experiments 24 Dutch Friesian dairy cows, calving in spring were used. All animals had calved 2-6 times. The animals were blocked in groups of 4 individuals of comparable age, calving date and milk production in the previous lactation; and then allotted at random to the four groups of six animals to be used in the experiments. The comparability of lactation cycle, date of calving and production data from the previous lactation between the four groups of animals is shown in Appendix 1.

5.2.2 Swards

The experiments were carried out on fields sown with a mixture of *Lolium perenne, Phleum pratense, Festuca pratensis* and *Trifolium repens*. The permanent pastures were established in the new polder East Flevoland on a light clay soil. The botanical composition of the swards was not determined during Experiments 3 and 4. However, the swards used were similar to those used in Experiments 1 and 2. In 1977 the swards contained 80-90% *Lolium perenne* as was shown by botanical analysis.

The three treatments were compared within the same sward. All swards were cut at the defoliation prior to the experimental grazing in order to avoid effects of faeces contamination on herbage intake and to achieve a high precision of the intake estimate. The primary growth was grazed by sheep only in early season to postpone the start of the experiments until the dairy cows were accustomed to grazing. Each sward was used only once during the grazing season in the experiments, so seasonal yields of areic mass or herbage intake could not be calculated from these experiments. In Appendix 2 some of the general data pertaining to the swards used are summarized. All swards received about 50 kg N/ha in March in the form of phosphate-ammonium-nitrate. During the rest of the season about 80 kg N/ha was supplied in the form of calcium-ammonium-nitrate immediately after cutting the previous harvest. In those experiments where the regrowth of residual herbage was measured 80 kg N/ha was supplied immediately after the animals of the experimental period had left the pasture.

The total area of the swards was about 2.8 ha. After excluding the edges of the field (about 0.2 ha) and the exclosure for measuring the undisturbed herbage accumulation (about 0.1 ha) a total grazing area of 2.5 ha was available. This area was split up in a fraction of 0.60 to be used in the preliminary period and a fraction of 0.40 to be used in the experimental period. The experimental plots varied from 0.1 to 0.4 ha. The rectangular grazed plots were electrically fenced by placing fence posts at a distance of 5 m from each other and by drawing 3 wires at heights of 40, 75 and 110 cm. Each group of animals had a separate electric fence system. The experimental plots were separated by a strip of 60 cm wide to diminish trampling by personnel during fencing and to make it possible to estimate herbage intake of cows outside of fences. Drinking water was always available in the field. Other aspects of methodology are described in Chapter 3.

5.3 RESULTS

5.3.1 Meteorological conditions

The precipitation was measured in the experimental fields. Other meteorological data were assumed to be equal to the data collected at the ir. A.P. Minderhoudhoeve (meteorological department of the Agricultural University in Swifterbant) at a distance of 10 km. Total precipitation, mean temperature and total solar radiation during the experimental periods are given in Appendix 3.

The temperature was relatively high in EP 3 of 1978 and EP 2 of 1979 and relatively low in EP 8 and 16 of 1978 and in EP 11 of 1979. In the other periods the temperature was normal for the time of the year. The solar radiation was relatively high in EP 1, 3 and 13 of Experiment 3 and in EP 1 of 4 of Experiment 4. That the level of solar radiation during a grazing period affects, among other things the undisturbed herbage accumulation was expressed by the correlation coefficient of 0.75 (n = 32) between solar radiation and herbage accumulation.

The summer of 1978 was wet as is shown by the high precipitation figures during EP 4, 8, 10, 12, 14 and 16. In 1979 only the spring period was wet, precipitation being high in EP 1 to 4.

5.3.2 Results during grazing periods

5.3.2.1 Details of experimental animals, swards and cutting conditions

Experiment 3 During Period 6, Cow no. 313 (Group 2) and Cow no. 183 (Group 4) showed symptoms of hypomagnesaemia although extra Mg-rich concentrates were given. Cow no. 313 was substituted by Cow no. 272 for the remainder of the experiment; Cow no. 183 recovered within a few days and was kept in the experiment. Cow no. 38 (Group 1) had mastitis in EP 8 and recovered during the interval of a month between EP 8 and 9. Therefore their data in EP 6 (Group 2 and 4) and EP 8 (Group 1) respectively were

Table 16. Number of reliable observations (grazing periods) per treatment (N).

Treatment		X	Y	Z	Total
1978	es	7	12	8	27
	ls	7	12	5	24
1979	es	6	8	8	22
	ls	6	8	8	22

excluded from all statistical analyses and tables with average results.

As shown in 4.1.3 adhesion of herbage to the lm can be used as an indicator of unreliable cutting results. Adhesion of herbage to the lm at start and/or finish of grazing occurred in EP 6, 7, 9, 12, 14 (Group 1 and 2) and 16. In EP 6 (group 1 and 3) and EP 9 the total areic mass of herbage could be corrected with the stubble mass results obtained with hand-cutting in these periods (Table 8). In EP 7 (Group 1 and 2) and EP 16 (Group 1 and 2) herbage stuck to the lm at both times of cutting and organic matter contents of herbage were comparable between start and finish of grazing, so these measurements were classified as reliable. All other values derived at sticking herbage conditions were excluded from statistical analyses and tables with average results. The number of remaining reliable figures was 27 in early summer and 24 in late summer. The distribution of reliable observations over the treatments per season is shown in Table 16.

Experiment 4 During Period 2 Cow no. 44 (Group 3) showed symptoms of acetonaemia, but recovered rapidly and was kept in the experiment. Cow no. 26 (Group 2) had slight mastitis in EP 4 and also recovered. The periods in which these animals were ill (EP 2 Group 3, EP 4 Group 2) were excluded from regression analysis and tables with average results.

During EP 2 the rainfall was 44 mm. The forming of large puddles after this heavy rainfall made the intake results very unreliable because cutting was not possible at the paired sample sites at the end of grazing. Because of the lack of alternatives during EP 13 a sward had to be used which had little or no vegetation over large areas above the drain pipes (due to effects of the hard winter before). It was impossible to measure the areic mass of herbage precisely on this heterogeneous sward with the available method. The results of both EP 2 and EP 13 were excluded from statistical analysis and tables.

Adhesion of herbage to the lm at the start and/or the end of grazing occurred in EP 1, 3, 4, 9 (Group 1 and 2), 12 (Group 1 and 2) and 15 (Group 1 and 2). In EP 1 (Group 1 and 2) and EP 3 (all groups) herbage stuck to the lm at both moments of cutting and organic matter contents of herbage were comparable between the start and finish of grazing, so these measurements were classified as reliable. All other values derived under sticking herbage conditions were excluded from statistical analysis and tables with average results. The number of remaining reliable figures was 22 in es and 22 in ls. In Table 16 the number of observations per treatment is shown.

The tables of Chapter 5 present the average results per treatment per season; the variation in the figures between experimental periods is given as standard devia-

Table 17. Daily herbage allowance (A_0).

Treatment			X	Y	Z	Mean
ms	1978	intended	15	20	30	
		es	14.69 (0.87)[1]	19.80 (1.26)	30.16 (1.67)	21.54 (6.20)
		ls	15.38 (1.09)	19.95 (1.44)	30.27 (2.69)	20.77 (5.60)
	1979	intended	15	23	30	
		es	15.30 (2.09)	24.59 (3.81)	31.13 (4.09)	24.43 (7.24)
		ls	16.01 (0.88)	24.69 (2.93)	30.91 (2.32)	24.59 (6.41)
ms + lm	1978	es	16.55 (1.21)	22.62 (1.67)	33.84 (2.24)	24.37 (6.95)
		ls	19.15 (1.85)	24.45 (2.12)	37.00 (2.67)	24.52 (6.77)
	1979	es	18.86 (3.63)	29.77 (6.90)	38.08 (7.25)	29.82 (9.84)
		ls	22.63 (2.44)	34.11 (5.00)	42.58 (2.96)	34.06 (8.81)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

tion (s_x) in brackets. Some of the basic observations per experimental period are shown in Appendix 4.

5.3.2.2 Daily herbage allowance

The average level of herbage allowance in the treatments applied (>4.5 cm) corresponded very reasonably with the intended levels (Table 17). The standard deviation as calculated between periods and the figures of Appendix 4 however, indicate that there was some variation within the treatments applied between periods. The reasons for this variation will be discussed later. The consequence of this was that regression methods were the most appropriate statistical analysis of the results.

In both years the allowances applied in es were comparable to those in ls when measured above 4.5 cm. However, when the cutting height of the lawn-mower was chosen as the reference level, then the allowance level in ls was significantly ($P < 0.01$) higher than in es due to the difference in areic mass of herbage cut by lm between seasons (Section 4.1). The allowance levels applied differed significantly from each other ($P < 0.001$) at both levels of cutting.

Variation in cutting height of the ms between swards and periods was the greatest disadvantage of choosing the herbage mass cut by ms, as the basic measurement for calculating A. Another problem with this reference level might be consumption by the animals from below cutting height, however this risk was small in these experiments (Section 4.4.1). Advantages of the cutting height of the lm as the reference level for calculating A were the good reproducibility of this height and the negligible consumption of herbage below this height (Section 4.4.1). However, the variation in areic mass of herbage cut by the lm between swards and seasons was large (Section 4.1.2). Because this lm fraction was difficult to reach for the animal variation in mass (and allowance) of this fraction will have influenced animal response only marginally.
In order to check the influence of the cutting level, at which the allowance was determined, on the allowance/intake relationship the results of both cutting heights were analysed.

5.3.2.3 Areic mass of herbage and sward height

The aim of the experiment was to compare different allowances at a constant level of herbage mass (M). Therefore in each EP the treatments were applied on the same pasture. The differences in M between treatments during an experimental period were small (Appendix 4); these small differences can be attributed to variation in M within the pasture and to differences in the day of start of grazing (two groups on Monday; two groups on Tuesday).

The mean M_0 per treatment per season is shown in Table 18. Differences in average levels of M between treatments were small and can be attributed to differences in M between pastures (EP's) combined with a variable number of animal groups receiving the treatments Y and Z (Table 15) and to missing observations. In EP 1 + 2 and EP 3 + 4 of 1978 pastures of 4.3 ha were used for 2 succeeding weeks. This was done in order to examine possible allowance - areic mass interactions. The high levels of M obtained in these weeks led to the high mean values of M in the es of 1978. In both years the M_0 (ms) in es was higher than in ls. This was however compensated by a higher M_0 (lm) in ls than M_0 (lm) in es, so the total areic mass of herbage (ms + lm) did not differ much between seasons in 1979.

The height of the sward at the start of grazing did not differ significantly between treatments (Table 18). The differences in sward height between seasons and years show the same pattern as the herbage mass due to a high correlation between h and M_0, especially in es (Lantinga, 1979; Flikweert, 1980).

The residual herbage (M^f) per grazing period is shown in Appendix 4; the mean residual herbage per treatment per season is given in Table 19. The residual herbage was significantly affected by level of A_0 ($P < 0.01$). Results of regression analysis of A - M^f relationships are not given here because an extensive statistical analysis of areic consumption of herbage (= M - M^f with a correction for herbage accumulation)

Table 18. Areic mass of herbage and sward height at start of grazing.

Treatment				X	Y	Z	Mean
M_0	ms	1978	es	2743 (718)[1]	2535 (1013)	2780 (711)	2662 (838)
			ls	1942 (299)	1947 (294)	2040 (344)	1965 (294)
		1979	es	1800 (528)	1946 (573)	1838 (500)	1867 (516)
			ls	1609 (366)	1660 (377)	1580 (222)	1617 (311)
	ms + lm	1978	es	3121 (802)	2895 (1054)	3160 (780)	3032 (893)
			ls	2447 (293)	2418 (288)	2537 (356)	2451 (294)
		1979	es	2232 (490)	2353 (512)	2273 (469)	2291 (470)
			ls	2308 (254)	2328 (279)	2236 (181)	2289 (232)
h		1978	es	23.96 (4.53)	22.64 (5.92)	23.85 (4.45)	23.34 (5.03)
			ls	18.93 (1.64)	18.88 (1.38)	19.04 (1.59)	18.95 (1.44)
		1979	es	19.52 (6.19)	21.53 (5.65)	18.91 (4.59)	20.03 (5.31)
			ls	16.16 (3.10)	16.09 (3.29)	15.01 (2.76)	15.72 (2.96)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

Table 19. Areic mass of herbage and sward height at finish of grazing.

Treatment				X	Y	Z	Mean
M_0^f	ms	1978	es	626(287)[1]	906(429)	1592(454)	1036(548)
			ls	361(121)	511(145)	907(172)	550(242)
		1979	es	292(186)	769(345)	989(294)	719(380)
			ls	294(45)	609(88)	825(140)	602(236)
	ms + lm	1978	es	1109(362)	1427(477)	2110(478)	1547(586)
			ls	1005(161)	1201(211)	1557(168)	1218(268)
		1979	es	863(344)	1345(349)	1539(261)	1284(410)
			ls	1244(128)	1451(126)	1590(136)	1445(187)
h^f		1978	es	9.79(1.28)	11.85(2.66)	15.68(2.66)	12.45(3.25)
			ls	8.06(0.50)	8.75(0.54)	10.84(0.49)	8.98(1.13)
		1979	es	7.59(0.80)	11.05(2.38)	12.35(2.49)	10.58(2.82)
			ls	7.03(0.70)	8.46(1.00)	9.45(1.37)	8.43(1.43)

1. The figure in brackets is the standard deviation of the estimate (s_x) as calculated from the measurements in different periods.

will be given later. The differences in M_0^f (ms) and in M_0^f (lm) between es and ls were of the same order and direction as those at the start of grazing.

The sward height at the end of grazing significantly increased at higher levels of herbage allowance (Table 19). In es the estimate of the linear regression coefficient was 0.29 ($P < 0.01$) and 0.23 ($P < 0.01$) cm herbage per kg A_0 (ms) in 1978 and 1979 respectively with a standard deviation of 0.06 both. In ls the linear regression coefficient was 0.15 ($P < 0.01$) and 0.16 ($P < 0.01$) cm herbage per kg A_0 (ms) in the respective years with a standard deviation of 0.03 both.

5.3.2.4 Areic consumption of herbage

The areic consumption of herbage (C_0) per grazing period is given in Appendix 4; the mean areic consumption per treatment per season is shown in Table 20. In es C_0 was higher than in ls corresponding with differences in M_0 between es and ls; the effects of M_0 on C_0 (within seasons) will be discussed in Chapter 6.

Table 20. Areic consumption of herbage (C_0).

Treatment			X	Y	Z	Mean
ms	1978	es	2397(517)[1]	1927(641)	1560(277)	1940(597)
		ls	1754(358)	1633(319)	1366(281)	1613(340)
	1979	es	1768(426)	1504(369)	1179(284)	1458(416)
		ls	1497(399)	1256(393)	953(186)	1211(388)
ms + lm	1978	es	2293(547)	1765(645)	1421(328)	1800(620)
		ls	1614(343)	1415(300)	1213(295)	1431(331)
	1979	es	1628(406)	1335(363)	1064(253)	1316(396)
		ls	1246(356)	1082(316)	842(155)	1040(315)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

Table 21. Probabilities corresponding to F-values based on multiple regression analysis of areic consumption of herbage (C_0). Each term is tested eliminating the preceding terms and ignoring the following.

A_0		Se	Se EP	G	M_0	A_0	A_0 Se	A_0^2	A_0^2 Se	N
ms	1978	***	***	***	n.s.	***	***	n.s.	n.s.	n.s.
	1979	***	***	n.s.	n.s.	***	**	***	n.s.	n.s.
ms + lm	1978	***	***	***	*	***	***	***	n.s.	n.s.
	1979	***	***	n.s.	***	***	***	***	*	n.s.

Regression analysis was performed with the C_0 data determined with ms + lm and A_0 data determined both with ms and with ms + lm. Variables in the multiple regression analysis per year were subsequently the season (Se), the experimental period (EP), the group of animals (G), the areic mass of herbage (M_0), the daily herbage allowance (A_0) both linear and quadratic, interactions between A and Se (A Se, A^2 Se) and residual effects of the treatments in the preceding period (N). The probabilities corresponding to the calculated F-values are shown in Table 21.

In fact this procedure is an hierarchical analysis of variance. Subsequent terms are adjusted for the preceding ones but ignore the other effects. The order of the terms is as given in Table 21. Effects of allowance could only be examined after adjustment for other variables such as season, EP and group. Analysis of regression did show significant effects of A_0 on C_0 and showed a significant A_0-Se interaction. Inclusion of A_0^2 in the regression improved the fit of the regression line with all sets of data except those of 1978 (ms). The A_0-Se interaction indicated that the effect of A_0 on C_0 differed significantly ($P < 0.01$) between seasons. Estimations of regression coefficients were therefore based on the combined data per season.

Using multiple regression analysis per season adjustments were made for the effects of EP, G and M_0. After correction for these variables the effects of A_0 and A_0^2 on C_0 (ms + lm) were examined. The results are presented in Table 22 and Figure 4. If the inclusion of A_0^2 in the regression significantly increased the fraction of the

Table 22. Regression coefficients in the multiple regression of areic consumption of herbage on daily herbage allowance (after adjustment for the effects of EP, G and M_0).

A_0			$C_0 = a + b A_0$			$C_0 = a + b A_0 + c A_0^2$					
			b	s_b	P	b	s_b	P(b)	c	s_c	P(c)[1]
ms	es	1978	-52.5	5.1	***						n.s.
		1979	-31.7	5.5	***	-119.3	26.6	***	1.88	0.56	***
	ls	1978	-32.9	3.0	***	- 87.9	22.2	***	1.18	0.47	*
		1979	-18.8	2.0	***						n.s.
ms + lm	es	1978	-46.9	4.7	***						n.s.
		1979	-24.8	4.7	***	- 88.3	13.8	***	1.07	0.23	***
	ls	1978	-25.5	1.5	***						n.s.
		1979	-13.0	1.4	***						n.s.

1. Effect of inclusion of A_0^2 in the regression after A_0 has already been included.

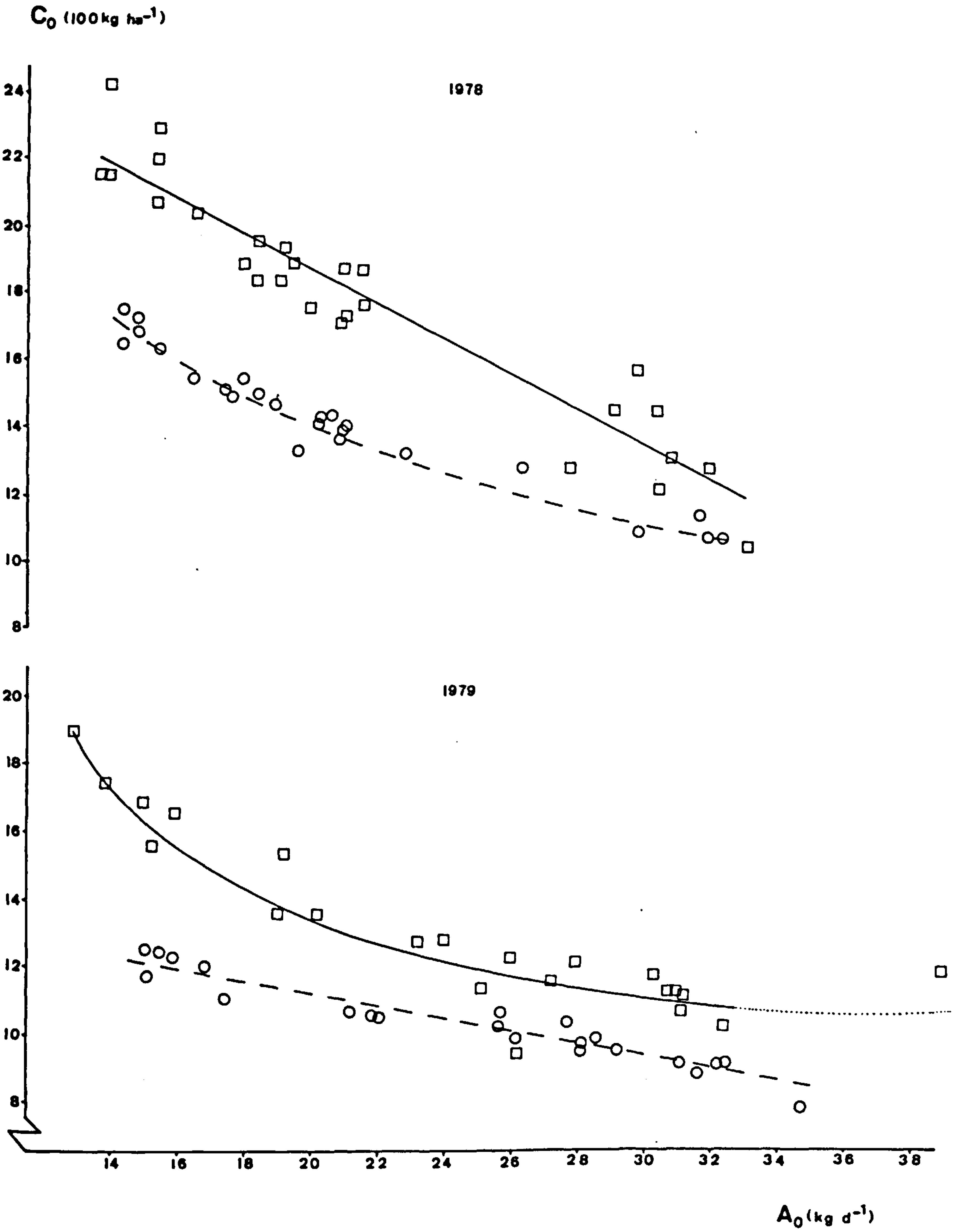


Figure 4. Effect of daily allowance of organic matter of herbage (A_0, ms) on areic consumption of organic matter of herbage (C_0, ms + lm), after correction for effects of experimental period and animal group. □ early summer, solid lines; ○ late summer, broken lines.

variance of C_0 that is attributable to the multiple regression also the curvilinear relationship is given. A linear A_0-C_0 relationship gave a good fit for the data in 1978 (es and ls) and 1979 (ls) both if allowance was estimated above ms cutting height and above ms + lm cutting height. The addition of A_0^2 resulted in a significant depression of the variation around the regression line in the es of 1979 (ms and ms + lm) while this contribution was just significant in ls of 1978 when A_0 was measured with ms alone. The decrease of C_0 at increasing A_0 in es was stronger than that in ls. When the A_0 was determined with ms the regression coefficients in Table 22 were higher than when the cutting height of the lm was chosen as the reference level.

5.3.2.5 Daily herbage intake

The daily herbage intake (I_0) per grazing period is reported in Appendix 4; the mean I_0 per treatment per season is shown in Table 23. Regression analysis was performed with the I_0 data determined with ms + lm and the A_0 data determined both with ms and with ms + lm. The variables in the multiple regression analysis per year were the same as used for C_0 (Section 5.3.2.4). The probabilities corresponding to the F-values are shown in Table 24.

Regression analysis did show significant effects of A_0 on I_0 eliminating effects of Se, EP, G and M_0, and it showed an A_0-Se interaction in 1978 only. Inclusion of A_0^2 in the regression did not significantly depress variation around the regression line, however there was an A_0^2-Se interaction in the ls of 1979 when allowance was expressed above lm cutting height.

Seasonal intake data (ms + lm) were used for the estimation of the regression coefficients of the A_0-I_0 relationship. Adjustments for the effects of EP, G and M_0 were first made in the multiple regression analysis. (The effect of M_0 on I_0 in these experiments will be analysed in Chapter 6). The results are presented in Table 25 and Figure 5.

In all seasons a strong effect of A_0 on I_0 could be shown. The addition of A_0^2 resulted in a significant reduction of the variation around the regression line in the ls of 1979 only (A_0 ms + lm); but the curves indicate that there was also a ten-

Table 23. Daily herbage intake (I_0).

Treatment			X	Y	Z	Mean
ms	1978	es	11.68(0.64)[1]	13.64(0.70)	15.03(1.03)	13.54(1.48)
		ls	12.67(0.86)	15.11(0.97)	18.12(1.59)	15.03(2.20)
	1979	es	13.14(1.12)	16.24(1.87)	17.00(2.73)	15.67(2.56)
		ls	13.26(0.97)	16.29(1.87)	16.55(1.84)	15.56(2.14)
ms + lm	1978	es	11.13(0.73)	12.36(0.76)	13.58(1.01)	12.40(1.22)
		ls	11.66(0.94)	13.06(1.12)	16.04(1.81)	13.27(1.97)
	1979	es	12.06(0.83)	14.30(1.49)	15.30(2.05)	14.06(2.01)
		ls	11.04(1.24)	14.06(1.04)	14.61(1.24)	13.44(1.89)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

Table 24. Probabilities corresponding to F-values based on multiple regression analysis of daily herbage intake (I_0). Each term is tested eliminating the preceding terms and ignoring the following.

A_0		Se	Se EP	G	M_0	A_0	A_0 Se	A_0^2	A_0^2 Se	N
ms	1978	***	***	***	n.s.	***	***	n.s.	n.s.	n.s.
	1979	n.s.	**	n.s.	***	***	n.s.	n.s.	n.s.	n.s.
ms + lm	1978	***	***	***	n.s.	***	***	n.s.	n.s.	n.s.
	1979	*	***	n.s.	***	***	n.s.	n.s.	**	n.s.

Table 25. Regression coefficients in the multiple regression of daily herbage intake on daily herbage allowance (after adjustment for the effects of EP, G and M_0).

A_0			$I_0 = a + b\ A_0$			$I_0 = a + b\ A_0 + c\ A_0^2$					
			b	s_b	P	b	s_b	P(b)	c	s_c	P(c)[1]
ms	es	1978	0.157	0.025	***						n.s.
		1979	0.204	0.034	***						n.s
	ls	1978	0.293	0.028	***						n.s.
		1979	0.267	0.031	***						n.s.
ms + lm	es	1978	0.149	0.023	***						n.s.
		1979	0.176	0.023	***						n.s.
	ls	1978	0.238	0.019	***						n.s.
		1979	0.196	0.023	***	0.749	0.201	***	-0.008	0.003	*

1. Effect of inclusion of A_0^2 in the regression after A_0 has already been included.

dency for a curvilinear A-I relationship in the es of 1978. In both years the A-I regression coefficients in es were slightly lower than these in ls (although only sign. in 1978), while the differences in regression coefficients between years were small. When the A_0 was determined above the cutting height of the ms the value of b was higher than when the cutting height of the lm was chosen as the reference level.

Besides the polynomial function as described above ($I = a + b\ A + c\ A^2$) another regression model has been examined. This model has been described by Zemmelink (1980) and is of the form:

$$I = m\left\{1 - e^{-(p\ \frac{A}{m})^h}\right\}^{1/h} \quad \text{with } m > 0,\ h > 0 \text{ and } 0 < p \leq 1$$

in which

m is the upper limit (asymptote) of I_0

p is the fraction of the forage which may be considered edible

h is a shape parameter, such that I at the critical allowance level $A = m/p$ equals $m(1 - e^{-1})^{1/h}$

Low values of h correspond to a large despression of I at $A = m/p$.

A first analysis of the total material showed that p = 1; all the herbage offered

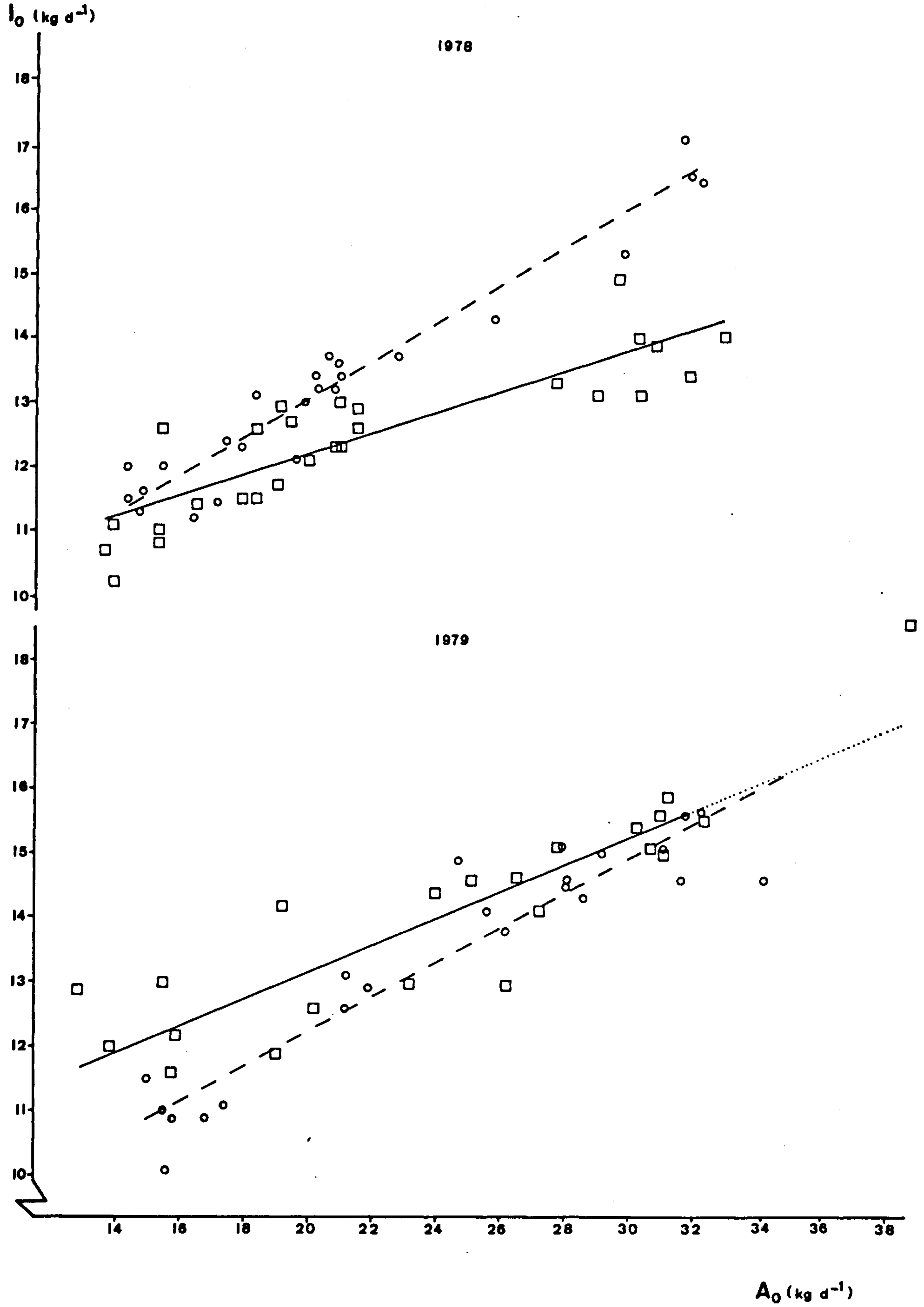


Figure 5. Effect of daily allowance of organic matter of herbage (A_O, ms) on daily intake of organic matter of herbage per animal (I_O, ms + lm), after correction for effects of experimental period and animal group. □ early summer, solid lines; ○ late summer, broken lines.

above 4.5 cm was consumable. In all other analysis a p value of 1 was assumed. Curves were adjusted per year a) for the total material b) per group of animals (over the seasons) c) per season (over the animal groups) both with A_0 (ms) and A_0 (ms + lm).

The estimates of the parameters m and h were strongly correlated. Adjustments of m at constant h (chosen at an appropriate level) were not significantly worse than those where both m and h were adjusted. Adjustments with parameters different for each of the animal groups were not better than the ones where m and h were assumed to be equal for all groups. The reduction of the residual mean square of the regression after adjustment of the curve with different parameters for animal groups did not justify the loss of degrees of freedom. The same conclusion could be drawn for the seasons.

The adjustments with the model of Zemmelink were on average worse than those with the polynomial model (the residual mean squares of the regression of the former model were about twice as high). The reason for this may be that 1) the allowance levels were too low to achieve maximum intake 2) the real relationship between allowance and intake differs from the description with this function or 3) that other factors than the ones investigated have influenced herbage intake.

5.3.2.6 Milk production, milk composition and live weight

The aim of the experiments was to determine the effects of A on I. The period in which a treatment was applied (1 week) was too short to get reliable effects of A_0 on milk production. From these short term trials only indications of possible treatment effects on milk production can be derived. The mean milk production, milk composition and fat-corrected milk production per treatment are shown in Table 26. At higher levels of herbage allowance the milk production and the protein content of the milk increased, while milk fat content tended to decrease. The fat-corrected milk yields were analysed with multiple regression.

After adjustment for the effects of Se, EP and G analysis of regression showed significant effects of A_0 on FCM (Table 27). Inclusion of A_0^2 just significant at the 5% level reduced variation around the regression line in 1979. Seasonal FCM data were used for the estimation of the regression coefficients of the A_0-FCM functions after adjustment for the effects of EP and G (Table 28). In all seasons a positive effect of A_0 on FCM yield could be shown; there was a tendency that this effect in es was smaller than in ls, however the difference was not significant. Addition of A_0^2 did not reduce variation around the regression line significantly in the seasonal data, so only linear relationships are reported. In both years the A_0-FCM regression coefficients in es were lower than these in ls. However, these differences were not significant. When A_0 was determined above cutting height of the ms the value of b was higher than when the cutting height of the lm was chosen as the reference level.

The mean live weight per treatment is also shown in Table 26. The animals were weighed just before the start of each EP and after 24 hours grazing. The differences in live weight between these two times of measurement were large due to differences in filling of the intestinal tract of the animals. It was thought that the mean of

Table 26. Milk production, milk composition and live weight.

Treatment			X	Y	Z	Mean
L	1978	es	26.4(1.36)[1]	27.1(1.72)	27.5(1.42)	27.0(1.56)
		ls	18.6(2.16)	20.1(1.75)	21.0(2.11)	20.1(2.10)
	1979	es	27.4(1.97)	28.6(1.73)	28.2(1.80)	28.2(1.82)
		ls	19.7(2.19)	20.9(2.11)	21.0(1.92)	20.8(2.11)
100 w_{XL}	1978	es	3.96(0.11)	3.94(0.10)	3.95(0.09)	3.95(0.10)
		ls	4.13(0.21)	4.03(0.11)	3.97(0.20)	4.03(0.17)
	1979	es	4.08(0.35)	4.05(0.32)	3.94(0.21)	4.02(0.29)
		ls	4.12(0.28)	4.09(0.24)	4.09(0.16)	4.10(0.22)
100 w_{XP}	1978	es	3.10(0.08)	3.12(0.08)	3.16(0.11)	3.13(0.09)
		ls	3.29(0.19)	3.34(0.14)	3.44(0.19)	3.36(0.17)
	1979	es	3.05(0.14)	3.08(0.12)	3.14(0.07)	3.09(0.11)
		ls	3.31(0.18)	3.37(0.20)	3.43(0.16)	3.38(0.18)
FCM	1978	es	26.2(1.37)	26.9(1.68)	27.2(1.34)	26.8(1.52)
		ls	18.9(1.82)	20.2(1.67)	20.6(1.50)	20.0(1.72)
	1979	es	27.9(3.06)	28.8(2.42)	27.9(2.29)	28.3(2.49)
		ls	20.0(1.84)	21.2(1.71)	21.3(1.86)	21.0(1.82)
W	1978	es	566(17.5)	568(21.9)	568(16.1)	567(18.7)
		ls	566(18.4)	568(18.4)	574(17.7)	569(18.8)
	1979	es	569(11.8)	567(12.2)	570(12.6)	569(11.9)
		ls	579(17.5)	580(15.7)	582(11.9)	580(14.3)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

Table 27. Probabilities corresponding to F-values based on multiple regression analysis of fat-corrected milk production (FCM). Each term is tested eliminating the preceding terms and ignoring the following.

A_0		Se	Se EP	G	M_0	A_0	A_0 Se	A_0^2	A_0^2 Se	N
ms	1978	***	***	***	n.s.	***	n.s.	n.s.	n.s.	n.s.
	1979	***	***	***	n.s.	***	n.s.	*	n.s.	n.s.
ms + lm	1978	***	***	***	n.s.	***	n.s.	n.s.	n.s.	n.s.
	1979	***	***	***	n.s.	***	n.s.	*	n.s.	n.s.

Table 28. Regression coefficients in the multiple regression of fat-corrected milk production on daily herbage allowance (after adjustment for the effects of EP and G).

A_0		FCM = a + b A_0					
		ms			ms + lm		
		b	s_b	P(b)	b	s_b	P(b)
es	1978	0.076	0.018	***	0.067	0.021	***
	1979	0.038	0.019	*	0.033	0.016	*
ls	1978	0.105	0.015	***	0.086	0.015	***
	1979	0.091	0.016	***	0.065	0.012	***

these two weights would give a reasonable estimation of the average weight of the animals during the grazing period. The treatments were already applied in the pre-periods. The tendency of a higher live weight at increasing levels of A_0 (which reached significance in 1978) can probably be attributed to differences in fill of the forestomachs of the animals at the end of the pre-periods.

5.3.2.7 Grazing time and rate of biting

The mean grazing time per treatment in Experiment 4 is shown in Table 29. In ls grazing time was longer than in es; there was a tendency of a shorter grazing period on the first day of grazing. The mean grazing time over the whole grazing period was analysed first with multiple regression. Grazing time differed significantly between seasons, experimental periods and groups of animals, but consistent effects of treatments could not be shown (Table 31). Probably the treatment effect on grazing time depends on the moment of the grazing period because the effect of allowance can best be shown on the last day of grazing. Analysis of the grazing time on the last (third) day of the grazing period showed a significant increase of grazing time at lower levels of allowance (Table 31).

The rates of biting by the animals in Groups 3 and 4 in 1979 were measured on the second day of grazing; those of the Groups 1 and 2 were measured on the third day of grazing. The rate of biting for three animals per group (3 measurements for each cow) was measured during EP 3 to 16 (Table 30). This limited number of observations was

Table 29. Grazing time (min d^{-1}) during the grazing periods of 1979.

Treatment		X	Y	Z	Mean
es	Day 1	437	438	452	442
	Day 2	464	452	454	455
	Day 3	493	437	440	452
	Mean	465	442	449	450
ls	Day 1	464	459	447	456
	Day 2	497	489	470	484
	Day 3	496	495	463	483
	Mean	486	481	460	474

Table 30. Rate of biting (bites min^{-1}) on the second and third day of the grazing periods of 1979.

Treatment		X	Y	Z	Mean
es	Day 2	57.7	50.3	50.0	51.8
	Day 3	55.4	54.4	54.8	54.8
	Mean	56.6	52.1	52.7	53.3
ls	Day 2	55.4	52.4	53.6	53.7
	Day 3	50.6	55.8	55.8	54.7
	Mean	52.7	54.1	54.6	54.2

Table 31. Probabilities corresponding to F-values based on multiple regression analysis of grazing time and rate of biting. Each term is tested eliminating the preceding terms and ignoring the following.

	Grazing day	Se	Se EP	G	Se G	A_0(ms)	A_0 Se
grazing time	1	n.s.	n.s.	***	n.s.	n.s.	n.s.
	2	n.s.	n.s.	*	n.s.	n.s.	n.s.
	3	*	***	*	n.s.	**	n.s.
	Mean	**	*	***	n.s.	n.s.	n.s.
rate of biting	2	n.s.	***	n.s.	n.s.	n.s.	n.s.
	3	n.s.	***	n.s.	n.s.	n.s.	n.s.
	Mean	n.s.	***	**	n.s.	n.s.	n.s.

used for a multiple regression analysis (Table 31). On the third day of the grazing period no effect of the allowance treatment on rate of biting could be shown. However on the second day of grazing rate of biting significantly ($P < 0.06$) increased at lower levels of herbage allowance (in Table 31 indicated as not significant because the 5% level of probability was not reached).

5.3.2.8 Chemical composition, digestibility and nutritive value of herbage

The chemical analysis and in-vitro digestibility was determined in the samples cut with the ms as well as in the samples cut with the lm. The chemical composition of the herbage samples cut at the start of grazing is shown in Table 32. The in-vitro digestibility of samples of M per grazing period is shown in Appendix 4. The mean in-vitro digestibility and nutritive value of M per treatment per season is presented

Table 32. Chemical composition of herbage mass and of residual herbage.

				$100\ w_T$	$100\ w_O/T$	$100\ w_{XP}/O$	$100\ w_{XF}/O$	$100\ w_{NDF}/O$
M	ms	1978	es	17.2	89.5	23.3	25.3	53.5
			ls	17.9	88.3	27.3	24.5	53.7
		1979	es	17.9	88.7	25.8	23.1	50.0
			ls	20.9	89.6	27,5	22.6	52.7
	lm	1978	es	29.7	83.8	21.8	27.0	58.2
			ls	38.7	78.9	23.4	27.5	63.6
		1979	es	28.9	73.9	24.1	24.2	57.8
			ls	42.6	73.9	24.8	25.1	60.3
M^f	ms	1978	es	18.2	88.2	19.9	28.3	58.5
			ls	25.6	84.0	22.0	27.8	62.5
		1979	es	23.0	84.1	21.5	25.4	55.8
			ls	27.5	84.3	23.1	25.0	57.7
	lm	1978	es	26.2	84.0	20.5	27.5	59.4
			ls	43.5	76.2	23.0	27.4	64.1
		1979	es	35.8	73.3	23.1	24.9	59.0
			ls	45.5	72.2	24.3	25.0	60.3

Table 33. In-vitro O digestibility of herbage mass and of residual herbage ($100\ w_{dO}/O = 100\ d_O$).

Treatment				X	Y	Z	Mean
M	ms	1978	es	79.6(3.30)[1]	79.7(3.53)	79.3(3.26)	79.5(3.27)
			ls	74.5(2.17)	74.3(1.86)	73.9(1.50)	74.3(1.82)
		1979	es	81.0(2.25)	80.5(1.73)	80.4(2.51)	80.6(2.10)
			ls	77.0(2.36)	76.6(2.29)	76.5(1.50)	76.7(1.97)
	lm	1978	es	64.0(6.56)	65.2(6.28)	65.2(5.02)	64.9(5.80)
			ls	42.7(5.46)	42.0(4.86)	41.9(4.38)	42.2(4.75)
		1979	es	57.4(6.77)	55.4(6.10)	56.9(5.90)	56.5(5.97)
			ls	44.0(5.01)	44.8(4.80)	42.6(2.55)	43.8(4.09)
M^f	ms	1978	es	73.3(6.40)	76.5(4.42)	78.0(2.48)	76.1(4.76)
			ls	58.4(2.31)	65.3(2.78)	69.6(2.39)	64.2(4.84)
		1979	es	71.5(3.19)	76.6(2.82)	78.7(2.76)	76.0(4.05)
			ls	63.5(5.62)	70.4(3.04)	73.6(3.02)	69.7(5.51)
	lm	1978	es	66.1(3.75)	66.7(5.34)	67.0(4.59)	66.6(4.59)
			ls	44.2(5.49)	45.1(5.51)	43.5(3.50)	44.5(4.99)
		1979	es	58.6(8.90)	57.1(4.09)	60.0(6.93)	58.6(6.49)
			ls	46.0(5.81)	47.1(5.15)	45.7(2.16)	46.3(4.34)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

in Table 33 and Appendix 5 respectively. Differences in herbage quality between the means were small and could be attributed to differences in d_O and in nutritive value between pastures (EP's) combined with a variable number of animal groups receiving the treatments Y and Z and to missing observations. The w_T, w_{XF}/O and w_{NDF}/O of herbage samples cut by the lm were significantly ($P < 0.01$) higher than those of samples cut by the ms; the w_O/T, w_{XP}/O and d_O of herbage samples cut by the lm were significantly ($P < 0.01$) lower than those of samples cut by the ms. The chemical composition, in-vitro digestibility and nutritive value of the total herbage mass cut by ms and lm can be calculated when herbage masses and parameters of herbage quality of each of the fractions are combined (Appendix 5). The w_{dXP}/O of M in ls was higher than that in es (1978: $P < 0.01$, 1979: $P < 0.05$). The d_O of M in ls was significantly ($P < 0.01$) lower than that in es both when measured with ms, lm and ms + lm (Table 33 and Appendix 5); this resulted also in a significantly ($P < 0.01$) higher e_{NE_1} in es than in ls.

The in-vitro digestibility of samples of M^f per grazing period is shown in Appendix 4. The mean chemical composition, in-vitro digestibility and nutritive value of samples of residual herbage per treatment per season are shown in Table 32, 33 and Appendix 5 respectively. In the fraction of herbage cut by the ms the w_{XF}/O and w_{NDF}/O of M^f were significantly ($P < 0.01$) higher than those of M. The w_{XP}/O and d_O of M were significantly ($P < 0.01$) higher than those of M^f. In the lawn-mower fraction no differences in w_{XF}/O, w_{NDF}/O and w_{XP}/O between M and M^f could be shown. The d_O of M^f cut by the lm was significantly higher than the d_O of M (lm). This is in agreement with the lower cutting efficiency of the ms at the end of grazing (Chapter 4), resulting in the displacement of a part of the highly digestible ms fraction into the lm fraction.

Table 34. Regression coefficients in the multiple regression of digestibility of residual herbage on daily herbage allowance (after adjustment for the effects of EP and G).

A_0			$d_0 = a + b\,A_0$			$d_0 + a + b\,A_0 + c\,A_0^2$					
			b	s_b	P(b)	b	s_b	P(b)	c	s_c	P(c)[1]
ms	es	1978	0.304	0.060	***	1.746	0.497	***	−0.0316	0.018	**
		1979	0.608	0.083	***						n.s.
	ls	1978	0.753	0.075	***						n.s.
		1979	0.706	0.094	***						n.s.
ms + lm	es	1978	0.275	0.053	***	1.457	0.465	***	−0.0231	0.0090	**
		1979	0.497	0.073	***						n.s.
	ls	1978	0.624	0.066	***						n.s.
		1979	0.485	0.085	***	2.403	0.586	***	−0.0288	0.0088	***

1. Effect of inclusion of A_0^2 in the regression after A_0 has already been included.

The derived nutritive value of M^f was always lower than that of M. The effects of the differences between M and M^f in the digestibility of the herbage on the digestibility of the herbage ingested will be discussed in Section 5.4.4.

The differences in chemical composition between ms and lm samples of residual herbage were in the same direction and of the same order of magnitude as at start of grazing; only the w_{XF}/O and the w_{XP}/O of the ms and lm fraction did not differ significantly from each other. Also the differences in digestibility and nutritive value between es and ls were in the same direction and of the same order of magnitude as at the start of grazing.

The effect of the treatments on the in-vitro O digestibility of the residual herbage (ms + lm) was tested by multiple regression analysis. There was a significant influence of season ($P < 0.01$), EP ($P < 0.01$) and animal group ($P < 0.05$) on d_0 of M^f in both years. After adjustment for the effects of Se, EP and G regression analysis did show significant effects of A_0 on d_0 of M^f ($P < 0.01$) and showed an A_0-Se interaction in 1978 only. Inclusion of A_0^2 in the regression depressed variation around the regression line both in 1978 ($P < 0.01$) and 1979 ($P < 0.05$).

Seasonal digestibility data were used for the estimation of the regression coefficients of the A_0-d_0 of M^f (ms + lm) relationships. Adjustments for the effects of EP and G were first made in the multiple regression analysis. The results are presented in Table 34 and Figure 6. In all seasons a strong effect of A_0 on d_0 of M^f (ms + lm) could be shown. The addition of A_0^2 resulted in a significant reduction of the variation around the regression line in the es of 1978 and in the ls of 1979 (A_0 ms + lm only). There was a tendency towards higher values of b in ls than in es; this effect was only significant in 1978. Comparable regression coefficients would have been derived from the data on d_0 of M^f cut by ms (compare Table 33 with Appendix 5).

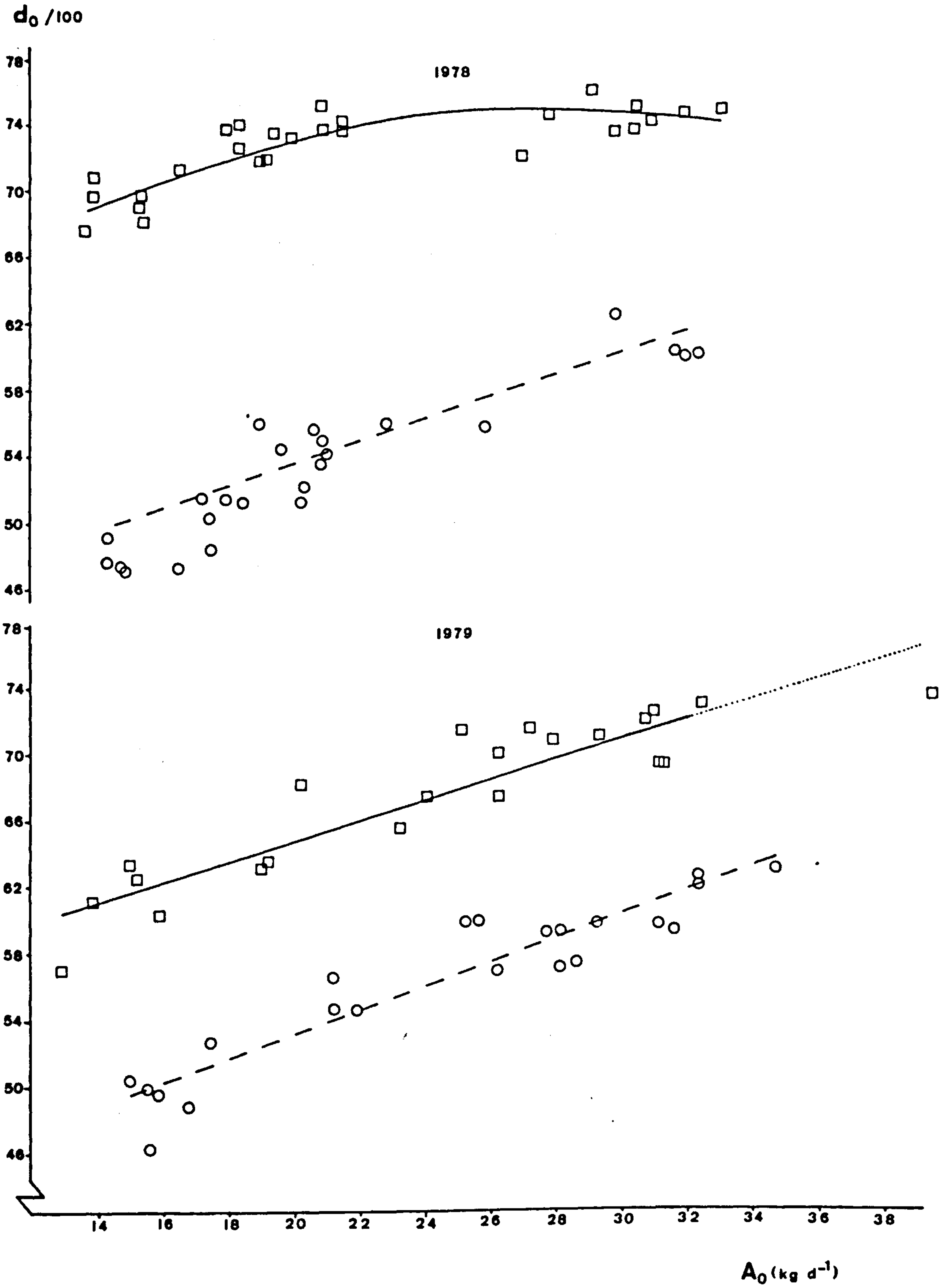


Figure 6. Effect of daily allowance of organic matter of herbage (A_0, ms) on in-vitro digestibility of organic matter of residual herbage (d_0 of M^f, ms + lm), after correction for effects of experimental period and animal group. □ early summer, solid lines; ○ late summer, broken lines.

Table 35. Areic consumption of nutrients (ms + lm).

Treatment			X	Y	Z	Mean
C_{dXP}	1978	es	447(70)[1]	354(91)	307(56)	364(91)
		ls	379(65)	341(64)	305(59)	344(66)
	1979	es	349(76)	307(71)	263(43)	302(70)
		ls	310(89)	263(67)	217(47)	259(75)
C_{dO}	1978	es	1868(462)	1460(541)	1160(277)	1477(516)
		ls	1300(297)	1149(240)	976(208)	1157(267)
	1979	es	1372(337)	1132(295)	880(209)	1106(332)
		ls	1022(373)	885(277)	681(115)	869(279)
C_{NE_1} [2]	1978	es	2536(592)	1993(702)	1595(348)	2016(671)
		ls	1794(403)	1592(326)	1360(279)	1602(361)
	1979	es	1889(437)	1572(392)	1233(278)	1535(440)
		ls	1491(437)	1266(378)	956(166)	1214(388)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.
2. kVEM ha^{-1}.

5.3.2.9 Areic mass and consumption of nutrients from herbage

The areic mass of nutrients as measured by ms + lm sampling was calculated by multiplying the areic mass of O of herbage (kg ha^{-1}) by the nutritive value of herbage expressed in organic matter. The mean areic mass of nutrients at start and finish of grazing per treatment per season are shown in Appendix 6. Differences in M_{dXP}, M_{dO} and M_{NE_1} between treatments were small and can be attributed to the division of the treatments over the EP's (Table 15). The areic mass of residual nutrients was significantly (P <0.01) affected by the treatments. Regression coefficients are not reported here; but the results of multiple regression analysis of the areic consumption of nutrients are shown below.

The change in areic mass of nutrients during grazing was calculated by subtracting M^f_{dXP} from M_{dXP}; the same was done with areic mass of d_O and of NE_1. The areic consumption of nutrients was corrected for herbage accumulation during grazing; the assumption was made that the nutritive value of the herbage accumulated during grazing was the same as the nutritive value of the areic mass of herbage at start of grazing cut by ms. The areic consumption of digestible herbage per grazing period is given in Appendix 4. The mean areic consumption of nutrients per treatment is shown in Table 35; there was a strong negative effect of A_O on areic consumption of nutrients.

Regression analysis was performed with the C_{dO} data determined with ms + lm and A_O data determined both with ms and with ms + lm. C_{dO} was significantly affected by Se (P <0.01) and EP (P <0.01) in both years and by G only in 1978 (P <0.01). After adjustment for the effects of Se, EP and G regression analysis did show significant effects of A_O on C_{dO} (P <0.01) and showed an A_O-Se interaction (P <0.01 in 1978, P <0.05 in 1979). The contribution of A_O^2 to the regression was only significant in 1979.

Seasonal data were used for the estimation of the regression coefficients. The regression coefficients of the A_O-C_{dO} relationships, after adjustment for the effects

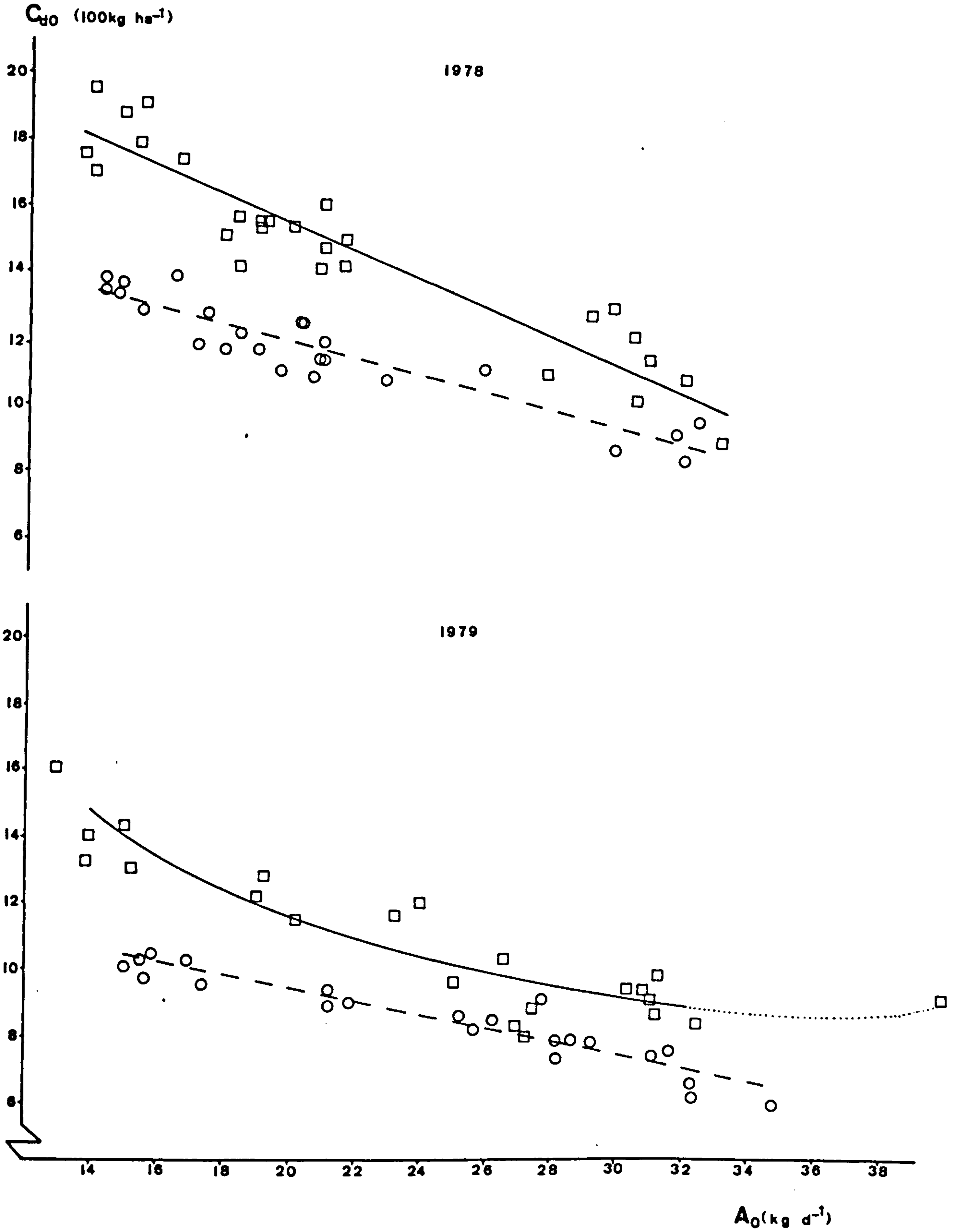


Figure 7. Effect of daily allowance of organic matter of herbage (A_0, ms) on areic consumption of digestible organic matter of herbage (C_{d0}, ms + lm), after correction for effects of experimental period and animal group. □ early summer, solid lines; ○ late summer, broken lines.

Table 36. Regression coefficients in the multiple regression of areic consumption of digestible herbage on daily herbage allowance (after adjustment for the effects of EP and G).

A_0			$C_{d0} = a + b\ A_0$			$C_{d0} = a + b\ A_0 + c\ A_0^2$					
			b	s_b	P(b)	b	s_b	P(b)	c	s_c	P(c)[1]
ms	es	1978	-42.3	4.4	***						n.s.
		1979	-29.0	4.7	***	-89.4	25.5	***	1.26	0.53	*
	ls	1978	-26.1	3.1	***						n.s.
		1979	-19.6	2.3	***						n.s.
ms + lm	es	1978	-37.9	4.0	***						n.s.
		1979	-23.4	4.2	***	-72.2	15.2	***	0.80	0.24	***
	ls	1978	-21.7	2.6	***						n.s.
		1979	-14.3	1.6	***						n.s.

1. Effect of inclusion of A_0^2 in the regression after A_0 has already been included.

of EP and G, are presented in Table 36. The shape of the relationship is shown in Figure 7. Only in the es of 1979 did the addition of A_0^2 result in a significant reduction of the variation around the regression line. In both years the A_0-C_{d0} regression coefficients in ls were significantly lower than these in es. If A_0 was determined with ms the value of b was higher than when the lm cutting height was the reference level.

5.3.2.10 Daily intake of nutrients and degree of nutrient balance

The daily intake of digestible herbage (D_0) per grazing period is given in Appendix 4. The mean daily intake of nutrients from herbage per treatment per season is shown in Table 37. There was a strong positive effect of A_0 on daily intake of nutrients both on D_{XP}, D_0 and I_{NE_1}. Regression analysis was performed with the D_0 data (ms + lm) and the A_0 data (ms and ms + lm). D_0 was significantly affected by Se ($P < 0.01$), EP ($P < 0.01$) and G (only in 1978 $P < 0.01$). After adjustment for the effects of Se, EP and G significant effects of A_0 on D_0 ($P < 0.01$) were evident, there was an A_0-Se interaction in 1978 ($P < 0.25$) and an A_0^2-Se interaction in 1979 ($P < 0.05$).

After adjustment for the effects of EP and G regression coefficients of A_0-D_0 relationships were calculated (Table 38 and Figure 8). The addition of A_0^2 resulted in a significant ($P < 0.01$) reduction of variation around the regression line in the es of 1979 only. In both years the A_0-D_0 regression coefficients in es were lower than these in ls (only significant in 1978) while the differences between years were small. The value of b was higher when A_0 was determined with the ms than when determined with ms + lm.

The cows received a small amount of concentrates (Section 5.1). The intake of nutrients from the total ration (herbage + concentrates) is shown in Appendix 7. Because all animals were supplied with equal amounts of concentrates the differences in total intake of nutrients between treatments were the same as for the intake of nutrients from the herbage.

Table 37. Daily intake of nutrients from herbage (ms + lm).

Treatment			X	Y	Z	Mean
D_{XP}	1978	es	2.23(0.42)[1]	2.61(0.55)	3.04(0.78)	2.63(0.65)
		ls	2.76(0.30)	3.17(0.39)	4.07(0.48)	3.24(0.60)
	1979	es	2.68(0.67)	3.40(0.80)	3.86(0.77)	3.37(0.86)
		ls	2.75(0.45)	3.45(0.30)	3.72(0.44)	3.36(0.55)
D_0	1978	es	9.06(0.67)	10.18(0.72)	11.08(1.19)	10.16(1.14)
		ls	9.37(0.90)	10.62(0.92)	12.94(1.09)	10.74(1.56)
	1979	es	10.19(0.91)	12.15(1.20)	12.67(1.83)	11.81(1.69)
		ls	9.43(0.94)	11.79(0.91)	11.84(1.02)	11.16(1.42)
I_{NE_1} [2]	1978	es	12.35(0.86)	13.98(0.88)	15.30(1.62)	13.95(1.57)
		ls	12.96(1.28)	14.73(1.31)	18.06(1.45)	14.91(2.22)
	1979	es	14.10(1.54)	16.97(1.91)	17.82(2.70)	16.49(2.57)
		ls	13.18(1.36)	16.45(1.26)	16.62(1.43)	15.62(2.00)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.
2. kVEM d^{-1}.

The degree of nutrient balance k showed whether the daily intake of nutrients from the total ration was sufficient for the estimated requirement of nutrients (Section 3.9). The degree of nutrient balance significantly increased at higher levels of daily herbage allowance (Appendix 7). In all seasons and for all treatments far more digestible protein was consumed than required. Particularly in ls, digestible protein consumption was high. In all seasons the lowest allowance treatment showed a degree of net energy balance of less than unity. Because of the lower milk production of the cows in ls (in a later part of the lactation period) the degree of net energy balance in this period was much higher than in es.

A degree of net energy balance that differs from 1 will result in loss or gain in energy of the animal. This might result in changes in body weight of the animal. The average live weight of all animals in es 1978 decreased 15 kg over 7 weeks (ΔW = -0.31

Table 38. Regression coefficients in the multiple regression of daily intake of digestible herbage on daily herbage allowance (after adjustment for the effects of EP and G).

A_0			$D_0 = a + b\,A_0$			$D_0 = a + b\,A_0 + c\,A_0^2$					
			b	s_b	P(b)	b	s_b	P(b)	c	s_c	P(c)[1]
ms	es	1978	0.140	0.022	***						n.s.
		1979	0.163	0.028	***						n.s.
	ls	1978	0.226	0.018	***						n.s.
		1979	0.201	0.023	***	0.776	0.141	***	-0.012	0.003	***
ms + lm	es	1978	0.123	0.020	***						n.s.
		1979	0.137	0.022	***						n.s.
	ls	1978	0.189	0.015	***						n.s.
		1979	0.144	0.018	***	0.557	0.128	***	-0.006	0.002	***

1. Effect of inclusion of A_0^2 in the regression after A_0 has already been included.

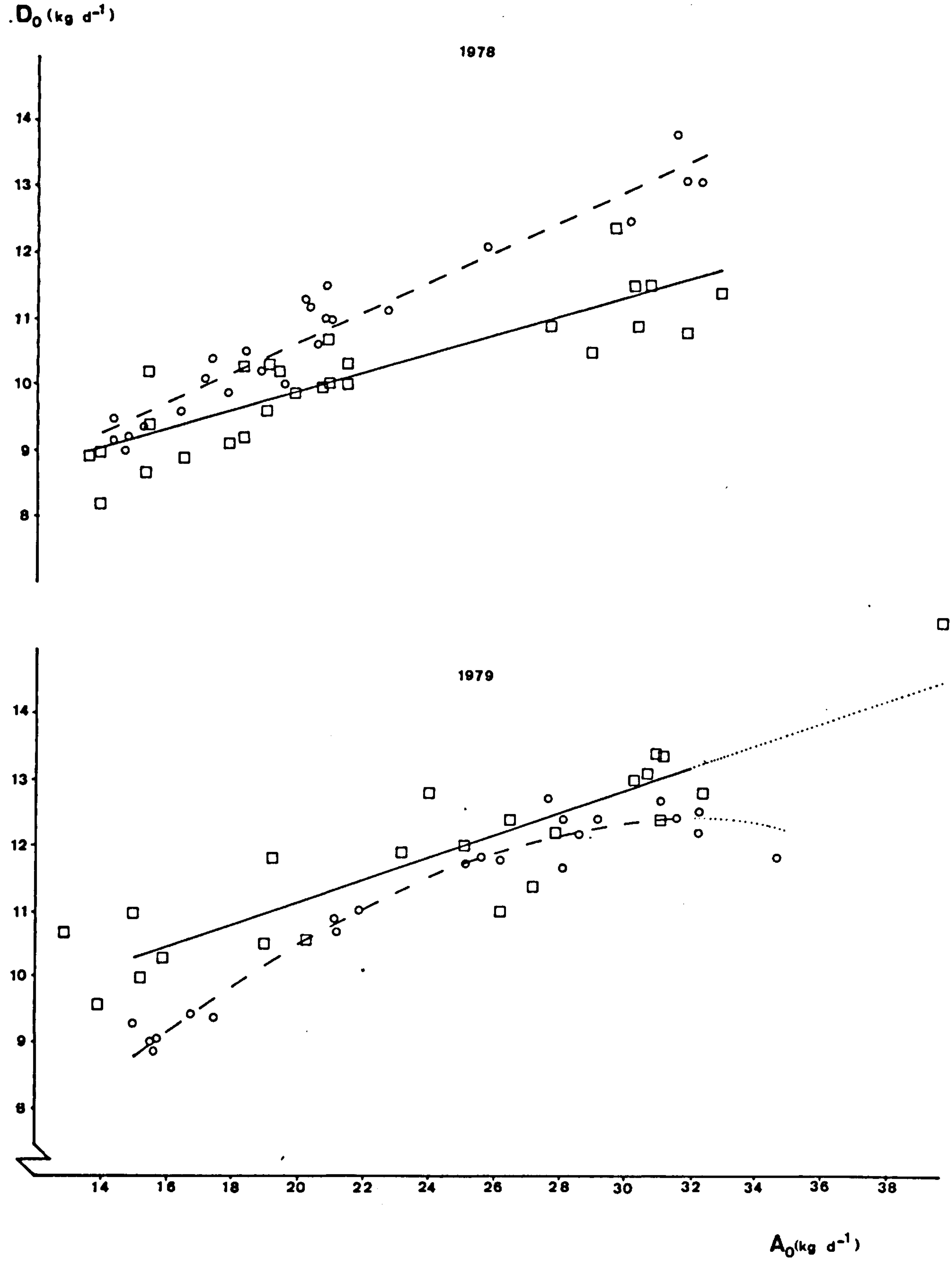


Figure 8. Effect of daily allowance of organic matter of herbage (A_0, ms) on daily intake of digestible organic matter of herbage per animal (D_0, ms + lm), after correction for effects of experimental period and animal group. □ early summer, solid lines; ○ late summer, broken lines.

Table 39. Number of reliable observations (regrowth periods) per treatment (N)

Treatment		X	Y	Z	Total
1978	es	4	8	4	16
	ls	3	6	3	12
1979	es	3	6	3	12
	ls	2	3	5	10

kg d^{-1} for a k_{NE_1} of 0.86).In es 1979 the degree of net energy balance was 0.99 corresponding to an increase of live weight of 3 kg (ΔW = 0.06 kg d^{-1}). In the ls of 1978 and 1979 the mean k_{NE_1} was 1.06 and 1.08 respectively for increases of W from EP 9 to EP 16 of 19 and 24 kg respectively (ΔW = 0.39 and 0.49 kg d^{-1} respectively).

5.3.3 *Results during regrowth periods*

5.3.3.1 Details of experimental swards and cutting conditions

Experiment 3 The regrowth of Group 3 and 4 in EP 11 could not be measured due to a lawn-mower defect. Adhesion of herbage to the lm at the start or at the end of the regrowth period occurred in EP 5, 11 (Group 1 and 2) and 13. These measurements were excluded from statistical analyses and tables of average results. The number of reliable observations is shown in Table 39.

Experiment 4 The observations taken in EP 2 and EP 13 were not taken into account for reasons already given (Section 5.3.2). Adhesion of herbage to the lm at the start or at the finish of the regrowth period occurred in EP 4, 9 (Group 1 and 2) 10 (Group 1 and 2) and 12 (group 3 and 4). These measurements were excluded from statistical analysis and tables of average results. The number of reliable regrowth observations over the treatments per season is shown in Table 39. Some of the data by experimental period are shown in Appendix 8.

Table 40. Areic mass of herbage after regrowth ($M_{i+1,0}$).

Treatment			X	Y	Z	Mean
ms	1978	es	2215(573)[1]	3193(180)	4180(174)	3195(776)
		ls	1008(183)	1386(271)	2118(372)	1474(491)
	1979	es	1923(808)	3311(743)	3858(319)	3101(973)
		ls	1122(564)	1670(290)	1798(146)	1625(370)
ms + lm	1978	es	2725(577)	3682(168)	4696(218)	3696(779)
		ls	1663(66)	2074(122)	2742(230)	2138(425)
	1979	es	2276(774)	3645(704)	4202(275)	3442(948)
		ls	2016(332)	2494(217)	2649(164)	2476(314)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

5.3.3.2 Areic mass and accumulation of herbage

The areic mass of herbage after 19 days regrowth for each individual grazing period is given in Appendix 8. The mean areic mass of herbage after regrowth per treatment is shown in Table 40. There was a significant effect of A_0 on $M_{i+1,0}$ ($P < 0.01$). Due to variation in weather conditions (and therefore in growing conditions) over time the variation in $M_{i+1,0}$ between experimental periods was sometimes high. The areic mass of herbage after regrowth depends on the residual herbage of the preceding grazing period, on the accumulation of new plant material and on the losses of herbage due to decay.

The accumulation of herbage during regrowth (ΔM_i^r) gives an estimation of the balance between growth of new plant material and losses due to senescence and decomposition.

Table 41. Accumulation of herbage during regrowth ($\Delta M_{i,0}^r$).

Treatment			X	Y	Z	Mean
ms	1978	es	1608(700)[1]	2133(531)	2547(634)	2105(654)
		ls	631(211)	787(286)	1163(393)	842(339)
	1979	es	1632(735)	2340(579)	2705(317)	2254(659)
		ls	811(572)	1030(421)	880(120)	911(299)
ms + lm	1978	es	1619(696)	2103(538)	2584(520)	2102(641)
		ls	578(129)	741(286)	1128(268)	797(313)
	1979	es	1537(696)	2254(572)	2627(284)	2168(649)
		ls	726(407)	983(304)	886(130)	883(235)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

Table 42. Regression coefficients in the multiple regression of accumulation of herbage during regrowth on daily herbage allowance (after adjustment for the effects of EP and G).

A_0			$\Delta M_{i,0}^r = a + b\,A_0$			$\Delta M_{i,0}^r = a + b\,A_0 + c\,A_0^2$					
			b	s_b	P(b)	b	s_b	P(b)	c	s_c	P(c)[1]
ms	es	1978	51.8	11.0	***	255.7	71.7	***	-4.49	1.57	**
		1979	69.9	10.2	***						n.s.
	ls	1978	33.4	7.8	***						n.s.
		1979	38.0	10.7	***	151.7	2.8	***	-2.21	0.05	***
ms + lm	es	1978	46.3	10.1	***	224.2	68.6	***	-3.51	1.35	*
		1979	62.3	9.9	***						n.s.
	ls	1978	27.7	6.4	***						n.s.
		1979	28.9	8.3	***	139.0	2.1	***	-1.63	0.03	***

1. Effect of inclusion of A_0^2 in the regression after A_0 has already been included.

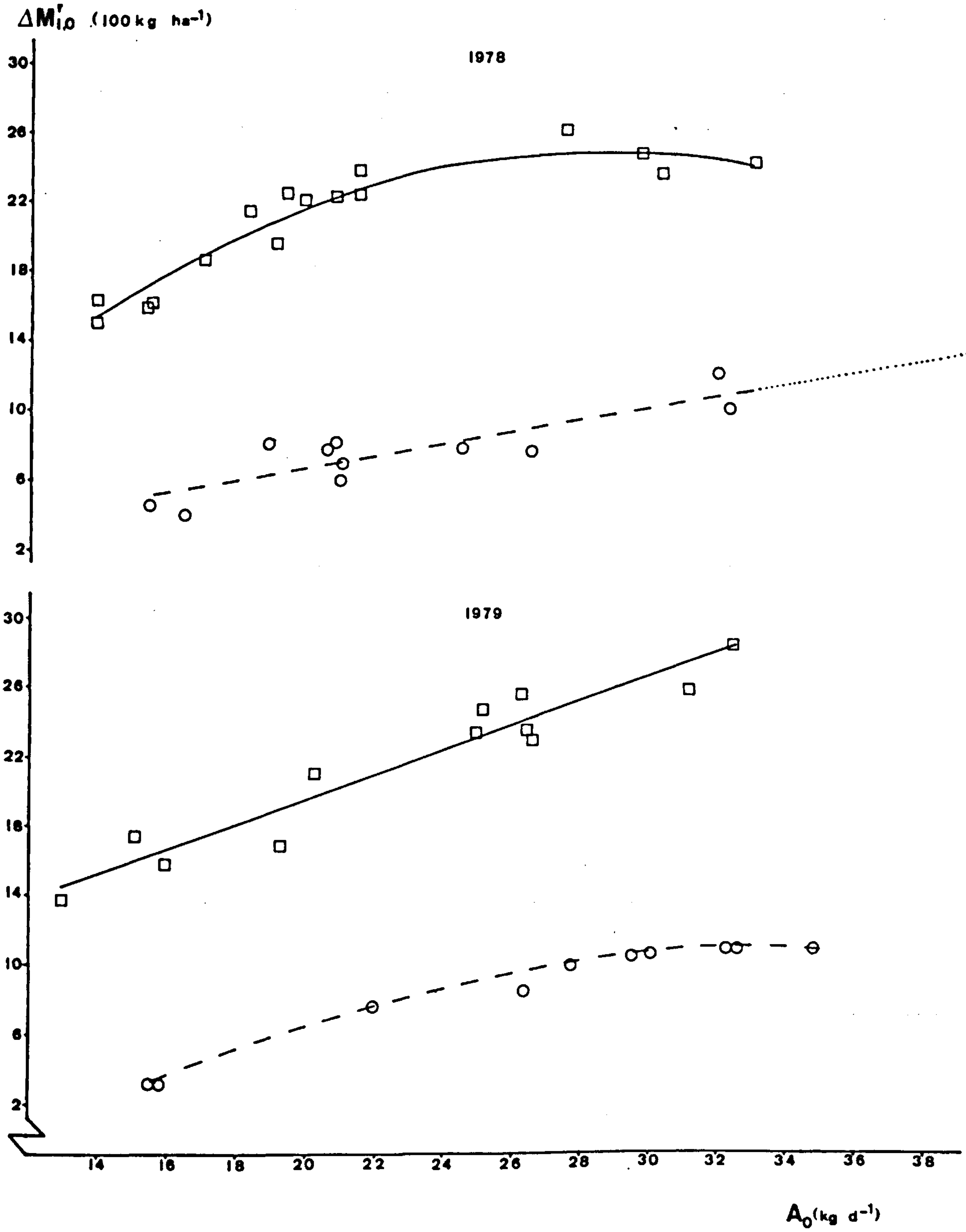


Figure 9. Effect of daily allowance of organic matter of herbage (A_0, ms) on accumulation of organic matter of herbage during regrowth ($\Delta M^r_{1,0}$), after correction for effects of experimental period and animal group. □ early summer, solid lines; ○ late summer, broken lines.

The mean accumulation of herbage during regrowth is shown in Table 41; data per grazing period can be found in Appendix 8. In es $\Delta M^r_{i,0}$ was much higher than in ls due to the better growing conditions in es (Appendix 3). The A_0 had a significant effect on $\Delta M^r_{i,0}$; particularly the effects were strong in es. A multiple regression analysis was performed with the $\Delta M^r_{i,0}$ data (ms + lm) and the A_0 data (ms and ms + lm). Analyses showed significant effects of Se ($P < 0.01$), EP ($P \leq 0.01$), G (only in 1978, $P < 0.05$), A_0 ($P < 0.01$), A_0 Se (only in 1979, $P < 0.025$) and A_0^2 Se (only in 1978, $P < 0.05$) on $\Delta M^r_{i,0}$ when the respective terms were put in the regression with the same order.

After adjustment for the effects of EP and G regression coefficients of A_0-$\Delta M^r_{i,0}$ relationships were calculated (Table 42 and Figure 9). In the es of 1978 and the ls of 1979 the addition of A_0^2 improved regression results significantly. The values of b in ls were much lower than in es and were higher when A_0 was determined with ms than when the low level was taken as the reference level.

5.3.3.3 Chemical composition, digestibility and nutritive value of herbage

The in-vitro digestibility of the herbage after regrowth, in each grazing period, is given in Appendix 8. The mean chemical composition, in-vitro digestibility and nutritive value of the herbage after regrowth is shown in Tables 43, 44 and Appendix 9 respectively. The differences in chemical composition and in-vitro digestibility between ms and lm samples of M_{i+1} were in the same direction and of the same order of magnitude as at the start of grazing period i (Section 5.3.2.8). The differences in w_{dXP}, d_0 and e_{NE_1} between es and ls were also in the same direction and of the same order of magnitude as at the start of the preceding grazing period.

The w_{XP}/O of M_{i+1} was significantly ($P < 0.01$) higher than that of M^f_i. Sampled at cutting height of the ms, only in ls the w_{XF}/O and w_{NDF}/O of M_{i+1} were significantly lower than those of M^f_i. Except in the es of 1978 the d_0 (ms) of M_{i+1} was significantly higher than that of M^f_i. The nutritive value (both w_{dXP}, w_{dO} and e_{NE_1}) of the herbage after regrowth (ms + lm) was significantly higher than that of residual herbage. Because of the content of mature material in M_{i+1} and to the high level of M_{i+1} (especially in es) the d_0 (ms and ms + lm) and e_{NE_1} (ms + lm) of M_{i+1} were significantly lower than those of M_i; the difference in w_{dXP} between M_{i+1} and M_i varied between

Table 43. Chemical composition of herbage after regrowth (M_{i+1}).

			100 w_T	100 w_O/T	100 w_{XP}/O	100 w_{XF}/O	100 w_{NDF}/O
ms	1978	es	16.0	89.8	23.0	27.8	59.3
		ls	19.9	87.1	25.4	23.2	55.1
	1979	es	15.9	88.8	23.9	26.6	55.6
		ls	20.7	88.5	27.7	22.7	53.4
lm	1978	es	26.5	84.0	20.9	28.9	61.3
		ls	33.4	78.6	23.1	25.3	62.3
	1979	es	23.9	73.2	21.3	26.5	58.5
		ls	38.7	70.8	24.7	24.5	58.2

Table 44. In-vitro O digestibility of herbage after regrowth (100 w_{dO}/O of M_{i+1}).

Treatment			X	Y	Z	Mean
ms	1978	es	77.5(4.33)[1]	76.9(3.45)	76.6(1.62)	77.0(3.15)
		ls	71.4(2.51)	72.7(4.32)	71.2(3.03)	72.0(3.43)
	1979	es	81.3(1.58)	78.9(0.57)	78.7(1.70)	79.5(1.53)
		ls	75.5(2.12)	75.3(2.05)	77.0(2.69)	76.2(2.32)
lm	1978	es	63.8(3.25)	63.2(3.87)	63.2(2.62)	63.4(3.73)
		ls	45.7(4.87)	46.9(4.05)	45.8(3.76)	46.3(3.83)
	1979	es	58.1(7.96)	60.8(5.81)	59.0(8.81)	59.7(6.52)
		ls	43.3(10.61)	45.3(3.76)	44.0(5.47)	44.3(5.43)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.

periods.

The effect of A_0 on the in-vitro digestibility of $M_{i+1,0}$ (ms + lm !) was examined by multiple regression analysis. There were significant effects of Se ($P < 0.01$), Se EP ($P < 0.01$) and A_0 ($P < 0.05$ in 1978, $P < 0.01$ in 1979) on d_0 of M_{i+1} when put in the regression with this order of terms. A significant A_0-Se interaction could be shown in 1978 ($P < 0.05$) and in 1979 ($P < 0.01$). Effects of A_0^2 were only significant in 1978 ($P < 0.01$). After adjustment for the effects of EP and G, regression coefficients of A_0-d_0 of M_{i+1} relationships were calculated (Table 45 and Figure 10). In the early summer non-significant regression coefficients were established; only in the ls of 1978 d_0 of M_{i+1} significantly increased at higher levels of A_0. In the ls of 1979 the effect of A_0 was in the same direction but not significant probably due to the low number of measurements.

This regression analysis was performed with the d_0 of $M_{i+1,0}$ cut by ms and lm. When the same analysis was done with the herbage samples cut by ms only, no effects of A_0 could be shown (compare also Table 44 with Appendix 9)!

Table 45. Regression coefficients in the multiple regression of digestibility of herbage after regrowth on daily herbage allowance (after adjustment for the effects of EP and G).

A_0			$d_0 = a + b A_0$			$d_0 = a + b A_0 + c A_0^2$					
			b	s_b	P(b)	b	s_b	P(b)	c	s_c	P(c)[1]
ms	es	1978	0.022	0.065	n.s.						n.s.
		1979	-0.013	0.057	n.s.						n.s.
	ls	1978	0.221	0.064	***	1.400	0.181	***	-0.0217	0.0033	***
		1979	0.585	0.220	n.s.						n.s.
ms + lm	es	1978	0.020	0.059	n.s.						n.s.
		1979	-0.010	0.051	n.s.						n.s.
	ls	1978	0.177	0.057	***	1.091	0.280	***	-0.0131	0.0039	*
		1979	0.420	0.197	n.s.						n.s.

1. Effect of inclusion of A_0^2 in the regression after A_0 has already been included.

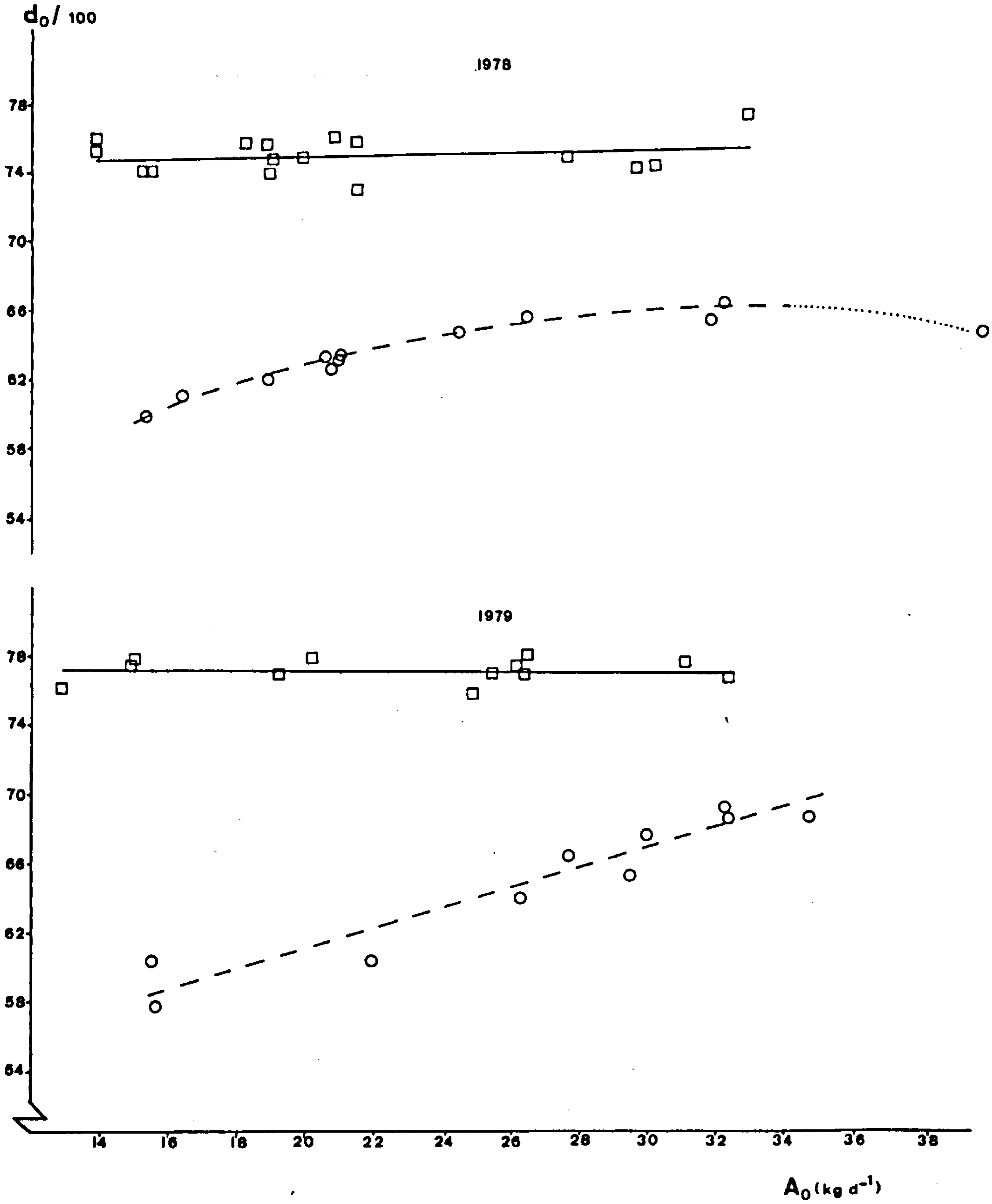


Figure 10. Effect of daily allowance of organic matter of herbage (A_0, ms) on in-vitro digestibility of organic matter of herbage after regrowth (d_0 of M_{i+1}, ms + lm), after correction for effects of experimental period and animal group. □ early summer, solid lines; ○ late summer, broken lines.

Table 46. Accumulation of nutrients during regrowth of herbage (ms + lm).

Treatment			X	Y	Z	Mean
$\Delta M^r_{i,dXP}$	1978	es	357(122)[1]	416(88)	435(104)	406(98)
		ls	150(65)	178(52)	201(67)	177(56)
	1979	es	322(56)	419(37)	494(43)	413(75)
		ls	200(85)	260(61)	221(43)	228(55)
$\Delta M^r_{i,dO}$	1978	es	1253(580)	1583(489)	1901(464)	1580(527)
		ls	506(129)	614(221)	827(274)	640(232)
	1979	es	1281(589)	1769(391)	2033(257)	1713(474)
		ls	638(439)	798(323)	630(111)	682(237)
$\Delta M^r_{i,NE_1}$ [2]	1978	es	1718(778)	2136(646)	2509(622)	2125(691)
		ls	703(193)	849(290)	1098(346)	875(298)
	1979	es	1759(752)	2380(466)	2735(343)	2314(598)
		ls	902(598)	1121(441)	882(154)	957(326)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.
2. kVEM ha^{-1}.

5.3.3.4 Areic mass and accumulation of nutrients from herbage

The mean areic mass of nutrients from herbage after regrowth is shown in Appendix 10. This areic mass of nutrients was significantly ($P < 0.01$) affected by treatments; regression coefficients are not given here because these were only estimated for the net accumulation of digestible herbage during regrowth (see below).

The change in areic mass of nutrients during regrowth was calculated by subtracting $M^f_{i,dXP}$ from $M_{i+1,dXP}$; the same was done with the areic masses of d_O and NE_1. The means per treatment are shown in Table 46; data per grazing period can be found in Appendix 8. There was a strong positive effect of A_O on the accumulation of nutrients during regrowth. Regression analysis was performed with the $\Delta M^r_{i,dO}$ data (ms + lm) and

Table 47. Regression coefficients in the multiple regression of accumulation of digestible herbage during regrowth on daily herbage allowance (after adjustment for the effects of EP and G).

A_O			$\Delta M^r_{i,dO} = a + b A_O$			$\Delta M^r_{i,dO} = a + b A_O + c A_O^2$					
			b	s_b	P(b)	b	s_b	P(b)	c	s_c	P(c)[1]
ms	es	1978	34.5	8.5	***	177.6	60.5	***	-3.16	1.33	*
		1979	47.6	7.2	***						n.s.
	ls	1978	19.0	5.6	**						n.s.
		1979	24.7	6.0	*						n.s.
ms + lm	es	1978	30.8	7.8	***						n.s.
		1979	42.6	6.8	***						n.s.
	ls	1978	15.7	4.7	**						n.s.
		1979	18.7	4.9	*						n.s.

1. Effect of inclusion of A_O^2 in the regression after A_O has already been included.

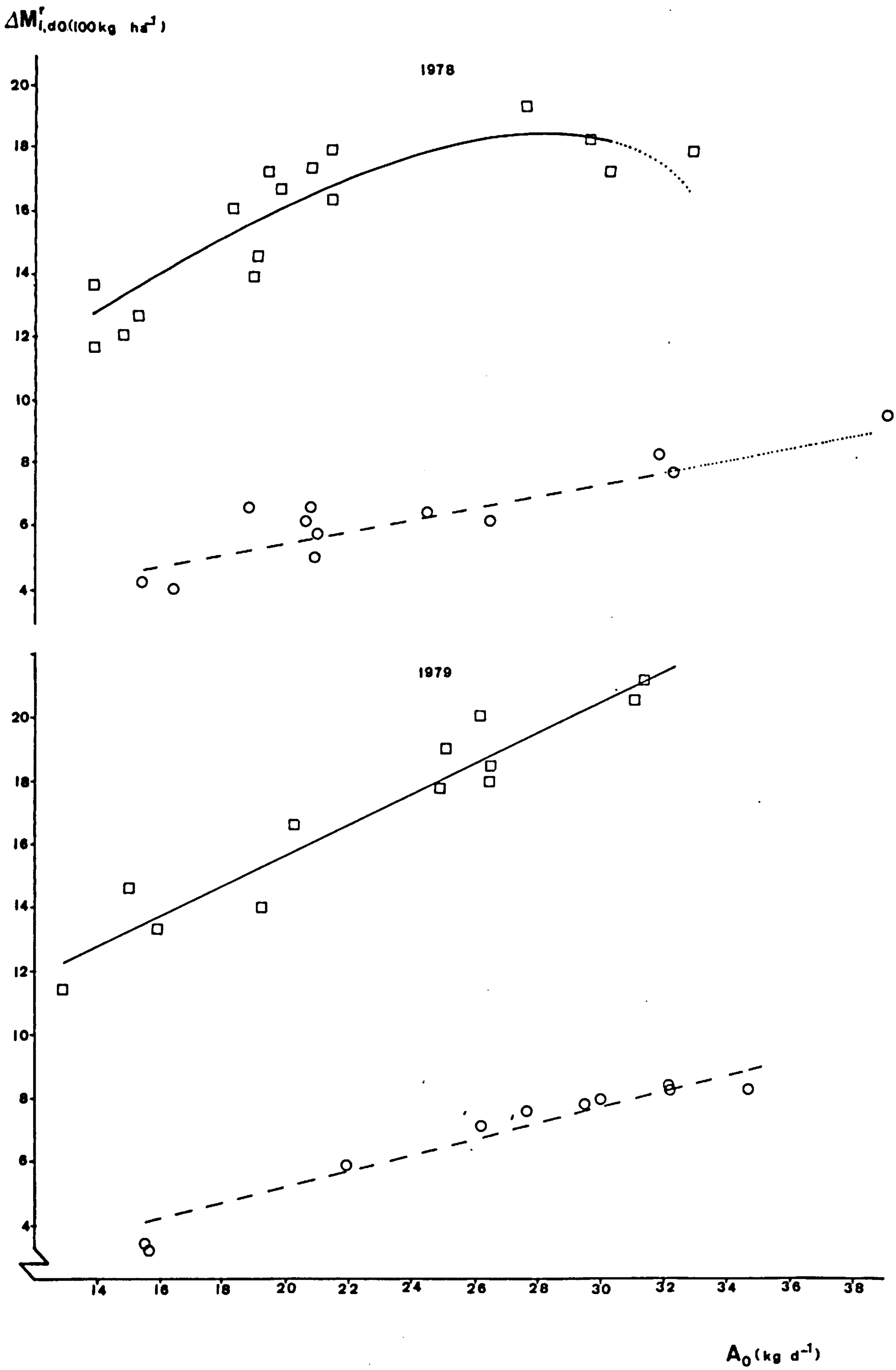


Figure 11. Effect of daily allowance of organic matter of herbage (A_O, ms) on accumulation of digestible organic matter of herbage during regrowth ($\Delta M^r_{i,dO}$) after correction for effects of experimental period and animal group. □ early summer, solid lines; ○ late summer, broken lines.

A_0 data determined both with ms and with ms + 1m. The $\Delta M^r_{i,dO}$ was significantly affected by Se (P <0.01), Se EP (P <0.01), G (P <0.05 only in 1978) and A_0 (P <0.01) when put in the regression with this order of terms. The A_0-Se interaction was only significant in 1979 (P <0.025).

After adjustment for the effects of EP and G regression coefficients of A_0-$\Delta M^r_{i,dO}$ relationships were calculated (Table 47 and Figure 11). In the es of 1978 the addition of A_0^2 improved regression results significantly, in the 1s of 1979 this effect was not significant, probably due to the low number of measurements. The value of b in the 1s of 1979 was significantly lower than in the es.

5.3.4 Combination of results during grazing and regrowth periods

The data for periods where both consumption and regrowth were measured, are shown in the Tables 48 (O), 49 (dXP), 50 (dO) and 51 (kVEM). Both the absolute levels of areic herbage masses, of changes in areic herbage masses and of herbage consumption, as the relative values of the treatments Y and Z in relation to treatment X (= 100) are reported. The observations of both years were added together per season due to the low number of observations per season per year.

I_0 of herbage increased at higher levels of A_0, however the increase of I_0 was small relative to the increase in A_0 (which is also shown in the regression coefficients in Section 5.3.2.5). This resulted in a strong negative effect of A_0 on C_0 and on degree of consumption (c). The high M^f_0 at high levels of A_0 however had a positive influence on the rate of herbage accumulation during regrowth. In these trials with regrowth periods of 19 days, the lower areic consumption of herbage was about equal to the higher herbage accumulation during regrowth at higher levels of A_0, which is shown in the comparable levels of $C_{i,O} + \Delta M^r_{i,O}$ for the treatments.

In these trials it was not possible to graze the pastures a second time after regrowth, so consumption of M_{i+1} was not measured. The areic mass of herbage after regrowth however, can also be used after cutting e.g. as hay or silage. When the assumption is made that M_{i+1} cut above the cutting height of the ms is consumed completely, the total areic consumption of both periods was equal to $C_i + M_{i+1}$ (ms). The $C_{i,O} + M_{i+1,O}$ (ms) increased at higher levels of A_0, while areic consumption in grazing period i alone decreased at higher A_0.

The same calculations of $C_i + M_{i+1}$ (ms) were done assuming total losses (1) in the utilization of M_{i+1} (ms) in preserved form of fractions of 0.15, 0.20, 0.20 and 0.25 for O, dXP, dO and NE_1 respectively (Weissbach, 1970; Honig, 1976). In the tables $C_i + (1 - 1)M_{i+1}$ (ms) is indicated as U. There was a positive effect of A_0 on U_0. When calculating U the assumption was made that total losses in the utilization of M_{i+1} were equal for the treatments; and also the daily intake of the preserved herbage was assumed to be equal for the treatments. The digestibility of the herbage after regrowth cut by ms did not differ between treatments (Table 44), therefore differences in daily intake between treatments due to the quality of the herbage cannot be expected. The more intensive contamination of preserved herbage with faeces at low allowances could possibly work to the advantage of the high allowance treatments.

Table 48. Combination of data of grazing and regrowth periods (absolute and relative); all expressed in O (1978 + 1979; ms + lm).

	es				ls				es + ls
Treatment	X	Y	Z	Mean	X	Y	Z	Mean	Mean
A_i (ms)	14.7(100)[2]	20.9(142)[2]	30.3(206)[2]	22.1	15.6(100)	22.2(142)	32.5(208)	22.5	22.3
I_i[1]	11.5(100)	12.6(110)	13.7(119)	12.6	11.7(100)	13.9(119)	16.4(140)	13.8	13.2
c	0.78(100)	0.60(77)	0.45(58)	0.57	0.75(100)	0.63(84)	0.50(67)	0.61	0.59
M_i	2888(100)	3063(106)	2930(101)	2977	2509(100)	2526(101)	2550(102)	2526	2767
M_i^f	981(100)	1548(158)	1982(202)	1527	1126(100)	1353(120)	1679(149)	1359	1449
M_{i+1} (ms)	1988(100)	3008(151)	3828(193)	2982	934(100)	1439(154)	1947(208)	1401	2248
M_{i+1}	2471(100)	3490(141)	4342(176)	3474	1743(100)	2238(128)	2698(155)	2192	2879
C_i	2195(100)	1864(85)	1334(61)	1793	1593(100)	1413(89)	1157(73)	1409	1615
ΔM_i^r	1491(100)	1942(130)	2361(158)	1947	617(100)	885(143)	1019(165)	833	1430
$C_i + \Delta M_i^r$	3686(100)	3806(103)	3695(100)	3740	2210(100)	2298(104)	2176(98)	2242	3045
$C_i + M_{i+1}$ (ms)	4183(100)	4872(116)	5162(123)	4775	2527(100)	2852(113)	3104(123)	2810	3863
U (ms)	3885(100)	4421(114)	4588(118)	4328	2387(100)	2636(110)	2812(118)	2600	3526

1. ms + lm if not specified.
2. Relative values (X = 100).

Table 49. Combination of data of grazing and regrowth periods (absolute and relative); all expressed in dXP (1978 + 1979; ms + lm).

	es				ls				es + ls
Treatment	X	Y	Z	Mean	X	Y	Z	Mean	Mean
A_i (ms)	2.65(100)[2]	3.62(137)[2]	5.46(206)[2]	3.91	3.33(100)	4.63(139)	6.82(205)	4.74	4.30
I_i[1]	2.27(100)	2.56(113)	3.16(139)	2.66	2.87(100)	3.37(117)	4.20(146)	3.41	301
M_i	520(100)	531(102)	528(102)	528	536(100)	527(98)	535(100)	532	530
M_i^f	149(100)	227(152)	298(200)	227	196(100)	237(121)	300(153)	239	233
M_{i+1} (ms)	396(100)	553(140)	657(166)	542	212(100)	308(145)	387(183)	296	428
M_{i+1}	481(100)	631(131)	734(153)	622	367(100)	456(124)	523(143)	444	539
C_i	425(100)	369(87)	302(71)	364	384(100)	339(88)	294(77)	342	354
ΔM_i^r	332(100)	404(122)	436(131)	394	171(100)	219(128)	223(130)	205	306
$C_i + \Delta M_i^r$	757(100)	773(102)	738(97)	758	555(100)	558(101)	517(93)	547	660
$C_i + M_{i+1}$ (ms)	821(100)	922(112)	959(117)	906	596(100)	647(109)	681(114)	638	782
U (ms)	742(100)	811(109)	828(112)	798	554(100)	585(106)	604(109)	579	696

1. ms + lm if not specified.
2. Relative values (X = 100).

Table 50. Combination of data of grazing and regrowth periods (absolute and relative); all expressed in dO (1978 + 1979; ms + lm).

	es				ls				es + ls
Treatment	X	Y	Z	Mean	X	Y	Z	Mean	Mean
A_i (ms)	11.61(100)[2]	16.58(143)[2]	23.85(205)[2]	17.44	10.69(100)	15.30(143)	22.10(207)	15.45	16.52
I_i[1]	9.59(100)	10.62(111)	11.38(119)	10.57	9.74(100)	11.51(118)	13.10(134)	11.33	10.92
M_i	2280(100)	2430(107)	2306(101)	2353	1719(100)	1741(101)	1734(101)	1733	2065
M_i^f	679(100)	1140(168)	1499(221)	1125	538(100)	741(138)	1008(187)	740	946
M_{i+1} (ms)	1565(100)	2326(149)	2926(187)	2303	686(100)	1060(155)	1442(210)	1033	1713
M_{i+1}	1861(100)	2622(141)	3238(174)	2604	1075(100)	1446(135)	1768(164)	1406	2047
C_i	1827(100)	1566(86)	1108(61)	1498	1325(100)	1166(88)	922(70)	1158	1340
ΔM_i^r	1181(100)	1481(125)	1739(147)	1479	537(100)	704(131)	760(142)	666	1101
$C_i + \Delta M_i^r$	3008(100)	3047(101)	2847(95)	2977	1862(100)	1870(100)	1682(90)	1824	2441
$C_i + M_{i+1}$ (ms)	3392(100)	3892(115)	4034(119)	3801	2011(100)	2226(111)	2364(118)	2191	3053
U (ms)	3079(100)	3427(111)	3449(112)	3340	1874(100)	2014(107)	2076(111)	1984	2710

1. ms + lm if not specified.
2. Relative values (X = 100).

Table 51. Combination of data of grazing and regrowth periods (absolute and relative); all expressed in kVEM (1978 + 1979; ms + lm).

Treatment	es X	es Y	es Z	es Mean	ls X	ls Y	ls Z	ls Mean	es + ls Mean
A_i (ms)	15.46(100)[2]	22.20(144)[2]	32.03(207)[2]	23.35	14.55(100)	20.73(142)	29.95(206)	20.96	22.24
I_i[1]	13.09(100)	14.56(111)	15.82(121)	15.55	13.56(100)	16.00(118)	18.35(135)	15.79	15.13
M_i	3037(100)	3253(107)	3097(102)	3149	2340(100)	2359(101)	2350(100)	2351	2779
M_i^f	883(100)	1485(168)	1966(223)	1469	696(100)	965(139)	1325(190)	965	1235
M_{i+1} (ms)	2122(100)	3119(147)	3888(183)	3084	939(100)	1441(153)	1940(207)	1401	2303
M_{i+1}	2508(100)	3500(140)	4287(171)	3472	1448(100)	1941(134)	2364(163)	1887	2736
C_i	2486(100)	2140(86)	1535(62)	2051	1839(100)	1617(88)	1290(70)	1610	1846
ΔM_i^r	1625(100)	2015(124)	2322(143)	2003	753(100)	976(130)	1039(138)	922	1501
$C_i + \Delta M_i^r$	4111(100)	4155(101)	3857(94)	4054	2592(100)	2593(100)	2329(90)	2532	3347
$C_i + M_{i+1}$ (ms)	4608(100)	5259(114)	5423(118)	5135	2778(100)	3058(110)	3230(116)	3011	4149
U (ms)	4078(100)	4479(110)	4451(109)	4364	2543(100)	2698(106)	2745(108)	2661	3573

1. ms + lm if not specified.
2. Relative values (X = 100).

The levels of $C_i + \Delta M_i^r$ (ms + lm) when expressed in mass of nutrients (dXP, dO and kVEM) were about equal for the treatments; due to the smaller differences between treatments in ΔM_{dXP}^r, ΔM_{dO}^r and $\Delta M_{NE_1}^r$ than in ΔM_0^r there was a tendency of declining $C_i + \Delta M_i^r$ at higher A_0. The positive effect of A_0 on $C_i + M_{i+1}$ (ms) when expressed in mass of nutrients was comparable to this effect measured in mass of organic matter, however the relative differences between treatments were somewhat smaller (e.g. if treatment X = 100 then $C_i + M_{i+1}$ (ms) of treatment Z was on average over the seasons 123 (O), 116 (dXP), 118 (dO) and 117 (kVEM).

If corrections were made for the total losses when M_{i+1} was utilized in preserved form, a positive effect of A_0 on U_0 (expressed in mass of nutrients) could be shown. However the relative differences between treatments were smaller than when the A_0 effect on U_0 was measured in mass of organic matter (e.g. if treatment X = 100 then treatment Z was on average over the seasons 118 (O), 111(dXP), 112 (dO) and 109 (kVEM).

When the assumption is made that the daily intake of M_{i+1} in preserved form did not differ between treatments (at comparable digestibility between treatments) these results show that both herbage consumption per animal and areic herbage consumption were affected positively by daily herbage allowance when the results of the grazing and regrowth periods were taken together.

5.4 DISCUSSION

5.4.1 Daily herbage allowance

Variation in the treatment levels of daily herbage allowance were caused by:
- Differences between the expected and the actual rate of herbage accumulation in the exclosure. This was the case in EP 1, 3, 5 and 13 in 1978 and in EP 7, 10 and 11 in 1979. With the present-day accuracy of weather forecast (especially the solar radiation) over 3-day periods this source of bias in determining A is inevitable.
- Differences between the rapid method of estimating T-content of exclosure samples and the laboratory method. This was the case in EP 7, 10 and 16 in 1978 and in EP 3 in 1979.
- Variation in herbage mass within the sward. Although the swards used were quite homogeneous, values of M_0 (cut on the same day) between treatments varied from 0 to 160 kg ha^{-1}. The spatial distribution of the herbage was regular, due to the use of the pre-cut swards which consisted predominantly of perennial ryegrass. Reducing variation in M between treatments still further is hardly possible, only the use of the cutting results in the plots to be grazed (instead of in the exclosure) for calculating areas to be fenced might give some improvement. However, the time needed for cutting, dry matter analysis and fencing would give a rather large time lag between moment of cutting and moment of start of grazing then, with possible changes in herbage mass during this period.
- The accumulation factor g was taken as a constant (0.50) when calculating areas to be fenced. However, the real figures as calculated with Linehan's equation when all data on herbage mass were available differed between treatments (Section 4.2).

The influence of most of the factors mentioned above was in the same direction for all levels of A, therefore the differences between treatments were not influenced within EP's. Although there was variation in each of the A_0 levels between periods the total ranges of each of the three treatments did not overlap each other. As a consequence of variation in A_0 between EP's, regression methods were used for the statistical analysis of the results.

It will be realized that the treatments were not applied daily but that the levels of 'daily' herbage allowance were given at the start of the grazing period by supplying 3 times A_0 for the whole 3-day period. On the first grazing day all animals grazed in an abundant amount of herbage. However on the third grazing day the available herbage mass differed strongly between treatments, so the treatment effects increased through time.

Both the ms and lm cutting height were taken as the reference level for A_0 (Section 5.3.2.2). In some allowance trials in the literature ground level was taken as the cutting height. The stubble from ground level to lm cutting height in our experiments contained a layer of dead organic material, therefore the areic mass of this stubble was rather high. The variation in stubble mass of O between periods (swards) was very large (Table 8: from 1 000 to 2 700 kg ha^{-1}); therefore it is impossible to make an estimation of allowance treatments at ground level for comparisons with experiments in the literature.

5.4.2 Areic consumption of herbage

At a comparable level of M_0 for the different treatments the residual herbage increased at higher A_0. Therefore the extra supply of herbage at higher A_0 was not consumed completely but increased the residual herbage. As a consequence a negative effect of A_0 on C_0 was evident in all periods.

The effect of allowance on areic consumption of herbage can also be expressed as the degree of consumption (c) = the fraction of areic mass of herbage (including herbage accumulation) that was consumed. The degree of consumption was calculated by combining Table 17 and Table 23. In es 1978 the degrees of consumption for the treatments X, Y and Z were 0.76, 0.62 and 0.45 respectively; in ls 1978 the ratios were 0.76, 0.65 and 0.53 respectively. In 1979 the degrees of consumption for the treatments X, Y and Z were 0.79, 0.58 and 0.49 respectively; in ls 1979 the ratios were 0.69, 0.57 and 0.47 respectively. In these calculations A_0 was determined above 4.5 cm. When the lm cutting height is taken as the reference level the degrees of consumption were about 0.10 lower than at the ms cutting height.

These results indicate that c depends on the cutting height of the samples from which A was derived. The degree of consumption also depends largely on the amount of herbage initially available per area, because if the herbage is grazed down to a given quantity of residue, the larger the herbage mass originally, the higher will be c.

Harkess et al. (1972) found degrees of consumption of 0.87, 0.75, 0.70 and 0.56 in a first grazing cycle with sheep at levels of A_0 above ground level of 23, 33, 58 and 96 g W^{-1} d^{-1}, respectively.

Broster et al. (1963) found a linear decrease of degree of consumption from 0.88 to 0.64 at higher A_T over a narrow range of A_T from 27 to 39 g W^{-1} d^{-1} with growing dairy heifers (the cutting height was not stated).

It should be realized that these degrees of consumption are only valid for a single defoliation. The efficiency of consumption for a series of grazings is much higher than the averaged degrees of consumption at single grazings because residual herbage is used as new at each subsequent grazing (Leaver, 1974, 1976; Marsh, 1977).

Wilkinson & Prescott (1970) found efficiencies of consumption of 1.11 and 0.77 in their first experiment where A_0 of 4.2 and 6.5 kg d^{-1} (>0 cm) were supplied to calves. The impossible value of 1.11 was attributed by the authors to consumption of herbage outside of the fences. However a more likely explanation is that the method of estimation of herbage intake was biased (incomplete marker recovery, d_0 of cut herbage $\neq$ d_0 of selected herbage).

Efficiency of consumption was also measured in a grazing experiment with dairy cows by Gordon et al. (1966). In their second and third experiment the plots were clipped very closely after each grazing to minimize the differential effects of treatments on plant accumulation. At levels of A_T of 11, 15 and 19 kg d^{-1} (>4 cm) the efficiency of consumption was 0.95, 0.83 and 0.65, respectively. Efficiency of consumption over the grazing season has also been measured in allowance trials of Greenhalgh (1970), Harkess et al. (1972), Leaver (1974) and Marsh (1977) and declined in all trials at higher A_0. However in these experiments the paddocks were not trimmed after grazing, so herbage mass after regrowth was not the same for the treatments. The combined effects of herbage allowance and herbage regrowth on areic herbage consumption will be discussed in 5.4.10.

The shape of the A_0-C_0 relationships in the experiments was more or less the same for the 4 seasons examined (Figure 4). In the es of 1979 however the estimated C_0 from the regression equation increased above levels of A_0 higher than 32 kg d^{-1} (>4.5 cm); however the shape of the relationship was determined by one measurement only (EP 7 Group 3). In theory C_0 must steadily decline at higher levels of A_0 once maximal individual intakes have been reached, which also occurred in the other seasons. Therefore the shape of the A_0-C_0 curve in the A_0 range above 32 kg d^{-1} in the es of 1979 was judged as unreliable and was indicated with a dotted line.

If we assume that the effect of A_0 on I_0 is the same at different levels of M_0, then the regression coefficient of the A_0-C_0 relationship depends largely on the absolute level of M: e.g. compare A_0 levels of 15 and 30 kg d^{-1} with corresponding I_0 levels of 11.4 and 14.9 kg d^{-1}; at a M_0 (inclusive of disturbed herbage accumulation) of 1 500 the C_0 would have been 1 140 and 745 kg ha^{-1} with a linear regression coefficient of 26 kg C_0/kg A_0; at a M_0 of 3 000 kg ha^{-1} the C_0 would have been 2 280 and 1 490 kg ha^{-1} respectively with a linear regression coefficient of 53 kg C_0/kg A_0. So at higher levels of M_0 the regression coefficients of the A_0-C_0 relationship will increase. Thus the differences in regression coefficients between seasons and years (Table 22) can mainly be attributed to differences in M_0 (Table 18).

The ratios of the different allowance treatments when determined with ms were of course the same as when determined with ms + 1m (M_0 (ms) and M_0 (1m) were the same for the treatments). However the absolute differences between treatments determined with ms were not the same as when determined with ms + 1m because the allowance in the 1m fraction was affected with the same factor as in the ms fraction. The absolute differences in A_0 (ms) between treatments X and Z in 1978 and 1979 were 15.2 and 15.4 kg d^{-1} respectively the differences in A_0 (ms + 1m) between treatments X and Z were 17.8 and 19.6 kg d^{-1} respectively. These differences in absolute levels of A_0 between treatments explain the higher regression coefficients with A_0 (ms) than with A_0 (ms + 1m).

5.4.3 Daily herbage intake

In most strip grazing experiments with dairy cows a curvilinear relationship between A_0 and I_0 was established (Table 3). Kirchgessner & Roth (1972a) and Stehr & Kirchgessner (1976) found that intake increased linearly with A_T up to allowances of 35 kg d^{-1}; however the treatments were not applied simultaneously. The A_0-I_0 relationship of Experiments 3 and 4 could best be described with a linear function (Table 25 and Figure 5). On theoretical grounds Zemmelink (1980) built up a curvilinear exponential A_0-I_0 curve which was shown to fit reasonably well on experimental results where tropical forages were fed to sheep indoors. When this model was applied to the experimental results the fit of the data around the regression line was worse than when the linear (or linear + square) function was applied (Section 5.3.2.5). In 1978 (especially in es) there was only a small tendency toward an exponential curve (Figure 5); in the ls of 1979 an exponential curve would fit reasonably well. Due to the very high herbage consumption of Group 3 in EP 7 of 1979 the A_0-I_0 relationship did still curve upwards in the es of 1979 at allowance levels over 30 kg d^{-1}. Although there are no reasons for doubt on this intake figure the single measurement in this A_0-range cautions against paying too much attention to the shape of the relationship in this period.

The seasonal regression coefficients varied from 0.16 to 0.29 kg I_0/kg A_0 (ms). Greenhalgh et al. (1966a, 1967) found a linear regression coefficient of 0.13 kg I_0/kg A_0 (>4 cm) over a smaller A_0 range (at a lower level) in strip grazing experiments. Mott (1974) found regression coefficients of 0.40 and 0.32 kg I_T/kg A_T, however in these trials the swards were repeatedly grazed (without topping) so allowance effects were confounded with contamination effects. Combellas & Hodgson (1979) and Le Du et al. (1979b) determined A_0 at ground level; from their results linear regression coefficients ranging from 0.05 to 0.15 kg I_0/kg A_0 can be calculated; however as shown in Figure 2 of the publication of Le Du et al. (1979b) linear regression coefficients should not be calculated in these strip grazing experiments because the curves were curvilinear. The length of the grazing period in the trials of Gordon et al. (1966) was not stated but it was probably more than one day; their regression coefficients of 0.25 kg I_T/kg A_T was obtained over the A_T range of 11.1 to 19.2 kg d^{-1} (Experiments 2 and 3).

Compared with the literature the allowance effects on I_0 in our experiments were large. The allowance effects on I_0 when grazing periods of more than one day are used may be stronger than with 1-day strip grazing as is also indicated by the results of Gordon et al. (1966).

This difference may be explained by the fact that in our experiments the effects of the 'daily' herbage allowance were the strongest at the end of the grazing period i.e. that the ratio of the treatments applied on the third day was not the same ratio as that at the start of grazing. This can be shown in the next example (relative figures in brackets)

	Treatment	X	Z
	mean 'daily' herbage allowance	15 (100)	30 (200)
(1)	total herbage allowance (3 days)	45 (100)	90 (200)
(2)	daily herbage intake on the first day	15	15
(1)-(2)	total herbage allowance on the second day	30 (100)	75 (250)
(3)	daily herbage intake on the second day	12	15
(1)-(2)-(3)	total herbage allowance on the third day	18 (100)	60 (333)
(4)	daily herbage intake on the third day	7	15
$\frac{(2)+(3)+(4)}{3}$	mean 'daily' herbage intake	11.3	15

The ratio of the treatments X and Z was 1:2 at the start of grazing. The cows of treatment X however had ample supply of herbage on the first grazing day and consumed probably as much as the cows on treatment Z then (due to a preliminary period with the same treatment the X-cows may have been so hungry that they consumed even more than the Z cows on the first day). Consequently the amount available for the resting two days was relatively less than calculated with the mean allowance. On the third day the consequences of this effect were the most clear and the daily herbage intake declined strongly.

The lower A_0-I_0 regression coefficients when A_0 was determined with ms and lm compared with the ms only can be attributed to differences in absolute levels of A_0 between treatments (Section 5.4.2). The low regression coefficients of Combellas & Hodgson (1979) and Le Du et al. (1979b) can also partly be attributed to the low level of cutting (ground level) they applied. The results of studies by Combellas (1977) emphasize the influence of the level of milk yield on the relationship between A_0 and I_0. Herbage intake of high yielding cows is more sensitive to restrictions in herbage allowance than that of low yielding cows. The daily FCM production in the strip grazing experiments in the literature (Table 3) was close to 15 kg d^{-1}. However in our experiments the FCM production was on average 24 kg d^{-1} (es 27.6, ls 20.5 kg d^{-1}), which probably also added to the positive effect of A_0 on I_0 at high levels of A_0.

There was a good agreement between the estimates of the A_0-I_0 regression coefficients in different years. In ls the regression coefficients were higher than in es, although this effect was only significant in 1978. The high regression coefficient in the ls of 1978 was caused by some measurements of high herbage intake of treatment Z (EP 9, 11, 13). An explanation for this effect cannot be given but it is possible determined by factors related to the spatial distribution of the herbage mass on these swards (In these periods the sward density was the highest in 1s). A possible explanation of the allowance effects on I_0 will be given in Section 5.4.5.

5.4.4 Digestibility of the herbage

The digestibility of the herbage samples was determined in-vitro. In 1979 five in-vivo digestibility trials were carried out with sheep to check the in-vitro method especially for products with an exceptional composition e.g. ms fractions of M^f and lawn-mower fractions of M or M^f. The in-vivo O digestibility of M (ms) in EP 5, M^f (ms) in EP 6 treatment Y, M^f (ms) in EP 6 treatment Z, M^f (lm) in EP 6 treatment Y, M^f (lm) in EP 12 treatment Z was 0.814, 0.728, 0.747, 0.512 and 0.605 respectively. Corresponding in-vitro estimates of O digestibility using 3-4 standard herbage samples were 0.816, 0.712, 0.742, 0.511 and 0.584 respectively. From these results the conclusion could be drawn that the in-vitro method of Tilley and Terry can provide reliable estimates of the in-vivo digestibility of herbage, even in samples with a very high crude ash content, provided that standard samples of known in-vivo digestibility are included in each in-vitro series.

The tendency of the grazing animal to selective intake has already been pointed out in the review of the literature (Section 1.3.3.2). Comparison of the quality of herbage at start and finish of grazing can provide information on this selective intake by grazing animals. The higher content of XL and NDF in M^f and the lower content of XP in M^f compared to those fractions in M are in agreement with results of Waite et al. (1950), Kirchgessner & Roth (1972a) and Leaver (1974). The higher digestibility of M in comparison with M^f in the experiments is in agreement with the ground-cutting results of Harkess et al. (1972) and Walters & Evans (1979) both using grazing sheep. The difference in quality between M and M^f depends on the quantity of the residual herbage. In our experiment a strong positive effect of A_0 on d_0 of M^f could be shown (Table 33 and 34). Comparable results were achieved by Harkess et al. (1972) in a first grazing cycle with sheep where d_0 of M^f declined from 0.78 to 0.69 at an A_0 range from 96 to 23 g W^{-1} d^{-1}.

From these results the conclusion can be drawn that due to selection the digestibility of M^f was lower than that of M and therefore that the d_0 of the available herbage was lower than that of the herbage actually grazed. To compare the extent of the selectivity, for the different treatments the quality of the selected diet can be calculated using the equation:

$$d_0 \text{ (of } C_0) = \frac{d_0 \text{ (of } M_0) \ (M_0 + g \ \Delta M_0^e) - d_0 \text{ (of } M_0^f) \ M_0^f}{(M_0 + g \ \Delta M_0^e) - M_0^f} = \frac{C_{d0}}{C_0}$$

or

$$d_0 \text{ (of } I_0) = \frac{d_0 \text{ (of } A_0) \ A_0 - d_0 \text{ (of } R_0) \ R_0}{A_0 - R_0} = \frac{A_{d0} - R_{d0}}{A_0 - R_0} = \frac{D_0}{I_0}$$

Estimating d_0 using this method necessitates the in-vitro digestibility determination of two sets of samples as well as sampling for herbage mass before and after grazing; consequently the errors associated with the estimates on quality of grazed herbage are the results of accumulated errors for estimates of the four components. In the next example information from the Tables 17, 23 and 33 is combined to show the effects of A_0 on the digestibility of the grazed diet at the most extreme treatments.

Example of average results in the ls of 1978:

Treatments		X	Z
d_0 of A_0	ms	0.74	0.74
A_0	ms + lm	19.2	37.0
d_0 of A_0	ms + lm	0.68	0.68
A_{d0}	ms + lm	13.1	25.2
R_0	ms + lm	7.5	21.0
d_0 of R_0	ms + lm	0.49	0.59
R_{d0}	ms + lm	3.7	12.3
$A_0 - R_0 = I_0$	ms + lm	11.7	16.0
$A_{d0} - R_{d0} = D_0$	ms + lm	9.4	12.9
d_0 of I_0 (D_0/I_0)	ms + lm	0.81	0.81

Although the digestibility of the residual herbage differed 0.10 between the treatments in this example no difference between X and Z could be shown in the digestibility of the consumed diet. The strong selection effect in ls on both treatments is shown in the 0.07 difference in d_0 between A_0 (ms) and I_0 (ms + lm).

In this example the most extreme selection in the trials reported has been shown. In the es and ls of 1978 and in the es and ls of 1979 the difference in d_0 between A_0 (ms) and I_0 (ms + lm) were 0.024, 0.067, 0.035 and 0.066 respectively. These results are in agreement with figures of Harkess et al. (1972); they also found that digestibility of herbage consumed was higher than that of herbage available with differences of 0.034 in es and of 0.085 in ls using grazing sheep at variable allowance levels. The lower d_0 of herbage in ls compared with es was also found in the treatment with the high level of defoliation of Harkess et al. (1972) and by Harkess & Alexander (1969), Combellas & Hodgson (1979) and Le Du et al. (1979b). Possibly the low d_0 of herbage in ls can be explained by a high content of dead material in the sample especially in the lower regions of the sward. Selection for live material might possibly also explain the larger selection effects in ls compared with es. It is a pity that not more measurements have been done on live/dead ratio of herbage to check these assumptions.

As already shown in the example the d_0 of I_0 was not affected by treatment in the ls of 1978; also in the other seasons allowance levels had no significant influence on the digestibility of the selected diet on our pre-cut swards. Harkess et al. (1972) found a lower d_0 of M^f than of M, averaged over the season the differences were 0.04, 0.07, 0.11 and 0.15 for respective O allowance levels of 96, 58, 33 and 23 g W^{-1} d^{-1}. At the respective allowance levels the d_0 of I_0 was 0.05, 0.05, 0.06 and 0.07 higher than that of the available herbage. At the lowest allowance level the sheep also exercised condiderable selection showing that there is a limit to the extent to which sheep will defoliate a sward (Harkess et al., 1972). In our experiments and in the trials of Harkess et al. (1972) the digestibility of I_0 was estimated indirectly by use of the sward-cutting technique. Some caution with the results is necessary due to

- the low precision of the estimate (combination of errors in both mass and digestibility of M and M^f); however Walters & Evans (1979) found that CV's of estimates of digestibility of herbage grazed were only marginally higher by this method than by indirect animal techniques
- a possible bias in the estimate due to the assumption that the quality of the accumulated herbage during grazing was the same as that of M (ms) as in the experiments reported or the assumption that herbage growth during grazing can be neglected in 1.5-3 day grazing periods (Harkess et al., 1972).

The effect of herbage allowance on the d_0 of I_0 was also determined in strip grazing experiments with dairy cows (Table 3). Even at more severe defoliation of the swards (A_0 of 10.4 kg d^{-1} above 4 cm) in these trials than in the experiments reported here the same conclusion could be drawn: the d_0 of I_0 was not affected by the levels of A_0 applied (Greenhalgh et al., 1966a, 1967; Greenhalgh, 1970). This was even true when digestibility fell to a level which is extremely low for their climatic conditions (0.68). These results were confirmed later by Combellas & Hodgson (1979) and Le Du et al. (1979b).

Both the experimental results and the results from literature indicate that the digestibility of the ingested herbage was not influenced by variation in A_0. Therefore the decreasing intake at low allowance cannot be explained by differences in the digestibility. It should be realized that our trials and most of the allowance trials reported in the literature have been carried out on swards which were cut at the previous defoliation or which were topped each time; information on d_0 of repeatedly grazed swards (without topping) is very scarce in the literature. Apart from digestibility however there may be differences in rate of passage, and consequently in intake, between the leaf and stem fractions of herbage even at the same level of digestibility (Laredo & Minson, 1973, 1975; Ellis, 1978; Zemmelink, 1980). When the digestibility of the leaf and stem fractions in the trials reported did not differ much between treatments there may have been differences in the leaf/stem ratio of ingested herbage between treatments. However the herbage has not been split up in morphological components in these trials, so this possibility cannot be checked.

5.4.5 Grazing behaviour

Herbage intake is the product of grazing time, rate of biting and bite size (Section 1.4.1). In the experiments grazing time increased at lower levels of A_0 at the end of the grazing period. In strip grazing experiments with calves Jamieson & Hodgson (1979) however found a reduction in grazing time at low allowance in their first experiment and a less clear effect in their second experiment. They suggested that the observed differences in grazing time may involve an element of conditioning to the effects of strip grazing such that the calves were balancing the difficulty of prehension of herbage with the anticipation of an imminent fence move. At low allowances grazing time of dairy cows was also substantially depressed in a strip grazing trial of Le Du et al. (1979b). Available herbage was consumed rapidly and the animals simply abandoned any attempt to graze closer to the ground but waited for the next allocation of feed. Chacon & Stobbs (1976) however found that the grazing time of their cows first increased and then declined as *Setaria* swards were grazed down progressively over 10 days in spring. Allden & Whittaker (1970) have characterised this response showing that although grazing time initially increases in response to declining herbage mass during grazing, eventually a limit is reached beyond which grazing time does not increase. These results indicate that differences in the effect of A_0 on grazing time may exist between strip grazing and grazing of an area for more days due to differences between systems in the anticipation of animals of an imminent fence move.

Rate of biting was only measured during part (2 hours) of the day and consequently can not provide an estimate of the average daily biting rates however for comparative purposes it can be used (Jamieson, 1975; Le Du et al., 1979b). In the trials reported, rate of biting increased at lower allowance levels on the second day of grazing; on the third day however no differences in biting rates could be established. Strip grazing experiments with calves and dairy cows indicated that mean rates of biting were not substantially different across allowances (Jamieson & Hodgson, 1979) or showed a small decrease of biting rate at low allowance (Le Du et al., 1979b). When *Setaria* was grazed during 10-14 day periods Chacon & Stobbs (1976) however observed that rate of biting increased progressively as cows grazed down the plots. The differences in response may reflect differences in duration of grazing an area, the structure of the swards grazed or the different measurement procedures.

Bite size was not measured in Experiments 3 and 4. Direct observations of bite size were made by Stobbs (1973a, 1973b) who examined the effect of various sward factors in determining the bite size of cows fitted with oesophageal fistulae grazing tropical pastures. Bite size was strongly affected by herbage mass. In later experiments Chacon & Stobbs (1976) observed that bite size declined progressively as cows grazed down plots over 10-14 days periods. Jamieson & Hodgson (1979) also measured bite size directly in strip grazing experiments with calves. Mean bite size did not differ significantly between allowances; however the mean was calculated by taking the measurements made at the beginning and towards the end of grazing on a strip of herbage and probably overestimated the true mean with declining allowance.

In the trials reported here herbage intake declined strongly at low A_0, however calculated over the whole 3-day grazing period there were tendencies of increasing rates of biting and grazing time at decreasing allowance. Because herbage intake is the product of rate of biting, grazing time and bite size from these observations the qualitative conclusion can be drawn that bite size decreased at lower levels of A_0.

This is also shown in the next example based on relative figures for the means of the 3-day grazing periods:

Example with relative figures for grazing behaviour:

treatment	grazing time	rate of biting	bite size[1]	daily herbage intake
Z	100	100	100	100
X	105	102	73	78

1. bite size = daily herbage intake/grazing time · rate of biting

The mean size of bite decreased with progressive defoliation at lower levels of A_0, so the rate of intake decreased with defoliation.

The relative significance of the regulatory mechanisms which control the feed intake of penned animals may be modified in the pasture where the process of food collection adds further to the complexity of the factors regulating feed consumption. Metabolic limits were unlikely to have been of importance at low allowance. Physical factors are related to the capacity of the reticulo rumen and the rate of disappearance of digesta from the gastro-intestinal tract. Up to a critical level of d_0 intake increases with digestibility; there are indications from the literature that this critical level is 0.70 for grazing dairy cows (Section 2.4.1). In all seasons the d_0 of M^f (ms) was higher than 0.70 (Table 33), so it is unlikely that digestibility is the explaining factor. This theory is the more improbable if the quality of the selected diet was estimated reliably with the sward method i.e. no difference could be shown in the digestibility of the selected material between treatments (Section 5.4.4).

As already mentioned it is a pity that the herbage has not been divided in leaves and stems to check whether the leaf/stem ratio of ingested herbage differed between treatments. Due to the lack of this information the explanation of the decreasing intake at low allowances by limiting rate of passage of herbage from the reticulo rumen cannot be excluded. Nevertheless it seems probable that herbage intake was restricted at low allowance by behavioural limitations i.e. that a major factor influencing estimated intake probably was the size of bite ingested.

5.4.6 Consumption of nutrients and milk production

The effects of A_0 on C_{d0} were comparable to the effects of A_0 on C_0 and will not be discussed in detail. The relative differences in C_{d0} between treatments were about the same as those for C_0 (e.g. compare Table 48 and 50). This was due to the lack of differences in d_0 of I between treatments. However the absolute differences in C_{d0} between treatments were smaller than those in C_0 (due to the multiplication with about the same factor) and therefore the A_0-C_{d0} regression coefficients (Table 36) were smaller than the A_0-C_0 regression coefficients (Table 22).

The relative differences in D_0 between treatments were also about the same as those for I_0. Due to the smaller absolute differences between treatments in D_0 than those in I_0 the regression coefficients of the A_0-D_0 relationships were smaller than those of the A_0-I_0 regression. In the strip grazing allowance trials from the literature consumption of nutrients was not calculated.

The effects of A_0 on FCM production were much smaller than predicted on the basis of effects of A_0 on I_{NE_1}. However the periods in which the treatments were applied (1 week) were too short to get reliable effects of A_0 on milk production due to the ability of the cows to store or mobilize energy reserves. Measurements of milk yield responses were also of secondary interest in the studies of Combellas & Hodgson (1979) also applying short experimental periods. But in fact there were substantial effects of herbage allowance upon the yield of milk within 1 week of the treatments being imposed. Greenhalgh et al. (1966a), using experimental periods of 3-4 weeks, also observed a significant depression in milk yield with declining herbage allowance in strip grazing experiments. In later trials effects of herbage allowance over longer periods were studied; the effects of A_0 on FCM were small (Greenhalgh et al., 1967; Greenhalgh, 1970). This may simply reflect the relatively low yield of cows (12-15 kg d^{-1}); the low positive effect of A_0 on milk production in these trials is in agreement with positive effects of A_0 on live weight change (Greenhalgh et al., 1966a; Greenhalgh et al., 1967; Greenhalgh, 1970). However when the longer-term influence of A_0 upon milk yield of dairy cows initially yielding in excess of 25 kg d^{-1} was studied in strip grazing trials (Le Du et al., 1979b) very clear effects on milk production could be shown.

5.4.7 Degree of nutrient balance

It is possible to make a rough check on the accuracy of the I_0 measurements from the calculated nutrient consumption and the theoretical nutrient requirement of the cows. It should be realised that errors in the estimation of intake, as well as in the estimation of the quality of the diet ingested as well as in the reliability of the feeding standards may cause differences between nutrient intake and nutrient requirements.

The possibility of high random errors of the estimate of the nutritive value of the diet consumed with the sward-cutting technique has already been discussed (Section 5.4.4). The milk production and live weight of the animals were measured intensively in the trials described; however variation in live weight between days was high due to variation in the weight and water content of the rumen contents and to variable excretion of faeces or urine. The nutrient requirements calculated did not include a correction for changes in live weight because live weight changes could not be measured accurately during the short experimental periods of 1 week; however not accounting for realised live weight changes during longer periods (e.g. es or ls) will produce a degree of nutrient balance different from 1 which can be compared with the live weight gain or loss.

Degrees of net energy balance have been calculated with two assumptions
- The maintenance requirement of the grazing cow is 120% of that for stall-fed cows (as already indicated in Section 3.9 the surplus may range between 15 and 30%).

- ME values applying to the maintenance level of feeding are corrected to values at other feeding levels by decreasing the ME content by 1.8% per multiple of the maintenance feeding level (Section 3.9).

Averaged over all treatments in the es and ls of 1978 and in the es and ls of 1979 degrees of NE_1 balance of 0.86, 1.06, 0.99 and 1.08 were obtained in correspondence with changes in live weight of -15, +19, +3 and +24 kg respectively. The absolute difference between I_{NE_1} and K_{NE_1} (total ration) in the respective periods was -2 204, +942, -112 and +1 305 VEM d^{-1}. Assuming an energy content of 3 000 VEM per kg body weight change (Van Es, 1978) the predicted live weight change was -0.73, +0.31, -0.04 and +0.43 kg d^{-1}, respectively. Over the whole 51-days measurement period of live weight the predicted changes in live weight were -37, +16, -2 and + 22 kg. The predicted changes of live weight (predicted from degrees of nutrient balance) agreed very well with the actual changes when the animals improved in body condition (ls of 1978 and 1979).

In the es of 1979 the daily intake of nutrients with the total ration was much higher than that in the es of 1978 due to among others a higher mean A_0 (and consequently a higher mean I_0), a somewhat higher e_{NE_1} of ingested herbage and the supply of somewhat more concentrates in 1979. At a comparable level of milk production in the es of both years the cows in 1979 were about in nutrient balance due to the higher consumption of nutrients which was also shown in a rather constant live weight. In the es of 1978 however the animals had to mobilize their reserves to supply nutrients for their production and then the loss of live weight was somewhat less than predicted. This can partly be explained by the higher efficiency of ME utilization for milk production (about 0.8) for that part of the milk energy which was made from mobilized tissues in comparison with a lower (about 0.6) efficiency for fat deposition during lactation (or for milk energy production from feed). Possibly part of the reserve energy in the first month of lactation was mobilized from the body tissues without diminishing live weight (replacement of fat by water). The effect of lower changes in live weight than predicted from the degree of net energy balance of cows in early lactation with an insufficient intake of nutrients has also been found with stall-fed cows (De Visser, 1980; personal communication).

The reasons for the use of the 20% surplus for the net energy requirements for maintenance of grazing dairy cows in comparison with stall-fed cows are given in Section 3.9. This 20% surplus is not in agreement with the actual Dutch feeding standards where no surplus is accounted for due to the compensation by another process i.e. the expected lower depression of digestibility at high levels of feeding of cows consuming herbage in comparison with cows fed on winter diets. The available Dutch information of the effects of feeding level on digestibility and net energy content is described now.

On mixed forage-concentrate diets (excluding grass) the energy digestibility decreases 2-3 units per feeding level increase. However at higher feeding levels methane and urine energy losses, expressed as a fraction of gross energy decrease. So the ME content of the gross energy decreases more slowly than the content of DE at higher feeding levels during lactation. The rate of decrease is about 1 unit i.e.

1.8% relatively (Van Es, 1975).

Trials in Wageningen (Van Es & Van der Honing, 1977) where fresh herbage was fed to dairy cows indoors, however, established no difference between the d_0 measured at the high feeding level of these cows and the predicted d_0 from chemical composition and in-vitro digestibility for sheep at maintenance level. The predicted ME-content of the herbage was lower than the value actually measured in energy balance experiments (Van der Honing et al., 1977; Van Es & Van der Honing, 1977). In-vivo digestibilities of sheep at maintenance unfortunately were not measured in these trials.

Later trials at Lelystad (Van der Honing, 1977; Van der Honing & Van Es, 1981) where fresh herbage was both fed to dairy cows at production level (2.5-3 times maintenance) and to wether sheep at maintenance level provided a large variation in the depression of digestibility ranging from zero, as estimated from the Wageningen trials, to depressions as found on winter diets. On average the depression on grass diets was lower than on winter diets. However, the conversion of ME to NE tended to a lower efficiency in the trials at Lelystad (not at Wageningen) than on winter diets, so the smaller effect of the feeding level on digestibility was partly compensated. Due to the rather low precision of energy balance trials it is doubtful whether these differences between locations are significant. Therefore more experiments at high levels of feeding are necessary. Probably more experimental evidence is needed then to investigate if utilization of ME from herbage depends on location (i.e. on herbage species, soil, etc.).

The recent information of the respiration trials in Lelystad led to the choice made in these experiments of the same depression of digestibility at higher levels of feeding on herbage diets than on winter diets. The good agreement between actual and predicted changes of live weight, as pointed out earlier, may be another indication of a valid assumption made. But of course it will always be difficult to make conclusions on the magnitude of the depression of digestibility at higher levels of feeding from degrees of nutrient balance and from changes in live weight because all errors of a trial are accumulating in the first figure and because the composition of live weight is not known. Therefore more respiration trials with fresh herbage are necessary.

5.4.8 Accumulation of herbage during regrowth

The study of the regrowth showed quite clearly that 19 days after grazing the areic mass of herbage was greater the higher the allowance level. The differences in herbage mass after regrowth could be both attributed to residual herbage remaining after grazing and to differences in herbage accumulation during the regrowth period between treatments. Averaged over both years the daily rates of herbage accumulation during regrowth ($\Delta_t M_0^r$) for the treatments X, Y and Z were 83, 114 and 137 kg ha^{-1} d^{-1} in the es and 33, 43 and 52 kg ha^{-1} d^{-1} in the ls respectively. Wieling et al. (1977) calculated average daily rates of herbage accumulation of cut swards during the whole season; during comparable growth periods in the es and ls their estimates of mean $\Delta_t M_0^r$ were 77 and 50 kg ha^{-1} d^{-1} respectively. In the es $\Delta_t M^r$ of treatment X was at the same level as the mean figures of Wieling et al. (1977); higher allowances (treatment Y and Z) resulted in a faster regrowth. In the 1s the mean level of $\Delta_t M^r$ of treatment Z was at the same level as the mean data from the cutting trials; the daily regrowth rates of treatment X and Y were lower. Possibly a relatively high content of dead material in our grazed swards in 1s might explain the somewhat lower rates of herbage accumulation in 1s compared to those in continuously cut swards of Wieling et al. (1977).

A positive effect of A on herbage mass after regrowth has also been found by Greenhalgh et al. (1967), Greenhalgh (1970), Harkess et al. (1972), Leaver (1974) and Marsh (1977). Information on the effects of A on ΔM^r (accumulation during regrowth) is more variable in the literature and will be split up here into single grazed swards and into cumulative effects through the season following repeated grazing. For ΔM^r the term 'net regrowth' is also often used.

In trials of Greenhalgh et al. (1967) and of Greenhalgh (1970) calculation of net regrowth was not based on measurements of residual herbage but on indirect estimation of M^f (M-C as measured with indirect animal methods). With this method 'negative' amounts of residual herbage on low allowance treatments were calculated by Greenhalgh et al. (1967) resulting in high regrowth rates. Differences in regrowth rates between the moderate and high allowance treatments were not significant; however the authors themselves doubted the method of determining net regrowth in these trials. After the first grazing cycle of later experiments (Greenhalgh, 1970) levels of A_0 of 10.4, 14.6 and 18.8 kg d^{-1} (>4 cm) resulted in ΔM_T^r of 1 800, 2 000 and 2 350 kg ha^{-1} respectively. The positive effect of residual herbage on net regrowth was also shown in the first grazing cycle of the experiments of Mott & Müller (1971).

Greenhalgh (1970) applied the same allowance levels during the whole season and topped the residues only once. Later in the grazing season the net regrowth at high allowance levels was the same or even lower than at low or moderate A. The summed net regrowth over 5 grazing cycles did not differ between treatments if herbage removed by topping was taken into account. The summed net regrowth over 4 grazing cycles as measured by Mott & Müller (1971) did not differ between swards topped after each grazing (residual herbage zero) and swards not topped (increasing residual herbage in time). The increasing content of mature tillers with a low photosynthetic activity in the residual herbage when high allowances are applied during a large part of the grazing season might explain the difference of the M^f-ΔM^r effects between swards grazed once and swards grazed repeatedly.

However Harkess et al. (1972) and Leaver (1974) found contrasting results using swards repeatedly grazed during the season. In grazing trials with sheep Harkess et al. (1972) showed a strong positive relationship between allowance and net regrowth over het A_0 range of 23 to 96 g W^{-1} d^{-1} in the months June, July and August. There was no indication that this effect decreased during the grazing season. A depression in net herbage regrowth (measured over the whole grazing season) with decreasing herbage allowance was also observed with calves and heifers by Leaver (1974) and with dairy cattle by Gordon et al. (1966) in their first experiment. However it is not clear whether Gordon et al. (1966) calculated net accumulation or the sum of herbage mass at start of grazing so these results should be treated with caution.

The positive effect of A_0 on ΔM_r in single grazed swards was in agreement with most of the literature; the information in literature on this effect in repeatedly grazed swards ranged from no effect to positive effects of A_0 on ΔM^r averaged over the season.

5.4.9 Digestibility of herbage after regrowth and accumulation of nutrients during regrowth of herbage

The magnitude of the influence of herbage residues upon the digestibility of a sward will depend upon the proportion of residual herbage which is allowed to mature, the rate of change in d of this material with advancing maturity, the rate at which residual herbage senescences and decays and the rate of production of new material with a high digestibility. Only the total balance of all these processes has been measured in M_{i+1} so the material is not suited to provide a wider explanation of the effects established.

The effect of A_0 on d_0 of M_{i+1} when cut by ms + lm in ls was due to the different M(ms)/M(lm) ratios between treatments combined with the large difference in d_0 between both fractions. When the ms or lm fractions are considered separately no effect of A_0 on d_0 of M_{i+1} could be shown! The strong differences in digestibility of residual herbage at the end of grazing period i was compensated for by different proportions of new material and at the start of period i+1 no differences in d_0 between treatments could be established. Preferably the d_0 of the ms samples of M_{i+1} should be used because the herbage above 4.5 cm is consumable for grazing animals or can only be cut. Another reason was that the d_0 of M_{i+1} when cut by ms + lm depended on the ratio of M(ms)/M(lm), therefore the length of the rest period has a large effect on this figure.

In grazing trials with sheep Harkess et al. (1972) found the same lack of effect of A_0 on d_0 of M_{i+1} as in the trials reported.

Because M_{i+1} cannot be split up in a part consisting of the residual herbage and a part consisting of new plant tissue it was not possible to determine the quality of both components. Because the digestibility of the residues decreased during the rest period the measured 'accumulation' of nutrients during regrowth is the product of two processes: the maturing residual herbage and the production of new material. Because the levels of maturing residual herbage increased at higher A_0 the relative differences in $\Delta M^r_{i,d0}$ between treatments were smaller than in $\Delta M^r_{i,0}$ (e.g. compare Table 48 and 50). Due to the smaller absolute differences between treatments in $\Delta M^r_{i,d0}$ than those in $\Delta M^r_{i,0}$ the regression coefficients of the A_0-$\Delta M^r_{i,d0}$ relationship were smaller.

5.4.10 The areic consumption of herbage combined during grazing and regrowth periods

In the experiments only pre-cut swards were used. On these single grazed swards a strong negative effect of A_0 on C_0 was compensated for by a strong positive effect of A_0 on ΔM^r_0 (Table 48). However the consumption of the herbage after regrowth when grazed was not measured. Total areic consumption could only be calculated by combining grazing + cutting with assumptions on total losses occurring in the field, during preservation and during feeding of the cut herbage (Section 5.3.4). In the example of Tables 48-51 the cut herbage was used in preserved form; the cut herbage can also be used fresh (zero grazing). The figures for $C_i + (1-1) M_{i+1}$ (ms) when the cut herbage is fed fresh will be between $C_i + M_{i+1}$ (ms) and U (Section 5.3.4) because the losses will be smaller than if the herbage is fed in preserved form.

Due to the equal digestibility of M_{i+1} between treatments the assumption was made that the daily intake of the cut herbage (fresh or after preservation) was not different for the treatments, so the degrees of consumption were assumed to be equal. It was shown then that both daily herbage consumption per animal and areic herbage consumption were affected positively by daily herbage allowance when the results of the grazing and regrowth periods were taken together. Alternating grazing and cutting combined with a high level of daily herbage allowance seems to be a way to improve areic consumption of herbage; however more research is needed on the expected equal daily consumption of the cut herbage. Alternating grazing/cutting however cannot be applied during the whole season on most farms because too few pastures would be available for grazing. Then the question arises what is the effect of high levels of A_0 on C_0 and I_0 of repeatedly grazed swards. Possibly the decreasing digestibility of the maturing residues may get such a strong influence that the daily herbage intake declines (and the efficiency of consumption declines) when swards are grazed repeatedly. Or due to senescence and decomposition of the residual herbage the herbage accumulation is possibly affected negatively. Both processes might lead to a reduced areic consumption of herbage on repeatedly grazed swards. In the literature a few experiments can be found in which the effects of A_0 on C_0 were measured on swards repeatedly grazed during the season, including differences in ΔM^r between treatments.

Gordon et al. (1966) compared A_T (>4 cm) of 11.1, 18.7 and 28.2 kg d^{-1} and found C_T (over the season) of 6 423, 6 147 and 5 888 kg ha^{-1} in their first experiment with dairy cows. The differences between treatments would have been smaller when corrections would have been made for herbage accumulation during grazing because long grazing periods were used. Greenhalgh (1970) also found a decreasing C_0 (over the season) of 14% at higher levels of A over the A_0 range (>4 cm) of 10.4 to 18.8 kg d^{-1}. The positive regrowth effect on C_0 could not be maximal due to topping residual herbage once during the season. However these results should be treated with caution because the areic consumption was calculated using an extrapolation procedure: intake was measured for a total of 42 days out of 150 and with only a part of the total number of dairy cows.

Leaver (1974) compared 3 stocking densities with calves and heifers and found no difference in seasonal areic consumption of herbage between treatments. This is in agreement with results of grazing experiments with steer calves by Marsh (1977) using levels of A_0 of 30, 45 and 60 g W^{-1} d^{-1}. At the highest allowance level of 75 g W^{-1} d^{-1} however C_0 decreased strongly. Harkess et al. (1972) could find an optimal A_0 in his range of allowances applied to grazing sheep. The seasonal C_0 was 12.7, 14.4, 17.2 and 16.9 tonnes ha^{-1} at respective A_0 of 23, 33, 58 and 96 g W^{-1} d^{-1}. So in these trials both herbage consumption per animal and areic herbage consumption (on a seasonal basis) increased at higher allowance levels over the range 23-58 g W^{-1} d^{-1}.

The results from literature with grazing sheep, steers, calves and heifers indicate that C_0 of repeatedly used swards was constant over a wide range of allowances or showed a parabolic relationship with a maximum at high allowance levels (about 60 g W^{-1} d^{-1}). Contrasting results were obtained in the trials with dairy cows, however these results were unreliable on the grounds pointed out above. The effect of A_0 on C_0 of repeatedly grazed swards by dairy cows needs more investigation if conclusions have to be made.

5.5 CONCLUSIONS

Different levels of daily herbage allowance (A_0), ranging from 15 to 30 kg d^{-1} above 4.5 cm, were achieved in grazing experiments with productive dairy cows by varying the area grazed at comparable number of grazing-days and of animals and at equal levels of areic mass of herbage for the treatments. From the results of 95 measurements, during grazing periods of 3 days each, on swards which were cut at the previous defoliation, the following conclusions could be drawn:

- At a comparable level of herbage mass for the different treatments, the residual herbage increased at higher A_0. As a consequence a negative effect of A_0 on areic consumption of O from herbage was shown.
- A strong positive effect of A_0 on daily intake of O from herbage was established; the use of grazing periods of 3 days (in comparison with strip grazing) and especially the use of high productive cows may explain the lack of a clear asymptote in the intake.
- The digestibility and nutritive value of residual herbage were lower than these of herbage mass at start of grazing. The digestibility of the residual herbage decreased more at lower quantities of residual herbage and thus at lower allowances.
- The digestibility of herbage consumed tended to be higher than that of herbage available; the digestibility of ingested herbage was not affected by variation in A_0. Therefore the decreasing intake at low allowances could not be explained by differences in digestibility between treatments.
- The relative differences in areic consumption of nutrients from herbage between treatments were comparable to the differences in areic consumption of O from herbage; the relative differences in daily intake of nutrients from herbage were also comparable to the differences in daily intake of O from herbage.
- The grazing time of the cows increased at lower levels of A_0 at the end of the grazing period. There was a slight tendency of increasing biting rates at lower levels of A_0 in the middle of the grazing period. Together these data indicate that bite size decreased with progressive defoliation at lower levels of A_0.
- Although milk yield responses were of secondary interest in these short-term studies a positive effect of A_0 on FCM production could be shown.
- The intake of nutrients from the total ration was in good agreement with the theoretical nutrient requirements for milk production, maintenance and live weight change when measured over 8-week periods.

After a regrowth period of 19 days the areic mass of herbage was again determined during 50 periods from which the following conclusions could be drawn:
- The areic mass of herbage after regrowth increased at higher allowance levels which could be both attributed to more residual herbage remaining after the prior grazing and to positive effects of the residual herbage on the herbage accumulation during the regrowth period (net regrowth).
- No effect of A_0 on the digestibility of the herbage mass after regrowth could be shown, due to different proportions of new and dead material between treatments.
- The lower areic consumption of herbage in the grazing period at higher levels of A_0 was about equal to the higher rate of herbage accumulation during the 19-day regrowth.

The consumption of herbage after regrowth could not be measured by grazing. However if the cut herbage was assumed to be used indoors with equal daily herbage consumption due to the equal digestibility between treatments, calculations on the combined results of the grazing and regrowth periods provided the following conclusion:
- The total areic consumption of herbage (both expressed in O as in nutrients) increased at higher levels of A_0 when the regrowth was cut.

These results show that both daily herbage intake per animal and areic consumption of herbage were affected positively by higher daily herbage allowance when grazing was alternated with cutting i.e. when the positive effect of A_0 on net regrowth was included. The limited information in the literature showed that these results cannot be extrapolated fully to repeatedly grazed swards.

6 The influence of the length of the rest period on herbage intake of dairy cows (Experiments 1 and 2)

6.1 TREATMENTS AND DESIGN

Experiment 1 was carried out in 1976, Experiment 2 in 1977, both at the Institute for Livestock Feeding and Nutrition Research at Lelystad. The treatments were different levels of areic mass of herbage, established by allowing the swards to grow for periods of time of variable length either as a primary cut or following a preliminary cutting. The higher the level of areic mass of herbage the higher also its maturity. Two comparable swards of about 3 ha were chosen in each trial; one was used for grazing the other one was partially cut daily and its herbage was fed indoors.

During Experiment 1 in total 3 trials were performed in May, June and August; during Experiment 2 in total 4 trials were performed in May, June, August and September. Each trial had a length of 3 weeks during which the areic mass of herbage increased. In Experiment 1 (1976) each week consisted of a 3-day preliminary period around the weekend without intake measurements, followed by a 4-day experimental period (EP) from Monday to Friday. In Experiment 2 (1977) each week was also split up in a 3-day and a 4-day period but measurements were done not only as above but also from Friday to Monday.

All levels of areic mass of herbage were compared within animals. Thus, in the course of each 3-week trial the same group of animals was eating herbage of the same sward, however from different parts of it. With advancing time the herbage of the subsequent parts of the sward offered had a higher areic mass and was more mature. After an adaptation period of 7-10 days the experiment started at a level of areic mass of T of about 1 500 kg ha^{-1} above 4.5 cm. The intention was to allow the sward to grow for three weeks and to measure herbage intake at parts of the sward during this period. The herbage intake of the stall-fed dairy cows was measured daily during each 3 week trial. The grazing cows however stayed 3 or 4 days within the same plot, so their average herbage intake was determined over 3-4 days once (1976) or twice (1977) a week during the 3 week growing period of the herbage.

The change from winter feed to herbage in spring was made gradually over a two week period; in the first week the roughage part was gradually reduced to zero and replaced by herbage, in the second week the concentrate level was adapted to the summer level. In Experiments 1 and 2 each cow was offered only 1 kg of concentrates per day in the milking parlour.

The intention was to determine the effects of the length of the rest period on intake at a constant level of daily herbage allowance. The constant allowance could be achieved for the grazing animals by diminishing the area grazed at increasing levels of herbage mass. The stall-fed animals were fed fresh herbage six times daily, in such amounts that at least 15% of the herbage was left uneaten.

In the weeks between the trials of May-June and August-September the grazing cows grazed with the rest of the milking herd; the stall-fed cows stayed indoors. Only during the whole of July the stall-fed cows were pastured with the other cows.

6.2 MATERIALS

6.2.1 Animals

Spring-calving Dutch Friesian dairy cows were used in the experiments. The grazing group consisted of 12 cows, the stall-fed group contained 11 cows in Experiment 1 and 12 cows in Experiment 2. The animals were classified in pairs of comparable age, calving date and milk production in the previous lactation; afterwards they were allotted at random to the stall-fed and grazing group. The average data after division of the two animal groups can be found in Appendix 11.

Because intake was the most important dependent variable in these trials it would have been better to make a division of animal groups based on previous intake and production data than on milk production data but intake data were not available. The stall-fed and grazing animals were comparable as to age, calving time and milk production during the previous lactation. The average live weight of the stall-fed cows in Experiment 2 was however 30 kg higher than that of the grazing cows.

6.2.2 Swards

The experiments were carried out on fields sown with a mixture of *Lolium perenne*, *Phleum pratense*, *Festuca pratensis* and *Trifolium repens*. The permanent pastures were established in the new polder East-Flevoland on a light clay soil. In 1977 the botanical composition of the swards was determined by estimating dry mass of each component.

The main component of the sward on all used pastures was *Lolium perenne* (78-93%). The content of total other grass species was relatively low (5-20%). From these other grass species *Phleum pratense* was the largest fraction (3-9% of total mass), the remaining fraction consisted of *Poa trivialis*, *Poa annua* and *Agropyron repens*. The content of *Trifolium repens* varied from 0.5 to 3%. The content of weeds varied around 1%. In 1976 the botanical composition was not determined, but due to the use of partly the same and partly comparable swards the herbage was also assumed to contain 80-90% *Lolium perenne* (perennial ryegrass).

The swards used for the grazing and the stall-fed cows should be comparable. Therefore pairs of swards were formed with the same grassland management until they were used in the experiments. All swards used should be as homogeneous as possible to obtain a high precision of the estimate of herbage intake. Also to avoid disturbance of treatment-effect with effects of faeces contamination in the preceding period, the swards used were cut at the previous defoliation. Only the primary growth was pre-grazed by sheep, with the aim to postpone the start of the experiments until the dairy cows were accustomed to grazing. Each sward was used only once during the grazing season, so seasonal yields of areic mass or of herbage intake could not be calculated from these experiments.

In Appendix 12 some general data of the swards used are summarized. Due to the dry weather conditions of 1976 the growth of herbage in mid summer was so low that insufficient herbage was available to continue the experiment in September. All swards received about 50 kg N/ha in March in the form of phosphate-ammonium-nitrate; all other nitrogen was supplied in the form of calcium-ammonium-nitrate. About 80 kg N/ha was given immediately after the previous harvest had been cut on the sward.

The total area of the swards was about 3.0 ha. After excluding the edges of the field (about 0.2 ha) and the area for measurement of the 'undisturbed' herbage accumulation (about 0.1 ha) a total grazing area of about 2.7 ha was available. The experimental plots used for a period of 3 or 4 days varied from 0.2 to 0.7 ha due to the variation in herbage mass at constant daily herbage allowance. A comparable area was cut for the stall-fed cattle. In June and August 1977 the available pasture for the stall-fed group was 2.5 ha, sufficient for only 4 experimental periods (two weeks in total instead of the usual 3 weeks).

The rectangular grazing plots were fenced by placing fence-posts at a distance of 5 m from each other. A wire was drawn at a height of 70 cm and a battery-operated electric fencer was used. Drinking water was always available in the field. Other aspects of methodology are described in Chapter 3.

6.3 RESULTS

6.3.1 Meteorological conditions

Rainfall was measured in the experimental fields. The other climatological data were assumed to be equal to the data collected at the ir. A.P. Minderhoudhoeve in Swifterbant at a distance of 10 km (meteorological department of the Agricultural University in Wageningen).

Total precipitation, mean temperature and total solar radiation during the experimental periods are given in Appendix 13. During the trials of June and August 1976 the meteorological conditions were extreme, with high temperatures and solar radiation and a minimum of rainfall. During the trial of August 1977 the solar radiation was low. In September 1977 the precipitation was low at relatively high levels of solar radiation.

6.3.2 Zero grazing of stall-fed cows

6.3.2.1 Details on experimental animals and swards

Experiment 1 On the last day of the trial of May Cow no. 179 had mastitis, but had recovered by the start of the trial of June. The intake of animal group III in May EP 3 was based on 3 instead of 4 days of measurement.

Due to the very dry summer of 1976 the growing conditions during June, July and

August were very extreme. This resulted in a low rate of herbage accumulation in these trials and in open swards. The planned intake experiment of September could not be carried out because clean pastures were not available due to the use by animals of the farm herd in the preceding period.

Experiment 2 During the period of May Cow no. 217 suffered with tympany and was replaced by Cow no. 46. Cow no. 25 stood on a teat in the trial of September, however milk production was not affected.

During the trials of June and August the available pastures were too small to perform the trials for three weeks; due to the slow accumulation of herbage, especially in EP 4 of June and during August, after 4 EP's instead of 6 the trials had to be stopped.

6.3.2.2 Areic mass, daily allowance and daily intake of herbage

The length of the rest period, after a preliminary cutting, ranged from 18 to 42 days (Table 52). The areic mass of herbage was determined at each cutting time twice a day. The daily herbage allowance was calculated from the offered total herbage mass per animal. The mean areic mass (M), daily herbage allowance (A), daily herbage intake (I) and degree of consumption (c) per EP are also shown in Table 52. In all trials, except June 1976, M_0 increased considerably in time with advancing maturity. The rate of herbage accumulation was relatively low in EP 3 of June 1976 (very dry), EP 4 of June 1977 (low radiation) and during the whole August period of 1977 (wet, low radiation).

The aim of the feeding system was to supply a residual mass fraction of total material of at least 0.15. Due to variation in T content of supplied herbage the absolute level of daily herbage allowance varied between days and EP's; however in all EP's a fraction of residual herbage of 0.15 or higher was reached.

A linear regression analysis of M_0 on I_0 was performed with the M_0 and I_0 data of each trial. Daily intakes per individual animal (1977) or per group of 2-3 animals (1976) were used. The 12 (1977) or 4 (1976) derived regression coefficients were averaged and tested.

The null hypothesis that the real regression coefficient is zero was tested against the alternative that the null hypothesis is not true using Students t-test. A non-zero regression coefficient would indicate that I_0 depends on M_0. Results of regression analysis are shown in Table 53. In the es the regression coefficients were negative and only significant in June 1977; in ls there was a tendency for higher daily intakes at increasing M_0 which was only significant in September 1977. At the end of the trials of May and June of 1977 the daily herbage allowance was low compared with the preceding experimental periods, due to the low T content of the herbage in these periods. Therefore the regression analysis was also carried out with exclusion of the last 2 days of May and the last 3 days of June. The results in May were not influenced, in June however the regression coefficient decreased to 0.000009 (not significant) when these days were excluded. So there is not much evidence of an effect of M_0 on I_0

Table 52. Areic mass, allowance and intake of herbage of stall-fed cows.

		EP	Rest period[1]	M_0	A_0	I_0	c
1976	May	1	0	1760	15.3(0.26)[2]	12.9(0.20)	0.85(0.007)
		2	7	2817	15.4(0.23)	13.1(0.51)	0.85(0.021)
		3	14	4070	15.5(0.25)	12.6(0.32)	0.81(0.012)
	June	1	21	1361	16.3(0.22)	13.4(0.13)	0.82(0.006)
		2	28	2054	17.9(0.18)	12.6(0.28)	0.71(0.020)
		3	35	2030	19.9(0.24)	13.2(0.50)	0.68(0.022)
	August	1	28	1640	19.3(0.13)	13.2(0.25)	0.68(0.008)
		2	35	1974	19.8(0.29)	13.9(0.36)	0.71(0.010)
		3	42	2646	16.7(0.03)	13.4(0.26)	0.80(0.016)
	mean			2261	17.3(0.20)	13.1(0.31)	0.77(0.010)
1977	May	1	0	1717	19.8(0.42)[3]	13.0(0.44)	0.65(0.012)
		2	3	2284	20.4(0.40)	13.4(0.32)	0.66(0.005)
		3	7	2831	19.5(0.52)	14.1(0.47)	0.72(0.008)
		4	10	3335	18.8(0.50)	13.9(0.49)	0.74(0.010)
		5	14	4348	18.2(0.62)	13.4(0.43)	0.74(0.005)
		6	18	4822	16.1(0.50)	12.7(0.49)	0.79(0.013)
	June	1	18	1957	19.5(0.50)	14.2(0.57)	0.73(0.012)
		2	21	2512	17.2(0.57)	14.5(0.43)	0.84(0.006)
		3	24	3152	18.2(0.55)	14.0(0.48)	0.77(0.005)
		4	28	3392	15.3(0.52)	12.3(0.51)	0.80(0.008)
	August	1	14	1251	15.3(0.38)	11.6(0.49)	0.76(0.013)
		2	17	1331	15.5(0.49)	12.6(0.48)	0.81(0.010)
		3	20	1724	13.9(0.43)	11.8(0.43)	0.85(0.008)
		4	23	1694	15.4(0.36)	12.3(0.36)	0.80(0.009)
	September	1	20	1056	16.0(0.37)	13.1(0.44)	0.81(0.011)
		2	24	1516	17.4(0.44)	13.7(0.30)	0.79(0.005)
		3	27	1607	16.9(0.32)	13.9(0.32)	0.82(0.005)
		4	31	1915	16.2(0.30)	13.4(0.30)	0.83(0.006)
		5	34	2251	17.8(0.36)	14.3(0.29)	0.80(0.004)
	mean			2352	17.2(0.45)	13.3(0.42)	0.77(0.008)

1. Number of growing days between the removement of the cut herbage at the prior defoliation and the first day of the experimental period (for the first growth in May the fictive value of zero was taken in EP 1 in order to express the relative figures in the other EP's).
2. The figure in brackets is the standard deviation of the mean ($s_{\bar{x}}$) as calculated from the measurements on the mean values of 4 groups consisting of 3 animals each.
3. The figure in brackets is the standard deviation of the mean ($s_{\bar{x}}$) as calculated from the measurements on 12 individual fed animals.

when the allowance is kept constant.

Although in all EP's degrees of consumption of 0.85 or lower were reached the question arose whether even at such high levels of residues, daily herbage intake could have been affected by daily herbage allowance. However these effects can only be shown when different levels of A_0 are fed during the same period of more days to comparable animals as was done with tropical forages fed to sheep by Zemmelink (1980). In Experiments 1 and 2 this was not done, each animal was fed as much herbage that residues of 15% would be left. Only the effect of allowance on intake within animals (or groups of animals) due to variation in allowance in time can be examined in these experiments.

Therefore a multiple regression analysis was performed on the total data per year

Table 53. Regression coefficients and probabilities corresponding to t-values in the simple linear regression of daily herbage intake on areic mass of herbage of stall-fed cows.

	$I_0 = a + b\,M_0$						
	1976			1977			
	May	June	August	May	June	August	September
b	-0.000130	-0.000735	0.000250	-0.000056	-0.000762	0.000318	0.001028
P	n.s.	n.s.	n.s.	n.s.	**	n.s.	***

Table 54. Probabilities corresponding to F-values based on multiple regression of daily herbage intake (I_0) of stall-fed cows. Each term is tested eliminating the preceding terms and ignoring the following.

	G/An	Se	M_0	T	T-1	A_0	Da	T G/An	T-1 G/An	A_0 G/An	G/An Se
1976	***	**	n.s.	n.s.	*	***	n.s.	n.s.	n.s.	n.s.	n.s.
1977	***	***	n.s.	***	***	***	***	n.s.	n.s.	*	***
	G/An	Se	T	T-1	A_0	M_0	Da	T G/An	T-1 G/An	A_0 G/An	G/An Se
1976	***	**	n.s.	*	***	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
1977	***	***	***	***	***	***	***	n.s.	n.s.	*	***

of the individual intakes (or the average intake of 2-3 animals in 1976) per day (Table 54). Variables used were G (group) or An (animal), Se (season:month), M_0, T (dry matter content), T-1 (dry matter content on the preceding day), A_0, Da (day) and a set of interactions.

In the dry summer of 1976 no effect of T (ranging from 0.16 to 0.40) on I_0 could be shown, however I_0 depended on the T content of the preceding day. In 1977 both T (ranging from 0.12 to 0.23) and T-1 affected I_0 significantly. Variation in daily herbage allowance (in time) had a strong effect on I_0 in both years. If the effect of M_0 on I_0 is examined without preceding correction for the effects of T, T-1 and A_0 the regression coefficient was not significant (Table 54, upper part). After correction for G, Se, T and T-1 also no effect of M_0 on I_0 could be shown in both years. However after correction for G, Se, T, T-1 and A_0, only in 1977 the effect of M_0 on I_0 was significant (Table 54, lower part), with a low positive regression coefficient of 0.00027 kg I_0/kg M_0 corresponding to 0.27 kg I_0/tonne M_0.

6.3.2.3 Milk production, milk composition and live weight

The average milk production, milk composition and live weight per EP are shown in Table 55; in 1977 these variables were not determined during the EP's containing the weekend. There was a strong decline of milk production (L) at increasing herbage mass; however this M_0 effect is correlated with the effect of lactation stage on L. The effects of M_0 on w_{XL} and w_{XP} of the milk varied between months and were not clear.

Table 55. Milk production, milk composition and live weight of stall-fed cows.

		EP	L	100 w_{XL}	100 w_{XP}	FCM	W
1976	May	1	28.0	3.78	3.05	27.1	526
		2	28.4	3.81	3.06	27.4	533
		3	25.2	3.81	3.08	24.5	538
	June	1	22.7	3.74	3.20	21.8	532
		2	20.4	3.77	3.09	19.7	533
		3	19.7	3.78	3.15	19.1	531
	August	1	19.7	3.79	3.26	19.1	533
		2	17.6	3.65	3.31	16.7	541
		3	16.2	4.05	3.41	16.3	539
	mean		22.0	3.80	3.18	21.3	534
1977	May	2	26.5	3.38	3.15	24.0	551
		4	24.2	3.40	3.11	21.9	554
		6	22.7	3.53	3.10	21.0	557
	June	1	25.1	3.76	3.15	24.2	547
		3	24.2	3.64	3.16	22.9	554
	August	1	18.4	4.12	3.35	18.7	540
		3	18.7	4.16	3.28	19.1	542
	September	1	17.9	3.94	3.35	17.7	554
		3	17.9	3.95	3.48	17.7	567
		5	17.3	3.97	3.51	17.2	576
	mean		21.3	3.79	3.26	20.4	554

The FCM production declined in time at increasing maturity of the herbage, especially in es.

To separate the effects of lactation stage from the effects of herbage mass on FCM production the lactation curve (in FCM) over the grazing season was made first. If the effect of the stage of lactation is known, differences in milk production between EP's due to lactation stage can be corrected and deviations from the lactation curve in the EP's can be attributed to treatments applied.

The lactation curve was calculated from lactation week 9 to week 25 in 1976 and from lactation week 11 to lactation week 32 in 1977 by regression of weekly FCM production per day on time (week of lactation). The difference between the actual FCM production per cow and the average lactation value was calculated for each animal. Afterwards these differences were related with herbage mass by regression analysis. When the nutrient intake is high the FCM production will be relatively higher than the average lactation value (the difference will be positive). When the intake of nutritive value is low the FCM production will be low in comparison with the lactation value (the difference will be negative). Under this hypothesis negative effects of increasing herbage masses (and decreasing quality) on FCM production will result in a negative regression coefficient in the regression of the difference between the actual and expected FCM production on areic mass of herbage.

The 11 (1976) and 12 (1977) regression coefficients for the different animals were averaged per year and tested by Students t-test (Table 56). In May and June of both

Table 56. Regression coefficients and probabilities corresponding to t-values in the simple linear regression of the difference between actual and expected FCM production on areic mass of herbage of stall-fed cows.

$\Delta FCM = a + b\ M_0$

	1976			1977			
	May	June	August	May	June	August	September
b	-0.000853	-0.001566	-0.001943	-0.000814	-0.000666	0.001867	0.000063
P	***	*	**	***	**	***	n.s.

years the FCM production decreased significantly at higher levels of M_0. In August 1976 when mature herbage was fed grown under very dry conditions also a negative effect of M_0 on FCM production could be shown. However in August and September of 1977 the regression coefficient was positive and significant only in August. In May and June the negative effect of the length of the rest period on FCM production was strong with regression coefficients ranging from -0.67 to -1.57 kg I_0/tonne M_0.

6.3.2.4 Chemical composition, digestibility and nutritive value of herbage

The mean chemical composition of A and R is shown in Table 57. The in-vitro digestibility and nutritive value of A and R for each EP are given in Table 58. The w_{XP}/O nor the w_{dXP}/O differed significantly between A and R. In 1976 the residues were only analysed for w_{XP}.

In 1977 w_{XF}/O between A and R did not differ significantly; however w_{NDF}/O of A was significantly ($P < 0.05$) lower than of R corresponding with a higher digestibility of A than of R ($P < 0.01$) when tested with Students t-test.

The relationship between M_0 and the in-vitro O digestibility of M was tested by regression analysis (Table 59). In May and June of both years d_0 of M decreased at higher levels of M. With the flowering herbage of June the magnitude of this effect was much greater than in May. In August and September of both years the effects of M_0 on d_0 of herbage offered were in the same direction as in the other months but not significantly different from zero.

Table 57. Chemical composition of herbage offered and of residual herbage of stall-fed cows.

		w_T	w_O/T	w_{XP}/O	w_{XF}/O	w_{NDF}/O
A	1976	0.257(0.067)[1]	0.891(0.009)	0.211(0.030)	0.256(0.023)	0.533(0.034)
	1977	0.170(0.026)	0.891(0.012)	0.236(0.068)	0.250(0.030)	0.518(0.046)
R	1976	0.330(0.107)	0.852(0.037)	0.213(0.039)	-	-
	1977	0.186(0.031)	0.870(0.017)	0.238(0.067)	0.261(0.029)	0.540(0.041)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different experimental periods.

Table 58. In-vitro digestibility and nutritive value of herbage offered and of residual herbage of stall-fed cows.

		EP	A			R		
			$w_{dXP}/0$	d_0	$e_{NE_1}/0$[1]	$w_{dXP}/0$	d_0	$e_{NE_1}/0$[1]
1976	May	1	0.219	0.817	1125	0.231	-	-
		2	0.185	0.800	1077	0.198	-	-
		3	0.147	0.786	1032	0.142	-	-
	June	1	0.171	0.785	1045	0.174	-	-
		2	0.138	0.754	979	0.148	-	-
		3	0.117	0.701	889	0.095	-	-
	August	1	0.163	0.701	916	0.173	-	-
		2	0.151	0.689	892	0.153	-	-
		3	0.164	0.688	897	0.155	-	-
	mean		0.162	0.747	984	0.163	-	-
1977	May	1	0.143	0.821	1083	0.147	0.785	1031
		2	0.124	0.832	1088	0.131	0.804	1049
		3	0.109	0.824	1066	0.110	0.818	1057
		4	0.087	0.813	1036	0.091	0.817	1044
		5	0.083	0.804	1020	0.085	0.803	1019
		6	0.111	0.793	1020	0.098	0.790	1008
	June	1	0.185	0.812	1096	0.185	0.784	1052
		2	0.177	0.800	1072	0.186	0.783	1052
		3	0.153	0.784	1031	0.153	0.767	1007
		4	0.142	0.742	963	0.151	0.739	964
	August	1	0.261	0.779	1093	0.255	0.736	1024
		2	0.246	0.783	1090	0.235	0.743	1022
		3	0.242	0.765	1059	0.239	0.709	974
		4	0.246	0.763	1059	0.249	0.713	986
	September	1	0.250	0.808	1130	0.258	0.771	1079
		2	0.252	0.814	1141	0.247	0.768	1067
		3	0.240	0.796	1106	0.247	0.765	1063
		4	0.232	0.790	1092	0.237	0.739	1017
		5	0.233	0.799	1106	0.235	0.759	1046
	mean		0.185	0.796	1071	0.186	0.768	1030

1. VEM kg^{-1}

Table 59. Regression coefficients and probabilities corresponding to F-values in the simple linear regression of in-vitro digestibility of herbage offered on areic mass of herbage of stall-fed cows.

$d_0 = a + b\ M_0$

	1976			1977			
	May	June	August	May	June	August	September
b	-0.00135	-0.00846	-0.00163	-0.00109	-0.00539	-0.00330	-0.00146
P	**	**	n.s.	***	**	n.s.	n.s.

6.3.2.5 Daily intake of nutrients and degree of nutrient balance

The daily intake of nutrients from herbage is shown in Table 60. In 1977 both the herbage offered and the residues were analysed completely. The nutritive value of the herbage ingested was calculated using quantity and quality of the herbage offered and of the residual herbage on the way as discribed in Section 5.4.4 for the quality of the ingested herbage by grazing animals. The small difference in the digestibility between A and R (0.796 and 0.768 respectively) resulted in a very small selection effect of the stall-fed animals in 1977. The digestibility of the herbage ingested was on average 0.008 higher than that of the herbage offered. In 1976 the residual herbage was not analysed for in-vitro digestibility. Therefore the digestibility and nutritive value of

Table 60. Daily intake of nutrients from herbage and from total ration and degree of nutrient balance of stall-fed cows.

		EP	Herbage			Total ration			
			D_{XP}	D_O	I_{NE_1} [1]	D_{XP}	k_{dXP}	I_{NE_1} [1]	k_{NE_1}
1976	May	1	2.79	10.54	14.51	2.89	1.40	15.40	0.91
		2	2.39	10.47	14.09	2.49	1.19	14.98	0.87
		3	1.87	9.93	13.06	1.97	1.04	13.95	0.88
	June	1	2.09	9.67	12.89	2.17	1.12	13.83	0.86
		2	1.67	9.47	12.26	1.76	1.10	13.20	0.98
		3	1.70	9.28	11.86	1.78	1.14	12.80	0.97
	August	1	2.08	9.23	12.03	2.16	1.38	12.97	0.98
		2	2.08	9.54	12.36	2.17	1.53	13.30	1.09
		3	2.20	9.15	11.97	2.29	1.64	12.91	1.08
	mean		2.10	9.70	12.78	2.19	1.28	13.70	0.96
1977	May	1	1.82	10.91	14.44	1.90	0.98	15.34	0.95
		2	1.62	11.36	14.88	1.70	0.90	15.79	1.01
		3	1.45	11.10	14.38	1.53	0.81	15.29	0.98
		4	1.19	11.28	14.37	1.27	0.73	15.28	1.04
		5	1.10	10.73	13.62	1.18	0.68	14.53	1.00
		6	1.45	10.11	13.04	1.52	0.90	13.95	0.98
	June	1	2.62	11.65	15.76	2.74	1.45	16.70	1.06
		2	2.54	11.63	15.60	2.66	1.43	16.54	1.07
		3	2.10	11.07	14.59	2.22	1.22	15.53	1.02
		4	1.72	9.13	11.85	1.83	1.03	12.79	0.86
	August	1	3.05	9.21	12.97	3.12	2.02	13.91	1.06
		2	3.14	10.01	13.97	3.20	2.06	14.91	1.13
		3	2.86	9.16	12.71	2.92	1.86	13.65	1.03
		4	3.01	9.52	13.24	3.07	2.01	14.18	1.09
	September	1	3.23	10.66	14.92	3.35	2.25	15.86	1.25
		2	3.45	11.28	15.87	3.57	2.40	16.81	1.32
		3	3.33	11.18	15.55	3.44	2.31	16.49	1.29
		4	3.10	10.73	14.85	3.21	2.17	15.79	1.24
		5	3.33	11.58	16.06	3.45	2.36	17.00	1.35
	mean		2.43	10.65	14.35	2.52	1.56	15.28	1.09

1. kVEM d^{-1}.

Table 61. Regression coefficients and probabilities corresponding to F-values in the simple linear regression of daily intake of net energy from herbage on areic mass of herbage of stall-fed cows.

	$I_{NE_1} = a + b\ M_0$						
	1976			1977			
	May	June	August	May	June	August	September
b	-0.000630	-0.001221	-0.000075	-0.00050	-0.003056	-0.000225	0.000443
P	n.s.	n.s.	n.s.	***	*	n.s.	n.s.

the herbage ingested was assumed to be equal to the digestibility of the herbage offered. The results of 1977 indicate that no large bias can be made with this assumption due to the small selection effect by the stall-fed animals.

The nutritive value was based on analysis done in mixed samples collected during each EP for all animals. Regression analysis was therefore performed with daily intake of NE_1 from herbage for the total stall group averaged per EP. In May and June I_{NE_1} decreased at higher levels of M_0; in 1976 this effect was not significant probably due to the low number of EP's (n = 3). No significant effect of M_0 on I_{NE_1} could be shown in August and September (Table 61).

The daily intake of nutrients from the total ration and the degree of nutrient balance is also shown in Table 60. The amount of concentrates consumed was the same in all periods; therefore differences in intake of nutrients from herbage between EP's were the same as those in intake of nutrients from the total ration.

In May and June 1976 NE_1 intake was below NE_1 required for maintenance and milk due to the high milk production of the cows. In May and June of 1977 the degree of NE_1 balance varied around 1; the live weight of the animals was reasonably constant in es of both years. In August (both years) and especially in September (1977) the consumption of NE_1 was higher than the requirement resulting in degrees of NE_1 balance above 1; there was a tendency for increasing live weights during these periods.

Except in May 1977 when a sward with a low protein content was used, in all periods the degree of dXP balance was much higher than 1, an usual phenomenon for dairy cows fed with highly digestible fresh herbage.

6.3.2.6 Effect of level of milk production on daily herbage intake

Individual data of daily herbage consumption and daily FCM production were available for the stall-fed cows in 1977. All animals had calved within a month and showed a variation in actual daily milk production among others due to genetic potential and lactation cycle (age). Regression analysis was performed on the individual I_0 and FCM data, averaged per trial (month) or over the whole grazing season (Table 62).

In May and June 1977 the regression coefficients were significant. Due to the smaller variation in daily milk production between animals in ls, the regression coeffi-

Table 62. Regression coefficients and probabilities corresponding to F-values in the simple linear regression of daily herbage intake (between animals) on FCM production of individual fed stall-housed cows in 1977.

	$I_0 = a + b$ FCM				
	May	June	August	September	Total
b	0.38	0.49	0.34	0.29	0.39
P	***	***	n.s.	n.s.	***

cients were just not significant in August and September ($0.05 < P < 0.10$). Averaged over all measurements I_0 increased 0.39 kg per 1 kg FCM production (between animals).

6.3.3 *Grazing*

6.3.3.1 Details on experimental animals, swards and cutting conditions

Experiment 1 During all EP's the weather conditions were very dry except EP 3 of August. Cutting conditions at the start and end of grazing were comparable and sticking of herbage to the lm did not occur in any of the periods.

Experiment 2 In EP 2 and EP 3 of the trial of June some cows broke out of their plots during the night. The time of break-out corresponded with a fraction of 6 and 4% respectively of the total grazing period. The animal-days per pasture were corrected for these periods; however the intake during the rest of the day on the experimental swards may have been influenced by the consumption during the break-out. The residual herbage in EP 1 of June was cut by lm only on 4 strips due to a defect in the machine.

Adhesion of herbage to the lm at start and at finish of the grazing period occurred in May EP 1, probably without influence on the estimation of herbage intake. In June EP 1 sticking of herbage occurred at start of grazing, so these intake results can be classified as unreliable. Because of the problems with cows breaking out (June EP 2 and 3) and variable cutting conditions between the start and finish of grazing (June EP 1) the results of the trial of June should be considered with caution.

6.3.3.2 Areic mass of herbage and daily herbage allowance

The length of the rest period, after a preliminary cutting of the grazed swards, ranged from 18 to 42 days as on the cut swards (Table 52). The areic mass of herbage at the start and finish of grazing and the daily herbage allowance per EP are presented in Table 63. In all trials M_0 considerably increased in time, with advancing maturity. Particularly in the es the rate of herbage accumulation was high. Although an attempt was made to keep A_0 constant, some variation in A_0 between EP's occurred, especially in 1977. The reasons for this variation in A_0 have already been mentioned in Section 5.4.1.

At higher levels of M_0 the residual herbage (M_0^f) also increased, especially in es. However this effect was disturbed by variation in A_0. Regression analysis of M_0 on M_0^f

Table 63. Areic mass, allowance and consumption of herbage by grazing cows.

		EP	M_0		M_0^f		C_0		A_0		I_0		c_0[1]	
			ms	ms + lm	ms	ms + lm	ms	ms + lm	ms	ms + lm	ms	ms + lm	ms	ms + lm
1976	May	1	1757	-	658	-	1518	-	21.5	-	15.0	-	0.70	-
		2	2728	-	689	-	2311	-	19.6	-	15.1	-	0.77	-
		3	3461	-	973	-	2785	-	20.3	-	15.1	-	0.74	-
	June	1	1289	-	537	-	1020	-	22.0	-	14.4	-	0.65	-
		2	2280	-	731	-	1786	-	21.4	-	15.2	-	0.71	-
		3	2686	-	888	-	2006	-	23.2	-	16.2	-	0.70	-
	August	1	1656	-	648	-	1219	-	25.4	-	16.6	-	0.65	-
		2	1780	-	524	-	1304	-	20.0	-	14.3	-	0.72	-
		3	2119	-	708	-	1531	-	24.1	-	16.5	-	0.68	-
	mean		2195	-	706	-	1720	-	21.9	-	15.4	-	0.70	-
1977	May	1	1626	1893	608	984	1305	1195	21.8	24.9	14.9	13.6	0.62	0.55
		2	2120	2333	916	1258	1558	1429	24.0	26.1	15.1	13.9	0.58	0.53
		3	2259	2463	746	1002	1848	1796	18.7	20.1	13.3	12.9	0.69	0.64
		4	3223	3497	1261	1601	2142	2075	22.2	24.0	14.0	13.6	0.61	0.57
		5	3569	3804	1405	1912	2955	2683	23.2	24.4	15.7	14.3	0.62	0.50
		6	4601	5049	1858	2499	3329	3145	26.2	28.4	16.8	15.9	0.61	0.56
	June	1	1998	2588	1248	1712	1173	1298	28.4	35.3	13.8	15.2	0.54	0.43
		2	2799	3193	874	1313	2253	2207	21.9	24.6	15.8	15.4	0.70	0.63
		3	3232	3627	929	1437	2632	2519	20.9	23.3	15.5	14.8	0.71	0.64
		4	3298	3750	575	1087	2847	2787	15.2	17.2	12.7	12.4	0.82	0.72
	August	1	1333	1851	364	855	1134	1163	19.2	25.9	14.5	14.9	0.78	0.58
		2	1911	2313	472	899	1553	1527	21.4	25.6	16.4	16.1	0.75	0.63
		3	1987	2274	688	1088	1458	1344	25.3	28.7	17.2	15.8	0.62	0.55
		4	2375	2564	556	996	2009	1758	21.8	23.4	17.1	14.9	0.68	0.64
	September	1	1999	2274	849	1351	1511	1284	28.9	32.3	18.5	15.7	0.54	0.49
		2	2179	2495	859	1380	1568	1362	23.5	26.5	15.2	13.2	0.56	0.50
		3	2329	2660	680	1218	1795	1588	22.3	25.3	16.2	14.3	0.64	0.57
		4	2514	2847	675	1227	1999	1780	21.8	24.5	16.3	14.5	0.67	0.59
		5	2690	2992	646	1234	2163	1878	21.5	23.9	16.6	14.4	0.67	0.60
	mean		2528	2867	854	1319	1960	1832	22.5	25.5	15.5	14.5	0.65	0.57

1. 1976: I_0 and A_0 both determined with ms; 1977: I_0(ms + lm) and A_0(ms) or A_0(ms + lm).

was not performed because a comprehensive analysis of effects of M_0 on C_0 (M_0 - M_0^f with a correction for accumulation during grazing) will be given below.

6.3.3.3 Areic consumption of herbage

The areic consumption of herbage per grazing period is also shown in Table 63. There was a strong relationship between M_0 and C_0; in es C_0 was higher than in ls corresponding to differences in M_0 between seasons.

Linear regression analysis was performed with the C_0 data determined with ms + lm and M_0 data determined with ms. Due to some variation in A_0 between periods this variable was also taken into account (measured with ms). Let F_r be the F-value in the simple linear regression (in fact the t^2 when testing the regression coefficient with Students t) then:

$$F_r = \frac{\text{Mean Square of regression variable}}{\text{Mean Square of residual}}$$

The real variance (between intake measurements on different times) mainly consists of the variance of the sampling errors involved in the intake estimate. The variation in real intake between animals or for the same animal between times presumably is small compared with this sampling variance. Thus the estimation of the variance of the intake ($S_{\bar{C}}^2$, Section 4.3.1) seems a reasonable estimate of the relevant variance. The Mean Square of residual is an unbiased estimate of the relevant variance if the model used in the regression is the right one. Otherwise it is an overestimate of the true variance. Therefore the regression model can be tested with F_{model} (F_m):

$$F_m = \frac{\text{Mean Square of residual}}{S_{\bar{C}}^2}$$

If F_m is high, the model is probably wrong; if F_m is low then the model may be right. $S_{\bar{C}}^2$ is a more precise estimate of the relevant variance than $MS_{residual}$ and can therefore better be used to test the regression coefficients. The F-value connected with this test is called $F_{alternative}$ (F_a):

$$F_a = \frac{\text{Mean Square of regression variable}}{S_{\bar{C}}^2}$$

The results of the regression analyses of the C_0 data are given in Table 64 (the average $S_{\bar{C}}^2$ per month was used). As already indicated the A_0 was not constant. The results of the allowance trials (Experiments 3 and 4) were used to convert the consumption data to a standardized allowance level of 22 kg d^{-1} (the mean A_0 of 1976 and 1977). A linear regression coefficient of C_0 on A_0 of -42 and -26 was used in es and ls respectively

Table 64. Regression coefficients and probabilities corresponding to F-values in the simple linear regression of areic consumption of herbage on daily herbage allowance and on areic mass of herbage of grazing cows (Experiments 1 and 2).

y	x		$y = a + b x$						
			1976			1977			
			May	June	August	May	June	August	September
C_0	A_0	b	-476	198	1.83	162	-116	-0.05	-68
		F_r	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.
		F_m	***	***	**	***	*	***	**
		F_a	***	n.s.	n.s.	***	***	n.s.	***
C_0	M_0	b	0.749	0.718	0.673	0.662	1.074	0.542	0.932
		F_r	*	*	n.s.	***	***	n.s.	***
		F_m	n.s.	n.s.	*	n.s.	n.s.	n.s.	n.s.
		F_a	***	***	**	***	***	***	***
$C_{0,cor}$	M_0	b	0.779	0.694	0.661	0.604	1.422	0.454	1.180
		F_r	n.s.	n.s.	n.s.	***	*	n.s.	***
		F_m	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		F_a	***	***	**	***	***	***	***

(Section 5.3.2.4). The C_0 corrected for variation in A_0 ($C_{0,cor}$) is shown in Appendix 14. The same regression analysis as done with C_0 was performed with the $C_{0,cor}$ data (Table 64).

The C_0-A_0 regression was not a suitable model (F_m was significant in all periods). The C_0-M_0 and $C_{0,cor}$-M_0 regressions were suitable models in all trials except in August 1976. In all trials a significant and positive effect of M_0 on C_0 and on $C_{0,cor}$ existed (the P-value of F_a was <0.025 in all trials).

In Experiments 1 and 2 different levels of M_0 were achieved and compared within the same sward by using a variable length of rest period. The effect of M_0 on C_0 in Experiments 3 and 4 has not yet been examined in Chapter 5. In Experiments 3 and 4 (1978/1979) in every EP other swards were used with a different level of M_0 due to variation in length of rest period, season and sward density. Combining the C_0 data of all EP's gave the possibility to examine the influence of M_0 (between EP's) on C_0. Regression analysis was performed with the C_0 data (ms + 1m) and M_0 data (ms and ms +

Table 65. Probabilities corresponding to F-values based on multiple regression of areic consumption of herbage (C_0; Experiments 3 and 4). Each term is tested eliminating the preceding terms and ignoring the following.

A_0 and M_0		G	Se	A_0	A_0^2	A_0 Se	A_0^2 Se	M_0	M_0^2	M_0 Se	M_0^2 Se
ms	1978	***	***	***	*	***	n.s.	***	**	***	n.s.
	1979	n.s.	***	***	n.s.	*	n.s.	***	n.s.	n.s.	n.s.
ms + 1m	1978	***	***	***	***	n.s.	n.s.	***	n.s.	***	n.s.
	1979	n.s.	***	***	n.s.	n.s.	n.s.	***	n.s.	**	n.s.

Table 66. Regression coefficients in the multiple regression of areic consumption of herbage on areic mass of herbage; after adjustment for the effects of G and A_0 (Experiments 3 and 4).

A_0		$C_0 = a + b\,M_0$					
		ms			ms + lm		
		b	s_b	P	b	s_b	P
es	1978	0.642	0.037	***	0.583	0.032	***
	1979	0.591	0.053	***	0.554	0.056	***
ls	1978	1.089	0.045	***	0.992	0.065	***
	1979	0.812	0.068	***	0.955	0.094	***

lm). Effects of areic herbage mass could only be examined after adjustment for the effects of A_0. The probabilities corresponding to the F-values of the multiple regression analyses are shown in Table 65. The effects of M_0 and of M_0^2 (only in es 1978) were significant; there was a significant M_0-Se interaction in 1978 and in 1979 (ms + lm). So the effect of M_0 was different in es compared with ls.

Estimations of the M_0-C_0 regression coefficients were made for the combined data per season. In the multiple regression analysis per season adjustments were first made for the effects of G, A_0 and A_0^2. After correction for these factors the effects of M_0 and M_0^2 were examined. The addition of M_0^2 did not depress the variation around the regression line (in all periods) so only linear relationships are reported. (Table 66). In both years the M_0-C_0 regression coefficients in es were lower than in ls.

6.3.3.4 Daily herbage intake

The daily herbage intake per grazing period is shown in Table 63. Linear regression analysis was performed with the I_0 data (ms + lm) and M_0 data (ms). Due to variation in A_0 between periods this variable was also taken into account. The results of the regression analysis are shown in Table 67; the meaning of the different F-values has already been explained (Section 6.3.3.3). The results of the allowance trials (Experiments 3 and 4) were used to convert the intake data to a standardized allowance level of 22 kg d^{-1} (the mean A_0 of Experiments 1 and 2). A linear regression coefficient of I_0 on A_0 of 0.18 and 0.28 was used in es and ls respectively (Section 5.3.2.5). The I_0 corrected for variation in A_0 ($I_{0,cor}$) is shown in Appendix 14. The same regression analysis as done with I_0 was performed with the $I_{0,cor}$ data (Table 67).

The I_0-M_0 was not a suitable regression model in June 1977 ($P < 0.025$); in all other trials both I_0-A_0, I_0-M_0 and $I_{0,cor}$-M_0 could be used as regression models. There was a significant effect of A_0 on I_0 in May ($P < 0.05$) and June ($P < 0.01$) 1977. Only in June 1977 there was a significant negative effect of M_0 on I_0, however this regression model cannot be used (Section 6.3.3.3). After correction for variation in A_0 between EP's no effects of M_0 on $I_{0,cor}$ could be shown.

Table 67. Regression coefficients and probabilities corresponding to F-values in the simple linear regression of daily herbage intake on daily herbage allowance and on areic mass of herbage of grazing cows (Experiments 1 and 2).

y	x		$y = a + b\,x$						
			1976			1977			
			May	June	August	May	June	August	September
I_0	A_0	b	-0.047	0.553	0.447	0.362	0.211	0.132	0.188
		F_r	*	n.s.	n.s.	**	n.s.	n.s.	n.s.
		F_m	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		F_a	n.s.	n.s.	n.s.	*	***	n.s.	n.s.
I_0	M_0	b	0.00004	0.00160	0.00122	0.00074	-0.00139	0.00019	-0.0011
		F_r	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		F_m	n.s.	n.s.	n.s.	n.s.	**	n.s.	n.s.
		F_a	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.
$I_{0,cor}$	M_0	b	0.00017	0.00106	0.00110	0.00048	0.00010	-0.00069	0.0018
		F_r	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.
		F_m	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		F_a	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 68. Probabilities corresponding to F-values based on multiple regression analysis of daily herbage intake (I_0; Experiments 3 and 4). Each term is tested eliminating the preceding terms and ignoring the following.

A_0 and M_0		G	Se	A_0	A_0^2	A_0 Se	A_0^2 Se	M_0	M_0^2	M_0 Se	M_0^2 Se
ms	1978	*	***	***	n.s.	***	n.s.	**	n.s.	***	n.s.
	1979	n.s.	n.s.	***	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
ms + lm	1978	n.s.	**	***	n.s.	n.s.	n.s.	*	n.s.	***	n.s.
	1979	n.s.	n.s.	***	n.s.	n.s.	n.s.	n.s.	n.s.	**	n.s.

Table 69. Regression coefficients in the multiple regression of daily herbage intake on areic mass of herbage (after adjustment for the effects of G and A_0; Experiments 3 and 4).

		$I_0 = a + b\,M_0$					
A_0		ms			ms + lm		
		b	s_b	P	b	s_b	P
es	1978	0.0002	0.0002	n.s.	0.0003	0.0002	n.s.
	1979	0.0005	0.0005	n.s.	0.0003	0.0005	n.s.
ls	1978	0.0027	0.0005	***	0.0029	0.0008	***
	1979	0.0018	0.0007	**	0.0046	0.0009	***

In Experiments 1 and 2 different levels of M_0 were compared within the same sward by using a variable length of rest period. The effect of M_0 on I_0 in Experiments 3 and 4 has not yet been examined in Chapter 5. In Experiments 3 and 4 (1978/1979) in every EP different swards were used with a variable level of M_0 due to variation in length of rest period, season and sward density. Combining the I_0 data of all EP's gave the possibility to examine the influence of M_0 on I_0. Effects of M_0 could only be examined after adjustment for A_0. The probabilities corresponding to the F-values of the multiple regression analysis are shown in Table 68. Significant effects of M_0 could only be shown in 1978; there was a significant M_0-Se interaction in 1978 and 1979 (only ms + lm), so the regression coefficient for M_0 seemed to be different in es and ls.

Estimates of the M_0-I_0 regression coefficients were obtained for the combined data per season. In the multiple regression analysis per season adjustments were first made for the effects of G, A_0 and A_0^2. The addition of M_0^2 did not depress the variation around the regression line. So only linear relationships are reported (Table 69). In the es no effect could be shown of M_0 on I_0, in agreement with the results of Experiments 1 and 2. However in ls all sets of data showed a significant increase of I_0 at higher levels of M_0. These results will be discussed in Section 6.4.1.

6.3.3.5 Milk production, milk composition and live weight

The average milk production, milk composition and live weight per EP are shown in Table 70; in 1977 these variables were not determined during the EP's containing

Table 70. Milk production, milk composition and live weight of grazing cows.

		EP	L	100 w_{XL}	100 w_{XP}	FCM	W
1976	May	1	28.7	4.21	3.20	29.6	515
		2	28.6	3.83	3.17	27.8	519
		3	26.6	3.89	3.20	26.2	526
	June	1	26.4	3.66	3.36	25.1	530
		2	23.5	3.80	3.23	22.8	522
		3	21.4	3.86	3.17	21.0	523
	August	1	19.8	3.82	3.38	19.3	545
		2	20.4	3.82	3.41	19.9	543
		3	19.1	4.09	3.56	19.4	536
	mean		23.8	3.88	3.30	23.5	529
1977	May	2	26.4	3.96	3.45	26.2	519
		4	25.2	3.68	3.31	24.0	533
		6	22.7	3.99	3.31	22.6	533
	June	1	25.2	3.92	3.47	24.9	538
		3	23.1	3.77	3.34	22.3	533
	August	1	21.0	3.92	3.52	20.7	549
		3	19.7	3.99	3.48	19.5	543
	September	1	19.2	3.90	3.61	18.9	553
		3	18.3	3.93	3.69	18.1	556
		5	17.2	4.12	3.75	17.4	561
	mean		21.6	3.92	3.49	21.3	542

Table 71. Regression coefficients and probabilities corresponding to t-values in the simple linear regression of the difference between actual and expected FCM production on areic mass of herbage of grazing cows.

$\Delta FCM = a + b\ M_O$

	1976			1977			
	May	June	August	May	June	August	September
b	-0.001259	-0.001949	0.001479	-0.001065	-0.001749	-0.001653	-0.000790
P	**	***	n.s.	***	***	***	n.s.

the weekend. Milk production and FCM production declined in time at increasing maturity of the herbage, however the effect of herbage mass is confounded with the effect of lactation stage. The effects of M_O on w_{XL} and w_{XP} of the milk varied between months and were not clear.

To divide the effects of lactation stage from the effects of herbage mass on FCM production an average lactation curve over the grazing season was first made. The same procedure for calculating the lactation curve and for the regression analysis was followed as described in 6.3.2.3. The 12 regression coefficients per animal were averaged and tested by Students t (Table 71). In May and June of both years FCM production decreased significantly at higher levels of M_O. In August 1977 also a negative effect of M_O on FCM production could be shown. However in August 1976 and in September 1977 no significant effects of M_O on FCM production could be shown. In May and June the negative effects of the length of the rest period on FCM production was strong, with regression coefficients ranging from -1.07 to -1.95 kg I_O/tonne M_O.

6.3.3.6 Chemical composition, digestibility and nutritive value of herbage

The mean chemical composition of M and M^f is shown in Table 72. The in-vitro digestibility and nutritive value of M and M^f per EP are given in Table 73. The w_{NDF}/O of M^f was significantly ($P < 0.01$) higher than that of M, for w_{XF}/O this difference was only significant ($P < 0.05$) in 1977 when tested by Students t-test.

Table 72. Chemical composition of herbage mass and of residual herbage of grazing cows.

			w_T	w_O/T	w_{XP}/O	w_{XF}/O	w_{NDF}/O
M	ms	1976	0.271(0.063)[1]	0.901(0.005)	0.205(0.030)	0.267(0.302)	0.542(0.044)
		1977	0.179(0.031)	0.892(0.012)	0.225(0.054)	0.257(0.026)	0.528(0.044)
	lm	1977	0.284(0.103)	0.845(0.029)	0.198(0.040)	0.273(0.031)	0.575(0.057)
M^f	ms	1976	0.366(0.108)	0.865(0.054)	0.168(0.017)	0.279(0.028)	0.582(0.048)
		1977	0.213(0.029)	0.878(0.028)	0.189(0.050)	0.279(0.034)	0.569(0.054)
	lm	1977	0.309(0.083)	0.839(0.021)	0.193(0.042)	0.283(0.033)	0.590(0.051)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different experimental periods.

Table 73. In-vitro digestibility and nutritive value of herbage mass and of residual herbage of grazing cows.

		EP	M					M^f				
			ms	lm	ms + lm[1]			ms	lm	ms + lm[1]		
			d_O	d_O	w_{dXP}/O	d_O	e_{NE_1}/O[2]	d_O	d_O	w_{dXP}/O	d_O	e_{NE_1}/O
1976	May	1	0.808	-	0.216	0.808	1109	0.782	-	0.140	0.782	1022
		2	0.803	-	0.179	0.803	1078	0.756	-	0.128	0.756	975
		3	0.777	-	0.124	0.777	1004	0.724	-	0.092	0.724	907
	June	1	0.773	-	0.157	0.773	1019	0.733	-	0.142	0.733	950
		2	0.726	-	0.143	0.726	940	0.710	-	0.102	0.710	892
		3	0.706	-	0.124	0.706	899	0.683	-	0.117	0.683	862
	August	1	0.686	-	0.168	0.686	897	0.605	-	0.130	0.605	760
		2	0.679	-	0.148	0.679	875	0.584	-	0.114	0.584	722
		3	0.682	-	0.144	0.682	877	0.580	-	0.117	0.580	719
	mean		0.738	-	0.156	0.738	966	0.684	-	0.120	0.684	868
1977	May	1	0.835	0.814	0.165	0.832	1114	0.820	0.805	0.141	0.814	1071
		2	0.837	0.814	0.146	0.835	1106	0.812	0.784	0.120	0.804	1043
		3	0.837	0.782	0.110	0.833	1081	0.818	0.760	0.090	0.803	1023
		4	0.825	0.766	0.105	0.821	1058	0.795	0.766	0.076	0.789	993
		5	0.810	0.754	0.089	0.807	1028	0.799	0.763	0.069	0.789	989
		6	0.796	0.714	0.102	0.789	1010	0.765	0.730	0.083	0.756	948
	June	1	0.816	0.765	0.170	0.806	1077	0.787	0.726	0.135	0.770	1001
		2	0.793	0.670	0.162	0.779	1032	0.748	0.703	0.131	0.733	944
		3	0.774	0.645	0.142	0.761	992	0.740	0.699	0.110	0.725	920
		4	0.753	0.670	0.115	0.743	949	0.717	0.677	0.091	0.698	869
	August	1	0.764	0.556	0.239	0.711	979	0.709	0.557	0.189	0.622	819
		2	0.760	0.563	0.219	0.727	991	0.693	0.588	0.188	0.643	848
		3	0.758	0.579	0.218	0.737	1004	0.715	0.653	0.190	0.692	919
		4	0.749	0.593	0.210	0.738	1000	0.729	0.640	0.197	0.690	921
	September	1	0.749	0.514	0.222	0.724	988	0.718	0.560	0.186	0.659	871
		2	0.752	0.496	0.200	0.722	972	0.718	0.555	0.172	0.656	859
		3	0.756	0.500	0.205	0.726	981	0.705	0.542	0.173	0.633	826
		4	0.764	0.476	0.210	0.731	992	0.705	0.509	0.178	0.617	808
		5	0.765	0.460	0.208	0.735	997	0.714	0.550	0.167	0.636	827
	mean		0.784	0.639	0.170	0.766	1019	0.748	0.661	0.141	0.712	921

1. In 1976 only ms.
2. VEM kg^{-1}.

Table 74. Regression coefficients and probabilities corresponding to F-values in the simple linear regression of in-vitro digestibility of herbage on areic mass of herbage of grazing cows.

		$d_0 = a + b\ M_0$						
		1976			1977			
		May	June	August	May	June	August	September
M	b	-0.00175	-0.00479	-0.00494	-0.00103	-0.00433	0.00273	0.00181
	P	n.s.	***	n.s.	**	***	*	*
M^f	b	-0.00337	-0.00334	-0.00451	-0.00178	-0.00418	0.00692	-0.00487
	P	***	*	n.s.	***	***	n.s.	n.s.

The w_{XP}/O (ms), w_{dXP}/O (ms + 1m) and d_0 (ms and ms + 1m) of M^f were significantly ($P < 0.01$) lower than these of M.

The relationship between M_0 and in-vitro d_0 of M and M^f was tested by regression analysis (Table 74). In May and June of both years d_0 (ms + 1m) of M and d_0 of M^f significantly decreased at higher levels of M (in May 1976 only not significant). With the flowering herbage of June the magnitude of this effect was much greater than in May. In August and September the effects of M on d_0 of M and on d_0 of M^f were small and not significant; only in 1977 d_0 of M significantly ($P < 0.05$) increased at higher levels of M in these periods.

6.3.3.7 Areic consumption of nutrients from herbage

The areic consumption of nutrients from herbage is shown in Table 75. Linear regression analysis was performed with the C_{NE_1} data (ms + 1m) and M_0 data (ms); results

Table 76. Regression coefficients and probabilities corresponding to F-values in the simple linear regression of areic consumption of net energy from herbage on daily herbage allowance and on areic mass of herbage of grazing cows.

y	x		$y = a + b\ x$						
			1976			1977			
			May	June	August	May	June	August	September
C_{NE_1}	A_0	b	-481	130	8.5	160	117	15.5	-75
		F_r	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		F_m	***	***	**	***	***	***	***
		F_a	***	n.s.	n.s.	***	***	n.s.	***
C_{NE_1}	M_0	b	0.685	0.563	0.601	0.653	0.898	0.510	1.06
		F_r	n.s.	n.s.	n.s.	***	***	n.s.	***
		F_m	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		F_a	***	***	***	***	***	***	***
$C_{NE_{1,cor}}$	M_0	b	0.717	0.541	0.599	0.592	1.28	0.415	1.33
		F_r	n.s.	n.s.	n.s.	***	**	n.s.	***
		F_m	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		F_a	***	***	**	***	***	***	***

Table 75. Areic consumption of nutrients from herbage and daily intake of nutrients from herbage by grazing cows.

			EP	C_{dXP}	C_{dO}	C_{NE_1} [1]	D_{XP}	D_O	I_{NE_1} [2]
ms	1976	May	1	377	1244	1740	3.72	12.29	17.21
			2	449	1888	2563	2.93	12.32	16.74
			3	375	2215	2891	2.02	11.98	15.64
		June	1	168	810	1076	2.37	11.45	15.22
			2	285	1308	1715	2.41	11.09	14.55
			3	254	1436	1837	2.04	11.57	14.81
		August	1	229	889	1182	3.11	12.06	16.05
			2	212	935	1222	2.31	10.22	13.36
			3	240	1116	1454	2.58	12.01	15.66
		mean		288	1316	1742	2.61	11.67	15.47
ms + 1m	1977	May	1	220	1013	1374	2.51	11.55	15.69
			2	241	1232	1660	2.33	11.94	16.10
			3	219	1526	1999	1.57	10.96	14.38
			4	263	1753	2301	1.72	11.45	15.03
			5	276	2199	2831	1.46	11.70	15.08
			6	369	2566	3327	1.86	12.94	16.79
		June	1	281	1106	1528	3.30	12.98	17.93
			2	397	1781	2392	2.77	12.44	16.72
			3	402	1969	2602	2.36	11.56	15.30
			4	347	2121	2734	1.53	9.36	12.07
		August	1	321	902	1276	4.11	11.55	16.35
			2	362	1186	1642	3.83	12.54	17.36
			3	323	1039	1441	3.81	12.24	16.98
			4	382	1346	1837	3.24	11.43	15.61
		September	1	333	1018	1426	4.07	12.46	17.47
			2	311	1075	1480	3.01	10.41	14.34
			3	366	1266	1745	3.29	11.39	15.72
			4	414	1442	1991	3.37	11.75	16.24
			5	441	1504	2080	3.37	11.51	15.95
		mean		330	1476	1982	2.82	11.69	15.85

1. kVEM ha^{-1}.
2. kVEM d^{-1}.

are shown in Table 76. The meaning of the different F values and of $C_{NE_1,cor}$ is already explained (Section 6.3.3.3).

The C_{NE_1}-A_O regression model was not suited (F_m was significant in all trials). The C_{NE_1}-M_O and $C_{NE_1,cor}$-M_O regression models were suitable in all trials. A significant positive effect of M_O on C_{NE_1} and on $C_{NE_1,cor}$ could be shown in all trials (P-value of F_a <0.025).

6.3.3.8 Daily intake of nutrients and degree of nutrient balance

The daily intake of nutrients from herbage per grazing period is also shown in Table 75. Linear regression analysis was performed with the I_{NE_1} data (ms + 1m) and M_O data (ms). The meaning of the different F-values is already explained (Section 6.3.3.3); the way of calculating $I_{O,cor}$ is given in Section 6.3.3.4. Results of regression ana-

Table 77. Regression coefficients and probabilities corresponding to F-values of simple linear regression of daily intake of net energy from herbage on daily herbage allowance and on areic mass of herbage of grazing cows.

y	x		y = a + b x						
			1976			1977			
			May	June	August	May	June	August	September
I_{NE_1}	A_0	b	0.349	0.840	0.517	0.308	0.445	0.088	0.215
		F_r	n.s.	n.s.	n.s.	**	*	n.s.	n.s.
		F_m	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		F_a	n.s.	n.s.	*	n.s.	***	n.s.	n.s.
I_{NE_1}	M_0	b	-0.000898	-0.000365	0.000771	0.000291	-0.00349	-0.000517	-0.000698
		F_r	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		F_m	n.s.	n.s.	*	n.s.	***	n.s.	n.s.
		F_a	n.s.	n.s.	n.s.	n.s.	***	n.s.	n.s.
$\dot{I}_{NE_1,cor}$	M_0	b	-0.000755	-0.000444	0.000644	0.000024	-0.001800	-0.001478	0.002261
		F_r	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
		F_m	n.s.	n.s.	n.s.	n.s.	**	n.s.	n.s.
		F_a	n.s.	n.s.	*	n.s.	***	n.s.	n.s.

lysis are shown in Table 77.

The I_{NE_1}-M_0 regression model was not suitable in August 1976 and June 1977; in June 1977 also the $I_{NE_1,cor}$-M_0 model was not suited. There was a significant effect of A_0 on I_{NE_1} in August 1976 and June 1977. In May and June 1976 there was a tendency of lower I_{NE_1} and $I_{NE_1,cor}$ at increasing M_0, probably due to the low number of measurements per trial ($n = 3$) the effects were not significant.

In May 1977 the M_0-I_{NE_1} regression coefficient was positive; however when EP 6 was excluded from regression analysis (Section 6.4) the regression coefficients were -0.00032 and -0.00042 ($P < 0.05$) for the regressions of M_0-I_{NE_1} and of M_0-$I_{NE_1,cor}$ respectively. In June 1977 the M_0-I_{NE_1} and M_0-$I_{NE_1,cor}$ regressions were significantly negative; however these models cannot be used (Section 6.3.3.1). In August 1976 $I_{NE_1,cor}$ significantly increased at higher levels of M_0. In the ls of 1977 no effects of M_0 on I_{NE_1} could be shown.

The daily intake of nutrients from the total ration and the degree of nutrient balance are given in Appendix 15. Due to the same consumption of concentrates in all grazing periods the differences in consumption of nutrients from the total ration between EP's were the same as those from herbage alone.

The degree of NE_1 balance was below 1 in May and June 1976 and above 1 in August 1976. It should be realized that the consumption of herbage in 1976 was probably overestimated due to the use of the ms alone when estimating herbage mass (Chapter 4). In May and June of 1977 the degree of NE_1 balance varied around Unity. In August and September of that year the NE_1 consumption was much higher than the NE_1 requirement, resulting in an increasing live weight during ls. Except in May 1977 all other periods showed a degree of dXP balance over 1.

6.4 DISCUSSION

6.4.1 Daily herbage intake

The different levels of areic mass of herbage were successively applied in time by lengthening the period of growth. The advantage of this procedure was that the treatments could be compared within the same group of animals but a disadvantage however was that the effects of areic mass were correlated with all other variations in time of other factors influencing herbage intake. Apart from variation in areic mass and digestibility through time at changing maturity of the herbage, the most important factors variable in time were the lactation stage of the animals, the weather and the daily herbage allowance (the last factor, however, is also important when comparing the treatments at the same time). There are indications from the literature that the effect of stage of lactation on herbage intake of grazing cows is small when measured over long periods (Section 2.3.3). The treatments were compared within 3-week periods so it is unlikely that herbage intake is affected by lactation stage in these short experimental periods. However variation in meteorological conditions and allowance levels between periods may have influenced results.

The daily herbage allowance of the grazing cows differed from the intended level in several EP's. As already pointed out in Section 5.4.1 this can be attributed to: 1) differences between the expected rate of herbage accumulation in the exclosure and the actual rate (May EP 6, June EP 4), 2) differences between the rapid method of estimating T content of exclosure samples and the laboratory method (June EP 1), 3) variation in herbage mass within the pasture between the exclosure and the grazed plots (June EP 4, August EP 3, September EP 1), 4) a variable accumulation factor g. In May and June of 1977 significant effects of allowance on herbage intake could be shown. However the results of Experiments 3 and 4 gave the possibility to apply corrections for this variation in A_0. After correction to a standardized allowance level no significant effects of areic mass on I_0 could be shown. There is too little information available in the literature on the effects of weather on herbage intake of grazing animals to attribute differences in I_0 between periods to variation in climatical conditions. Comparisons of areic mass effects with those reported in the literature will be made in Section 6.4.2.

In Experiments 3 and 4 (!) each week different pastures were used with a variable level of M_0 as described in Chapter 5. Variation in M_0 between EP's in Experiments 3 and 4 was not only caused by variation in the maturity of the herbage, as in Experiments 1 and 2, but also by variation in the density of the herbage (kg ha^{-1} cm^{-1}) of the swards used. Using a wide variation of M_0 (and of d_0) in the es of both years, no effects could be shown of M_0 on I_0 in these periods, which was in agreement with the results of Experiments 1 and 2. However in the ls of Experiments 3 and 4, when the variation in M_0 (and especially d_0) was much smaller than in es, I_0 significantly increased at higher levels of M_0. This effect in ls could not be shown in Experiments 1 and 2 at variable maturity of the herbage and at a constant herbage density at variable M_0 within the same sward. Further analysis of the M_0 effect on I_0 in the ls of Experiments 3 and 4 showed that I_0 increased with the density of the herbage offered (ms); the correlation coefficient ranged from 0.44 (1979) to 0.81 (1978). So the denser the sward the higher was the daily herbage intake in ls.

Sward density also accounted for a significant proportion of the variation in herbage intake of sheep in trials of Arnold & Dudzinski (1967b) and Allden & Whittaker (1970). The effect of sward density on herbage intake can probably be explained by the major influence of sward density on bite size as was shown for dairy cows by Stobbs (1973a, b), Chacon & Stobbs (1976) and Chacon et al. (1978). In the short, vegetative herbage of ls bite size probably decreased at more open swards; if this effect could not be compensated for by increased grazing time or rate of biting herbage intake also declined. In the es M_0 was higher than in ls, possibly raising bite size, and the effect of sward density was probably confounded with differences in the proportion of flowering tillers in the sward between weeks (also making the measurement of sward height and sward density with a disk very difficult).

The herbage fed to the cows in the stall had a high T content (ranging from 0.16 to 0.40) in the dry summer of 1976. Except in EP 3 of August the T content increased during the grazing season due to the lack of rain; in the dry herbage no effect of T content on I_0 could be shown in this year. However in 1977 a significant positive effect of w_T of herbage on I_0 of stall fed cows could be shown (regression coefficient

0.36 kg I_0/100 w_T) at a range of T content from 0.12 to 0.23. So when the T content of herbage was low on a day the intake decreased at that time, however the next day this effect was partly compensated for which is shown in the negative regression coefficient of -0.28 kg I_0 per 100 w_T of the herbage fed on the day before. After adjustment for the effects of animal, season and T content of herbage no influence of M_0 on I_0 could be shown, in agreement with the results of the grazing trials.

When freshly cut herbage was fed to cattle a positive correlation between w_T and I_0 has also been shown by Halley & Dougall (1962), Holmes & Lang (1963), Demarquilly (1966), Vérité & Journet (1970) and Rohr (1972). Holmes & Lang (1963) have questioned whether the fluctuations in I_0 were due to the changes in w_T or to the changes in the amount of dry matter offered. In the trials reported so much fresh herbage was supplied that fresh residues of at least 15% were left behind each day, so this feeding schedule resulted in some variation in the herbage allowance (A_0) between days due to the variation in w_T between days. The high correlation between w_T and A_0 was also shown in the results of the regression analysis on data per year: after adjustment for the effects of A_0 the effects of w_T on I_0 were not significant. For future trials it can be recommended not to feed to a given level of fresh residues but to supply a constant amount of dry or organic matter per day to avoid correlation between w_T and A_0.

The effect of daily herbage allowance on herbage intake of stall-fed animals can be estimated when different levels of A_0 are fed to comparable animals over longer periods. This was not done in the experiments so the allowance effect could not be checked. However allowance levels varied between days partly due to variation in T content. After correction for the effect of w_T, regression analysis showed significant effects of this variation in A_0 from day to day on I_0 (within animals), however it is doubtful whether this effect would have been established also when different A_0 levels were supplied over longer periods. Assuming that this allowance effect was reliable multiple regression analysis showed a small but significant positive effect of M_0 on I_0 (0.27 kg I_0 per tonne M_0). It is recommended to check in future trials whether the short-term allowance effect (within animals) can also be shown when different levels of A_0 are supplied over periods of e.g. a week to comparable (groups of) animals.

6.4.2 Digestibility of herbage

The digestibility of the herbage samples was determined in-vitro. In 1976 additionally four digestibility trials were performed both with wether sheep and lactating cows to compare in-vitro with in-vivo estimates and to provide standard samples for the in-vitro procedure. The herbage offered to the stall-fed cows was used for these digestibility trials in June EP 1 and 2 and August EP 1 and 2 respectively. The in-vivo d_0 of herbage samples fed to sheep around maintenance was 0.788, 0.749, 0.712 and 0.691 in the respective periods (Van der Honing, 1977). Corresponding in-vitro estimates of the samples gathered in the intake experiment were 0.785, 0.756, 0.696 and 0.687 respectively. These results indicate that the in-vitro method of Tilley & Terry can provide reliable estimates of the in-vivo digestibility of herbage if standard samples of known in-vivo digestibility are included in each in-vitro series.

Different levels of areic mass were achieved in the experiments described by variation in the maturity of the herbage. However at changing maturity of herbage digestibility is also affected (Green et al., 1971) therefore the factor areic mass and digestibility of herbage are interrelated. In the es the herbage supplied to the stall-fed and grazing cows showed a strong decline in digestibility with increasing maturity (or areic mass); this effect was the most significant with the flowering herbage in June. In ls the small differences in areic mass at increasing maturity were accompanied by insignificant changes in digestibility (stall-fed herbage of both years, grazed herbage in 1976) or even with a very small increase in d (grazed herbage in 1977). The changes in the digestibility of the residues in the stall or of the residual herbage at pasture with increasing maturity were comparable to the changes in het herbage offered.

The d_0 of A (stall and grazing) in May was always higher than 0.78. In June the lowest d_0 levels of A attained were 0.70 in 1976 and 0.74 in 1977. Due to the very dry weather conditions very mature herbage had to be used in August 1976 with a d_0 of about 0.69. In the ls of 1977 herbage was used with a d_0 of 0.75 or higher. These results indicate that the d_0 of the supplied herbage was high even at high levels of areic mass. The d_0 of the residual herbage in 1977 was lower than the d_0 of supplied herbage both at stall (0.768 vs. 0.796) and at grazing (0.712 vs. 0.766, determined with ms + lm); in 1976 this effect could not be examined due to lack of estimates of d in residues at stall and to the use of the ms as single cutting machine. The quality of the diet ingested was calculated with the equations given in Section 5.4.4.

The selection effect of the grazing animals is shown in the difference between d_0 of A_0 (ms) and of I_0 (ms + lm) which was on average 0.023 in 1977. The selection effect of the stall-fed animals in 1977 was much smaller and on average 0.008. So the digestibility of the diet ingested by the grazing animals was a few units higher than that of the herbage offered.

At a d_0 higher than 0.70 in all periods, the stall-fed cows showed no significant reduction of herbage intake at increasing levels of areic mass; only in the extreme dry period of August 1976 a d_0 level of 0.69 was reached which was rather constant at increasing M_0 and also did not affect I_0. These results are in agreement with the literature (Section 2.4.1) where the digestibility of herbage offered indoors had little or no influence on the herbage intake of dairy cows if the d_0 of the herbage was above 0.70 (Hutton, 1962; Hutton et al., 1964; Demarquilly, 1966; Lomba et al., 1970; Rohr, 1972).

The d_0 of the herbage mass at start of grazing (ms) was always higher than 0.70 in 1976 and higher than 0.75 in 1977; only in August 1976 a rather constant d_0 level of 0.68 was reached. Variation in digestibility above these levels with advancing maturity did not affect herbage intake. Due to selection by the animals the lowest level of d_0 of ingested herbage was 0.72 in 1976 and 0.76 in 1977. In experiments of Greenhalgh & Runcie (1962) there was no obvious causative relationship between d_0 and I_0 of grazing dairy cows using a d_0 range of 0.72 to 0.79. Holmes & Jones (1965) also concluded that above a level of d_0 of 0.74 further improvement of d_0 was of little value for I_0 of dairy cows in agreement with results of Rohr & Kaufmann (1967) and

Curran & Holmes (1970). However Corbett et al. (1963) found a small decrease of I_0 at a fall of d_0 from 0.80 to 0.68 but levels of A_0 (which possibly influenced results) were not measured in these trials. The positive linear relationship between d_0 of herbage offered over the range 0.64 to 0.82 and I_0 in trials of Stehr & Kirchgessner (1976) can probably partly be attributed to progressive effects of faeces contamination following repeated grazings and to variation in herbage supply and concentrate supplementation. There are a few indications from literature that I_0 of grazing cows is affected negatively at levels of d_0 of ingested herbage below 0.70 (Jamieson, 1975; Hodgson & Wilkinson, 1968). The experimental results confirm the indications from the literature that above a level of d_0 of ingested herbage of 0.70 no effects of d_0 on I_0 could be shown neither with grazing nor with stall-fed dairy cows.

Apart from digestibility, I_0 of the grazing cows could have been affected by other factors related to the areic mass of herbage such as the structure of the sward. However the lack of any effect of M_0 on I_0 in the trials reported is in agreement with results of Berngruber (1977) who compared young and old pastures at digestibilities over 0.75 (estimated from chemical composition) in grazing trials with steers. In strip grazing experiments with calves Jamieson (1975) and Hodgson et al. (1977) concluded that intake is not likely to be markedly affected by the areic mass of herbage (after correction for the digestibility effects). In an experiment of Combellas & Hodgson (1979) with dairy cows herbage intake however declined at higher levels of herbage mass at comparable levels of d_0 (Table 2).

Altough the interaction between A_0 and M_0 was not significant there was a tendency in these trials for the small negative effect of M_0 on I_0 (at comparable d_0) to decline at higher levels of A_0. At the highest allowance level of 90 g W^{-1} d^{-1} no effect of M_0 on I_0 could be shown as in the experiments reported; this A_0 level is equivalent to the average level of 22 kg d^{-1} per animal in our experiments, if it is assumed that in the experiments of Combellas & Hodgson (1979) the areic mass of O of herbage below ms sampling height was 2 000 kg ha^{-1} (Le Du et al., 1979b). Another reason for some doubt on the negative M_0-I_0 relationship as stated by Combellas & Hodgson (1979) is the difference between periods where the opposite effect was found: period II (M_0 = 5 625 kg ha^{-1}, I_0 = 13.0 kg d^{-1}) and period III (M_0 = 4 185 kg ha^{-1}, I_0 = 12.1 kg d^{-1}) while the differences in d_0 were small (0.809 and 0.782 respectively).

It should be realized that the lack of effect of M_0 on I_0 in the experiments reported was established at rather high allowance levels; the results of Combellas & Hodgson (1979) indicate that negative effects of M_0 on I_0 might exist at low allowance levels. The swards used contained a high proportion of a highly digestible perennial ryegrass; the digestibility was further improved by the use of pre-cut swards which received a high amount of nitrogen fertilizer. For extrapolation of the present results to conditions with a lower allowance, another botanical composition of the sward or a lower digestibility of the herbage data of studies under such conditions are needed.

6.4.3 Daily intake of nutrients, milk production and degree of nutrient balance

In the es the d_0 and w_{dXP} of the herbage declined with increasing areic mass and so also the e_{NE_1} of the herbage offered and of the herbage ingested. When this effect was combined with the I_0 (which was not affected by M_0), the daily intake of nutrients from herbage of the stall-fed and grazing cows decreased at higher levels of M_0 in es. Probably due to the low number of measurements this effect was not significant in 1976; in 1977 this effect was significant. This probably led to the lower FCM production of both the stall-fed and grazing cows at higher levels of M_0 in all trials in es. In August 1976 the I_{NE_1} of the stall-fed cows declined at increasing herbage maturity which was also accompanied by a negative effect on FCM production. Due to a high level of A_0 in EP 3 of August 1976 at pasture the negative effects of M_0 on e_{NE_1} could be compensated for and no negative effects of M_0 on I_{NE_1} nor on FCM production could be shown. In the ls of 1977 no significant effects of M_0 on I_{NE_1} could be established neither at pasture nor indoors; these results were in agreement with the absence of an effect of M_0 on FCM production. Only in August 1977 the FCM production of the stall-fed cows increased at higher levels of M_0 due to a low FCM figure in EP 1 which could not be explained. Comparative information in the literature is scarce; Corbett et al. (1963) found comparable effects of M_0 on D_0 and on FCM production in the es as reported here.

The results of our trials are not suited to compare the estimated nutrient intake with the theoretical nutrient requirements accurately (as was done in Section 5.4.7 for the allowance trials with 8-week measurement periods) because the total length of EP's per month was probably too short to get reliable information on changes in live weight. It was also not possible to combine the information of both months in es or of both months in ls because they did not connect. Another problem in 1976 was the probable overestimation of herbage intake of the grazing cows due to the use of the ms alone; another problem in 1977 was that the FCM production and live weight of the cows were only measured in the EP's during the week (and not over the weekends) so extrapolation was needed to calculate degrees of nutrient balance during the weekend EP's. Despite these complications the general trend of the zero grazing and grazing trials was in agreement with the results described in Section 5.4.7: the predicted changes of live weight (predicted from degrees of net energy balance) agreed reasonably well with the actual changes when the animals gained weight (ls of both years) or when the animals were in approximate nutrient balance (es of 1977); however when the animals had to mobilize their reserves to supply nutrients for their production the loss of live weight was less than predicted (es of 1976 where cows in the first part of the lactation were used).

6.4.4 Areic consumption of herbage and of nutrients by the grazing cows

At a standardized allowance level I_0 was not affected significantly by M_0. Thus the degree of consumption (c) was not affected by different levels of M_0 (Appendix 14). As a consequence of the constant degree of consumption at increasing M_0 both the areic consumption and the areic mass of residual herbage were proportional to the areic mass of herbage at start of grazing. This effect can be illustrated in the next example:

M_0 (including g ΔM^e)	1 500	3 000
A_0	20	20
I_0	14	14
c	0.70	0.70
C_0	1 050	2 100
M_0^r	450	900

After corrections for differences in allowance levels C_0 increased linearly at higher levels of M_0 in all periods. This effect could be shown in Experiments 1 and 2 where differences in M_0 were achieved on the same sward at variable lengths of rest period and in Experiments 3 and 4 where M_0 differed between swards (a combination of maturity and sward density).

At higher levels of areic mass C_0 increased linear giving the possibility of more animal-days with the same daily intake on the same area; the higher mass was obtained with longer periods of growth i.e. less grazing cycles per season or year when converted into a practical situation, From cutting experiments it is known that less frequent defoliation of herbage increases herbage accumulation (Section 7.1).

Berngruber (1977) and Mott & Ernst (1980) compared short and long grass during the whole grazing season on the same swards using topping of residues. They found a 15% higher seasonal accumulation of herbage at long grass (achieved by an infrequent defoliation) than at short grass in grazing trials with steers; the differences in areic consumption of herbage between treatments were of the same order and direction. The effects of variation in areic mass of herbage by varying the length of the rest period between grazings without topping residues have been determined in comparisons of grazing systems and will be discussed in Chapter 7.

Due to the decreasing nutritive value of herbage at higher levels of M_0 (especially in es) the ratios in C_{NE_1} between low and high levels of M_0 were smaller than the ratios in C_0 between treatments. In all periods still a significant positive effect of M_0 on C_{NE_1} could be shown.

6.4.5 Milk production and daily herbage intake

The stall-fed cows of 1977 had calved within a month and showed a variation in actual daily milk production due to among others genetical potential and variation in lactation cycle (age). Regression analysis with individual daily intake and production data per month and over the whole grazing season showed that herbage intake was higher at higher levels of actual milk production at comparable lactation stages. This relationship was determined during the weeks 11 to 28 of lactation (average calving date was 21 February 1977), with cows producing 6 000 kg milk/lactation cycle and at supplementation of 1 kg concentrates per animal per day. Averaged over the season I_0 increased 0.39 kg per 1 kg FCM production.

The e_{NE_1}/O of the consumed herbage of the stall-fed cows in 1977 was on average 1 080 VEM kg^{-1}. So herbage consumption increased 421 VEM per kg FCM. Comparing this value with the net energy requirement for each kg FCM at a milk production level of 20 kg d^{-1} of 448 VEM (Section 3.9) leads to the conclusion that the differences in consumption between the cows, due to differences in FCM production, were nearly equal to the differences which could be calculated by using the feeding standards.

The regression coefficient of 0.39 kg I_O/kg FCM as obtained with stall-fed cows agreed favourably well with the regression coefficient of 0.39 kg I_O/kg FCM as found by 't Hart (1979a) who compared herbage consumption of two groups of grazing cows with different production capacities at comparable stages of lactation (Section 2.3.4).

6.5 CONCLUSIONS

Different levels of areic mass of herbage (M_O) were established by allowing swards to grow for successively longer periods of time. The length of the rest period, after a preliminary cutting, ranged from 18 to 42 days. The resulting different levels of areic mass, at the same time of different maturity, were compared within a constant group of grazing dairy cows and within a constant group of stall-fed dairy cows in time. From the results of 28 experimental periods of 3 or 4 days, both indoors and with grazing cows, on swards which were cut at the previous defoliation the following conclusions could be drawn:

- M_O increased significantly in time with advancing maturity of the herbage; in the es M_O (>4.5 cm) ranged from 1 400 to 4 800 kg ha^{-1}, in the ls M_O ranged from 1 000 to 2 700 kg ha^{-1}.
- A positive effect of the dry matter content of herbage supplied (ranging from 0.12 to 0.23) to the stall-fed cows on daily herbage intake could be shown in 1977; after correction for this effect no significant influence of M_O on daily intake of O from herbage was established.
- At a standardized allowance level the daily intake of O from herbage of the grazing cows was not affected significantly by M_O.
- In es the herbage supplied to and consumed by the grazing and stall-fed cows showed a strong decline in digestibility at increasing levels of areic mass; in ls however the changes of digestibility were small and not significant at a smaller range of M_O.
- Except in August of the extreme dry summer of 1976 the digestibility of the herbage ingested by both groups of cows was always higher than 0.70 which probably explained the lack of any effect of M_O on daily herbage intake.
- In es the daily intake of nutrients from herbage of both groups of cows declined significantly at higher levels of M_O and also affected FCM production in this period negatively. In the ls, however, no significant effects of M_O on daily intake of nutrients from herbage or on FCM production could be shown neither at grazing nor indoors.
- At a constant level of daily herbage allowance the degree of consumption of herbage was not affected significantly by M_O. As a consequence the areic consumption of herbage (both O and nutrients) by the grazing cows and the areic mass of residual herbage

were proportional to M_0.
- At comparable stages of lactation a strong relationship between daily FCM production and daily herbage intake could be shown when seasonal intakes of individual cows, differing in actual milk yield, were compared indoors.

Variation in areic mass of herbage can also be achieved by varying the density of the sward. There are strong indications from the allowance experiments (Chapter 5) that the daily herbage intake by grazing cows increased at higher M_0 when the variation in M_0 is caused by differences in sward density in 1s. The effect of variation in M_0 due to sward density, on herbage intake by grazing cows needs more research in future with special attention to the effects on grazing behaviour. The possible effect of daily herbage allowance on intake of stall-fed cows also needs more investigation in future.

In the es the declining digestibility of herbage at increasing maturity, although not affecting intake of O from herbage negatively at the highly digestible herbage used, affected the daily intake of nutrients from herbage and also the daily milk production negatively. If a high individual performance has to be achieved therefore low levels of M_0 are recommended then.

In the 1s however neither the daily intake of O from herbage, nor the daily intake of nutrients from herbage nor the FCM production were affected by a higher M_0. A higher areic consumption of herbage can then be achieved by taking longer rest periods between grazings. The possible effects of the higher levels of residual herbage resulting from higher levels of M_0, on regrowth of herbage or even on botanical composition of the sward on the long run have not been determined in our short-term trials.

The effect of using longer rest periods between grazing on daily herbage intake and on areic consumption of herbage on repeatedly grazed swards will be discussed in Section 7.2.

7 General discussion

Most of the results obtained in Experiments 1, 2, 3 and 4 have already been discussed in Chapter 4, 5 and 6. The sward-cutting technique used to estimate herbage intake by grazing cows in our experiments has been discussed in Section 4.4. The effects of daily herbage allowance on daily herbage intake, areic consumption of herbage, digestibility of herbage and on herbage accumulation during regrowth have been discussed in Section 5.4. The effects of areic mass of herbage by varying length of rest period on daily herbage intake, digestibility of herbage and on areic consumption of herbage were discussed in Section 6.4.

In the first part of this chapter the mean daily herbage intake of grazing dairy cows in our experiments will be compared with values reported in the literature. In the second part of this chapter some possibilities of combining a high daily intake with a high areic consumption of herbage will be discussed and also some practical applications of the results of our four experiments will be given.

7.1 DAILY HERBAGE INTAKE BY GRAZING DAIRY COWS

The mean I_0 from herbage in Experiments 1, 2, 3 and 4 was 13.5 kg d^{-1} (I_T = 15.0 kg d^{-1}) at a mean 0 allowance level (>4.5 cm) of 22.7 kg d^{-1}. The mean 0 intake of concentrates was 1.17 kg d^{-1} at a production of FCM of 23.6 kg d^{-1} and a mean live weight of 563 kg. In Table 78 our intake figures are compared with data on the herbage intake of grazing dairy cows from the literature. Some of the possible factors affecting interpretation of the intake results are included in the table. Both the technique used for the estimation of the herbage consumption and the level of all factors affecting herbage intake may explain differences in I_0 between experiments.

In all the trials cited in Table 78 where the faecal-index technique has been used, the following assumptions were made:

- the recovery of the faecal indicator (chromic oxide) was complete
- the faecal-index relationships obtained with cut herbage fed indoors can be used for grazing animals
- the faecal-index relationships as derived with sheep or steers can be applied to lactating dairy cattle (except Greenhalgh & Runcie, 1962; Corbett et al., 1963).

As pointed out in Sections 1.3.2.2 and 1.3.3.3 these assumptions are not valid in all conditions and therefore bias in the intake estimate may result. Continuous digestibility trials were performed in most of the faecal-index trials of Table 78. However due to the use of faecal-indicator relationships derived in other periods or from other swards bias in the intake estimate may have been introduced in the experiments of Jones et al. (1965), Holmes et al. (1966), Leaver et al. (1969b), Holmes et al. (1972) and Archibald et al. (1975). This bias in the technique may explain the relatively high intake figures as found by Jones et al. (1965), Holmes et al. (1966), Holmes et al. (1972) and Archibald et al. (1975). Some of these high intake figures are the more unlikely when considering the low levels of A_0 in the trials of Holmes et al. (1972) and Archibald et al. (1975). The mean I_0 (kg d^{-1}) was higher than the mean A_0 in these trials; however I_0 was not measured in all periods so comparison was difficult.

Holmes & Jones (1965), Jones et al. (1965) and Holmes & Curran (1967) made an arbitrary reduction of 1.5 digestibility units when calculating herbage intake of lactating dairy cows from indoor digestibility data from sheep (due to an expected effect of level of feed intake on d); however all other authors using the faecal-index or in-vitro digestibility technique did not make any correction for this effect.

't Hart (1979a) cut the residual herbage with a motor scythe only, however raking and cutting was done in two directions possibly reducing the underestimation of the residual herbage (Chapter 4). Hijink (1978) also only used a motor scythe in one direction, so his estimates of intake are probably too high due to an underestimation of residual herbage.

In all trials the digestibility of the consumed herbage was above 0.70 and in most trials even above 0.75, therefore it was expected that variation in daily herbage intake between experiments could not be attributed to the digestibility of the herbage consumed (Section 2.4.1 and Chapter 6).

In most of the experiments in the literature the supplementation of herbage with organic matter of other feeds was zero or below 1 kg d^{-1}, so little if any substitution effect might be expected. However Kirchgessner & Roth (1972a) fed the grazing cows with a lot of other products such as hay, maize silage, beet pulp and concentrates; the low I_0 can therefore be explained by substitution effects. Concentrate supplementation of grazing cows may also explain the very low intake figure of Stehr & Kirchgessner (1976) combined with the low allowance level (above 2 cm!) and the repeated use of swards in the season with infrequent topping. A small part of the lower I_0 in Experiments 3 and 4 in comparison with Experiments 1 and 2 may also be attributed to differences in the concentrate consumption between these experiments.

The daily herbage intake by grazing dairy cows on pre-cut swards did not differ much from I_0 as measured on pre-grazed swards where the residual herbage was topped each time (Table 78). Therefore the intake figures of both groups of experiments were combined. The daily herbage allowance was not measured in the trials of Holmes & Osman (1960), Greenhalgh & Runcie (1962), Corbett et al. (1963) and Marsh et al. (1971a); therefore these experiments cannot be used for comparing herbage intake with other trials. The different cutting heights, used in the experiments, make it very difficult to compare levels of daily herbage allowance.

If it is assumed that in the experiments of Jamieson (1975), Combellas & Hodgson (1979) and Le Du et al. (1979b) M_0 below ms sampling height was 2 000 kg ha^{-1} (Le Du et al., 1979b) the A_0 levels above 4.5 cm would be about 15, 15 and 13 kg d^{-1} in the respective experiments.

Except in some recent Dutch trials the daily herbage 0 allowance above 4-5 cm in the strip grazing experiments was about 15 kg d^{-1}, ranging from 13 to 18 kg d^{-1}. The

Table 78. Daily herbage intake data by grazing dairy cows.

Author(s)	Year	Method[1]	Length of grazing period (days)	Number of preceding grazing periods	Topping of residual herbage	Animal breed[2]	Supplementation of 0 (kg d^{-1})	Milk production[3] (kg d^{-1})	Live weight (kg)
Holmes & Osman	(1960)	F	1	2-6	+	A	0	14.4 *	513
Greenhalgh & Runcie	(1962)	F	1	0		A/BF	0	14.5	512
Corbett et al.	(1963)	F	1	0-1	-	A	0	13.8	435
Holmes & Jones	(1965)	F	1	0-1	-	A	0	15.9	487
Jones et al.	(1965)	F	14	0-1	-	A	0	17.5	479
Greenhalgh et al.	(1966a)	F	1	0		A	0	15.4	483
Holmes et al.	(1966)	F	1	0-3	+	A	0	13.2	537
Holmes & Curran	(1967)	F	1	1-4	+	A	0.77	12.4	475
Greenhalgh et al.	(1967)	F	1	0-1	-	A	0	13.7	486
Leaver et al.	(1969b)	F	1	0-5	+(cycle 1,3,5)	A	0.70	12.9	521
Greenhalgh & Reid	(1969a)	F	1	0		A	0	14.8	?
Greenhalgh & Reid	(1969b)	F	1	?	?	A/BF	0	16.5	?
Greenhalgh	(1970)	F	1	0-5	+(only cycle 2)	?	0	15.9	?
Marsh et al.	(1971a)	F	1	0-4	-	A/BF	0.70	13.8	?
Kirchgessner & Roth	(1972a)	S	0.5	0-4	+(cycle 2,4)	F	± 2	13.5	660
Holmes et al.	(1972)	F	1	0-4	-	A/BF	1.07	15.5	534
Reid et al.	(1972)	F	1	0-2	+	A/BF	0	16.6	473
Archibald et al.	(1975)	F	1	0-2	-	A/BF	0.80	17.8	551
Jamieson	(1975)	D	1	0		BF	0	18.4 *	496
Stehr & Kirchgessner	(1976)	S	0.5	0-4	+(cycle 1,3)	S	?	17.5	675
Combellas & Hodgson	(1979)	D	1	0		BF	0	15.6	481
't Hart	(1979a)	S	1(partly 4)	0		DF	0.80	20.9	489
't Hart	(1979a)	S	1	0		DF,BF·DF, HF·DF	0.80	21.5	534
Le Du et al.	(1979b)	D	1	0-5	+	BF	0	14.6	503
Hijink	(1978)	S	2-8	0-4 irregular		DF	1.08	17.5	563
Meijs	(1981)	S	3-4	0		DF	0.80	22.4	536
		S	3	0		DF	1.28	24.0	571
		S	3	0		DF	1.28	23.2	570

1. S = sward cutting (see 1.1) F = faecal index (see 1.2.2.2) D = in-vitro digestibility (using
2. A = Ayrshire; BF = British Friesian; DF = Dutch Friesian; HF = Holstein Friesian; F = Fleckvieh;
3. Without *: FCM production; with *: production of milk (L).
4. Without *: d of ingested herbage; with *: d of offered herbage.
5. In 1976 I_0 was corrected with the lm effects as derived in Experiments 2-4 (ΔC_0 = 155 kg ha^{-1}).
6. Assumption: average live weight is 500 kg.

Herbage digestibility[4] (w_{dO})	Daily herbage allowance of O (kg d^{-1})	cutting height (cm)	Daily herbage consumption of O (kg d^{-1})	(g d^{-1} kg$^{-0.75}$)	Notes
0.70	?		11.6	108	
0.74	?		12.8	119	
0.75	?		10.7	112	
0.76	18.2	5	14.3	138	
0.78	?		14.4	141	high yielding cows
0.75	18.1	2.5-5	12.0	116	
0.75	17.3	5	14.2	127	
0.75	16.4	5	12.2	120	
0.75	14.3	2.5-5	11.5	111	
0.77	15.9	5	11.5	105	
0.75	18.4	2.5-5	11.7	111[6]	
0.79	17.3	2.5-5	12.5	118[6]	ryegrass
0.77	14.3	2.5-5	10.6	100[6]	
0.77	?		12.2	115[6]	
?	20.5	2-3	12.9	99	
0.78	13.6	5	14.3	129	1969, treatment A
0.78	13.5	?	10.5	104	control cows in phase I
0.79	13.2	2.5	15.4	135	control cows
0.77	26.8	0	15.1	144	
0.73	24.1	2	10.6	80	
0.80	25.9	0	12.3	120	
0.80 *	19.2	4	13.3	128	high producing cows
	20.8	4	13.2	119	cows in early lactation
0.79	22.5	0	12.4	117	
?	19.0	4.5	12.4	107	control cows
0.76 *	22.2	4.5	14.3[5]	128	Experiments 1 and 2
0.78 *	22.8	4.5	13.3	114	Experiments 3 and 4(average of all treatments)
0.78 *	15.3	4.5	11.5	99	Experiments 3 and 4 (treatment X)

fistulated animals: see 1.3.3.4).
S = Simmenthal.

mean A_0 in our experiments was much higher (22-23 kg d^{-1}). For comparative purposes the mean intake of treatment X (A_0 = 15 kg d^{-1} above 4.5 cm) in Experiments 3 and 4 is also included in Table 78.

The daily herbage O intake determined by indirect animal methods by strip grazing dairy cows on swards which were cut or topped before, ranged from 104 to 127 g d^{-1} $kg^{-0.75}$ (Greenhalgh et al., 1966a; Holmes & Curran, 1967; Greenhalgh & Reid, 1969b; Reid et al., 1972; Le Du et al., 1979b; Combellas & Hodgson, 1979) while Jamieson (1975) found an extreme high O intake of 144 g d^{-1} $kg^{-0.75}$. The mean I_0 of treatment X in Experiments 3 and 4 was 99 g d^{-1} $kg^{-0.75}$. This was not expected because in our experiments the daily FCM production (23 kg d^{-1}) was much higher than in the strip grazing experiments (about 15 kg d^{-1}). In our experiments however the total intake of net energy was in agreement with the theoretical requirements for milk production, maintenance and live weight change (Section 5.4.7).

The higher I_0 at lower milk production levels by strip grazing cows in the literature should have resulted in high rates of live weight gain. However in these strip grazing experiments mean rates of live weight gain were small (ranging from 0.05 to 0.27 kg d^{-1}) or even negative (-0.67 kg d^{-1}, Jamieson, 1975), already indicating possible bias in the methods applied.

Another way to check the levels of I_0 in the strip grazing experiments is to compare the intake of nutrients with the theoretical requirements. This was done in the way described in Sections 3.9 and 5.4.7. In the trials of Greenhalgh et al. (1966a), Greenhalgh & Reid (1969b) and Reid et al. (1972) the intake of net energy was about equal to the requirement for net energy; at an O allowance level of 15 kg d^{-1} I_0 ranged from 105 to 111 g d^{-1} $kg^{-0.75}$. In the experiments of Holmes & Curran (1967), Jamieson (1975), Combellas & Hodgson (1979) and Le Du et al. (1979b) I_0 ranged from 120 to 144 g d^{-1} $kg^{-0.75}$ at an O allowance level of 15 kg d^{-1}. However in these experiments the actual change of live weight was much smaller than the predicted increase of live weight (based on consumption of net energy). The difference between actual and predicted change of live weight ranged between 0.30 and 1.53 kg d^{-1}. It should be realised of course that changes of live weight can best be determined over long periods (which ranged in the described trials from 36 to 168 days) and that an assumption had to be made on the net energy content of the live weight (Section 5.4.7). Provided that the live weight was measured correctly and that the assumption made on the net energy content of it was right, these results indicate that the estimated I_0 in the experiments of Holmes & Curran (1967), Jamieson (1975), Combellas & Hodgson (1979) and Le Du et al. (1979b) was too high. Possible explaining sources of bias have been described in Section 1.3.

The cows in the strip grazing experiments mentioned (except these of Jamieson, 1975) would have been in nutrient balance if I_0 was about 13% lower i.e. if I_0 was about 104 g d^{-1} $kg^{-0.75}$; a value not much different from the I_0 at treatment X in our experiments. Combined with the experiments, where the cows were in nutrient balance about, these results indicate that strip grazing dairy cows consumed 104-111 g d^{-1} $kg^{-0.75}$ of organic matter on pre-cut swards at A_0 (>4.5 cm) and FCM of about 15 kg d^{-1}. Compared with the value of 99 g d^{-1} $kg^{-0.75}$ of treatment X in Experiments 3 and 4 these results suggest that the mean herbage consumption of cows grazing 3-4 days on a pasture might be lower than that of strip grazing cows, if all other possible explaining factors are ignored. However if no concentrates were supplied in our trials I_O might have been somewhat higher than the actual value, due to the lack of substitution of herbage by concentrates. At substitution rates of 0.3 and 0.5, I_O would become 102 and 104 g d^{-1} $kg^{-0.75}$ respectively. The difference between the intake figures estimated with the animal methods and our experiments was small then. Also from the comparable I_O of the mainly strip grazing cows of 't Hart (1979a) and the cows grazing 3-4 days on our pastures at allowance levels differing only 2 kg d^{-1} no considerable difference in I_O between both systems could be shown. If the underestimation of the residual herbage by cutting with a ms only (Chapter 4) was not corrected totally by cutting and raking in two directions, the estimation of I_O may have even been somewhat too high in the trials of 't Hart (1979a). Waite et al. (1952) found a 16% higher (!) herbage intake by paddock grazed cows (grazing periods of 4 days) in comparison with strip grazed animals; but the authors themselves doubted the precision of their sward method of intake estimation in the paddock grazing. The incomplete information on the effect of the length of the grazing period on mean I_O as described above leads to the recommendation to compare I_O of strip grazing cows with I_O of cows grazing 3-4 days on a pasture in future experiments.

From Table 78 another group of intake figures can be separated, those where swards were repeatedly grazed without or with infrequent topping of residual herbage. On these swards I_O ranged from 100 to 111 g d^{-1} $kg^{-0.75}$ at strip grazing (Greenhalgh et al., 1967; Leaver et al., 1969b; Greenhalgh, 1970) and was about 100 g d^{-1} $kg^{-0.75}$ at grazing periods of 2-8 days (Hijink, 1978) at levels of A_O of 15 kg d^{-1}. The data of Hijink (1978) were probably too high due to the use of a ms only when estimating herbage mass (Chapter 4). At the relatively high I_O figure of 111 g d^{-1} $kg^{-0.75}$ of Greenhalgh et al. (1967) the intake of net energy was in agreement with the requirements for net energy when calculated with the methods described earlier. Except the figure of Greenhalgh et al. (1967) I_O on previously grazed not topped swards tended to be lower than on pre-cut swards; in agreement with the literature reviewed in Section 2.5.3.

At a live weight of 550 kg a daily herbage O intake of 120 g d^{-1} $kg^{-0.75}$ as found in our experiments is equal to 13.6 kg d^{-1}. The mean net energy content of the consumed herbage by our grazing cows (e_{NE1}/O) was 1 130 VEM kg^{-1} (e_{NE1}/T = 1 020 VEM kg^{-1}). The daily net energy intake from herbage then was 15.4 kVEM, enough for a daily FCM production of about 22 kg (see Section 3.9 for calculation). In our experiments the mean net energy intake by concentrates was 1 280 VEM d^{-1} giving a net energy intake of the total ration of 16.7 kVEM, enough for a daily FCM production of about 24 kg. When no concentrates were consumed by our animals it can be expected that I_O would have been somewhat higher than the actual figures, due to the lack of herbage substitution by concentrates then. This leads to the conclusions that cows grazing for 3-4 days on pre-cut pastures consume 120-130 g d^{-1} $kg^{-0.75}$ of organic matter if no concentrates are fed at a herbage O allowance level of 23 kg d^{-1} above 4.5 cm. This herbage consumption will be sufficient for a daily FCM production of 22-23 kg.

It should be realized that our intake estimates of the grazing cows are means for groups of six animals. From results with indirect techniques in the literature and from our zero grazing experiments it can be expected that there was a large variation in daily herbage intake between animals.

7.2 COMBINING A HIGH DAILY INTAKE WITH A HIGH AREIC CONSUMPTION OF HERBAGE

The main purpose of the experiments described was to study some of the factors influencing the daily herbage intake by grazing animals. A high daily intake and a high digestibility of the ingested herbage are necessary for a high production and for a high feed conversion efficiency by the individual grazing cow with a high milk production. The effects of the timing of the start and finish of grazing in view of the available areic mass of herbage (two of the most important decisions to be taken by the farmer in grazing management) on daily herbage intake and digestibility were examined in the trials reported. No significant effects of higher levels of areic mass of herbage on daily intake of O from herbage could be shown on swards which were cut at the prior defoliation, however in the es the digestibility of the herbage ingested decreased at increasing maturity. Higher levels of residual herbage (achieved by higher levels of daily herbage allowance) had significant positive effects on daily O intake of herbage and no effect on the digestibility of the diet ingested on swards which were cut at the prior defoliation.

However, maximal animal production per area of grassland should be pursued. The output of animal products from grassland depends on the quantity and quality of herbage produced, on the proportion of herbage grown that is eaten by livestock and on the efficiency of conversion of the consumed herbage into animal products. The need for close defoliation if a high proportion of the herbage grown is to be eaten and to ensure a highly digestible regrowth is in contradiction however, with high intake and digestibility required for a high production of the individual grazing animal. The grazing intensity and so the herbage allowance is the most essential link between animal production (and consumption) per unit area and individual animal production and consumption. At increasing grazing intensity animal output per unit area rises, because of the increased number of animals, but it is achieved at the expense of a decreased output by the individual animal. This effect has become clear from many experiments, such as these reported by Mc Meekan (1960), Mott (1960), Mc Meekan & Walshe (1963), Conway (1968), Raymond (1969), Jones & Sandland (1974) and Smetham (1976). These results are in agreement with the contrasting effects of daily herbage allowance on daily herbage intake per animal and on areic consumption of herbage (Chapter 5).

It is therefore important to investigate grassland utilization systems in which at a given high production of herbage a high proportion of the herbage grown is eaten and in which nevertheless intake and performance of the individual animal (and so feed conversion) are high (Raymond, 1969). Possible methods of combining high intake per animal with high efficiencies of consumption (and thus areic consumption) are:

A) Dividing the animal population into animals with currently high and low nutrient requirements.
The former group graze first at low intensity and are followed in the rotation by the lower producing animals which can still satisfy their nutrient requirements at a high intensity of grazing. This leader/follower system applied to young stock has been successful. Grazing calves in front of older heifers has led to higher growth rates in calves compared with conventional grazing. This was due to allowing the calves to graze selectively but also to a better control of infections with stomach worms (Leaver, 1970). With this system a paddock system for young stock can be set up without the need for clean land (Leaver, 1975, 1976). A strong difference in animal performance and intake between the leading and the following group of grazing steers has been shown by Tayler & Rudman (1965) and 't Hart & Kleter (1974).

Bryant et al. (1961) found that leader cows selected herbage of higher digestibility than the follower cows and gave more milk (12.9 kg d^{-1}) than the followers (11.9 kg d^{-1}). Archibald et al. (1975) compared three groups of grazing cows: leaders, followers and a control group, all grazing within a rigid rotational system. Daily herbage intake of O from herbage of the leader cows was higher than that of the control cows; the intakes of the leader and control cows were significantly higher than those of the follower cows. The higher milk yields of the leading group were more than offset by the lower yields of the follower group. However the leader and follower group did not consist of low and high yielding cows in this trial but were balanced for stage of lactation and potential milk yield. Possibly the advantages of a leader/follower system may be higher when the daily allowance is kept constant over the grazing season instead of applying a rigid system with no adjustment in grazing pressure at changing herbage production. The FCM production in the trials of Archibald et al. (1975) was relatively low (16-19 kg d^{-1}). At higher milk production levels the advantages of the leader/follower system may be larger as was also shown in the higher response in milk production of the leader cows in early lactation compared with the effect in late lactation.

The leader/follower grazing system needs more investigation in future with special attention to:
- a great difference in production between the leading and the following group
- a constant daily herbage allowance during the season
- more information on the effects of the system on herbage production and consumption per unit area.

B) Giving supplements to animals grazing at high intensity (low allowance) to a level of nutrient intake which allows a high individual production.
It does seem that much of the failure of supplementary concentrate feeding at pasture (Leaver, 1968; Boxem, 1972) has been because the interaction with grazing intensity has not been well understood. Thus in experiments in which half the grazing animals are given concentrates, if the overall level of stocking (or daily allowance) is such that the herbage alone can give a reasonable level of herbage intake and animal production, little response of the supplement can be expected. An improved response to supplements can be expected when the quantity of available herbage is reduced.

Supplementary feeding should only be contemplated therefore where herbage availability is limited.

Supplementation of grazing animals can be used as a tactical management tool, to be used only when grazing pressure is so high that herbage intake is likely to be significantly reduced e.g. during parts of the grazing season at bad weather conditions, at low rates of herbage accumulation or at a low nutritive value of the herbage. However the supply of a certain amount of concentrates during the whole grazing season, irrespective of short term fluctuations in herbage allowance is an increasing way of grassland management on a lot of Dutch farms. In this way the stocking rate is increased (and the herbage allowance is decreased) without affecting individual animal performance and with positive effects on areic consumption and areic animal production. The area of land needed for the production of the supplements (home grown cereals such as barley or forages such as maize) should also be taken into account when calculating areic animal production as was also done by Holmes et al. (1966), Holmes & Curran (1967), Castle et al. (1968) and Leaver et al. (1969b).

Some zero grazing experiments indicate that the substitution rate of herbage by concentrates decreases at lower allowance levels (Section 2.5.2). This information is not yet available for grazing animals. However at this state of knowledge it seems very risky to apply substitution rates as determined at ample supply of herbage with grazing animals or even with stall-fed animals, to animals grazing at high stocking rates as is sometimes done.

Further experiments are needed in which the effects of supplementary feeds on milk production of high producing cows and on the intake of herbage are examined at high grazing pressures.

C) Applying a high level of daily herbage allowance and profiting from the positive effects of this allowance and the resulting residual herbage on net regrowth.
In the short term Experiments 3 and 4 a strong positive effect of daily herbage allowance on net regrowth was shown (Section 5.3.3.2) in agreement with the effects in the first grazing cycle of the experiments of Mott & Müller (1971) and Greenhalgh (1970). Harkess et al. (1972), Leaver (1974) and Gordon et al. (1976) have found that the positive effect of A_0 on net regrowth also occurred in repeatedly grazed swards during the season, however Greenhalgh (1970) and Mott & Müller (1971) reached equal seasonal net regrowth at different levels of residual herbage (Section 5.4.8). The herbage mass after regrowth can be used again by grazing or can be cut and fed in fresh or preserved form.

Some information on swards repeatedly grazed by sheep (Harkess et al., 1972), steers (Marsh, 1977) or young stock (Leaver, 1974) indicated that areic consumption of herbage was constant over a wide range of allowances or showed a parabolic relationship with an optimum at rather high allowance levels (Section 5.4.10). So over a wide range of allowances A_0 could be increased with positive effects on daily herbage intake and positive or no effects on areic consumption of herbage in these trials. Contrasting results were obtained in trials with dairy cows (Gordon et al., 1966; Greenhalgh, 1970), however these results were unreliable as pointed out in Section 5.4.10. The effect of

A_0 on areic consumption from swards repeatedly grazed by dairy cows needs more investigation.

The herbage mass after regrowth can be cut and fed fresh indoors as a supplement (partial zero grazing); the system of grazing during the day and zero grazing during the night is already practised on some farms in the Netherlands. The herbage after regrowth can also be preserved and the preserved products can be used at any time when grazing is inadequate for high daily animal production (principally during the winter, but also during periods of grass shortage in autumn). In Dutch grassland management grazing and cutting is alternating usually. It is important not only that as much as possible of the herbage should be preserved efficiently, but also that the digestibility and intake of the preserved feeds should allow high animal production. The digestibility of the herbage after regrowth in our experiments was greater than 0.75 in most periods (only in the ls of 1978 d_0 was 0.72; Table 44) probably giving a high digestibility of the preserved product. The digestibility of the herbage after regrowth did not differ significantly between allowances, and therefore it was assumed that herbage consumption of the preserved products was equal for the allowance treatments. Pre-cut swards were grazed in our trials which consisted for 80-90% of perennial ryegrass; it is questionable whether the same equal (between treatments) digestibility of herbage after regrowth would have been found on pre-grazed swards or on swards, with an other botanical composition. When the single grazing period and the regrowth period were combined and provided that the assumptions made on total losses with the preserved product and intake of preserved herbage are right our results suggest that both daily herbage intake per animal and areic consumption of herbage will be affected positively by greater daily herbage allowance.

The tables given in Section 5.3.4 show that the absolute positive effect of high allowance on areic consumption (grazing + cutting: U) was highest in es due to the high rates of herbage accumulation during regrowth at that time. High allowances should therefore preferable be applied in es in this alternating grazing/cutting system; if enough herbage is to be provided for grazing the system with high daily allowances cannot be applied during the whole season on most farms. The differences in areic consumption of nutrients (U) between the treatments Y and Z were very small (Tables 49 to 51); therefore the highest allowance giving maximal daily intake of herbage was not optimal in view of areic consumption of nutrients. Of course research with the combined grazing/cutting system and an economic analysis is needed before conclusions for practical use can be drawn.

D) Feeding fresh herbage indoors (zero grazing)

Greenhalgh & Runcie (1962) and Greenhalgh et al. (1972) found no significant difference in the daily herbage intake by dairy cows and beef cattle respectively when they compared zero grazing with grazing. However the daily herbage allowances were not determined, so comparison is difficult. Larsen & Johannes (1965) concluded that the herbage consumption of grazing cows was somewhat lower than that of stall-fed cows; however the authors had some doubt about their way of estimating herbage intake of the grazing cows. To reach the I_T of 17 kg d^{-1} an A_T of 25 kg d^{-1} had to be offered to the grazing cows; the zero grazed cows however consumed on average 20 kg T at an allowance of 20.4 kg d^{-1}. As a consequence the efficiency of consumption of herbage at zero grazing was significantly higher than at strip grazing. More information is available on the daily animal production for both systems: neither the daily live weight gain of beef cattle (Chenost & Demarquilly, 1969; Greenhalgh et al., 1972) nor the daily milk production of dairy cattle at a low production level of about 15 kg d^{-1} (Kennedy et al., 1960; Logan et al., 1960; Runcie, 1960; Greenhalgh & Runcie, 1962; Larsen & Johannes, 1965; Huguet et al., 1969) were affected when zero grazing and strip grazing were compared.

The areic consumption of herbage from zero grazing was higher than from strip grazing (Larsen & Johannes, 1965; Greenhalgh & Runcie, 1962; Greenhalgh et al., 1972). The areic live weight gain of beef cattle (Chenost & Demarquilly, 1969; Greenhalgh et al., 1972) and the areic milk production of dairy cattle (Larsen & Johannes, 1965; Huguet et al., 1969) from zero grazing were also higher than from strip grazing.

In Experiments 1 and 2 zero grazing and grazing however were not applied with the aim of comparing both systems of herbage use. Using different swards (although with comparable herbage yields) and different animals (although with comparable milk yields in the previous lactation) in both systems, makes it difficult to compare both systems. If it is assumed that differences in animal group and sward did not affect comparison of both groups the average results of 1977 showed a 1.2 kg d^{-1} lower O intake of herbage and a 0.9 kg d^{-1} lower FCM production of the zero grazed cows compared to the grazing cows. However to reach the high daily intake of the grazing cows a high A_0 of 22 kg d^{-1} above 4.5 cm had to be applied where the average A_0 of the stall-fed cows was only 17 kg d^{-1}. This resulted in a lower degree of consumption and areic consumption of herbage by the grazing cows than by the stall-fed cows. The intake of the grazing cows can be calculated at an allowance level comparable to that of the stall-fed cows by using the results of the allowance experiments described in Chapter 5. At a mean allowance effect of 0.20 kg I_0 per kg A_0 (>4.5 cm) the intake of the grazing cows at the stall allowance level of 17 kg d^{-1} would be 1 kg O lower. So at an equal level of A_0 the intake of the stall-fed and grazing cows did not differ probably.

These single grazed swards however do not provide a reliable estimation of the efficiency of consumption or of the areic consumption of herbage during grazing on a seasonal basis, which is needed for comparison with zero grazing. The much higher efficiency of consumption of repeatedly grazed swards compared to the mean of the degrees of consumption of single grazed swards has been shown by Campbell (1966), Lane & Holmes (1971), Leaver (1974, 1975, 1976) and Marsh (1977).

Greenhalgh et al. (1972) showed the importance of the stocking rate, and thus of daily herbage allowance on the comparison of grazed and zero grazed animals. Raymond (1970) pointed out that in most comparisons both grazing and zero grazing have generally been imposed on the same forage species and often at the same frequency and intensity of defoliation; this has ignored the possibility that different species and different patterns of defoliation may be appropriate to these methods of utilization. The use in zero grazing systems of more erect crops and of longer regrowth intervals between periods may be profitable with respect to areic production and consumption of herbage (Raymond, 1970); a small negative effect on digestibility and daily herbage consumption may then be compensated for by the supply of a small amount of concentrates.

The available information indicates that at low levels of daily milk production (<15 kg d^{-1}) the zero grazing system may be profitable, due to a higher areic consumption of herbage and areic animal production than at strip grazing without significant differences in daily herbage consumption and daily animal production between both systems. Experiments with highly productive dairy cows on this point are absent from the literature but our own results indicate that zero grazed cows might have the advantage of a higher areic consumption at a somewhat reduced daily intake of herbage which was achieved at a lower level of daily herbage allowance indoors; however these swards were only used once during the season. The methods of grazing and zero grazing must be examined as components of complete systems of land use for animal feeding. Therefore each method must be included in a near optimum management system before valid comparisons can be made.

E) Increasing the areic mass of herbage at start of grazing by using longer rest periods between grazings.

It is well known from the results of cutting experiments that increasing the length of the rest period between defoliation increases the total seasonal accumulation of herbage per area (Reid, 1966; Anslow, 1967. Campbell, 1969; Frame & Hunt, 1971; Wolton, 1972; Tainton, 1974; Garstang, 1975; Minderhoud et al., 1974). In grazed swards in New Zealand, Campbell (1969) recorded a 50% higher annual herbage accumulation with sheep when the grazing interval was increased from 7 to 28 days; this was in agreement with the results of Weeda (1965) who obtained a 60% higher annual yield in an experiment with cattle by increasing the grazing interval from 11 to 21 days. Tainton (1974) however showed that the herbage accumulation at a two week longer grazing interval was smaller than a short rotation cycle with sheep (due to different losses through decomposition) during the main reproductive growth period in late spring and early summer.

Using sheep-grazing infrequent defoliation gave higher seasonal yields than frequent defoliation comparable to the effects obtained with cutting (Frame & Hunt, 1971). In grazing experiments with steers Berngruber (1977) and Mott & Ernst (1980) found a 15% higher seasonal accumulation of herbage for long grass (by using an infrequent defoliation) than for short grass; after grazing the swards were topped each time. In a grazing experiment with calves and heifers (Leaver, 1975) a 35-day rotation produced only 4% more herbage dry matter per area than a 21-day rotation. This small difference was attributed to the build up of herbage residues (the sward was not topped or cut for preservation), with high losses due to decomposition and senescence on the 35-day rigid rotational system. In grazing trials with dairy cows McFeely et al. (1975) found no difference in herbage accumulation between a 13.5- and a 27-day grazing interval in the last two years of their experiment; the swards were not topped. This was in agreement with the results of Garstang (1975) comparing 21- and 28-day paddock systems for dairy cows.

These results show that in our conditions the positive effect of longer rest periods on seasonal accumulation of herbage as found in cutting experiments could only be shown when the sward was topped after each grazing giving high losses or when it was grazed very short (sheep trials). When the residual herbage was not topped the seasonal accumulation of herbage did not differ between long and short rest periods. So from the point of view of herbage production it seems not advisable to aim for higher levels of areic mass of herbage at the start of each grazing cycle. A possible negative effect of high levels of M_0 on the botanical composition of the sward on the long run also cautions against this system.

The influence of areic mass of herbage on daily herbage intake has been discussed in Section 6.4.2. The seasonal application of high levels of areic mass in grazing trials combined with topping of residues did not affect daily herbage O intake negatively, probably because the digestibility of the herbage was always higher than 0.70 (Berngruber, 1977; Mott & Ernst, 1980). It was expected that the low digestibility of the mature residues in the es would affect the digestibility of the herbage at the next defoliation negatively (without topping), and so reduce daily herbage intake possibly at that time; therefore the effects of M on I_0 might differ between single grazed swards and repeatedly grazed swards. However in the grazing trials with dairy cows of Marsh et al. (1971a) and of Garstang (1975) without topping residues no difference in I_0 could be shown between a 21- and 28-day rotational system, due to the lack of significant differences in d_0 of ingested herbage between treatments. These results indicate that a lack of effect of M on I_0, as in single grazed swards, might also exist in repeatedly grazed swards when experienced in rigid grazing systems with a variable rotational length.

In the es of Experiments 1 and 2 at higher levels of areic mass the daily animal production declined if d_0 decreased; while no effect could be shown in the ls (Chapter 6). This effect was also found in grazing trials performed over the whole season with beef cattle (Berngruber, 1977; Mott & Ernst, 1980). However in grazing trials with dairy cows, where different lengths of rotation were compared, no differences in daily milk production per cow between treatments could be shown (Marsh et al., 1971a; McFeely et al., 1975; Garstang, 1975) due to the small differences in digestibility between treatments and probably also due to the low level of milk production (<15 kg d^{-1}) in these trials.

The higher seasonal accumulation of herbage when using longer rest periods and higher levels of herbage mass as found by Berngruber (1977) and Mott & Ernst (1980) also showed itself in a higher seasonal areic consumption of O from herbage at this treatment. Probably due to a lower d_0 the areic live weight gain on long grass was somewhat lower than on short grass (Mott & Ernst, 1980). In rigid rotational grazing systems with young stock the areic consumption of herbage and the areic live weight gain were higher with longer rest periods between grazings (Excuder et al., 1971; Leaver, 1975). In rigid rotational grazing systems with dairy cattle in the literature the areic consumption was not determined; at equal seasonal accumulation of herbage the areic milk production was not affected by length of the rest period between grazings (Marsh et al., 1971a; McFeely et al., 1975; Garstang, 1975).

The few trials with young stock indicate that at longer rest periods between grazings C_0 was increased without affecting I_0 significantly. In rigid rotational systems with young stock without topping the advantage of longer rest periods also showed itself in a higher areic animal production; however if the difference in digestibility between long and short herbage was large (Mott & Ernst, 1980) the production of milk and meat per unit area and per animal may be affected negatively at longer rest periods.

The few trials with dairy cows show no advantage in terms of areic animal production, daily herbage intake and daily animal production to longer rest periods in rigid rotational systems. It is recommended that the effects of the length of the rest period be examined in a more flexible rotational system with constant levels of daily herbage allowance during the season.

Summary

The output of animal products per unit area from grassland depends on the quantity and quality of herbage produced, on the proportion of herbage grown that is eaten by the livestock and on the efficiency of conversion of the consumed herbage into animal products. The need for close defoliation if a high proportion of the herbage grown is to be eaten and to ensure a highly digestible regrowth is in contradiction however with high intake and digestibility required for a high production of the individual grazing animal. The aim of grassland management should be to find the optimum combination of ways of utilizing grassland in which the optimum between intake of digestible nutrients per individual animal and intake of digestible nutrients per area of grassland is reached.The main purposes of the experiments described were to establish a method which is acceptable in terms of accuracy and simplicity for estimation of the herbage intake by grazing animals and to study some of the factors influencing the daily herbage intake of grazing animals.

In Chapter 1 the literature on techniques for estimating herbage intake by grazing ruminants is reviewed. In total 9 methods for intake estimation are described with special attention being paid to the sward-cutting and indirect animal methods which provided most information in the literature.

In sward-cutting techniques the loss of herbage between the beginning and the end of a grazing period, with some correction for herbage accumulation during grazing, is taken to represent the total intake of the animal on the area grazed. Reliable estimates of intake could be obtained with this method if short grazing periods were applied (varying from 1 to 4 days), so that the rate of areic consumption of herbage was high relative to the rate of herbage accumulation in the grazed areas. The cutting of small areas at ground level and the cutting of larger areas by motor mowers at stubble heights of 3-5 cm are the alternative methods. However, too little information was available to draw conclusions on the comparability of the stubble masses after cutting at the beginning and at the end of the grazing period using one of the mentioned methods. With the sward-cutting technique the herbage intake could be estimated with a coefficient of variation of 6% if aftermath or topped pre-grazed pastures were used and if the pre-grazing and post-grazing sample sites were paired.

In the indirect animal methods the intake of herbage is calculated from estimates of faecal output and of the digestibility of the herbage. The faeces of grazing animals can be totally collected in bags using harnessed animals or can be estimated by using external faecal indicators. Total collection of faeces could be applied with grazing sheep and steers with a rather low risk of bias; however, for highly productive cows this method gave problems due to the high faeces production and the consequent stress

reactions of the animals or due to an exceptional grazing behaviour of the cows if the faeces was collected very intensively. When a faecal indicator is used it is necessary to determine the average bias of estimates of faeces output (i.e. due to an incomplete recovery of the indicator) by harnessing some animals for the total collection of faeces; however, total collection is no reliable check when high producing dairy cows are grazed. The recovery was often checked indoors, so the assumption was made that the recoveries of grazing and stall-fed animals were equal. The indicator has to be supplied over long periods to reach an equilibrium between intake and excretion. The total random variation of faeces collection using indicators was at least 7%.

The digestibility of the herbage, required for estimating intake with the indirect animal methods, can be estimated with marker-ratio techniques, faecal-index techniques and in-vitro methods, the last one combined with the use of fistulated animals. In the ratio techniques, digestibility is calculated from the relative contents of a naturally occurring indigestible marker in the herbage grazed and in the faeces; this method can only be applied when the selected diet is sampled with fistulated animals. Due to analytical problems with the available internal indicators such as lignin, chromogens and silicon, the lack of information on random variation of this method and the need to use fistulated animals, this method cannot be recommended.

In the faecal-index techniques the digestibility of herbage is predicted from the composition of the faeces. The regression equations relating a faecal indicator (e.g. nitrogen) to the digestibility of the herbage have to be derived indoors with material similar to that being selected by the grazing animal and can only be applied on swards used during the same period and with equivalent botanical composition and nitrogen fertilizer application. Therefore, continuous local digestibility trials during periods of intake estimation are necessary and under most conditions fistulated animals will be needed for providing samples of herbage selected by the grazing animal for the digestibility trials indoors. The random variation of the digestibility estimate was about 2% ($d_0 = 0.80$); the total random variation of the intake estimate using faecal-index techniques for the estimation of digestibility and using an external faecal indicator for the estimation of faecal production was at least 11%.

Oesophageal fistulated animals can provide samples of the grazed herbage which are fed indoors to animals in an in-vivo digestibility trial or are analysed in-vitro. Saliva contamination might influence digestibility or intake in the in-vivo trials and of course much labour is involved in the collection of enough material through a fistula for the in-vivo trials. Combined with an indirect estimation of faecal production the total random variation of the intake estimate will amount to at least 9% ($d_0 = 0.80$). The digestibility of the extrusa samples from the fistulated animals can also be determined in-vitro provided that standard extrusa samples of known in-vivo digestibility are included in each in-vitro series. The digestibility in-vitro is often standardized at maintenance level. At a higher production level however, digestibility can be affected negatively. Therefore experiments are in progress to determine the effect of the level of feeding on the digestibility of herbage of milk producing dairy cows. The random variation of the in-vitro digestibility estimate of the extrusa sample was about 3.5 to 4%; combined with an indirect estimation of faecal production the total random variation of intake estimate will at least amount to 15% (d_0 = 0.80).

If the problem of an incomplete recovery of herbage through the oesophagus fistula can be solved when estimating bite size, the grazing-behaviour methods can probably provide reliable estimates of herbage consumption. The problems with the other techniques to estimate herbage intake mentioned in Section 1.4 (live-weight methods, water-intake methods, animal-production methods and isotope techniques) are such that they cannot be recommended at this stage.

The literature on factors affecting the herbage intake of grazing ruminants is reviewed in Chapter 2. In the first part of this review a general description of the mechanisms involved in the regulation of feed intake is given. The factors determining the herbage intake of grazing animals were divided in factors of animal, sward and management origin (Figure 2).

In several grazing experiments both metabolic live weight and daily milk production affected daily herbage intake positively. However, the effects of milk production due to stage of lactation and due to genetical factors were often confounded. When differences in stage of lactation were associated with small differences in daily milk yield per cow no influence of stage of lactation on herbage intake could be shown; when the differences in daily milk yields were great (>3 kg), then the herbage intake was affected in the same direction, but much less than was expected from the declining milk yield. There is some information showing a positive effect of actual milk production per animal (at comparable stage of lactation) on herbage intake by grazing dairy cows with a magnitude comparable to that derived from the energetic requirements for the additional production of milk. Too little information is available from which conclusions can be drawn on the effects of animal species, animal breed, animal condition and animal pregnancy on herbage intake by grazing ruminants.

Most experiments with grazing dairy cattle indicated that when digestibility of the consumed herbage is 0.70 or higher there is no strong relationship between herbage intake and digestibility; below this level the relationship between digestibility and intake is positive. However, interactions of the digestibility with the daily herbage allowance may have occurred in some trials. At changing maturity of the herbage, variation in intake of cattle could mainly be attributed to changes in digestibility; the additional effects of areic mass of herbage over the (limited) range established were small. Few measurements have been made on the intake by dairy cows of different temperate plant species and varieties under grazing conditions; more work in this area is needed if conclusions are to be drawn.

In many strip grazing experiments with dairy cows a positive effect of daily herbage allowance on daily herbage intake could be shown; the magnitude of the effect depended among others on the milk production level of the cows. Supplementation with concentrates decreased the daily herbage intake of grazing animals. The magnitude of the substitution effect depended on the quantity and quality of the available herbage and of the supplement and on the season of the year. There was little information on the effect of supplementation on herbage intake at low allowance levels. Faeces contamination or the application of slurry to the sward reduced herbage intake. When the effects of nitrogen fertilization were studied at comparable age of the herbage, several trials showed no effect of nitrogen supply to the sward on herbage intake; however, the nitrogen supply effect can be different when compared at similar levels of areic mass of herbage and thus at shorter growing periods at a higher nitrogen supply. Effects of climate, season and grazing system on herbage intake by grazing ruminants could not be derived yet from the available data in the literature.

In Chapter 3 the methods used in our experiments are described. A sward-cutting technique was used to estimate the herbage intake by grazing dairy cows. Strips of herbage were first cut with a motor mower. After removing the cut herbage a lawn-mower of a smaller mowing width was then used to cut the same strips again.

Results of the sward-cutting technique in our experiments are presented and discussed in Chapter 4. After cutting by motor scythe only, the stubble height of post-grazing strips was higher than that of pre-grazing strips. The stubble mass (3.3-4.5 cm), after cutting pre- and post-grazing strips with a motor scythe was compared by cutting the same strips again with a lawn-mower. It was shown during 3-year experiments that the stubble mass of organic matter (O) of the post-grazing strips cut by the lawn-mower was on average 155 kg ha^{-1} higher than that of the pre-grazing strips. Without correction for this difference in stubble mass between pre- and post-grazing strips the herbage intake would have been overestimated by 10%.

The stubble (0-3.3 cm) that remained after the two-stage cutting operation described above, was sampled by hand-cutting at ground level in part of the experiments. It was concluded that areic mass of stubble was equal for pre- and post-grazing strips provided cutting conditions concerning the wetness of the lawn-mower stubble were similar during pre- and post-grazing sampling. Further studies indicated that systematic errors in estimating intake may be introduced by a difference in cutting conditions during pre- and post-grazing sampling. However, more research on this aspect is necessary because the ground-cutting results may also have been affected by the conditions of the stubble and so there may have been no reliable control due to the disturbance of a thick layer of dead organic material in the stubble. If the ground-cutting provided reliable results more research in the future is necessary to avoid or correct bad cutting results in very wet pastures.

Due to the use of short grazing periods the accumulation of herbage during grazing was low in comparison with the areic mass of herbage at start of grazing. The consumption of herbage as calculated with the equation of Linehan et al. (1952) using grazing periods of 3-4 days consisted on average of a fraction of disturbed herbage accumulation of 0.17; therefore potential bias in the accumulation factor had only marginal effects on the estimation of the herbage intake. There are strong indications from research at Wageningen that the first assumption made by Linehan et al. (1952) was correct i.e. that the rate of herbage accumulation at any time during the grazing period is proportional to the available quantity of herbage at that time. The correctness of their second assumption on the linear relationship between the rate of areic herbage consumption and the areic mass of herbage during grazing needs more investigation in future.

The precision of the intake estimate could be increased by using aftermath herbage with a high level of areic mass of herbage at start of grazing and a low level of residual herbage. Pairing of pre- and post-grazing strips reduced the number of samples required by a factor 2. Enlargement of the size of the post-grazing strips increased precision of intake estimate. On average the herbage consumption could be estimated in our experiments with a coefficient of variation of 5.5%.

In Chapter 5 the results of the experiments carried out in 1978 and 1979 are presented and discussed. In these experiments the influence of daily herbage allowance on herbage intake of grazing dairy cows and on herbage accumulation during regrowth was examined. Different levels of daily herbage allowance (A_0) ranging from 15 to 30 kg d^{-1} above 4.5 cm were achieved in grazing experiments with productive dairy cows by varying the area grazed at equal levels of areic mass of herbage for the treatments. The treatments were compared between groups of animals within the same period. In total 95 reliable intake trials were performed on swards which were cut at the previous defoliation. The grazing period was 3 days, during which the accumulation of herbage was estimated based on measurements of herbage accumulation on a plot not grazed within the same pasture.

At a comparable level of areic mass of herbage at the start of grazing for the different treatments the residual herbage increased at higher A_0. As a consequence a negative effect of A_0 on areic consumption of O from herbage and on areic consumption of nutrients from herbage was shown i.e. the degree of consumption declined at higher A_0. A significant positive effect of A_0 on daily intake of O from herbage and on daily intake of nutrients from herbage was established on the other hand. The digestibility of the residual herbage decreased at lower quantities of residual herbage and thus at lower allowances. The digestibility of herbage ingested was not affected significantly by variation in A_0. From measurements on the grazing time and biting rate of the cows the conclusion was drawn that the decreasing daily intake at lower levels of A_0 could probably be attributed to declining bite size at progressive defoliation of the sward. The daily intake of nutrients with the total rations was in good agreement with the theoretical nutrient requirements for milk production, maintenance and live weight change.

During 50 trials the areic mass of herbage was again determined after a regrowth period of 19 days. The areic mass of O from herbage after regrowth and the areic mass of nutrients from herbage after regrowth increased at higher allowance levels which could be both attributed to more residual herbage remaining after the prior grazing and to positive effects of higher levels of residual herbage on the herbage accumulation during the regrowth period ('net' regrowth). It was shown that there was no significant effect of A_0 on the digestibility of herbage mass after regrowth in these experiments.

The consumption of herbage after regrowth could not be measured by grazing. However, if the herbage cut after regrowth was assumed to be consumed indoors and when the assumption is made that the daily intake of the cut herbage was equal for the treatments (due to the equal digestibility) our results suggest that both daily herbage intake per animal (O and nutrients) and areic consumption of herbage (O and nutrients) were affected positively by greater daily herbage allowance when the results of the grazing and regrowth periods were taken together. The limited information in the literature showed that these results cannot be extrapolated fully to repeatedly grazed swards.

In Chapter 6 the results of experiments carried out in 1976 and 1977 are presented and discussed. In these experiments different levels of areic mass of herbage (M_0) were established by allowing parts of a sward to grow for periods of time of variable length. The variable maturity of the herbage also affected the digestibility of the herbage. The different levels of areic mass were compared in time within a constant group of dairy cows. At the same time the experiment was performed both indoors and at pasture. In total 28 intake trials were performed on swards which were a primary growth or which were cut at the previous defoliation. The herbage intake of the stall-fed cows was measured daily per animal (1977) or per group of 2 or 3 animals (1976). The grazing period of the grazing cows was either 3 or 4 days during which the average intake of a group of 12 cows was estimated. The accumulation of herbage during grazing was estimated based on measurements of herbage accumulation on a plot not grazed within the same pasture.

With advancing maturity of the herbage M_0 increased significantly in time. In the early summer M_0 (>4.5 cm) ranged from 1 400 to 4 800 kg ha^{-1}; in the late summer M_0 ranged from 1 000 to 2 700 kg ha^{-1}. The daily intake of O from herbage of the grazing and stall-fed cows was not affected significantly by the maturity of the herbage which could probably be explained by the high level of digestibility of the ingested herbage even at very high levels of areic herbage mass (d_0 >0.70). In early summer the herbage consumed by the grazing and stall-fed cows showed a strong decline in digestibility at increasing levels of M; as a consequence daily intake of nutrients from herbage of both groups declined significantly at higher levels of M_0 and also affected FCM production in this period negatively. However, in ls, when a smaller range of M_0 was achieved, the changes of digestibility were small and not significant and no significant effects of M_0 on daily intake of nutrients or on FCM production could be shown, neither at grazing nor indoors.

At a constant level of daily herbage allowance the daily herbage intake of the grazing cows was not affected by M_0 and so the degree of consumption was not affected by M_0. As a consequence the areic consumption of herbage (both O and nutrients) by the grazing cows and the areic mass of residual herbage were proportional to M_0.

The intake of the stall-fed cows in 1977 could be determined individually. At comparable stages of lactation a strong relationship between the daily FCM production and the daily intake of O from herbage could be shown when seasonal intakes of cows, differing in actual milk yield, were compared indoors.

The daily intake of O per animal was not affected significantly by variation in M_0 due to a variable maturity of the herbage. There were strong indications from the allowance experiments (Chapter 5) however, that the daily herbage intake by grazing dairy cows increased at higher M_0 if the variation in M_0 was caused by differences in sward density. This aspect needs more research in future with special attention to the effects of sward density on grazing behaviour.

In the general discussion of Chapter 7 the daily intake of herbage (I_0) by grazing dairy cows in our experiments was compared with values reported in the literature. At an allowance level of O of about 15 kg d^{-1} (above 4-5 cm) and a milk production of 15 kg d^{-1}, I_0 by strip grazing dairy cows determined by indirect animal methods ranged from 104 to 127 g d^{-1} $kg^{-0.75}$ on pre-cut or topped swards. Compared at about the same level of daily herbage allowance (treatment X of Experiments 3 and 4) the cows in our experiments consumed less (99 g d^{-1} $kg^{-0.75}$) although the daily FCM production was high (23 kg d^{-1}). In our experiments the intake of net energy was in agreement with the theoretical net energy requirements for milk production, maintenance and live weight change. In some of the strip grazing experiments in the literature however, the animal production was much less than predicted from the consumption of net energy; probably I_0 was overestimated in these trials due to bias in the indirect animal methods. Therefore the actual difference in I_0 between the strip grazing experiments using indirect methods for estimating I and our experiments probably was much smaller than the measured differences. Our levels of I_0 were in agreement with levels in strip grazing experiments using sward methods under comparable conditions. Due to the incomplete information on the effect of the length of the grazing period on I_0 it was recommended to compare I_0 of strip grazing cows with I_0 of cows grazing 3-4 days on a pasture in future experiments.

The conclusions was drawn that our cows consumed 120-130 g d^{-1} $kg^{-0.75}$ of organic matter if no concentrates were fed. Our cows grazed for 3-4 days on pre-cut pastures at a mean allowance level of O of 23 kg d^{-1} above 4.5 cm. At a live weight of 550 kg this intake of O was equal to 13.6-14.8 kg d^{-1}, sufficient, at the quality of herbage as in our trials, for a daily FCM production of 22-23 kg from herbage only.

The effect of the moment of start and finish of grazing (in view of the available areic mass of herbage) on daily herbage intake and digestibility was examined in the trials reported. The choice of both moments are two of the most important decisions to be taken by the farmer in grazing management. It was shown that there were no significant effects of higher levels óf areic mass of herbage at start of grazing (by taking longer rest periods) on daily intake of O from herbage on pre-cut swards neither indoors nor at pasture. However in early summer daily intake of nutrients and milk production decreased at increasing maturity. In late summer these effects were not significant. Higher levels of residual herbage (achieved by higher levels of daily herbage allowance) had significant positive effects on daily intake of O from herbage and on daily milk production per grazing animal while no effect on the digestibility of the herbage ingested on pre-cut swards could be shown. On the other hand maximal intake and animal production per area of grassland should be pursued. It is therefore important to investigate grassland utilization systems in which at a given high production of herbage a high proportion of the herbage is eaten and in which nevertheless intake and performance of the individual animal (and so food conversion) are high.

Possible methods of combining high intake per animal with high areic consumption of herbage are discussed:

- dividing the animal population into animals with currently high or low nutrient requirements
- giving supplements to animals grazing at high intensity (low allowance) to a level of nutrient intake at which they would be at high individual production
- applying a high level of daily herbage allowance and profiting from the positive effects of this allowance, and the resulting residual herbage, on net regrowth
- feeding fresh herbage indoors (zero grazing)
- increasing the areic mass of herbage at start of grazing by using longer rest periods.

The 5 methods mentioned need all more investigation in future grassland research in order to achieve the best way of grassland management.

Samenvatting

De produktie per oppervlakte-eenheid grasland van melk en vlees door weidend vee hangt af van de hoeveelheid en de kwaliteit van het geproduceerde gras, van het gedeelte van het geproduceerde gras dat door de dieren wordt opgenomen en van de efficiëntie van de omzetting van het opgenomen gras in het dierlijk produkt. De noodzaak het gras kort af te laten grazen, opdat een groot gedeelte van het geproduceerde gras wordt opgenomen en opdat de volgende snede goed verteerbaar zal zijn, is in strijd met de gewenste hoge opname van gras met een hoge verteerbaarheid per dier om een hoge produktie te bereiken. Het doel van het graslandonderzoek is die vorm van graslandgebruik te vinden, waarbij het optimum bereikt wordt tussen de opname van verteerbare nutriënten per dier enerzijds en de opname van verteerbare nutriënten per oppervlakte grasland anderzijds.

De belangrijkste doelstellingen van de proeven die worden beschreven waren het ontwikkelen van een nauwkeurige en toch zo eenvoudig mogelijke methode om de grasopname van weidende herkauwers te schatten en het bestuderen van de invloed van een aantal factoren op de dagelijkse grasopname van weidende melkkoeien.

In hoofdstuk 1 wordt een literatuuroverzicht gegeven van de beschikbare technieken om de grasopname van weidende herkauwers te meten. In totaal worden 9 methoden beschreven waarbij de meeste aandacht wordt besteed aan de uitmaaimethode en de indirecte diermethoden. Van deze twee methoden zijn de meeste gegevens beschikbaar.

Bij de uitmaaimethode wordt de opname van gras per oppervlakte berekend uit het verschil tussen de grasopbrengsten bij het begin en aan het einde van de beweidingsperiode. Als de beweide oppervlakte, het aantal dieren en het aantal weidedagen bekend zijn, kan de opname per dier per dag worden berekend. Omdat de grasproduktie tijdens de beweiding doorgaat moeten hiervoor correcties worden aangebracht. Redelijk betrouwbare schattingen van de opname leken met deze methode verkregen te kunnen worden als korte beweidingsperioden variërend van 1 tot 4 dagen werden toegepast, zodat de grasopname per oppervlakte hoog was in vergelijking met de grasproduktie tijdens de beweiding. Zowel het uitsnijden of knippen van kleine proefvakken op grondniveau als het maaien van grotere proefvakken op een hoogte van 3-5 cm met motormaaiers zijn toegepast. Er zijn echter te weinig gegevens in de literatuur om uit één van de genoemde methoden te kunnen concluderen dat de stoppelopbrengsten (dit is alles onder maaihoogte) bij het maaien aan het begin en aan het einde van de beweidingsperiode vergelijkbaar zijn. Dit bemoeilijkt een juiste interpretatie van de uitkomsten.

Indien percelen worden gebruikt die voorafgaand gemaaid of beweid en gebloot zijn en indien de proefvakken die geoogst worden bij inscharen gepaard worden met de proef-

vakken bij uitscharen, dan kan onder Nederlandse omstandigheden een variatiecoëfficiënt van de schatting van de opname van 6% worden bereikt.

Bij de indirecte diermethoden wordt de grasopname berekend uit schattingen van de mestproduktie en de verteerbaarheid van het gras. De verteerbaarheid van het opgenomen gras ligt onder Nederlandse omstandigheden meestal boven 75%. Bij dit hoge verteerbaarheidsniveau werkt een kleine fout in de schatting van die verteerbaarheid zeer sterk door in de aldus bepaalde opname.

De geproduceerde mest kan volledig worden opgevangen in mestzakken die met behulp van tuigen aan de grazende dieren zijn bevestigd. Bij schapen en ossen zijn met deze methode goede resultaten bereikt. Melkgevende koeien scheiden echter zoveel mest uit dat het gebruik van deze methode tot stress bij het dier leidde. Als getracht werd de stress te voorkomen door de mestzakken vaker te ledigen leidde dit tot een afwijkend graasgedrag.

De mestproduktie kan ook indirect worden geschat met behulp van een onverteerbare merkstof. Bij deze methode kunnen grote systematische fouten gemaakt worden o.a. als de toegediende hoeveelheid merkstof niet volledig met de mest wordt uitgescheiden, terwijl men aanneemt dat dit wel zo is. De methode kan alleen worden gebruikt als de indicator over een lange periode wordt verstrekt en er een evenwicht tussen opname en uitscheiding van de indicator kan worden bereikt. Het is dan ook noodzakelijk om de totale fout bij deze methode regelmatig te bepalen door bij een aantal dieren de mest kwantitatief te verzamelen; bij melkgevende melkkoeien is totale mestopvang in de weide echter niet goed mogelijk, zodat zal moeten worden uitgeweken naar de stal. De variatiecoëfficiënt van de schatting van de mestproduktie bij het gebruik van merkstoffen was minstens 7%.

De verteerbaarheid van het gras kan worden geschat met de 'ratio'-methoden, de 'faecaal-index'-technieken en de 'in-vivo'- of 'in-vitro'-methoden waarbij de laatste methoden worden gecombineerd met het gebruik van dieren met een slokdarmfistel.

Bij de ratiomethoden wordt de verteerbaarheid berekend uit de verhouding (ratio) van de gehalten van een natuurlijke vrijwel onverteerbare merkstof in de plant en in de faeces. Analytische problemen met de beschikbare indicatoren (o.a. lignine, kleurstoffen en silicium), het gebrek aan gegevens over de totale fout bij deze methode en de noodzaak om gefistuleerde dieren bij deze methode te gebruiken zijn redenen om de ratiomethoden af te raden.

Bij de faecaal-index-techniek wordt de vertaarbaarheid geschat uit de samenstelling van de mest. Er wordt op stal een verband afgeleid tussen het gehalte van een bepaalde component (meestal stikstof) in de mest en de verteerbaarheid van het gras. Dat gevonden verband wordt later toegepast bij de berekening van de grasopname in de weide. Het materiaal dat de dieren op stal opnemen moet overeenkomen met het door de dieren in de weide geselecteerde gras. Meestal zijn dan gefistuleerde dieren nodig. Omdat de relatie tussen de mestcomponent en de verteerbaarheid o.a. afhankelijk is van het seizoen, de stikstofbemesting en de botanische samenstelling kunnen redelijke resultaten alleen worden verkregen als tegelijk met de opnameproeven in de weide verteringsproeven op stal worden uitgevoerd. De variatiecoëfficiënt van de schatting van de verteerbaarheid was ongeveer 2%; gecombineerd met een bepaling van de mestproduktie met behulp van een merkstof was de variatiecoëfficiënt van de schatting van de grasopname minstens 11% (bij een verteerbaarheid van 0,80).

Als een grote hoeveelheid van het opgenomen gras met behulp van een slokdarmfistel kan worden verzameld, kan de verteerbaarheid ervan met dieren (in-vivo) op stal worden bepaald. De verontreiniging met speeksel kan echter de opname of verteerbaarheid van gras in de in-vivo verteringsproeven beïnvloeden. Uiteraard is deze verzameling van gras via een slokdarmfistel zeer arbeidsintensief. Gecombineerd met een indirecte schatting van de mestproduktie kon met deze methode een variatiecoëfficiënt van de schatting van de opname van 9% worden bereikt (bij een verteerbaarheid van 0,80).

De verteerbaarheid van de monsters uit de slokdarm kan ook met in-vitro methoden bepaald worden als standaardmonsters van bekende in-vivo verteerbaarheid bij elke in-vitro analyse worden meegenomen. De in-vitro verteerbaarheid wordt meestal gestandaardiseerd op onderhoudsniveau. Bij een hoger produktieniveau kan de verteerbaarheid negatief worden beïnvloed. Daarom is basisonderzoek naar het effect van het voerniveau op de verteerbaarheid van gras bij melkkoeien op diverse plaatsen in uitvoering, waarvan de resultaten bij het beweidingsonderzoek zullen worden toegepast. De variatiecoëfficiënt van de schatting van de verteerbaarheid van grasmonsters verzameld via de slokdarmfistel met de in-vitro methoden was ongeveer 3.5%; gecombineerd met een indirecte schatting van de mestproduktie was de totale variatiecoëfficiënt van de schatting van de grasopname minimaal 15% (bij een verteerbaarheid van 0,80).

De graasgedragmethode kan mogelijk een betrouwbare techniek zijn als het probleem van een onvolledige verzameling van het opgenomen gras door een slokdarmfistel, nodig voor het bepalen van de hapgrootte, kan worden opgelost. De onzekerheden met de andere technieken om de grasopname te meten (methoden die uitgaan van de bepaling van het diergewicht, de dierlijke produktie, de wateropname en technieken waarbij gebruik wordt gemaakt van isotopen) zijn nog zo groot dat ze op dit moment moeten worden afgeraden.

In hoofdstuk 2 wordt een literatuuroverzicht gegeven van de factoren die een rol spelen bij de opname door grazende herkauwers. In het eerste gedeelte van dit overzicht wordt een algemene beschrijving gegeven van de mechanismen die de voeropname reguleren. De factoren die de grasopname door weidende herkauwers bepalen werden opgesplitst in diergebonden, voergebonden en milieugebonden factoren (zie Figuur 2).

In verscheidene beweidingsproeven was er een positief effect van het metabolisch gewicht van de dieren en van de dagelijkse melkproduktie op de grasopname. Bij de effecten van melkproduktie werd de interpretatie bemoeilijkt, omdat de verschillen in melkproduktie als gevolg van verschillende lactatiestadia en als gevolg van verschil in erfelijke aanleg veelal verstrengeld waren. Als een verschil in lactatiestadium slechts geringe verschillen in melkproduktie veroorzaakte, kon geen significant effect van het lactatiestadium op de grasopname worden aangetoond; als de verschillen in dagelijkse melkproduktie groot waren, (>3 kg per dag) waren er ook de verschillen in grasopname. Dit was echter veel minder dan op grond van het verschil in melkproduktie kon worden verwacht. Bij een vergelijkbaar lactatiestadium nam de grasopname van weidende melkkoeien toe naarmate de dagelijkse melkproduktie (door erfelijke aanleg) hoger was; de grootte van dit effect kwam overeen met datgene wat op grond van de energetische behoefte voor het maken van extra melk kon worden verwacht. Er zijn te weinig gegevens beschikbaar om conclusies te kunnen trekken over de effecten van diersoort, ras, conditie en eventuele drachtigheid van het dier op de opname van grazende herkauwers.

Uit de meeste beweidingsproeven waarin het effect van de verteerbaarheid op de opname werd nagegaan, kwam naar voren dat boven een verteerbaarheid van het opgenomen gras van 0.70 er geen duidelijk effect was van de verteerbaarheid op de grasopname door weidende melkkoeien; beneden dit niveau was er een positieve relatie tussen verteerbaarheid en grasopname. In enkele proeven echter kunnen interacties tussen de verteerbaarheid en het grasaanbod per dier per dag een rol hebben gespeeld. Bij veroudering van gras konden eventuele effecten op de grasopname voornamelijk aan veranderingen in de verteerbaarheid van het gras worden toegeschreven; binnen de (beperkte) onderzochte grenzen waren de additionele effecten van de grasopbrengst (=grashoeveelheid per oppervlakte-eenheid) klein. Er zijn weinig waarnemingen bekend over de grasopname van melkkoeien bij beweiding van verschillende grassoorten of variëteiten.

In veel proeven met dagrantsoenbeweiding werd een positief effect van het grasaanbod per dier per dag op de grasopname van melkkoeien aangetoond; de grootte van het effect was o.a. afhankelijk van de melkproduktie van de koeien. Bijvoedering met krachtvoer leidde tot een vermindering van de grasopname door weidende melkkoeien. Het verdringingseffect was afhankelijk van de hoeveelheid en de kwaliteit van het beschikbare gras en krachtvoer en van het seizoen. Er zijn te weinig gegevens over het bijvoederingseffect op de grasopname bij lage niveaus van grasaanbod per dier per dag (overeenkomend met een hoge veebezetting).

Verontreiniging van de grasmat met mest of de toepassing van drijfmest verminderde de grasopname. Indien de effecten van stikstofbemesting werden bestudeerd bij gelijke ouderdom van het gras, kon in verschillende proeven geen effect van de stikstofbemesting op de grasopname worden aangetoond; het stikstofeffect kan verschillen als de percelen met verschillende stikstofbemestingen geoogst worden bij een vergelijkbare grasopbrengst en dus bij een kortere groeiperiode bij een hogere stikstofgift. Effecten van klimaat, seizoen en beweidingssysteem op de grasopname van weidende herkauwers konden uit de beschikbare gegevens nog onvoldoende worden afgeleid.

In hoofdstuk 3 worden de methoden die gebruikt zijn in de eigen proeven uitvoerig beschreven. De opname van grazende koeien werd bepaald met de uitmaaimethode. Daarbij werd getracht een zo kort en egaal mogelijke stoppel achter te laten door dezelfde strips achtereenvolgens met een motormaaier en een smallere gazonmaaier te maaien.

In hoofdstuk 4 worden de resultaten van de uitmaaimethode gepresenteerd en besproken. Na het maaien met alleen een motormaaier was de stoppelhoogte bij uitscharen (aan het einde van de beweidingsperiode) hoger dan bij inscharen (bij het begin van de beweidingsperiode). De stoppel in de laag van 3,3-4,5 cm, die overbleef na het maaien met de motormaaier, werd nog een keer gemaaid met een gazonmaaier. In proeven, die gedurende 3 jaren werden uitgevoerd, werd aangetoond dat de stoppelopbrengst aan organische stof (O) die bij het uitscharen gemaaid werd met de gazonmaaier gemiddeld 155 kg ha^{-1} hoger was dan bij inscharen. Zonder correctie voor dit verschil in stoppelopbrengst tussen in- en uitscharen zou de grasopname met 10% worden overschat.

De stoppel van 0-3,3 cm die overbleef na het maaien met beide machines werd in een aantal proeven met de hand tot de grond afgesneden. Onder vergelijkbare maaiomstandigheden bij in- en uitscharen (ten aanzien van het vochtgehalte van het gras dat gemaaid werd) konden geen verschillen in de resterende stoppelopbrengst van 0-3,3 cm worden aangetoond. De methode leek gevoelig voor systematische fouten als de maaiomstandigheden tussen in- en uitscharen sterk verschilden. Meer onderzoek is echter gewenst omdat het stoppelsnijden tot de grond mogelijk ook beïnvloed werd door de weersomstandigheden. Het stoppelsnijden is misschien geen betrouwbare controle op de uitmaaimethode, omdat bij nat weer mogelijk een groter gedeelte van een dikke laag dood organisch materiaal in de stoppel werd meegenomen in het monster dan bij droog weer. Indien de conclusies met betrekking tot het stoppelsnijden in aanvullend onderzoek worden bevestigd, is meer onderzoek nodig naar methoden om slechte maairesultaten onder natte omstandigheden te voorkomen of te corrigeren.

Door het gebruik van korte beweidingsperioden was de ongestoorde grasproduktie tijdens de beweiding, gemeten op een vergelijkbaar sub-perceel, klein vergeleken met de grasopbrengst bij inscharen. De gestoorde grasproduktie tijdens de beweiding was uiteraard nog kleiner tengevolge van o.a. het wegnemen en beschadigen van fotosynthetisch actief materiaal. De gestoorde bijgroei werd berekend met de formule van Linehan et al. (1952). Bij een 3-4-daagse beweidingsperiode was het aandeel van de grasproduktie tijdens de beweiding in de grasopname gemiddeld 17%. De maaihoogte, gebruikt voor de vaststelling van de hoeveelheid gras, had invloed op de factor voor de berekening van de grasproduktie tijdens de beweiding. Omdat het aandeel van de grasproduktie tijdens de beweiding in de opname vrij klein was, hadden systematische fouten in de factor voor de berekening van de (gestoorde) grasproduktie tijdens de beweiding slechts kleine effecten op de schatting van de grasopname.

Uit onderzoek uitgevoerd op de Landbouwhogeschool in Wageningen kwamen duidelijke aanwijzingen dat de eerste veronderstelling van Linehan et al. (1952) juist is, namelijk dat de grasproduktie per dag op elk moment tijdens de beweidingsperiode afhankelijk is van de beschikbare hoeveelheid gras. De juistheid van hun tweede veronderstelling, waarbij van een lineair verband tussen de grasopname per oppervlakte per dag en de grasopbrengst gedurende de beweiding wordt uitgegaan, kon met de uitkomsten van onze proeven niet worden bewezen.

De nauwkeurigheid van de schatting van de opname kon worden verbeterd door vooraf gemaaid grasland te gebruiken met een hoge grasopbrengst bij inscharen en een lage grasopbrengst bij uitscharen. Het paren van proefvakken bij in- en uitscharen verminderde het aantal benodigde proefvakken met een factor 2. Vergroting van de oppervlakte van de proefvakken bij uitscharen gaf een verbetering van de nauwkeurigheid van de schatting van de grasopname. De gemiddelde variatiecoëfficiënt van de schatting van de grasopname in de eigen proeven was 5,5%.

In hoofdstuk 5 worden de resultaten van de proeven die in 1978 en 1979 werden uitgevoerd gepresenteerd en besproken. In deze proeven werd de invloed nagegaan van het grasaanbod per dier per dag op de grasopname van weidende melkkoeien en op de grasproduktie tijdens de hergroeiperiode. De verschillende aanbodniveaus (A_O), die varieerden van 15-30 kg d^{-1} boven 4,5 cm, werden bereikt door het variëren van de beweide oppervlakte bij een gelijk aantal weidedagen en aantal koeien en bij vergelijkbare grasopbrengsten bij inscharen voor de diverse behandelingen. De behandelingen werden tussen diergroepen binnen dezelfde periode vergeleken. In totaal werden 95 opnameproeven uitgevoerd, waarin de weersomstandigheden bij het maaien bij in- en uitscharen vergelijkbaar waren. In een beweidingsperiode van 3 dagen werd de gemiddelde opname van groepen van 6 koeien bepaald. De grasproduktie tijdens de beweiding werd geschat op basis van metingen van de ongestoorde produktie op een vergelijkbaar subperceel. Alle proefpercelen waren vooraf gemaaid.

Bij een hoger aanbodniveau namen de grasopbrengsten bij uitscharen toe bij vergelijkbare grasopbrengsten bij inscharen voor de diverse behandelingen. Dientengevolge kon een negatief effect van het aanbodniveau op de grasopname per oppervlakte-eenheid (uitgedrukt zowel in organische stof (O) als in voederwaarde) worden aangetoond of met andere woorden het opnamegedeelte nam af bij hogere grasaanbodniveaus. Daarentegen kon een duidelijk positief effect van het aanbodniveau op de grasopname per dier per dag (uitgedrukt zowel in organische stof als in voederwaarde) worden vastgesteld. De verteerbaarheid van het gras bij uitscharen nam af naarmate de weideresten kleiner waren en dus naarmate het grasaanbod werd verlaagd. De verteerbaarheid van het opgenomen gras was hoger dan die van het aangeboden gras boven 4,5 cm; er kon geen duidelijk effect worden aangetoond van het grasaanbod per dier op de verteerbaarheid van het opgenomen gras. Uit metingen van de graasduur en de hapfrequentie van de weidende melkkoeien kon de conclusie worden getrokken dat de lagere dagelijkse grasopname per dier bij lagere aanbodniveaus waarschijnlijk kon worden toegeschreven aan de kleiner wordende hapgrootte bij het afgrazen tot een kortere stoppel. Er was een goede overeenstemming tussen de theoretische behoefte aan voederwaarde voor melkproduktie, onderhoud en gewichtsverandering en de dagelijkse opname aan voederwaarde met het totale rantsoen.

Tijdens 50 proeven werd de grasopbrengst opnieuw vastgesteld na een hergroeiperiode van 19 dagen. De grasopbrengst na hergroei (uitgedrukt zowel in organische stof als in voederwaarde) nam toe bij een hoger grasaanbod, hetgeen kon worden toegeschreven aan een grotere weiderest die overbleef na de voorafgaande beweiding en aan positieve effecten van de grotere weideresten op de grasproduktie tijdens de hergroeiperiode ('netto' hergroei). Bij deze proeven kon geen significant effect van het grasaanbod per dier per dag en de resulterende weiderest op de verteerbaarheid van de grasopbrengst na hergroei worden aangetoond.

Na de hergroei kon de opname tijdens beweiding helaas niet nogmaals bepaald worden. Als wordt aangenomen dat het gemaaide gras na hergroei op stal gevoerd wordt en dat de dagelijkse opname van het gemaaide gras, eventueel na conservering, gelijk is voor de aanbodniveaus (op grond van gelijke verteerbaarheid), dan kunnen de resultaten van de beweidings- en hergroeiperiode worden gecombineerd. Uit de gecombineerde resultaten kon worden afgeleid dat zowel de dagelijkse grasopname per dier (uitgedrukt zowel in organische stof als in voederwaarde) als de grasopname per oppervlakte (uitgedrukt zowel in organische stof als in voederwaarde) positief werden beïnvloed door een hoger grasaanbod per dier per dag. Uit de beperkte informatie in de literatuur bleek dat deze resultaten niet kunnen worden geëxtrapoleerd naar percelen met herhaalde beweiding tijdens het seizoen.

In hoofdstuk 6 worden de resultaten van de proeven die in 1976 en 1977 werden uitgevoerd gepresenteerd en besproken. In deze proeven werden verschillende grasopbrengstniveaus (M_0) verkregen door de lengte van de groeiperiode op subpercelen binnen eenzelfde perceel te variëren. Bij een variabele ouderdom van het gras werd de verteerbaarheid van het gras beïnvloed. De verschillende grasopbrengsten werden in de tijd vergeleken binnen dezelfde groep melkkoeien. De proef werd tegelijkertijd op stal en in de weide uitgevoerd. In totaal werden 28 opnameproeven uitgevoerd op grasland dat voor de eerste maal in het seizoen werd gebruikt of op grasland dat vooraf was gemaaid. De grasopname van de koeien op stal werd dagelijks individueel (1977) of per groep van 2 of 3 koeien (1976) gemeten. Elke beweidingsperiode was 3 of 4 dagen, waarin de gemiddelde opname van een groep van 12 koeien werd gemeten. De grasproduktie tijdens de beweiding werd geschat op basis van metingen van de ongestoorde produktie op een vergelijkbaar subperceel.

De grasopbrengst nam duidelijk toe met de ouderdom van het gras. In de voorzomer varieerde de grasopbrengst van 1400 tot 4800 kg ha^{-1}; in de nazomer van 1000 tot 2700 kg ha^{-1}. De dagelijkse opname van organische stof uit gras van de weidende en op stal gevoerde melkkoeien werd niet duidelijk beïnvloed door de ouderdom van het gras. Dit hield waarschijnlijk verband met de hoge verteerbaarheid van het opgenomen gras, die zelfs bij zeer hoge grasopbrengsten altijd hoger was dan 0,70. Bij toenemende grasopbrengsten nam in de voorzomer de verteerbaarheid van het opgenomen gras bij beide groepen koeien duidelijk af. Dientengevolge nam in de voorzomer de dagelijkse opname aan voederwaarde van beide groepen bij hogere grasopbrengsten significant af en werd ook de melkproduktie in deze periode negatief beïnvloed. In de nazomer echter waren de veranderingen in de verteerbaarheid bij de lagere grasopbrengsten gering en kon geen effect van de grasopbrengst op de dagelijkse opname aan voederwaarde of op de melkproduktie worden aangetoond, noch bij beweiding noch bij zomerstalvoedering.

Bij een constant grasaanbod per dier werd de dagelijkse grasopname van de weidende koeien niet beïnvloed door de grasopbrengst. Dat houdt in dat het opnamegedeelte van het beschikbare gras constant was bij een variabele grasopbrengst. Dientengevolge namen zowel de grasopname per oppervlakte-eenheid (zowel uitgedrukt in organische stof als in voederwaarde) als de weideresten evenredig toe bij een hogere grasopbrengst.

Bij de stalvoedering in 1977 werd de individuele grasopname bepaald. Daardoor kon in deze periode het verband worden nagegaan tussen de grasopname en de melkproduktie van individuele koeien die verschilden in actuele melkproduktie. Bij een vergelijkbaar lactatiestadium van de koeien kon een sterk verband worden aangetoond tussen de dagelijkse produktie van meetmelk en de dagelijkse opname van organische stof uit gras per dier.

De variatie in de grasopbrengst in de in dit hoofdstuk beschreven proeven werd verkregen door de lengte van de groeiperiode te variëren. De dagelijkse opname van organische stof per dier werd niet duidelijk beïnvloed door de ouderdom van het gras. Als de variatie in grasopbrengst echter werd veroorzaakt door verschillen in de zodedichtheid, zoals bij de aanbodproeven uit hoofdstuk 5, dan waren er duidelijke aanwijzingen dat de dagelijkse opname per dier positief werd beïnvloed bij een hogere grasopbrengst. Dit aspect verdient meer aandacht bij toekomstig onderzoek waarbij vooral gelet moet worden op de effecten van de zodedichtheid op het graasgedrag.

In de algemene discussie uit hoofdstuk 7 werd de grasopname door weidende melkkoeien van de eigen proeven vergeleken met waarnemingen uit de literatuur. Uit de literatuur bleek dat de opname van organische stof van weidende koeien bepaald met de indirecte diermethoden bij dagrantsoenbeweiding op voorafgaand gemaaid land 104-127 g d^{-1} $kg^{-0,75}$ was; het grasaanbod aan organische stof boven 4-5 cm was in deze proeven ongeveer 15 kg d^{-1} bij een meetmelkproduktie van 15 kg d^{-1}. Vergeleken bij ongeveer hetzelfde grasaanbodniveau (behandeling X van de proeven 3 en 4) was de opname van organische stof uit gras van onze koeien lager (99 g d^{-1} $kg^{-0,75}$), hoewel de dagelijkse melkproduktie hoger was (23 kg d^{-1}). In onze proeven was er een goede overeenstemming tussen de opname van netto-energie en de behoefte aan netto-energie voor melkproduktie, onderhoud en gewichtsverandering. In enkele proeven met dagrantsoenbeweiding uit de literatuur was de dierlijke produktie echter veel minder dan op grond van de opname aan netto-energie mocht worden verwacht. Waarschijnlijk werd de grasopname in sommige van deze proeven overschat tengevolge van systematische fouten bij de indirecte diermethoden. Daarom was het werkelijke verschil in de grasopname tussen de proeven met dagrantsoenbeweiding (die gebruik maakten van indirecte diermethoden) en onze proeven waarschijnlijk veel kleiner dan het gemeten verschil. De grasopname van onze koeien lag op hetzelfde niveau als de opname van koeien in Nederlandse proeven met dagrantsoenbeweiding die onder vergelijkbare omstandigheden werden uitgevoerd. Door de onvolledige informatie over het effect van de lengte van de beweidingsperiode op de grasopname werd de aanbeveling gedaan om in toekomstige proeven de grasopname te vergelijken van koeien die 3-4 dagen op een perceel lopen met die van koeien bij dagrantsoenbeweiding.

De conclusie kon worden getrokken dat de melkkoeien in onze proeven gemiddeld 120-130 g d^{-1} $kg^{-0,75}$ organische stof uit gras opnamen als geen krachtvoer werd verstrekt. De koeien graasden 3-4 dagen op vooraf gemaaid land, bij een grasaanbod aan organische stof per dier per dag van 23 kg boven 4,5 cm. Bij een lichaamsgewicht van 550 kg komt dit overeen met een opname aan organische stof van 13,6-14,8 kg d^{-1}, wat bij de kwaliteit van het gras in onze proeven voldoende is voor een dagelijkse meetmelkproduktie van 22-23 kg uit gras alleen.

In de beschreven proeven werden de effecten nagegaan van het moment van aanvang en einde van de beweiding (in relatie tot de beschikbare grasopbrengst) op de dagelijkse grasopname per dier en op de verteerbaarheid. De keuze van beide momenten behoort tot de belangrijkste beslissingen die de boer bij zijn graslandgebruik dient te nemen. Er konden geen significante effecten worden aangetoond van de in onze proeven bij langere rustperioden verkregen hogere grasopbrengsten bij inscharen op de dagelijkse opname van organische stof uit gras per dier. In de voorzomer nam de dagelijkse opname aan voederwaarde uit gras en melkproduktie af bij hogere grasopbrengsten. In de nazomer waren deze effecten echter niet aantoonbaar. Hogere grasopbrengsten bij uitscharen (bereikt door middel van hogere niveaus van grasaanbod per dier per dag) hadden significant positieve effecten op de dagelijkse opname van organische stof uit gras per dier en op de melkproduktie per dier en hadden geen significant effect op de kwaliteit van het opgenomen gras in onze proeven. Daartegenover staat dat naar een maximale opname en zo hoog mogelijke dierlijke produktie per oppervlakte-eenheid grasland dient te worden gestreefd. Het is daarom belangrijk om systemen van graslandgebruik te onderzoeken waarin bij een gegeven hoge grasproduktie een groot gedeelte van het geproduceerde gras wordt opgenomen en waarin toch een hoge individuele grasopname en dierlijke produktie (en dus ook een gunstige voederconversie) kan worden bereikt. Om een hoge grasopname per dier en een hoge grasopname per oppervlakte met elkaar te combineren worden de volgende methoden besproken:

- het verdelen van het veebestand in groepen dieren met een hoge en met een lage behoefte aan voederwaarde
- het bijvoederen van grazende dieren bij een hoge veebezetting (laag grasaanbod per dier per dag) tot een niveau van opname aan voederwaarde waarbij een hoge individuele produktie mogelijk is
- het toepassen van een hoog grasaanbod per dier per dag en het gebruik van de positieve effecten van dit hoge grasaanbod, en de resulterende weiderest, op de netto hergroei
- het toepassen van zomerstalvoedering
- het verhogen van de grasopbrengst bij inscharen door gebruik te maken van langere groeiperioden.

Meer onderzoek naar de vijf hierboven vermelde mogelijkheden met hoogproduktief melkvee is nodig om tot de beste methode van graslandgebruik te komen.

Appendices

Appendix 1. Comparability of grazing groups at the start of Experiments 3 and 4.

1978 animal group		1	2	3	4
average number of lactation		3.17	3.17	3.17	3.17
date of calving		3/4	5/4	7/4	3/4
live weight after calving (kg)		639	634	645	641
number of days	previous lactation	305	305	305	305
milk production (total kg)		6137	6182	6409	6118
100 w_{XL}		4.13	4.15	4.03	4.17
100 w_{XP}		3.34	3.33	3.29	3.35
L (kg d^{-1})		20.1	20.3	21.0	20.1
FCM (kg d^{-1})		20.5	20.7	21.0	20.6
1979 animal group		1	2	3	4
average number of lactation		3.83	3.83	3.83	3.83
date of calving		1/4	1/4	3/4	1/4
live weight after calving (kg)		580	577	578	550
number of days	previous lactation	298	283	296	298
milk production (total kg)		6059	5666	6120	6119
100 w_{XL}		4.44	4.48	4.27	4.31
100 w_{XP}		3.53	3.43	3.34	3.31
L (kg d^{-1})		20.4	20.0	20.7	20.5
FCM (kg d^{-1})		21.7	21.4	21.5	21.5

Appendix 2. General data of grazed swards in Experiments 3 and 4.

EP	1978			1979		
	Period of use[1]	Preceding use[2]	Kg nitrogen ha^{-1}	Period of use	Preceding use	Kg nitrogen ha^{-1}
1	11/5-19/5	GS	84	17/5-25/5	GS	91
2	18/5-26/5	GS	84	24/5- 1/6	GS	91
3	25/5- 2/6	H	77	31/5- 8/6	H	80
4	1/6- 9/6	H	77	7/6-15/6	GS-H	78
5	8/6-16/6	H	84	14/6-22/6	G-H	81
6	15/6-23/6	H	81	21/6-29/6	H	83
7	22/6-30/6	H-H	81	28/6- 6/7	G-H	84
8	29/6- 7/7	GS-H	84	5/7-13/7	GS-H	91
9	3/8-11/8	H-G-H	91	2/8-10/8	H-G-H	82
10	10/8-18/8	G-H-G-H	80	9/8-17/8	H-GS-G-H	73
11	17/8-25/8	G-H-G-H	83	16/8-24/8	H-G-G-H	72
12	24/8- 1/9	G-H-G-H	85	23/8-31/8	H-G-H-GS-H	77
13	31/8- 8/9	G-H-G-H	85	30/8- 7/9	GS-G-H-H	87
14	7/9-15/9	H-H-H-H	75	6/9-14/9	H-G-G-H	86
15	14/9-22/9	G-H-G-G-H	72	13/9-21/9	G-H-G-H	76
16	21/9-29/9	H-G-G-G-H	67	20/9-28/9	G-H-G-G-H	76

1. Pre-period (4 days) + experimental period (3 days); 1 day difference in grazing period between animal group 1 + 2 and group 3 + 4.
2. GS = grazing by sheep; G = grazing by cattle; H = mechanical harvesting.

Appendix 3. Meteorological data of Experiments 3 and 4.

EP	1978			1979		
	Rainfall[1]	Temperature[2]	Radiation[3]	Rainfall	Temparture	Radiation
1	0	12.0	1855	17.2	11.5	1317
2	1.0	11.4	879	44.3	17.9	1866
3	0	20.8	2664	12.0	14.5	1640
4	54.5	16.8	1706	23.6	12.5	850
5	0.4	13.4	1760	0	16.9	2667
6	10.5	14.4	2288	3.2	15.1	2186
7	13.0	13.3	836	0	14.5	1766
8	20.5	11.6	1348	0	15.8	2192
9	3.6	15.5	1832	18.5	15.0	1119
10	17.2	16.5	1533	0	16.2	1483
11	0	16.5	1871	6.4	12.2	1076
12	22.9	13.7	1048	0	15.2	1515
13	0	14.7	1484	5.2	14.9	1384
14	17.5	14.0	764	0	13.6	905
15	3.0	14.3	1234	12.1	13.8	625
16	22.0	11.4	602	3.3	11.5	802

1. Total precipitation (mm) from Tuesday to Friday.
2. Mean temperature (°C) from Tuesday to Friday.
3. Mean solar radiation (J cm^{-2} d^{-1}) from Monday to Thursday.

Appendix 4. Herbage allowance, mass, consumption and digestibility (per grazing period per group).

	EP	Group		ms					ms + lm			
				A_0	M_0	d_0 of M_0	M_0^f	d_0 of M_0^f	C_0	C_{d0}	I_0	D_0
1978	1	1	X	13.85	1822	0.824	479	0.813	1552	1302	9.73	8.16
		2	Y	19.10	1836	0.824	705	0.816	1404	1182	11.82	9.95
		3	Y	19.93	2111	0.824	771	0.804	1543	1319	12.20	10.36
		4	Z	30.28	2018	0.825	1178	0.818	1134	958	13.67	11.56
	2	1	Y	19.04	2996	0.832	1041	0.795	1978	1713	11.92	10.32
		2	Z	27.70	2978	0.832	1605	0.803	1477	1288	12.93	11.28
		3	X	13.88	3015	0.830	302	0.778	2714	2296	12.03	10.18
		4	Y	19.41	3137	0.830	909	0.799	2185	1859	12.88	10.97
	3	1	Z	29.66	2350	0.827	1245	0.800	1462	1268	15.12	13.11
		2	Y	18.34	2215	0.827	803	0.811	1658	1406	11.29	9.58
		3	Y	20.92	2587	0.823	927	0.800	1890	1622	12.93	11.10
		4	X	15.27	2635	0.823	646	0.763	2204	1887	10.97	9.39
	4	1	Z	33.04	4029	0.798	2503	0.772	1944	1563	14.57	11.72
		2	X	15.28	3846	0.798	1000	0.714	3150	2567	11.64	9.48
		3	Y	21.46	4186	0.798	1588	0.733	2864	2340	13.62	11.13
		4	Y	21.47	4229	0.798	1729	0.756	2712	2218	12.77	10.45
	5	1	Z	31.86	2843	0.765	1773	0.775	1309	1013	12.79	9.91
		2	X	15.37	2849	0.765	625	0.698	2356	1849	11.47	9.00
		3	Y	20.79	2934	0.765	1124	0.749	1920	1509	12.09	9.52
		4	Z	30.43	2818	0.765	1676	0.767	1348	1070	12.70	10.08
	6	1	X	15.65	3153	0.786	1001	0.748	2340	1842	10.90	8.54
		2 *[1]	Y	20.75	3060	0.786	1480	0.759	1609	1306	10.04	8.15
		3	Z	29.35	3348	0.781	1689	0.752	1775	1418	14.43	11.53
		4 *	Z	30.39	3109	0.781	1818	0.735	1322	1121	11.85	10.05

Appendix 4 continued.

	EP	Group		ms					ms + 1m			
				A_0	M_0	d_0 of M_0	M_0^f	d_0 of M_0^f	C_0	C_{d0}	I_0	D_0
1978	7	1	Y	20.85	1234	0.750	365	0.708	829	665	13.09	10.50
		2	Y	18.01	1119	0.750	306	0.703	741	589	11.08	8.73
		3 *	Z	31.27	1352	0.750	523	0.729	768	614	16.50	13.20
		4 *	X	16.39	1442	0.750	253	0.625	1118	909	11.97	9.73
	8	1 *	Y	19.99	1931	0.748	600	0.734	1114	902	10.07	8.16
		2	Z	29.01	1858	0.748	1068	0.750	924	704	12.45	9.48
		3	X	13.59	1880	0.743	330	0.617	1727	1333	11.23	8.68
		4	Y	18.29	1837	0.743	598	0.705	1450	1098	12.73	9.64
	9	1	Y	20.61	2192	0.733	515	0.669	1715	1333	14.68	11.41
		2	Z	31.94	2244	0.733	935	0.704	1317	1056	16.87	13.54
		3	X	16.37	2386	0.772	350	0.551	1999	1729	12.66	10.96
		4	X	20.87	2265	0.772	477	0.658	1787	1494	15.08	12.61
	10	1	X	15.37	1710	0.719	416	0.582	1371	1065	11.19	8.70
		2	Y	21.03	1739	0.719	579	0.660	1072	887	11.68	9.66
		3	Y	20.76	1838	0.721	575	0.587	1162	1011	11.92	10.38
		4	Z	32.30	1892	0.721	976	0.657	990	805	15.32	12.45
	11	1	Y	20.25	2065	0.758	447	0.664	1548	1296	13.90	11.63
		2	X	14.75	2022	0.758	295	0.592	1673	1387	11.23	9.32
		3	Z	29.78	2106	0.758	871	0.722	1213	1019	15.58	13.10
		4	Y	18.91	2000	0.758	412	0.675	1556	1282	13.47	11.08
	12	1 *	Y	24.32	1874	0.744	668	0.675	1322	986	15.49	11.55
		2 *	Y	26.31	2047	0.744	775	0.694	1335	1003	15.57	11.70
		3 *	Z	39.43	2037	0.741	953	0.718	1286	889	22.54	15.58
		4 *	X	18.64	1939	0.741	363	0.585	1825	1379	16.08	12.15
	13	1	Y	19.63	2280	0.751	675	0.683	1712	1341	12.84	10.04
		2	Y	20.25	2391	0.751	605	0.669	1819	1461	13.52	10.86
		3	Z	31.56	2426	0.751	1110	0.701	1647	1258	18.65	14.25
		4	X	14.64	2276	0.751	392	0.579	2127	1638	12.12	9.34
	14	1 *	Z	28.58	1726	0.764	738	0.716	1185	852	18.61	13.38
		2 *	Z	28.23	1689	0.764	842	0.703	1019	764	16.03	12.02
		3	X	14.89	1806	0.764	183	0.592	1529	1237	12.08	9.77
		4	Y	17.98	1652	0.764	302	0.677	1238	999	12.81	10.34
	15	1	Z	25.78	1534	0.733	643	0.698	897	740	13.80	11.38
		2	X	14.32	1577	0.733	315	0.625	1183	958	9.94	8.05
		3	Y	17.95	1564	0.733	372	0.622	1082	903	11.44	9.54
		4	Y	18.40	1546	0.733	368	0.631	1147	918	12.61	10.08
	16	1	X	17.37	1820	0.718	573	0.567	1418	1083	12.43	9.49
		2	Y	22.79	1833	0.718	806	0.646	1136	863	12.88	9.81
		3 *	Y	22.40	1888	0.732	700	0.485	1494	1271	16.34	13.91
		4 *	Z	34.49	1910	0.732	1095	0.634	1085	925	17.88	15.24
1979	1	1	X	15.03	1513	0.849	277	0.748	1437	1220	12.41	10.53
		2	Z	31.09	1548	0.849	1064	0.841	810	667	13.52	11.15
		3 *	Y	24.64	1764	0.849	1020	0.831	1081	904	13.04	10.91
		4 *	Y	26.13	1879	0.849	1027	0.844	1133	939	13.75	11.39
	3	1	Y	19.19	1963	0.808	455	0.731	1615	1389	13.92	11.98
		2	X	12.90	2036	0.808	48	0.658	2095	1728	12.13	10.01
		3	Y	20.22	2187	0.808	769	0.773	1526	1302	12.42	10.59
		4	Z	26.16	2120	0.808	988	0.787	1251	1066	13.38	11.41
	4	1 *	Y	21.05	2161	0.820	909	0.748	1377	1178	12.62	10.79
		2 *	Z	29.79	2172	0.820	1262	0.804	1083	885	13.85	11.32
		3 *	X	15.35	2370	0.820	503	0.667	1950	1675	12.10	10.40
		4 *	Z	27.95	2269	0.820	1142	0.785	1293	1086	14.96	12.57

Appendix 4 continued.

	EP	Group		ms					ms + lm			
				A_0	M_0	d_0 of M_0	M_0^f	d_0 of M_0^f	C_0	C_{d0}	I_0	D_0
1979	5	1	Z	32.39	2421	0.812	1425	0.797	1272	1076	14.46	12.23
		2	Y	25.07	2487	0.812	1253	0.790	1465	1204	12.67	10.52
		3	Y	26.46	2539	0.812	1298	0.751	1462	1298	13.10	11.63
		4	X	15.91	2481	0.812	545	0.736	2050	1769	11.57	9.97
	6	1	Y	23.22	1306	0.769	355	0.721	998	854	14.66	12.55
		2	Z	30.32	1244	0.769	573	0.753	796	652	15.64	12.81
		3	X	13.83	1209	0.786	0	-	1306	1045	12.59	10.07
		4	Z	31.00	1366	0.786	687	0.773	916	737	17.10	13.77
	7	1	X	18.99	1309	0.816	336	0.728	1111	995	13.03	11.68
		2	Y	30.65	1311	0.816	647	0.800	850	730	15.70	13.50
		3	Z	39.78	1374	0.824	773	0.805	830	714	19.09	16.42
		4	Y	27.92	1266	0.824	581	0.780	924	786	16.12	13.71
	8	1	Z	27.21	2137	0.790	1139	0.780	1200	960	13.33	10.67
		2	X	15.16	2251	0.790	546	0.703	1771	1473	10.67	8.88
		3	Z	31.16	2495	0.790	1263	0.762	1434	1167	15.93	12.97
		4	Y	24.01	2511	0.790	793	0.778	1841	1480	15.88	12.77
	9	1 *	Z	26.28	1156	0.758	658	0.675	797	605	16.11	12.22
		2 *	Y	20.43	1206	0.758	498	0.584	1154	863	17.71	13.24
		3	X	15.45	1252	0.755	305	0.573	1064	848	11.74	9.35
		4	Y	21.91	1244	0.758	497	0.678	894	723	13.96	11.30
	10	1	Y	25.61	1561	0.776	591	0.760	1091	909	14.93	12.44
		2	X	16.82	1566	0.776	255	0.649	1377	1170	12.51	10.63
		3	Y	26.21	1684	0.771	666	0.713	1094	956	14.32	12.51
		4	Z	32.37	1573	0.776	853	0.759	950	772	16.17	13.15
	11	1	X	15.63	1685	0.759	316	0.584	1254	1152	10.05	9.23
		2	Z	32.32	1818	0.759	853	0.743	1082	849	16.63	13.06
		3	Z	34.69	1964	0.758	1086	0.747	955	792	14.66	12.16
		4	Y	27.69	2118	0.759	755	0.707	1360	1114	15.78	12.92
	12	1 *	Z	29.62	2140	0.806	959	0.780	926	792	11.95	10.22
		2 *	Z	29.06	2131	0.806	839	0.778	919	800	11.72	10.20
		3	Y	21.12	2334	0.806	491	0.703	1699	1461	14.40	12.37
		4	X	15.80	2291	0.806	253	0.689	1882	1611	12.21	10.45
	14	1	Z	31.55	1405	0.783	759	0.765	645	541	13.59	11.40
		2	Y	21.24	1528	0.783	592	0.720	954	778	12.56	10.24
		3	X	15.03	1379	0.783	266	0.709	952	808	9.78	8.31
		4	Z	28.05	1330	0.783	654	0.757	658	536	12.97	10.55
	15	1 *	X	15.51	1704	0.759	319	0.592	1476	1268	12.78	10.98
		2 *	Y	24.53	1794	0.759	584	0.693	1303	1057	16.79	13.62
		3	Z	29.19	1616	0.759	909	0.715	856	666	14.12	10.97
		4	Z	28.10	1571	0.759	820	0.725	860	669	14.01	10.90
	16	1	Y	25.16	1401	0.738	625	0.690	853	687	13.70	11.04
		2	Z	31.08	1366	0.739	662	0.674	733	623	14.78	12.56
		3	Y	28.64	1412	0.738	658	0.658	714	638	12.88	11.51
		4	X	17.35	1481	0.739	368	0.607	944	817	9.96	8.61

1. Unreliable results (Section 5.3.2.1).

Appendix 5. Nutritive value of herbage at start and finish of grazing (ms + lm).

Treatment				X	Y	Z	Mean
M	$100\ w_{dXP}/O$	1978	es	18.2(3.79)[1]	18.8(3.66)	18.0(4.09)	18.4(3.69)
			ls	21.1(1.57)	21.0(1.52)	20.9(2.02)	21.0(1.57)
		1979	es	20.6(3.86)	20.4(3.55)	20.2(2.89)	20.4(3.25)
			ls	21.6(1.70)	21.0(1.05)	21.2(0.89)	21.2(1.17)
	$100\ w_{dO}/O$ $(= d_O)$	1978	es	77.8(3.65)	77.8(4.33)	77.7(3.43)	77.8(3.76)
			ls	68.3(3.85)	68.6(3.51)	68.1(2.09)	68.4(3.25)
		1979	es	76.5(3.79)	76.2(3.01)	76.1(3.67)	76.2(3.31)
			ls	67.4(4.52)	68.1(3.75)	67.3(1.27)	67.6(3.20)
	e_{NE_1}/O[2]	1978	es	1043(53)	1048(56)	1041(52)	1044(52)
			ls	925(57)	925(46)	920(35)	924(46)
		1979	es	1041(58)	1035(45)	1032(57)	1035(51)
			ls	917(63)	923(51)	913(22)	918(45)
M^f	$100\ w_{dXP}/O$	1978	es	14.3(3.43)	15.9(2.97)	15.0(3.09)	15.2(3.08)
			ls	16.9(1.39)	17.3(1.01)	17.3(1.50)	17.2(1.19)
		1979	es	17.9(3.24)	17.4(3.22)	16.8(3.08)	17.3(3.05)
			ls	18.2(1.12)	18.4(1.35)	18.9(0.60)	18.5(1.06)
	$100\ w_{dO}/O$ $(= d_O)$	1978	es	70.0(5.08)	72.4(5.44)	75.1(2.88)	72.6(4.94)
			ls	49.0(3.80)	53.5(4.63)	58.5(2.91)	53.2(5.19)
		1979	es	62.3(7.22)	67.5(5.00)	71.5(5.56)	67.5(6.70)
			ls	50.0(5.38)	57.0(3.12)	60.2(2.05)	56.3(5.36)
	e_{NE_1}/O[2]	1978	es	904(72)	949(70)	983(45)	948(69)
			ls	630(49)	693(62)	764(41)	690(71)
		1979	es	816(100)	889(66)	943(81)	889(93)
			ls	651(67)	748(36)	797(29)	739(73)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.
2. VEM kg^{-1}.

Appendix 6. Areic mass of nutrients at start and finish of grazing (ms + lm).

Treatment			X	Y	Z	Mean
M_{dXP}	1978	es	548(103)[1]	514(118)	548(102)	533(107)
		ls	514(60)	507(62)	526(70)	500(67)
	1979	es	446(60)	468(67)	449(59)	455(60)
		ls	496(63)	487(46)	476(46)	486(50)
M_{dO}	1978	es	2426(628)	2269(855)	2452(604)	2364(711)
		ls	1672(244)	1658(223)	1729(271)	1677(230)
	1979	es	1711(399)	1799(432)	1733(385)	1751(389)
		ls	1563(284)	1593(277)	1505(132)	1553(228)
M_{NE_1}[2]	1978	es	3229(791)	3040(1095)	3274(759)	3158(905)
		ls	2266(330)	2239(308)	2337(360)	2267(312)
	1979	es	2321(499)	2439(550)	2346(494)	2374(495)
		ls	2129(389)	2159(374)	2044(187)	2109(312)
M^f_{dXP}	1978	es	154(52)	216(49)	309(62)	228(79)
		ls	170(34)	207(34)	268(25)	209(47)
	1979	es	149(56)	227(43)	252(31)	215(59)
		ls	226(32)	268(35)	300(29)	268(43)
M^f_{dO}	1978	es	777(259)	1039(375)	1581(354)	1132(457)
		ls	490(77)	640(116)	912(128)	653(184)
	1979	es	537(220)	917(283)	1104(227)	881(329)
		ls	616(54)	824(60)	957(85)	816(152)
$M^f_{NE_1}$[2]	1978	es	1002(327)	1363(465)	2066(444)	1478(586)
		ls	631(102)	829(150)	1191(164)	847(242)
	1979	es	702(279)	1205(356)	1454(283)	1158(426)
		ls	804(74)	1082(77)	1268(116)	1074(207)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.
2. kVEM ha^{-1}.

Appendix 7. Daily intake of nutrients from total ration and degree of nutrient balance (ms + lm).

Treatment			X	Y	Z	Mean
D_{XP}	1978	es	2.38(0.43)[1]	2.76(0.55)	3.19(0.79)	2.78(0.66)
		ls	2.84(0.31)	3.26(0.40)	4.15(0.48)	3.32(0.60)
	1979	es	2.97(0.68)	3.69(0.80)	4.14(0.77)	3.66(0.87)
		ls	2.88(0.46)	3.58(0.31)	3.86(0.44)	3.49(0.55)
I_{NE_1}[2]	1978	es	14.06(1.08)	15.63(0.94)	17.00(1.58)	15.63(1.60)
		ls	13.89(1.29)	15.67(1.31)	18.98(1.46)	15.84(2.22)
	1979	es	16.24(1.58)	18.60(2.25)	19.89(2.75)	18.43(2.65)
		ls	14.12(1.36)	17.39(1.26)	17.56(1.43)	16.56(2.00)
k_{dXP}	1978	es	1.18(0.21)	1.33(0.30)	1.51(0.37)	1.34(0.32)
		ls	1.82(0.26)	1.97(0.23)	2.41(0.18)	2.02(0.31)
	1979	es	1.38(0.29)	1.74(0.42)	1.96(0.42)	1.72(0.44)
		ls	1.73(0.19)	2.08(0.13)	2.29(0.20)	2.06(0.28)
k_{NE_1}	1978	es	0.79(0.07)	0.86(0.06)	0.92(0.07)	0.86(0.08)
		ls	0.97(0.08)	1.05(0.06)	1.22(0.07)	1.06(0.11)
	1979	es	0.87(0.08)	1.00(0.15)	1.08(0.19)	0.99(0.17)
		ls	0.94(0.08)	1.12(0.06)	1.15(0.07)	1.08(0.11)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.
2. kVEM d^{-1}.

Appendix 8. Herbage mass, digestibility and accumulation after or during regrowth (per growing period per group).

EP	Group	A_0	1978			
			ms		ms + lm	
			$M_{i+1,0}$	d_0 of M_{i+1}	ΔM^r_0	ΔM^r_{d0}
1	1	X	2981	0.799	2561	2005
	2	Y	3258	0.787	2669	2006
	3	Y	3388	0.789	2552	1972
	4	Z	4028	0.775	2806	2077
2	1	Y	3273	0.779	2268	1730
	2	Z	4428	0.777	2899	2176
	3	X	1742	0.810	1449	1167
	4	Y	3190	0.790	2279	1770
3	1	Z	4162	0.770	2825	2142
	2	Y	3341	0.779	2387	1842
	3	Y	3146	0.800	2101	1717
	4	X	2326	0.776	1580	1248
4	1	Z	4101	0.742	1806	1207
	2	X	1811	0.713	886	592
	3	Y	2803	0.705	1166	715
	4	Y	3141	0.725	1405	914
5	1 *[1]	Z	3143	0.704	1221	772
	2 *	X	1276	0.719	531	375
	3 *	Y	1865	0.708	501	290
	4 *	Z	3013	0.727	1148	752
9	1	Y	1724	0.759	1206	963
	2	Z	2481	0.747	1432	1142
	3	X	1002	0.717	630	570
	4	Y	1436	0.741	954	775
10	1	X	828	0.687	431	358
	2	Y	1128	0.676	490	395
	3	Y	998	0.667	604	439
	4	Z	1738	0.696	924	647
11	1 *	Y	1102	0.716	486	407
	2 *	X	778	0.702	349	291
	3 *	Z	1809	0.732	-[2]	-
	4 *	Y	1019	0.764	-[2]	-
12	1	Y	1538	0.757	708	633
	2	Y	1489	0.759	486	479
	3	Z	2135	0.693	1029	692
	4	X	1194	0.737	674	590
13	1 *	Y	1317	0.715	468	329
	2 *	Y	1372	0.722	553	439
	3 *	Z	1894	0.732	571	453
	4 *	X	1018	0.719	387	322

EP	Group	A_0	1979			
			ms		ms + lm	
			$M_{i+1,0}$	d_0 of M_{i+1}	ΔM^r_0	ΔM^r_{d0}
1	1	X	2744	0.831	2339	1955
	2	Z	4117	0.804	2955	2329
	3	Y	4114	0.787	3012	2298
	4	Y	4045	0.785	2911	2196
3	1	Y	2136	0.798	1613	1344
	2	X	1128	0.801	1079	864
	3	Y	2887	0.788	2096	1666
	4	Z	3501	0.770	2456	1864
4	1 *[1]	Y	2965	0.807	2161	1775
	2 *	Z	3723	0.804	2573	2069
	3 *	X	2083	0.813	1672	1451
	4 *	Z	3766	0.787	2731	2113
5	1	Z	3956	0.788	2469	1907
	2	Y	3248	0.783	1892	1459
	3	Y	3433	0.794	1998	1654
	4	X	1897	0.807	1194	1025
9	1 *	Z	2133	0.781	1476	1213
	2 *	Y	1819	0.777	1337	1112
	3	X	1520	0.770	1014	948
	4	Y	1974	0.775	1331	1159
10	1 *	Y	1547	0.765	639	517
	2 *	X	831	0.786	310	261
	3	Y	1640	0.751	842	698
	4	Z	1880	0.778	859	761
11	1	X	723	0.740	438	327
	2	Z	1786	0.744	1009	656
	3	Z	1907	0.740	989	642
	4	Y	1397	0.734	775	536
12	1	Z	1869	0.797	891	637
	2	Z	1549	0.793	682	453
	3 *	Y	1640	0.756	927	713
	4 *	X	774	0.733	209	163

1. Unreliable results (Section 5.3.3.1).
2. Lawn-mower defect.

Appendix 9. Nutritive value of herbage after regrowth (ms + lm).

Treatment				X	Y	Z	Mean
M_{i+1}	100 $w_{dXP}/0$	1978	es	19.3(0.76)[1]	17.7(0.95)	16.2(1.14)	17.7(1.42)
			ls	20.2(2.72)	19.7(2.39)	17.7(2.76)	19.3(2.51)
		1979	es	20.2(3.22)	18.1(2.65)	17.9(1.96)	18.6(2.60)
			ls	21.7(0.49)	21.7(0.40)	20.4(1.47)	21.1(1.21)
	100 $w_{d0}/0$	1978	es	74.9(4.59)	75.1(3.60)	75.2(1.88)	75.1(3.32)
	(= d_0)		ls	61.0(5.72)	64.1(6.83)	65.2(4.65)	63.6(5.82)
		1979	es	77.1(3.89)	77.1(0.97)	77.0(2.34)	77.1(2.04)
			ls	59.9(12.16)	65.3(4.02)	66.5(4.07)	64.8(5.86)
	$e_{NE_1}/0$[2]	1978	es	1007(71)	1000(54)	991(32)	999(51)
			ls	817(92)	856(103)	859(69)	847(87)
		1979	es	1047(40)	1031(21)	1029(38)	1035(28)
			ls	814(168)	887(58)	897(53)	877(79)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.
2. VEM kg^{-1}.

Appendix 10. Areic mass of nutrients after regrowth (ms + lm).

Treatment			X	Y	Z	Mean
$M_{i+1,dXP}$	1978	es	524(114)[1]	650(45)	760(22)	646(105)
		ls	336(58)	408(54)	459(78)	409(78)
	1979	es	443(91)	644(58)	750(60)	620(131)
		ls	437(82)	541(55)	541(55)	520(69)
$M_{i+1,d0}$	1978	es	2046(493)	2769(233)	3529(156)	2778(610)
		ls	1017(116)	1332(187)	1795(278)	1369(342)
	1979	es	1771(679)	2809(555)	3239(283)	2657(746)
		ls	1227(444)	1635(243)	1757(99)	1614(290)
M_{i+1,NE_1}[2]	1978	es	2751(674)	3687(328)	4652(191)	3694(794)
		ls	1361(185)	1780(271)	2366(376)	1822(453)
	1979	es	2399(886)	3751(693)	4330(373)	3557(967)
		ls	1669(609)	2221(339)	2371(128)	2186(391)

1. The figure in brackets is the standard deviation (s_x) of the estimate as calculated from the measurements in different periods.
2. kVEM ha^{-1}.

Appendix 11. Comparability of stall-fed and pasture grazing cows at the start of Experiments 1 and 2.

	1976		1977	
animal group	Stall	Pasture	Stall	Pasture
number of cows in second lactation	5	6	5	5
number of cows in third lactation	6	6	3	3
number of cows in fourth lactation	-	-	4	4
date of calving	12/3	11/3	21/2	19/2
live weight after calving (kg)	555	547	604	575
number of days (previous lactation)	305	305	297	293
milk production (total kg) (previous lactation)	5835	5924	6062	6019
100 w_{XL} (previous lactation)	4.25	4.26	4.25	4.20
100 w_{XP} (previous lactation)	3.41	3.43	3.39	3.45
L ($kg\ d^{-1}$) (previous lactation)	19.1	19.4	20.4	20.5
FCM ($kg\ d^{-1}$) (previous lactation)	19.9	20.2	21.2	21.1

Appendix 12. General data of experimental swards (Experiments 1 and 2).

		Use	Preceding use[1]	Rest period[2]	Kg nitrogen ha^{-1}	Period of use[3]
1976	May	grazing	GS	-[4]	90	7/5-28/5
		zero grazing	GS	-	77	7/5-28/5
	June	grazing	G-H	21	76	18/6- 9/7
		zero grazing	G-H	21	78	18/6- 9/7
	August	grazing	H-G-H	28	89	13/8- 3/9
		zero grazing	H-G-H	28	78	13/8- 3/9
1977	May	grazing	GS	-[4]	72	13/5- 3/6
		zero grazing	GS	-	72	13/5- 3/6
	June	grazing	H	18	84	7/6-20/6
		zero grazing	H	18	84	7/6-20/6
	August	grazing	H-G-H	14	70	2/8-14/8
		zero grazing	H-G-H	14	98	2/8-15/8
	September	grazing	H-G-G-H	20	85	29/8-16/9
		zero grazing	H-G-G-H	20	85	29/8-16/9

1. GS = grazing by sheep; G = grazing by cattle; H = mechanical harvesting.
2. Number of growing days between the removement of the cut herbage at the prior defoliation and the first day of experimental period 1 of the trial.
3. In 1976: pre-periods (3 days) + experimental periods (4 days);
In 1977: experimental periods (3 and 4 days respectively).
4. First growth in the season.

Appendix 13. Meteorological data of Experiments 1 and 2.

	EP	1976			1977		
		Rainfall[1]	Temperature[2]	Radiation[3]	Rainfall	Temperature	Radiation
May	1	2.1	10.5	1797	14.5	9.3	1930
	2	6.3	13.0	1829	1.0	12.6	2079
	3	8.4	11.8	1692	0	12.7	1658
	4				0	15.4	2786
	5				0	12.4	2599
	6				4.5	12.3	2256
June	1	0	18.8	2496	1.3	14.7	1617
	2	0	19.5	2911	8.5	17.5	1998
	3	0	20.8	2860	13.9	16.3	1749
	4				0.2	13.5	573
August	1	0	17.8	1969	0	17.2	1759
	2	0	18.0	1980	6.5	16.1	1392
	3	22.0	13.3	1204	6.5	15.4	1031
	4				12.2	17.0	1056
September	1				0	16.1	1706
	2				1.0	14.1	1587
	3				6.2	14.9	893
	4				1.3	15.5	1005
	5				0	12.9	1156

1. Total precipitation (mm) during EP from Tuesday to Friday (or in 1977 from Saturday to Monday).
2. Mean temperature (°C) during EP from Tuesday to Friday (or in 1977 from Saturday to Monday).
3. Mean solar radiation (J cm^{-2} d^{-1}) from Monday to Thursday (or in 1977 also from Friday to Sunday).

Appendix 14. Areic consumption of herbage and daily herbage intake by grazing cows at a standardized O allowance level of 22 kg d^{-1} (>4.5 cm).

		EP	$C_{0,cor}$	$I_{0,cor}$	$C_{d0,cor}$	$D_{0,cor}$	$c_{0,cor}$[1]
1976	May	1	1539	15.1	1261	12.4	0.69
		2	2412	15.5	1971	12.7	0.70
		3	2856	15.4	2272	12.2	0.70
	June	1	1020	14.4	810	11.4	0.65
		2	1813	15.3	1328	11.2	0.70
		3	1955	15.9	1400	11.4	0.72
	August	1	1132	15.6	825	11.4	0.71
		2	1356	14.9	963	10.7	0.68
		3	1476	15.9	1076	11.6	0.72
1977	May	1	1195	13.7	1013	11.6	0.62
		2	1345	13.5	1160	11.6	0.61
		3	1937	13.5	1637	11.4	0.61
		4	2075	13.5	1763	11.5	0.61
		5	2633	14.1	2158	11.5	0.64
		6	2970	15.1	2423	12.3	0.69
	June	1	1030	14.1	878	12.0	0.64
		2	2215	15.5	1787	12.5	0.70
		3	2564	15.0	2004	11.7	0.68
		4	3071	13.6	2337	10.4	0.62
	August	1	1236	15.7	959	12.2	0.71
		2	1543	16.3	1199	12.7	0.74
		3	1259	14.9	973	11.5	0.68
		4	1758	15.0	1346	11.5	0.68
	September	1	1105	13.8	876	10.9	0.63
		2	1324	12.8	1045	10.1	0.58
		3	1580	14.2	1259	11.3	0.65
		4	1785	14.6	1446	11.8	0.66
		5	1891	14.5	1515	11.6	0.66

1. $I_{0,cor}/A_0$ (ms).

Appendix 15. Daily intake of nutrients from total ration and degree of nutrient balance of grazing cows.

			EP	D_{XP}	k_{dXP}	I_{NE_1} [1]	k_{NE_1}
ms	1976	May	1	3.82	1.73	18.10	0.95
			2	3.03	1.44	17.63	0.97
			3	2.12	1.06	16.53	0.95
		June	1	2.45	1.27	16.15	0.95
			2	2.50	1.40	15.49	0.98
			3	2.12	1.27	15.74	1.05
		August	1	3.19	2.02	16.99	1.18
			2	2.39	1.48	14.30	0.98
			3	2.66	1.68	16.60	1.16
		mean		2.70	1.48	16.39	1.02
ms + 1m	1977	May	1	2.59	1.27	16.59	0.94
			2	2.41	1.20	17.01	0.98
			3	1.65	0.85	15.28	0.91
			4	1.79	0.96	15.94	0.97
			5	1.54	0.84	15.98	0.99
			6	1.93	1.08	17.69	1.12
		June	1	3.36	1.74	18.88	1.11
			2	2.83	1.53	17.66	1.08
			3	2.42	1.37	16.24	1.04
			4	1.59	0.95	13.01	0.86
		August	1	4.17	2.49	17.29	1.15
			2	3.89	2.38	18.30	1.24
			3	3.87	2.43	17.99	1.24
			4	3.31	2.13	16.55	1.17
		September	1	4.19	2.69	18.41	1.29
			2	3.13	2.03	15.28	1.09
			3	3.40	2.25	16.66	1.20
			4	3.48	2.33	17.18	1.25
			5	3.49	2.37	16.89	1.24
		mean		2.90	1.73	16.78	1.10

1. kVEM d^{-1}.

References

Acosta, R.H. & M.M. Kothmann, 1978. Chemical composition of esophageal - fistula forage samples as influenced by drying method and salivary leaching. J. Anim. Sci. 47:691.

Adamson, A.H. & J.R. Garstang, 1979. Herbage intake and animal production from different grazing systems. Proc. III European Grazing Workshop.

Aitken, J.N. & T.R. Preston, 1964. The self feeding of complete milled rations to dairy cattle. Anim. Prod. 6:260.

Alder, F.E., 1969. The use of cattle with oesophageal fistulae in grassland experiments. J. Br. Grassld. Soc. 24:6.

Alder, F.E., 1970. Comparative studies of perennial ryegrass, timothy and meadow fescue. 2. Results obtained in grazing experiments. J. Br. Grassld. Soc. 25:53.

Alder, F.E. & E.M. Cooper, 1967. Comparative studies of perennial ryegrass and cocksfoot as food for the calf. J. Agric. Sci. 68:331.

Alder, F.E., S.J. Cowlishaw, J.E. Newton & D.T. Chambers, 1967. The effects of nitrogen fertilizer on beef production from grazed perennial ryegrass/white clover pastures. J. Br. Grassld. Soc. 22:194.

Alder, F.E. & D.J. Minson, 1963. The herbage intake of cattle grazing lucerne and cocksfoot pastures. J. Agric. Sci. 60:359.

Allden, W.G., 1969. The summer nutrition of weaner sheep: the voluntary feed intake, body weight change and wool production of sheep grazing the mature herbage of sown pasture in relation to the intake of dietary energy under a supplementary feeding regime. Austr. J. Agric. Res. 20:499.

Allden, W.G. & I.A.M. Whittaker, 1970. The determinants of herbage intake by grazing sheep: the interrelationship of factors influencing herbage intake and availability. Austr. J. Agric. Res. 21:755.

Anslow, R.C., 1967. Frequency of cutting and sward production. J. Agric. Sci. 68::377.

Archibald, K.A.E., R.C. Campling & W. Holmes, 1975. Milk production and herbage intake of dairy cows kept on a leader and follower grazing system. Anim. Prod. 21:147.

Arnold, G.W., 1970. Regulation of food intake in grazing ruminants. In: Phillipson (Ed.), Physiology of digestion and metabolism in the ruminant. Oriel press, Newcastle upon Tyne. p. 264.

Arnold, G.W. & M.L. Dudzinski, 1963. The use of faecal nitrogen as an index for estimating the consumption of herbage by grazing animals. J. Agric. Sci. 61:33.

Arnold, G.W. & M.L. Dudzinski, 1967a. Comparison of faecal nitrogen regressions and in-vitro estimates of diet digestibility for estimating the consumption of herbage by grazing animals. J. Agric. Sci. 68:213.

Arnold, G.W. & M.L. Dudzinski, 1967b. Studies on the diet of the grazing animal. II. The effect of physiological status in ewes and pasture availability on herbage intake. Austr. J. Agric. Res. 18:349.

Arnold, G.W., W.R. McManus, F.G. Bush & J. Ball, 1964. The use of sheep fitted with oesophageal fistulas to measure diet quality. Austr. J. Exp. Agr. Anim. Husb. 4:71.

Baile, C.A. & J.M. Forbes, 1974. Control of feed intake and regulation of energy balance in ruminants. Physiol. Rev. 54:160.

Baile, C.A. & J. Mayer, 1968. Effects of intravenous versus intraruminal injections of acetate on feed intake of goats. J. Dairy Sci. 51:1490.

Baile, C.A. & J. Mayer, 1970. Hypothalamic centres: feedbacks and receptor sites in the short-term control of feed intake. In: Phillipson A.T. (Ed.), Physiology of digestion and metabolism in the ruminant. Oriel Press, Newcastle upon Tyne. p. 254.

Balch, C.C. & R.C. Campling, 1969. Voluntary intake of food. In: Lenkeit W., K. Breirem & E. Grasemann (Eds.), Handbuch der Tierernährung II. Verlag Paul Parey, Hamburg. p. 554.

Baker, R.D., 1974. Estimating the faecal output of grazing animals. Proc. I European Grazing Workshop.

Baker, R.D., 1975. Effect of sward characteristics on herbage intake under grazing - nutritive quality, species and amount. In: Hodgson J. & D.K. Jackson (Eds.), Pasture utilization by the grazing animal. Br. Grassld.Soc. Occ. Symp. no. 8, p. 87.
Barth, K.M., J.E. Chandler, M.E. Fryer & H.C. Wang, 1970. Effects of saliva and drying temperature on composition and digestibility of forage samples collected through esophageal fistulas. J. Anim. Sci. 31: 794.
Barth, K.M. & N.T. Kazzal, 1972. Seperation of true selective grazing by cattle from effects of the esophageal fistula. J. Anim. Sci. 33:1124.
Baumgardt, B.R., 1970. Control of feed intake in the regulation of energy balance. In: Phillipson A.T. (Ed.), Physiology of digestion and metabolism in the ruminant. Oriel press, Newcastle upon Tyne. p. 235.
Benedictus, H.R., 1978. De invloed van het groeistadium op de opname van vers gras. Scriptie veevoeding en graslandcultuur, Landbouwhogeschool, Wageningen.
Benedictus, N., 1977. Een nieuw netto-energiesysteem voor herkauwers. Bedrijfsontw. 8:29.
Benjamin, R.W., M. Chen, A.A. Degen, N. Abdul Aziz & M.J. Al Hadad, 1977. Estimation of the dry and organic matter intake of young sheep grazing a dry mediterranean pasture and their maintenance requirements. J. Agric, Sci. 88:513.
Benjamin, R.W., A.A. Degen, A. Breight, A. Chen & N.H. Tadmor, 1975. Estimation of food intake of sheep grazing green pasture when no free water is available. J. Agric. Sci. 85:403.
Berngruber, K., 1977. Untersuchungen zur Färsenmast auf Weiden unter besonderer Berücksichtigung der Futterqualität und der Futteraufnahme. Bayer. Landw. Jahrbuch 7:771.
Bianca, W., 1965. Reviews of the progress in dairy science. Cattle in a hot environment. J. Dairy Res. 32:291.
Bines, J.A., 1971. Metabolic and physical control of food intake in ruminants. Proc. Nutr. Soc. 30:116.
Bines, J.A., 1976. Regulation of food intake in dairy cows in relation to milk production. Livest. Prod. Sci. 3:115.
Bines, J.A., 1979. Voluntary food intake. In: Broster W.H. & H. Swan (Ed.), Feeding stategy for the high yielding dairy cow. Granada Publishing Limited, London/Toronto/Sydney/New York. p.45.
Bines, J.A. & A.W.F. Davey, 1970. Voluntary intake, digestion, rate of passage, amount of material in the alimentary tract and behaviour of cows receiving complete diets containing straw and concentrates in different proportions. Br. J. Nutr. 24:1013.
Bines, J.A., S. Suzuki & C.C. Balch, 1969. The quantitative significance of long-term regulation of food intake in the cow. Br. J. Nutr. 23:695.
Blaxter, K.L., 1974. Metabolisable energy and feeding systems for ruminants. Proc. Nutr. Conf. Feed Manuf. :3.
Blaxter, K.L., A.J.H. van Es & G. Thorbek, 1973. Standardized abbreviations for quantities in energy metabolism studies. 6e Symposium on energy metabolism in farm animals (E.A.A.P.).
Blaxter, K.L., F.W. Wainman & R.S. Wilson, 1961. The regulation of food intake by sheep. Anim. Prod. 3:51.
Blaxter, K.L. & R.S. Wilson, 1962. The voluntary intake of roughages by steers. Anim. Prod. 4:351.
Bosch, S., 1956. The determination of pasture yield. Neth. J. Agric. Sci. 4:305.
Boxem, Tj., 1972. Bijvoeding van melkvee in de weide. Rapport nr. 5 P.R.
Boxem, Tj., 1976. Bijvoeding van melkvee in de weide. Publikatie nr. 6 P.R.
Boxem, Tj., 1979. Door bijvoeding met krachtvoer lagere grasopname. Bedrijfsontw. 10:53.
Bradley, N., P.G. Woolfolk, N. Stephens, R.B. Grainger & W.C. Templeton, 1956. Chromogen and protein excretion by wethers grazing fescue and ladino-alfalfa pastures. J. Anim. Sci. 15:1279.
Brisson, G.J., 1960. Indicator methods for estimating amount of forage consumed by grazing animals. Proc. VIII Int. Grassld. Congr.:435.
Brisson, G.J., W.J. Pigden & P.E. Sylvester, 1957. Effect of frequency of administration of chromic oxide on its fecal excretion pattern by grazing cattle. Can. J. Anim. Sci. 37:90.
Brockington, N.R., 1972. A mathematical model of pasture contamination by grazing cattle and the effects on herbage intake. J. Agric. Sci. 79:249.
Brody, S., 1945. Bioenergetics and growth. Reinhold, New York.
Broom, D.M., B.F. Pain & J.D. Leaver, 1975. The effects of slurry on the acceptability of swards to grazing cattle. J. Agric. Sci. 85:331.
Broster, W.H, V.J. Tuck & C.C. Balch, 1963. Effect of rationing grass on the growth rate of dairy heifers and on output per acre, with a note on its significance in experimental design. J. Agric. Sci. 60:371.

Brown, D., 1954. Methods of surveying and measuring vegetation. Bull. 42 Commonwealth bureau of pasture and field crops. Commonwealth Agricultural Bureaux, Bucks, England.
Brown, C.A., P.T. Chandler & J.B. Holter, 1977. Development of predictive equations for milk yield and dry matter intake in lactating cows. J. Dairy Sci. 60:1739.
Bryant, H.T., R.E. Blaser, R.C. Hammes & W.A. Hardison, 1961. Method for increased milk production with rotational grazing. J. Dairy Sci. 44:1733.
Burstedt, E., 1979. Some aspects of the nutritive value of grazed grass and carry over effects in the autumn. Proc. III European Grazing Workshop.
C.A.B., 1961. Research techniques in use at the Grassland Research Institute. Commonwealth Agricultural Bureaux, Bucks, England.
Campbell, A.G., 1966. Grazed pasture parameters. J. Agric. Sci. 67:199.
Campbell, A.G., 1969. Grazing interval, stocking rate, and pasture production. N.Z.J. Agric. Res. 12:67.
Campbell, C.M., K.S. Eng, A.B. Nelson & L.S. Pope, 1968. Use of the esophageal fistula in diet sampling with beef cattle. J. Anim. Sci. 27:231.
Campling, R.C., 1966. A preliminary study of the effect of pregnancy and of lactation on the voluntary intake of food by cows. Br. J. Nutr. 20:25.
Campling, R.C., 1970. Physical regulation of voluntary intake. In: Phillipson (Ed.), Physiology of digestion and metabolism in the ruminant.Oriel Press, Newcastle upon Tyne. p. 226.
Campling, R.C., 1975. Systems of grazing management for dairy cattle. In: Hodgson J. & D.K. Jackson (Eds.), Pasture utilization by the grazing animal. Br. Grassld. Soc. Occ. Symp. no. 8, p. 113.
Carlier, L., A. Andries & L. Delvaux, 1977. Beweidingssystemen: omweiden of intensieve standweide? Landb. Tijdschr. 4:859.
Carter, J.F., 1962. Herbage sampling for yield: tame pastures. In: American society of agronomy and others (Eds.). Pasture and range research techniques. Comstock publishing associates, Ithaca U.S.A.. p.90.
Castle, M.E., 1953. Grassland production and its measurement using the dairy cow. J. Br. Grassld. Soc. 8:195.
Castle, M.E., A.D. Drysdale & J.N. Watson, 1968. The effect of stocking rate and supplementary concentrate feeding on milk production. J. Br. Grassld. Soc. 23:137.
Castle, M.E. & J.N. Watson, 1978. A comparison of continuous grazing systems for milk production. J. Br. Grassld. Soc. 33:123.
Chacon, E. & T.H. Stobbs, 1976. Influence of progressive defoliation of a grass sward on the eating behaviour of cattle. Austr. J. Agric. Res. 27:709.
Chacon, E.A., T.H. Stobbs & M.B. Dale, 1978. Influence of sward characteristics on grazing behaviour and growth of Hereford steers grazing tropical grass pastures. Austr. J. Agric. Res. 29:89.
Chacon, E., T.H. Stobbs & R.H. Sandland, 1976. Estimation of herbage consumption by grazing cattle using measurements of eating behaviour. J. Br. Grassld. Soc. 31:87.
Chenost, M. & C. Demarquilly, 1969. Comparison entre le pasturage et l'affouragement en vert pour la production de viande bovine. Ann. Zootechn. 18:277.
Cochran, W.G., 1969. Sampling techniques. John Wiley & Sons, New York.
Colburn, M.W., J.L. Evans & C.H. Ramage, 1968. Apparent and true digestibility of forage nutrients by ruminant animals. J. Dairy Sci. 51:1450.
Combellas, J., 1977. Studies on the herbage intake and milk yield of dairy cows. Ph. D. Thesis, University of Reading.
Combellas, J. & J. Hodgson, 1979. Herbage intake and milk production by grazing dairy cows. 1. The effects of variation in herbage mass and daily herbage allowance in a short-term trial. Grass & Forage Sci. 34:209.
Conrad, H.R., 1966. Physiological and physical factors limiting feed intake. J. Anim. Sci. 25:227.
Conrad, H.R., A.D. Pratt & J.W. Hibbs, 1964. Regulation of feed intake in dairy cows. I. Change in importance of physical and physiological factors with increasing digestibility. J. Dairy Sci. 47:54.
Conway, A., 1968. Grazing management in relation to beef production. IV Effect of seasonal variation in the stocking rate of beef cattle on animal production and on sward composition. Ir. J. Agric. Res. 7:93.
Cook, C.W., 1964. Symposium on nutrition of forages and pastures: Collecting forage samples representative of ingested material of grazing animals for nutritional studies. J. Anim. Sci. 23:265.
Corbett, J.L., 1960. Faecal index techniques for estimating herbage consumption by grazing animals. Proc. VIII Int. Grassld. Congr.:438.

Corbett, J.L., 1979. Measuring animal performance. In: Mannetje, L. 't (Ed.), Measurement of grassland vegetation and animal production. Commonwealth Agricultural Bureaux, Bucks, England. p. 163.
Corbett, J.L. & A.W. Boyne, 1958. The effect of a low-protein food supplement on the yield and composition of milk from grazing dairy cows and on the composition of their diet. J. Agric. Sci. 51:95.
Corbett, J.L. & J.F.D. Greenhalgh, 1960. Measurement of the quantities of herbage consumed by grazing animals. In: Chemical aspects of the production and use of grass. Society of chemical industry, London. p. 167.
Corbett, J.L., J.F.D. Greenhalgh & E. Florence, 1959. Distribution of chromium sesquioxide and polyethyleneglycol in the reticulo-rumen of cattle. Br. J. Nutr. 13:337.
Corbett, J.L., J.F.D. Greenhalgh, P.E. Gwynn & D. Walker, 1958a. Excretion of chromium sesquioxide and polyethyleneglycol by dairy cows. Br. J. Nutr. 12:266.
Corbett, J.L., J.F.D. Greenhalgh & A.P. McDonald, 1958b. Paper as a carrier of chromium sesquioxide. Nature 182:1014.
Corbett, J.L., J.F.D. Greenhalgh, I. McDonald & E. Florence, 1960. Excretion of chromium sesquioxide administrated as a component of paper to sheep. Br. J. Nutr. 14:289.
Corbett, J.L., J.P. Langlands & G.W. Reid, 1963. Effects of season of growth and digestibility of herbage on intake by grazing dairy cows. Anim. Prod. 5:119.
Cowlishaw, S.J., 1951. The effect of sampling cages on the yields of herbage. J. Br. Grassld. Soc. 6:179.
Cowlishaw, S.J. & F.E. Alder, 1963. A comparative study of chromium sesquioxyde administrated to grazing steers to determine their faecal output. J. Br. Grassld. Soc. 18:328.
Crampton, E.W. & L.A. Maynard, 1938. The relation of cellulose and lignin content to the nutritive value of animal feeds. J. Nutr. 15:383.
Curran, M.K., R.C. Campling & W. Holmes, 1967. The feed intake on milk cows during late pregnancy and early lactation. Anim. Prod. 9:266.
Curran, M.K. & W. Holmes, 1970. Prediction of the voluntary intake of food by dairy cows. 2 Lactating grazing cows. Anim. Prod. 12:213.
Curran, M.K., J.D. Leaver & E.W. Weston, 1967. A note on the use of chromic oxide incorporated in a feed to estimate faecal output in ruminants. Anim. Prod. 9:561.
Curran, M.K., R.H. Wimble & W. Holmes, 1970. Prediction of the voluntary intake of food by dairy cows. 1. Stall-fed cows in late pregnancy and early lactation. Anim. Prod. 12:195.
C.V.B., 1977a. Handleiding voor de berekening van de voederwaarde van ruwvoermiddelen. Centraal Veevoederbureau in Nederland, Lelystad.
C.V.B., 1977b. Veevoedertabel. Centraal Veevoederbureau in Nederland, Lelystad.
Davies, T.H., 1976. The evolution of modern dairy cow grazing systems. ADAS Q. Rev. 22:275.
Davison, J., 1959. Experiences in the measurement of herbage consumption by livestock. In: Ivins, J.D. (Ed.), The measurement of grassland productivity. Butterwoths scientific publications, London. p. 79.
Deijs, W.B. & M.S.N. Bosman, 1953. The use of natural occuring plant pigments as indicators for the determination of digestibility of feed. Verslag van het C.I.L.O. over 1953: 155.
Deinum, B., 1966. Climate, nitrogen and grass. Mededelingen van de Landbouwhogeschool, Wageningen 66 no. 11.
Deinum, B., 1974. Kwaliteit van gras in afhankelijkheid van ouderdom en stikstofbemesting. Gebundelde verslagen nr. 13 Ned. Ver. v. Weide- en Voederbouw.
Deinum, B. & J.G.P. Dirven, 1974. A model for the description of the effects of different environmental factors on the nutritive value of forages. Proc. XII Int. Grassld. Congr. :338.
Deinum, B., A.J.H. van Es & P.J. van Soest, 1968. Climate, nitrogen and grass. 2. The influence of light intensity, temperature and nitrogen on vivo digestibility of grass and the prediction of these effects from some laboratory procedures. Neth. J. Agric. Sci. 16:217.
Deinum, B., H.J. Immink & W.B. Deijs, 1962. The excretion of chromium sesquioxide in faeces by cows after administration of Cr_2O_3 - containing paper. Mededeling 188 I.B.S. Wageningen.
Demarquilly, C., 1966. Valeur alimentaire de l'herbe des prairies temporaires aux stades d'exploitation pour le paturage. II Quantité ingérée par les vaches laitières. Ann. Zootech. 15:147.

Demarquilly, C., 1970. Influence de la fertilisation azotée sur la valeur alimentaire des fourrages verts. Ann. Zootech. 19:423.
Demarquilly, C. & R. Jarrige, 1971. The digestibility and intake of forages from artificial and natural grassland. Proc. IV Gen. Meeting Eur. Grassld. Fed. :91.
Demarquilly, C. & Ph. Weiss, 1971. Liaison entre les quantitées de matière sèche des fourrages verts ingérées par les moutons et celles ingérées par les bovins. Ann. Zootech. 20:119.
Dijkstra, N.D., 1971. Feed intake by grazing dairy cows, 3. Comparison of lactating and dry pregnant cows. Neth. J. Agric. Sci. 19:257.
Dijkstra, N.D. & A. Kemmink, 1970. De voederopname door grazende herkauwers. II. Versl. Landb.k. Onderz. 738.
Donaldson, E., 1979. Prediction of in-vivo digestibility by the use of cellulase solubilities or chemical parameters. Proc. III European Grazing Workshop.
Dyne, G.M. van, 1966. Use of a vacuum-clipper for harvesting herbage. Ecology 47:624.
Dyne, G.M. van & G.P. Lofgreen, 1964. Comparative digestion of dry annual range forage by cattle and sheep. J. Anim. Sci. 23:823.
Dyne, G.M. van & J.H. Meyer, 1964. Forage intake by cattle and sheep on dry annual range. J. Anim. Sci. 23:1108.
Dyne, G.M. & D.T. Torell, 1964. Development and use of the esophageal fistula: a review. J. Range Mangt. 17:7.
Dyne, G.M. van, W.G. Vogel & H.G. Fisser, 1963. Influence of small plot size and shape on range herbage production estimates. Ecology 44:746.
Edlefsen, J.L., C.W. Cook & J.T. Blake, 1960. Nutrient content of the diet as determined by hand plucked and esophageal fistula samples. J. Anim. Sci. 19:560.
Elam, C.J. & R.E. Davis, 1961. Lignin excretion by cattle fed a mixed ration. J. Anim. Sci. 20:484.
Elam, C.J., P.J. Reynolds, R.E. Davis & D.O. Everson, 1962. Digestibility studies by means of chromic oxide, lignin and total collection techniques with sheep. J. Anim. Sci. 21:189.
Elliott, R.C., K. Fokkema & C.H. French, 1961. Herbage consumption studies on beef cattle. Part II. Rhodesia Agric. J. 58:124.
Ellis, W.C., 1978. Determinants of grazed forage intake and digestibility. J. Dairy Sci. 61:1828.
Ellis, G.H., G. Matrone & L.A. Maynard, 1946. A 72 percent H_2SO_4 method for the determination of lignin and its use in animal nutrition studies. J. Anim. Sci. 5:285.
Ely, R.E., E.A. Kane, W.C. Jacobson & L.A. Moore, 1953. Studies on the composition of lignin isolated from orchardgrass hay cut at four stages of maturity and from the corresponding faeces. J. Dairy Sci. 36:346.
Ernst, P., 1978. Einfluss der Magnesia - Kainitdüngung auf die Schmackhaftigkeit des Weidefutters und auf den Futterverzehr durch Milchkühe. Dissertation Universität Giessen.
Ernst, P. & N. Mott, 1978. Comparison of rotational and continuous grazing management in experiments with heifers and dairy cows. Proc. VII Gen. Meeting Eur. Grassld. Fed. :5.15.
Ernst, P. & N. Mott, 1980. Beweidingsverliezen. Resultaten van een vierjarige beweidingsproef in Kleve-Kellen. Stencil Landesanstalt für Okologie, Landschaftsentwicklung und Forstplanung NW, Abt. Grünland und Futterbauforschung, Kleve-Kellen.
Es, A.J.H. van, 1974. Energy intake and requirement of dairy cows during the whole year. Livest. Prod. Sci. 1:21.
Es, A.J.H. van, 1975. Feed evaluation for dairy cows. Livest. Prod. Sci. 2:95.
Es, A.J.H. van, 1978. Feed evaluation for ruminants I. The system in use from May 1977 onwards in the Netherlands. Livest. Prod. Sci. 5:331.
Es, A.J.H. van, 1979. More food for mankind by plant and animal husbandry. In: Bowman, J.C. & P. Susmel (Eds.). The future of beef production in the European Community. Martinus Nijhoff publishers, The Hague/Boston/London. p. 567.
Es, A.J.H. van & Y. v.d. Honing, 1977. Het nieuwe energetische voederwaarderingssysteem voor herkauwers: wijze van afleiding en uiteindelijk voorstel. Rapport nr. 92 I.V.V.O.
Escuder, J.C., R.P. Andrews & W. Holmes, 1971. The effect of nitrogen, stocking rate and frequency of grazing by beef cattle on the output of pasture. J. Br. Grassld. Soc. 26:79.
Field, A.C., 1966. The effect of lactation on the intake of dry matter, magnesium, calcium and potassium by grazing cows. Proc. X Int. Grassld. Congr. 355.
Finger, H. & O. Werk, 1973. Anhebung des Natrium- and Magnesiumgehaltes der Weidefutterpflanzen und Beëinflussung des Futterverzehrs nach Düngung mit Magnesia-Kainit. Landw. Forsch; 28II:190.

Flatt, W.P., D.J. Horvath, L.C. De Costa, D.G. Stewart & R.G. Warner, 1957. Cautions regarding the use of anthroquinone violet as an indicator in digestion and absorption studies. J. Anim. Sci. 16:688.
Flikweert, S., 1980. De invloed van het grasaanbod per dier per dag op de grasopname van melkkoeien in de weide. Doc. rapport nr. 71 I.V.V.O.
Forbes, J.M., 1969. The effect of pregnancy and fatness on the volume of rumen contents in the ewe. J. Agric. Sci. 72:119.
Forbes, J.M., 1970. The voluntary food intake of pregnant and lactating ruminants; a review. Br. Vet. J. 126:1.
Forbes, J.M., 1977. Development of a model of voluntary food intake and energy balance in lactating cows. Anim. Prod. 24:203.
Forbes, J.M., 1979. Physiological aspects of the regulation of food intake. Proc. E.E.C. Seminar on energy and protein feeding standards for beef cattle: IIIa.
Forbes, J.M., P.M. Driver, A.A. El Shahat, T.G. Boaz & C.G. Scanes, 1975. The level of daylength and level of feeding on serum prolactin in growing lambs. J. Endocrin. 64:549.
Forbes, T.J., A.M. Raven, J.H.D. Irwin & K.L. Robinson, 1967. The utilization of grass fed indoors to young beef cattle with or without supplementary barley. J. Br. Grassld. Soc. 22:158.
Forbes, T.J., A.M. Raven & K.L. Robinson, 1966. Observations on the utilization of grass grazed by young beef cattle with and without barley supplementation. J. Br. Grassld. Soc. 21:167.
Frame, J. & I.V. Hunt, 1971. The effects of cutting and grazing systems on herbage production from grass swards. J. Br. Grassld. Soc. 26:163.
Frederiksen, J.H., 1976. The effects of concentrate supplementation, nitrogen fertilization and stocking rates on herbage intake and milk yield by grazing cattle. Proc. II European Grazing Workshop.
Garstang, J.R., 1975. A comparison of 21- and 28-day paddock systems for dairy cows. J. Br. Grassld. Soc. 30:93.
Gibb, M.J. and P.D. Penning, 1976. A note on factors influencing the accuracy of faecal organic matter outputs determined by the chromic oxide dilution technique. Personal communication.
Gibb, M.J. & T.T. Treacher, 1976. The effect of herbage allowance on herbage intake and performance of lambs grazing perennial ryegrass and red clover swards. J. Agric. Sci. 86:355.
Gibb, M.J. & T.T. Treacher, 1978. The effect of herbage allowance on herbage intake and performance of ewes and their twin lambs grazing perennial ryegrass. J. Agric. Sci. 90:139.
Gomez, P.O. & W. Holmes, 1976. The influence of pasture availability and supplementary feed on intake and performance of grazing beef cattle. Anim.Prod. 22:143.
Gordon, C.H., J.C. Derbyshire, C.W. Alexander & D.E. McCloud, 1966. Effects of grazing pressure on the performance of dairy cattle and pastures. Proc. X Int. Grassld. Congr. :470.
Gordon, F.J., 1973. The effect of high nitrogen levels and stocking rates on milk output from pasture. J. Br. Grassld. Soc. 28:193.
Green, J.O., 1949. Herbage sampling errors and grazing trials. J. Br. Grassld. Soc. 4:11.
Green, J.O., A.J. Corral & R.A. Terry, 1971. Grass species and varieties. Relationship between stage of growth, yield and forage quality. Technical Report nr. 8, Grassld. Res. Inst. Hurley.
Green, J.O., H.J. Langer & T.E. Williams, 1952. Sources and magnitudes of experimental errors in grazing trials. Proc. VI Int. Grassld. Congr.: 1374.
Greenhalgh, J.F.D., 1966. Studies of herbage consumption and milkproduction in grazing dairy cows. Proc. X Int. Grassld. Congr.: 351.
Greenhalgh, J.F.D., 1970. The effects of grazing intensity on herbage production and consumption and on milk production in strip-grazed dairy cows. Proc. XI Int. Grassld. Congr.:856.
Greenhalgh, J.F.D., 1974. Estimating the faecal output of grazing animals. Proc. I European Grazing Workshop.
Greenhalgh, J.F.D., 1975. Factors limiting animal production from grazed pasture. J. Br. Grassld. Soc. 30:153.
Greenhalgh, J.F.D., 1976. Relative nutritive value of early- and late-season pasture herbage. Proc. II European Grazing Workshop.
Greenhalgh, J.F.D., 1978. Maximising herbage utilization. Symposium British Grassland Society: Intensive grassland use & livestock health:25.
Greenhalgh, J.F.D., J.N. Aitken & G.W. Reid, 1972. A note on the zero-grazing of beef cattle. J. Br. Grassld. Soc. 27:173.

Greenhalgh, J.F.D. & J.L. Corbett, 1960. The indirect estimation of the digestibility of pasture herbage. I Nitrogen and chromogen as faecal index substances. J. Agric. Sci. 55:371.
Greenhalgh, J.F.D., J.L. Corbett & I. McDonald, 1960. The indirect estimation of the digestibility of pasture herbage. II Regressions of digestibility on faecal nitrogen concentration; their determination in continuous digestibility trials and the effect of various factors on their accuracy. J. Agric. Sci. 55:377.
Greenhalgh, J.F.D. & I. McDonald, 1978. The metabolizable energy system in practise: 3 Predicting feed intake. Anim. Prod. 26:350.
Greenhalgh, J.F.D. & G.W. Reid, 1969a. The herbage consumption and milk production of cows grazing S24 rye grass and S 37 cocksfoot. J. Br. Grassld. Soc. 24:98.
Greenhalgh, J.F.D. & G.W. Reid, 1969b. The effects of grazing intensity on herbage consumption and animal production. III Dairy cows grazed at two intensities on clean or contaminated pasture. J. Agric. Sci. 72:111.
Greenhalgh, J.F.D. & G.W. Reid, 1973. The effects of pelleting various diets on intake and digestibility in sheep and cattle. Anim. Prod. 16:223.
Greenhalgh, J.F.D., G.W. Reid & J.N. Aitken, 1967. The effects of grazing intensity on herbage consumption and animal production. J. Agric. Sci. 69:217.
Greenhalgh, J.F.D., G.W. Reid, J.N. Aitken & E. Florence, 1966a. The effects of grazing intensity on herbage consumption and animal production. I Short term effects in strip-grazed dairy cows. J. Agric. Sci. 67:13.
Greenhalgh, J.F.D., G.W. Reid & I. McDonald, 1966b. The indirect estimation of digestibility of pasture herbage. IV Regressions of digestibility on faecal nitrogen concentration: effects of different fractions of the herbage upon within and between period regressions. J. Agric. Sci. 66:277.
Greenhalgh, J.F.D. & K.V. Runcie, 1962. The herbage intake and milk production of strip- and zero-grazed dairy cows. J. Agric. Sci. 59:95.
Grimes, R.C., B.R. Watkin & J.R. Gallagher, 1966. An evaluation of pasture quality with young grazing sheep. II Chemical composition, botanical composition and in-vitro digestibility of herbage selected by oesophageal-fistulated sheep. J. Agric. Sci. 66:113.
Grimes, R.C., B.R. Watkin & P.F. May, 1965. The botanical and chemical analysis of herbage samples obtained from sheep fitted with oesophageal fistulae. J. Br. Grassld. Soc. 20:168.
Hadjipieris, G., J.G.W. Jones & W. Holmes, 1965. The effect of age and live-weight on the feed intake of grazing wether sheep. Anim. Prod. 7:309.
Halley, R.J. & B.N. Dougall, 1962. The feed intake and performance of dairy cows fed on cut grass. J. Dairy Res. 29:241.
Hardy, A., G. Philippeau & J. Tranchefort, 1978. L'estimation de la production d'herbe d'une prairie. Perspectives Agricoles 14:36.
Harkess, R.D., 1963. Studies in herbage digestibility. J. Br. Grassld. Soc. 18:62.
Harkess, R.D. & R.H. Alexander, 1969. The digestibility and productivity of selected herbage varieties. J. Br. Grassld. Soc. 24:282.
Harkess, R.D., J. de Bassita & I.A. Dickson, 1972. A portable-corral technique for measuring the effect of grazing intensity on yield, quality and intake of herbage. J. Br. Grassld. Soc. 27:145.
Hart, M.L. 't, 1979a. Experiments on the relation between milk production of dairy cows and herbage consumption in pasture. Stencil Landbouwhogeschool, III European Grazing Workshop.
Hart, M.L. 't, 1979b. Comparison of continuous and rotational grazing. Stencil Landbouwhogeschool, III European Grazing Workshop.
Hart, M.L. 't & H.J. Kleter, 1974. Zum Einfluss von Grasangebot und Weidevorbehandlung auf die Futteraufnahme von weidende Rindern. Jahrestagung der Arbeitsgemeinschaft Grünland und Futterbau in Kleve-Kellen nr. 10:48.
Hight, G.K., D.P. Sinclair & R.J. Lancaster, 1968. Some effects of shading and of nitrogen fertilizer on the chemical composition of freeze-dried and oven-dried herbage, and on the nutritive value of oven-dried herbage fed to sheep. N.Z.J. Agric. Res. 11:286.
Hijink, J.W.F., 1978. Supplementary feeding of maize silage to dairy cows during the grazing season. Publikatie nr. 12, P.R.
Hodgson, J., 1968. The relationship between the digestibility of a sward and the herbage consumption of grazing calves. J. Agric. Soc. 70:47.
Hodgson, J., 1969. The use of sheep fitted with oesophageal fistulae in grazing studies. J. Br. Grassld. Soc. 24:325.
Hodgson, J., 1974a. Estimating the faecal output of grazing animals. Proc. I European Grazing Workshop.

Hodgson, J., 1974b. The effect of the grazing animal on herbage quality and utilization. Proc. V Gen. meeting Eur. Grassld. Fed.:74.
Hodgson, J., 1975a. The influence of grazing pressure and stocking rate on herbage intake and animal performance. In: Hodgson, J. & D.K. Jackson (Eds.), Pasture utilization by the grazing animal. Br. Grassld. Soc. Occ. Symp. no. 8, p.93.
Hodgson, J., 1975b. The consumption of perennial rye grass and red clover by grazing lambs. J. Br. Grassld. Soc. 30:307.
Hodgson, J., 1979. Nomenclature and definitions in grazing studies. Grass & Forage Sci. 34:11.
Hodgson, J & J.M. Rodriguez, 1970. The measurement of herbage intake in grazing studies. A. Rep. Grassld. Res. Inst.:132.
Hodgson, J., J.M. Rodriguez Capriles & J.S. Fenlon, 1977. The influence of sward characteristics on the herbage intake of grazing calves. J. Agric. Sci. 89:743.
Hodgson, J. & J.C. Tayler, 1972. The effect of supplementary barley upon growth and efficiency of food conversion in calves kept at high grazing intensity. J. Br. Grassland Soc. 27:7.
Hodgson, J., J.C. Tayler & C.R. Lonsdale, 1971. The relationship between intensity of grazing and the herbage consumption and growth of calves. J. Br. Grassld. Soc. 26:231.
Hodgson, J. & J.M. Wilkinson, 1967. The relationship between live-weight and herbage intake in grazing cattle. Anim. Prod. 9:365.
Hodgson, J. & J.M. Wilkinson, 1968. The influence of the quantity of herbage offered and its digestibility on the amount eaten by grazing cattle. J. Br. Grassld. Soc. 23:75.
Hoehne, O.E., D.C. Clanton & C.L. Steeter, 1967. Chemical changes in esophageal fistula samples caused by salivary contamination and sample preparation. J. Anim. Sci. 26:628.
Holdefleiss,F., 1864. Landw. Jahrb. 103.
Holmes, J.C. & R.W. Lang, 1963. Effects of fertiliser nitrogen and herbage dry matter content on herbage intake and digestibility in bullocks. Anim. Prod. 5:17.
Holmes, W., 1968. The use of nitrogen in the management of pasture for cattle. Herbage Abstr. 38:265.
Holmes, W., 1970. Animals for food. Proc. Nutr. Soc. 29:237.
Holmes, W., R.C. Campling & N.D. Joshi, 1972. A comparison between a rigid rotational grazing system for dairy cows and a system in wich grazing alternated with cutting. Anim. Prod. 14:283.
Holmes, W. & M.K. Curran, 1967. Feed intake grazing cattle. V A further study of the influence of pasture restriction combined with supplementary feeding on production per animal and per acre. Anim. Prod. 9:313.
Holmes, W. & J.G.W. Jones, 1964. The efficiency of utilisation of fresh grass. Proc. Nutr. Soc. 23:88.
Holmes, W. & J.G.W. Jones, 1965. The feed intake of milk cows. II The effect of roughage quality during late pregnancy and lactation. Anim. Prod. 7:39.
Holmes, W.,J.G.W. Jones & C. Adeline, 1966. Feed intake of grazing cattle. IV A study with milk cows of the influence of pasture restriction combined with supplementary feeding on production per animal and per acre. Anim. Prod. 8:47.
Holmes, W., J.G.W. Jones & R.M. Drake-Brockman, 1961. The feed intake of grazing cattle. II The influence of size of animal on feed intake . anim. Prod. 3:251.
Holmes, W. & H.S. Osman, 1960. The feed intake of grazing cattle. I Feed intake of dairy cows on strip and free grazing. Anim. Prod. 2:131.
Holmes, W., R. Waite, D.L. Fergusson & I. Campbell, 1950. Studies in grazing management. I A comparison of the production obtained from close folding and rotational grazing of dairy cows. J. Agric. Sci. 40:381.
Honig, H., 1976. Schätzung der Verluste an Trockenmassa und Energie bei verschiedener Konservierungsverfahren. KTBL-Kalkulationsunterlagen: Grunddaten der Futterwirtschaft :4.
Honing, Y. van der, 1975. Intake and utilization of energy of rations with pelleted forages by dairy cows. Agric. Res. Rep. (Versl. Landbk. Onderzoek.) 836.
Honing, Y. van der, 1977. Vergelijking van de verteerbaarheid van weidegras door koeien en door hamels in 1976. Rapport nr. 108 I.V.V.O.
Honing, Y. van der, & A.J.H. van Es, 1981. Energy balance studies with lactating cows fed with fresh or frozen grass from pasture suitable for grazing. Proc. XIV Int. Grassld. Congr. (in press).
Honing, Y. van der, A. Steg & A.J.H. van Es, 1977. Feed evaluation for dairy cows: tests on the system proposed in the Netherlands. Livest. Prod. Sci. 4:57.
Hopper, J.T., J.W. Holloway & W.T. Butts, 1978. Animal variation in chromium sesquioxide excretion patterns of grazing cows. J. Anim. Sci. 46:1096.
Huguet, L., A. Mourguet & R. Traineau, 1969. Affouragement mécanisé en vert et pâturage rationné pour les vaches laitières. Fourrages 37:3.

Hull, J.L., J.H. Meyer & R. Kromann, 1961. Influence of stocking rate on animal and forage production from irrigated pasture. J. Anim. Sci. 20:46.
Hutchinson, K.J., 1956. Techniques applicable to grazing intake studies. Proc. Austr. Soc. Anim. Prod. 1:52.
Hutton, J.B., 1962. Studies of the nutritive value of New Zealand dairy pastures.II Herbage intake and digestibility studies with dry cattle. N.Z.J. Agric. Res. 5:409.
Hutton, J.B., 1963. The effect of lactation on intake in the dairy cow. Proc. N.Z. Soc. Anim. Prod. 23:39.
Hutton, J.B., J.W. Hughes, R.P. Newth & K. Watanabe, 1964. The voluntary intake of the lactating dairy cow and its relation to digestion. Proc. N.Z. Soc. Anim. Prod. 24:29.
Hutton, J.B. & K.E. Jury, 1964. Studies of the nutritive value of New Zealand dairy pastures.III The comparative value of various feed-faeces relationships in herbage intake studies with dairy cattle. N.Z.J. Agric. Res. 7:583.
Hyder, D.N., R.E. Bement, J.J. Norris & M.J. Morris, 1966. Evaluating herbage species by grazing cattle.Part I, food intake. Proc. X Int. Grassld. Congr.:970.
Irvin, H.M., H.G. Wiseman, J.C. Shaw & L.A. Moore, 1953. The role of plant pigments in digestion trial studies. J. Anim. Sci. 12:541.
Iwasaki, M., 1972. Comparison of some simplified methods for measuring the forage consumed by grazing animals. Bull. Nat. Grassld. Res. Inst. Japan 1:31.
Iwasaki, M., 1976. Influence of size and shape of quadrate upon distribution pattern of grass weight and number of samples necessary for estimation of grass weight on grassland. Bull. Nat. Grassl. Res. Inst. Japan 8:11.
Jackson, D.K., 1975. The influence of patterns of defoliation on sward morphology. In: Hodgson, J. & D.K. Jackson (Eds.), Pasture utilization by the grazing animal. Br. Grassld. Soc. Occ. Symp. no. 8, p. 51.
Jagtenberg, W.D., 1974. Opbrengstbepalen van grasland door visueel schatten en door meten van de graslengte. Publikatie nr. 3, P.R.
Jagtenberg, W.D. & Th. A. de Boer, 1958. De invloed van graskooien op de grasopbrengst. Landbk. Tijdschr. 70:879.
Jamieson, W.S., 1975. Studies on the herbage intake and grazing behaviour of cattle and sheep. Ph.D. Thesis, University of Reading.
Jamieson, W.S. & J. Hodgson, 1979. The effect of daily herbage allowance and sward characteristics upon the ingestive behaviour and herbage intake of calves under strip-grazing management. Grass & Forage Sci. 34:261.
Jarrige, R., C. Demarquilly & J.P. Dulphy, 1974. The voluntary intake of forages. Proc. V Gen. Meeting Eur. Grassld. Fed.:98.
Johnson, W.L., G.W. Trimberger, M.J. Wright, L.D. van Vleck & C.R. Henderson, 1966. Voluntary intake of forage by Holstein cows as influenced by lactation, gestation, body weight, and frequency of feeding. J. Dairy Sci. 49:856.
Jones, D.I.H. & R.W. Bailey, 1974. Hydrolysis of the cell-wall carbohydrates of grasses by carbohydrases in relation to voluntary intake by sheep. J. Agric. Sci. 83:105.
Jones, D.I.H. & M.V. Hayward, 1973. A cellulase digestion technique for predicting the dry matter digestibility of grasses. J. Sci. Food Agric. 24:1419.
Jones, G.M., 1972. Chemical factors and their relation to feed intake regulation in ruminants: a review. Can. J. Anim. Sci. 52:207.
Jones, J.G.W., R.M. Drake-Brockman & W. Holmes, 1965. The feed intake of grazing cattle. III The influence of level of milk yield. Anim. Prod. 7:141.
Jones, L.H.P. & K.A. Handreck, 1965. The relation between the silica content of the diet and the excretion of silica by sheep. J. Agric. Sci. 65:129.
Jones, R.J. & R.L. Sandland, 1974. The relation between animal gain and stocking rate. Derivation of the relation from the results of grazing trials. J. Agric. Sci. 83:335.
Journet, M. & C. Demarquilly, 1979. Grazing. Proc. III European Grazing Workshop.
Journet, M., M. Poutous & S. Calomite, 1965. Appêtit de la vache laitière. I Variations individuelles des quantitées d'aliments ingérées. Ann. Zootech. 14:5.
Journet, M. & B. Remond, 1976. Physiological factors affecting the voluntary intake of feed by cows: a review. Livest. Prod. Sci. 3:129.
Kampen, G.B. van, 1936. Een nieuw apparaat voor de bepaling van ruwe celstof. Versl. Landbouwk. Onderz. 42. E1.
Kane, E.A., E.R. Ely, W.C. Jacobson & L.A. Moore, 1953. A comparison of various digestion trial techniques with dairy cattle. J. Dairy Sci. 36:325.
Kane, E.A. & W.C. Jacobson, 1954. An improved method of using plant pigments as an indicator of digestibility. J. Dairy Sci. 37:672.
Kane, E.A., W.C. Jacobson & L.A. Moore, 1952. Diurnal variation in the excretion of chromium oxide and lignin. J. Nutr. 47:263.
Kaufmann, W. & A. Orth, 1966. Untersuchungen über Einflüsse des Futters und der Pansenfermentation auf die Speichelsekretion. Z. Tierphysiol. Tierernähr. Futtermittelk.21: 110.

Keen, A., 1979. Grasopnameproeven. C79 ST 01 01, IWIS-TNO, Wageningen.
Keen, A., 1981. Statistical analysis of intake experiments with grazing dairy cows by Meijs (1976-1979). C 81 ST 02 02, IWIS TNO, Wageningen.
Kellaway, R.C., 1969. The estimation of digestible energy intake from forages by ruminants. Austr. J. Exp. Agr. Anim. Husb. 9:578.
Kemmink, A. & N.D. Dijkstra, 1968. Feed intake by grazing ruminants.I Chromic oxide and polyethylene as added faecal markers and chromogen as an endogenous marker for estimating grass intake. Versl. Landbk. Onderz.:717.
Kemp, A. & J.H. Geurink, 1978. Grassland farming and minerals in cattle. Neth. J. Agric. Sci. 26:161.
Kennedy, W.K., A.H. Carter & R.J. Lancaster, 1959. Comparison of faecal pigments and faecal nitrogen as digestibility indicators in grazing cattle studies. N.Z.J. Agric. Res. 2:627.
Kennedy, W.K., J.T. Reid, M.J. Anderson, J.C. Wilcox & D.G. Davenport, 1960. Influence of system of grazing on animal and plant performance. Proc. VIII Int. Grassld. Congr. :640.
Keuning, J.A., 1980. Urine scorch in grassland. Proc. Int. Symp. Eur. Grassld. Fed.: The role of nitrogen in intensive grassland production :163.
Kirchgessner, M. & F.X. Roth, 1972a. Futterangebot und Futteraufnahme von Milchkühen auf der Weide. Das Wirtsch.eig. F. 1:23.
Kirchgessner, M. & F.X. Roth, 1972b. Zum Einfluss von Mengenelementen (P, Ca, Mg, Na, K) auf die Futteraufnahme von Milchkühen bei Weidegang. Das Wirtsch.eig. F. 4:316.
Klapp, E., 1963. Verfahren zur Ermittlung des Grünlandertrages. Das Wirtsch.eig. F. 4: 249.
Kleiber, M., 1961. Body size and metabolic rate. In: Kleiber, M. (Ed.). The fire of life. John Wiley & Sons, New York/London. p.177.
Kleter, H.J., 1972. Voederopname en produktie van weidend vee. II Onderzoekingen over de invloed van voorafgaand graslandgebruik op de voederopname en produktie van rundvee. Bedrijfsontw. 3:353.
Kleter, H.J., 1973. Enige factoren van invloed op de meetfout bij de opbrengstbepaling van grasland en de voederopnamemeting van weidend vee. Stencil Landbouwhogeschool, Wageningen.
Kleter, H.J., 1975. Voederopname en voederopnameverschil bij groepen hoog- en laagproduktief melkvee in voor- en nazomer bij beweiding ven etgroen. Stencil Landbouwhogeschool, Wageningen.
Kleter, H.J. & G. Hof, 1975. Enkele uitkomsten van de beweidingsproef op P.F.L. 1974. Stencil Landbouwhogeschool, Wageningen.
Kley, F.K. van der & H. van der Ploeg, 1955. Graasgewoonten en voedselopname van Nederlandse rundertweelingen. II Voedselverbruik en beweidingssysteem. Landbouwk. Tijdschr. 67:620.
Klooster, A.Th. van 't, A. Kemp, J.H. Geurink & P.A.M. Rogers, 1972. Studies on the amount and composition of digesta flowing through the duodenum of dairy cows. Neth. J. Agric. Sci. 20:314.
Koelen, C.J. van der & N.D. Dijkstra, 1971. Bepaling van de verteerbaarheid in-vitro als hulpmiddel bij de schatting van de voederwaarde van ruwvoeders. Landb.k. Tijdschr. 83:494.
Kolb, A.R. & T.D. Luckey, 1972. Markers in nutrition. Nutr. Abstr. Rev. 42:28.
Künzi, N., 1969. Beziehungen zwischen Futterverzehr und Milchleistung bei Fleckvieh-, Braunvieh- und Ayrshireкühen. Dissertation, Zürich.
Kurohiji, I., T. Mino, H. Iwanari, Y. Takimoto, M. Maoka & M. Kai, 1973. Nutrition and beef production of fattening young steers on pasture. I. The body weight gains and nutrient uptake of fattening young steers on the temperate grass pasture. J. Japanese Soc. Grassld. Sci. 19:11.
Lamberth, J.L., 1969. The effect of pregnancy in heifers on voluntary intake, total rumen contents, digestibility and rate of passage. Austr. J. Exp. Agric. Anim. Husb. 9:493.
Lambourne, L.J., 1965. Estimations of herbage intake and digestibility of grazed herbage. Techn. Rep. no. 1:8 Grassld. Res. Inst. Hurley.
Lambourne, L.J. & T.F. Reardon, 1962. Use of seasonal regressions in measuring feed intake of grazing animals. Nature 196:961.
Lambourne, L.J. & T.F. Reardon, 1963a. The use of chromium oxide to estimate the faecal output of merinos. Austr. J. Agric. Res. 14:239.
Lambourne, L.J. & T.F. Reardon, 1963b. The use of chromium oxide and faecal nitrogen concentration to estimate the pasture intake of merino wethers. Austr, J. Agric. Res. 14:257.

Lancaster, R.J., 1949. Estimation of digestibility of grazed pasture from faeces nitrogen. Nature 163:330.
Lancaster, R.J., 1954. Measurement of feed intake of grazing cattle and sheep. V. Estimation of the feed-to-faeces ratio from the nitrogen content of the faeces of pasture fed cattle. N.Z.J. Sci. Techn. 36:15.
Lancaster, R.J. & M.P. Bartrum, 1954. Measurement of feed intake by grazing cattle and sheep. IV. A source of error in the chromogen technique of estimating the digestibility of fodders. N.Z.J. Sci. Techn. 35:489.
Landbouwcijfers, 1978. Landbouweconomisch Instituut/Centraal Bureau voor de Statistiek.
Lane, I.R. & W. Holmes, 1971. The analysis of the structure of grass swards grazed on rigid rotational systems. J. Br. Grassld. Soc. 26:191.
Langlands, J.P., 1965. Diurnal variations in the diet selected by free-grazing sheep. Nature 207:666.
Langlands, J.P., 1966. Studies on the nutritive value of the diet selected by grazing sheep. I. Differences in composition between herbage consumed and material collected from oesophageal fistulae. Anim. Prod. 8:253.
Langlands, J.P., 1967a. Studies on the nutritive value of the diet selected by grazing sheep. II. Some sources of error when sampling oesophageally fistulated sheep at pasture. Anim. Prod. 9:167.
Langlands, J.P., 1967b. Studies on the nutritive value of the diet selected by grazing sheep. III. A comparison of oesophageal fistula and faecal index techniques for the indirect estimation of digestibility. Anim. Prod. 9:325.
Langlands, J.P., 1968. The feed intake of grazing sheep differing in age, breed, previous nutrition and live weight. J. Agric. Sci. 71:167.
Langlands, J.P., 1969a. Studies on the nutritive value of the diet selected by grazing sheep. IV. Variation in the diet selected by sheep differing in age, breed, sex, strain and previous history. Anim. Prod. 11:369.
Langlands, J.P., 1969b. Studies of the nutritive value of the diet selected by grazing sheep. V. Further studies of the relationship between digestibility estimated in-vitro from oesophageal fistula samples and from faecal and dietary composition. Anim. Prod. 11:379.
Langlands, J.P., 1974. Studies on the nutritive value of the diet selected by grazing sheep. VII. A note on hand plucking as a technique for estimating dietary composition. Anim. Prod. 19:249.
Langlands, J.P., 1975. Techniques for estimating nutrient intake and its utilization by the grazing ruminant. In: McDonald I.W. & A.C.I. Warner (Eds.). Digestion and metabolism in the ruminant. Proc. IV. Int. Symp. Ruminant Physiol. University of New England Publications Unit. p. 320.
Langlands, J.P. & J.E. Bowles, 1973. Studies on the nutritive value of the diet selected by grazing sheep. VI. The use of tritiated water as a marker to estimate the composition of the diet from material collected by oesophageally fistulated sheep. Anim. Prod. 16:59.
Langlands, J.P., J.L. Corbett, I. McDonald & G.W. Reid, 1963a. Estimation of the faeces output of grazing animals from the concentration of chromium sesquioxide in a sample of faeces. I: Comparison of estimates from samples taken at fixed times of day with faeces outputs measured directly. Br. J. Nutr. 17:211.
Langlands, J.P., J.L. Corbett, I. McDonald & G.W. Reid, 1963b. Estimation of the faeces output of grazing animals from the concentration of chromium sesquioxide in a sample of faeces II: Comparison of estimates from samples taken at fixed times of day with estimates from samples collected from the sward. Br. J. Nutr. 17:219.
Langlands, J.P., J.L. Corbett & I. McDonald, 1963c. The indirect estimation of the digestibility of pasture herbage III. Regression of digestibility on faecal nitrogen concentration: effects of species and individuality of animal and of the method of determining digestibility upon the relationships. J. Agric. Sci. 61:221.
Lantinga, E., 1979. De invloed van het grasaanbod op de grasopname door melkkoeien bij een 3-daags omweidingssysteem. Praktijkverslag landbouwplantenteelt /Scriptie veevoeding, Landbouwhogeschool, Wageningen.
Laredo, M.A. & D.J. Minson, 1973. The voluntary intake, digestibility and retention time by sheep of leaf and stem fractions of five grasses. Austr. J. Agric. Res. 24:875.
Laredo, M.A. & D.J. Minson, 1975. The voluntary intake and digestibility by sheep of leaf and stem fractions of Lolium Perenne. J. Br. Grassld. Soc. 30:73.
Larsen, H.J. & R.F. Johannes, 1965. Summer forage. Stored feeding, green feeding and strip grazing. Research Bull. 257, University of Wisconsin.
Leaver, J.D., 1970. A comparison of grazing systems for dairy herd replacements. J. Agric. Sci. 75:265.

Leaver, J.D., 1974. Rearing of dairy cattle. 5. The effect of stocking rate on animal and herbage production in a grazing system for calves and heifers. Anim. Prod. 18:273.
Leaver, J.D., 1975. Rearing of dairy cattle. 6. The effect of length of grazing rotation on animal and herbage production in a grazing system for calves and heifers. Anim. Prod. 21:157.
Leaver, J.D., 1976. Utilisation of grassland by dairy cows. In: Swan. H. & W.H. Broster (Eds.), Principles of cattle production. Butterworths, London p.307.
Leaver, J.D., R.C. Campling & W. Holmes, 1968. Use of supplementary feeds for grazing dairy cows. Dairy Sci. Abstr. 30:355.
Leaver, J.D., R.C. Campling & W. Holmes, 1969a. The effect of level of feeding on the digestibility of diets for sheep and cattle. Anim. Prod. 11:11.
Leaver, J.D., R.C. Campling & W. Holmes, 1969b. The influence of flexible and rigid grazing management and of supplementary feed on output per hectare and per cow. Anim. Prod. 11:161.
Le Du, Y.L.P., R.D. Baker & R.D. Newberry, 1979a. Supplementary feed in the diet of dairy cows offered fresh herbage. Anim. Prod. 28:413.
Le Du, Y.L.P., J. Combellas, J. Hodgson & R.D. Baker, 1979b. Herbage intake and milk production by grazing dairy cows 2. The effects of level of winter feeding and daily herbage allowance. Grass & Forage Sci. 34:249.
Le Du, Y.L.P. & P.D.P. Penning, 1979. Advances in the indirect techniques to determine herbage intake. Proc. III European Grazing Workshop.
Lesperance, A.L., V.R. Bohmann & D.W. Marble, 1960. Development of techniques for evaluating grazed forage. J. Dairy Sci. 18:682.
Lesperance, A.L., T.M. Smith & V.R. Bohman, 1967. Influence of sample preparation on intake and digestion. Proc. West. Sec. Am. Soc. Anim. Sci. 18:243.
Linehan, P.A., 1952. Use of cage and mower-strip methods for measuring the forages consumed by grazing animals. Proc. VI Int. Grassld. Congr. 1328.
Linehan, P.A., J. Lowe & R.H. Stewart, 1947. The output of pasture and its measurement. Part II. J. Br. Grassld. Soc. 2:145.
Linehan, P.A., J. Lowe & R.H. Stewart, 1952. The output of pasture and its measurement. Part III. J. Br. Grassld. Soc. 7:73.
Logan, V.S., W.J. Pigden, V.J. Miles, G.J. Brisson, A.I. Magee & K. Rasmussen, 1960. Mechanical grazing v. daily or strip grazing for lactating cows. Proc. VIII. Int. Grassld. Congr. 652.
Lomba, F., G. Chauvaux, I. Fumière, V. Bienfet, R. Paquay, R. de Baere & A. Lousse, 1970. Effect of grass maturity in dry cows. Part 1. Chemical composition of grass, voluntary intake and weight gain. Z. Tierphysiol. Tierernähr. Futtermittelk. 6:316.
Lonsdale, C.R. & J.C. Tayler, 1971. The effect of season of harvest and of milling on the nutritive value of dried grass. Anim. Prod. 13:384.
Luten, W., 1976. Zomerstalvoedering van verschillende grassoorten. Intern rapport nr. 66 P.R.
MacDiarmid, B.N. & B.R. Watkin, 1972. The cattle dung patch. 3. Distribution and rate of decay of dung patches and their influence on grazing behaviour. J. Br. Grassld. Soc. 27:48.
Mannetje, L. 't, 1978. Measuring quantity of grassland vegetation. In: Mannetje L. 't (Ed.), Measuring of grassland vegetation and animal production. Commonwealth Agricultural Bureaux, Bucks, England. p. 63.
Marchi, A., C.G. Girando & V.H. Haydar, 1973. Effect of harness and bag for collection of faeces on intake by cattle. Revista de investigaciones agropecuarias 10:153.
Marsh, R., 1975. A comparison between spring and autumn pasture for beef cattle at equal grazing pressures. J. Br. Grassld. Soc. 30:165.
Marsh, R., 1977. The effect of level of herbage dry matter per animal on efficiency of utilization of pasture by young Friesian cattle. Proc. N.Z. Soc. Anim. Prod. 37:62.
Marsh, R. & R.C. Campling, 1970. Fouling of pastures by dung. Herbage Abstr. 40:123.
Marsh, R., R.C. Campling & W. Holmes, 1971a. A further study of a rigid grazing management system for dairy cows. Anim. Prod. 13:441.
Marsh, R. & D.M. Chestnutt, 1977. Effect of supplementary concentrates on performance of early-weaned lambs at pasture. J. Br. Grassld. Soc. 32:123.
Marsh, R., M.K. Curran & R.C. Campling, 1971b. The voluntary intake of roughages by pregnant and by lactating dairy cows. Anim. Prod. 13:107.
Marsh, R. & J.C. Murdoch, 1974. Effect of high fertilizer nitrogen and stocking rates on live weight gain per animal and per hectare. J. Br. Grassld. Soc. 29:305.
Marten, G.C. & J.D. Donker, 1966. Animal excrement as a factor influencing acceptability of grazed forage. Proc. X. Int. Grassld. Congr.:359.

Martin, H.F. & C.A. Baile, 1972. Feed intake of goats and sheep following acetate or propionate injections into rumen, ruminal pouches, and abomasum as affected by local anesthetics. J. Dairy Sci. 55:606.
Masobuchi, T., K. Watanabe, K. Koike & M. Ogawa, 1976. Effect of levels of concentrate on voluntary intake of forage by lactating cows. Bull. Nat. Grassld. Res. Inst. Japan 9:41.
McCullough, M.E., 1963. Relationship between digestible dry matter of forage and average daily gain of dairy heifers. J. Dairy Sci. 46:861.
McDonald, I.W., 1968. The nutrition of grazing ruminants. Nutr. Abstr. Rev. 38:14.
McFeely, P.C., D. Browne & O. Carty, 1975. Effect of grazing interval and stocking rate on milk production and pasture yield. Ir. J. Agric. Res. 14:309.
McGraham, N.C., 1969. The influence of body weight (fatness) on the energetic efficiency of adult sheep. Austr. J. Agric. Res. 20:375.
McIntyre, G.A., 1952. A method for unbiased selective sampling using ranked sets. Austr. J. Agric. Res. 3:385.
McIntyre, G.A., 1978. Statistical aspects of vegetation sampling. In: Mannetje, L. 't (Ed.), Measurement of grassland vegetation and animal production. Commonwealth Agricultural Bureaux, Bucks, England. p.8.
McLusky, D.S., 1955. The quantities of herbage eaten by grazing dairy cows. Proc. Br. Soc. Anim. Prod.:45.
McLusky, D.S., 1960. Some estimates of the area of pasture fouled by the excreta of dairy cows. J. Br. Grassld. Soc. 15:181.
McManus, W.R., G.W. Arnold & F.J. Hamilton, 1962. Improved techniques in oesophageal fistulation of sheep. Austr. Vet. J. 38:275.
McManus, W.R., M.L. Dudzinski & G.W. Arnold, 1967. Estimation of herbage intake from nitrogen, copper, magnesium and silicon concentrations in faeces. J. Agric. Sci. 69:263.
McMeekan, C.P., 1960. Grazing management. Proc. VIII Int. Grassld. Congr. :21.
McMeekan, C.P. & M.J. Walshe, 1963. The inter-relationships of grazing method and stocking rate in the efficiency of pasture utilization by dairy cattle. J. Agric. Sci. 61: 147.
Meijer, A.B., 1979. Verdringen van gras door krachtvoer bij zomerstalvoedering. Jaarverslag regionaal onderzoekcentrum Cranendonck.
Meijs, J.A.C., 1976. Oriëntatiestudie Nederlands graslandonderzoek. Intern rapport 82 I.V.V.O.
Meijs, J.A.C., 1977a. Grasopnameproeven 1976. Documentatierapport 32 I.V.V.O.
Meijs, J.A.C., 1977b. Koe vreet gras in de wei, maar niemand weet hoeveel. De Boerderij 61:32VE.
Meijs, J.A.C., 1978. Grasopnameproeven 1977. Documentatierapport 19 I.V.V.O.
Meijs, J.A.C., 1979a. De invloed van het grasaanbod/dier/dag op de grasopname van melkkoeien. Documentatierapport 50 I.V.V.O.
Meijs, J.A.C., 1979b. Advances in the direct techniques to determine herbage intake. Proc. III European Grazing Workshop.
Meijs, J.A.C., 1980a. Hoe kan de opname van grazende herkauwers worden geschat? Stikstof 95/96:348.
Meijs, J.A.C., 1980b. Sward sampling techniques for measuring the nitrogen response in grazing trials. Proc. Int. Symp. Eur. Grassld. Fed.:The role of nitrogen in intensive grassland production:167.
Meijs, J.A.C., 1981. The effect of herbage mass and allowance upon the herbage intake by grazing dairy cows. Proc. XIV Int. Grassld. Congr. (in press).
Meijs, J.A.C., R.J.K. Walters & A. Keen, 1981. Sward methods. In: Leaver, J.D. (Ed.), Herbage intake measurement handbook. British Grassland Society (in press).
Merz, W., 1970. Neuer Automat zur Stickstoff-Schnellbestimmung. G.I.T. Fachzeitschrift für das Laboratorium, 14:617.
Meyer, J.H., G.P. Lofgreen & J.L. Hull, 1957. Selective grazing by sheep and cattle. J. Anim. Sci. 16:766.
Meyer, J.H., G.P. Lofgreen & N.R. Ittner, 1956. Further studies on the utilization of alfalfa by beef steers. J. Anim. Sci. 15:64.
Milne, J.A., 1974. Estimating the faecal output of grazing animals. Proc. I European Grazing Workshop.
Minderhoud, J.W., P.F.J. van Burg, B. Deinum, J.G.P. Dirven & M.L. 't Hart, 1974. Effects of high levels of nitrogen and adequate utilization on grassland productivity and cattle performance with special reference to permanent pastures in the temperate regions. Proc. XII Int. Grassld. Congr.: I:99.
Minson, D.J., C.E. Harris, W.F. Raymond & R. Milford, 1964. The digestibility and voluntary intake of S22 and H1 ryegrass, S170 tall fescue, S48 timothy, S215 meadow fescue and germinal cocksfoot. J. Br. Grassld Soc. 19:298.

Minson, D.J. & C.D. Kemp, 1961. Studies in the digestibility of herbage. IX. Herbage and faecal nitrogen as indicators of herbage organic matter digestibility. J. Br. Grassld. Soc. 16:76.
Minson, D.J. & W.F. Raymond, 1958. Sources of error in the use of faecal index relationships. A. Rep. Grassld. Res. Inst. Hurley, 1956-1957:92.
Minson, D.J., J.C. Tayler, F.E. Alder, W.F. Raymond, J.E. Rudman, C. Line & M.J. Head, 1960. A method for identifying the faeces produced by individual cattle or groups of cattle grazing together. J. Br. Grassld. Soc. 15:86.
Mitchell, P.J., 1973. Digestibility and voluntary intake measurements on regrowth of six Tasmanian pasture species. Austr. J. Exp. Agric. Anim. Husb. 13:158.
Morgan, P.J.K., J.P. Pienaar & R.A. Clark, 1976. Animal-based methods of determining herbage intake and quality under grazing conditions. Proc. Grassld. Soc. Sth. Afr. 11:73.
Morrison, I.M., 1973. A note on the evaluation of the nutritive value of forage crops by the acetyl bromide technique. J. Br. Grassld. Soc. 28:153.
Mott, G.O., 1960. Grazing pressure and the measurement of pasture production. Proc. VIII Int. Grassld. Congr.:606.
Mott, N., 1974. Die Futter- und Nährstoffaufnahme auf der Weide in Abhängigkeit von verschiedenen Faktoren. Jahrestagung der Arbeitsgemeinschaft Grünland und Futterbau in Kleve-Kellen nr. 10:18.
Mott, N. & G. Müller, 1971. Wirkung der Weidenachmahd auf Ertrag, Weiderest, Inhaltstoffe und Pflanzenbestand. Das Wirtsch. eig. F.17:245.
Mott, N., G. Müller & E. Kuttruff, 1972. Einfluss der Nachmahd auf Umfang und Dauer von Geilstellen. Das Wirtsch. eig. F.18:81.
Norman, H.J.T. & J.O. Green, 1958. The local influence of cattle dung and urine upon the yield and botanical composition of permanent pasture. J. Br. Grassld. Soc. 13:39.
Osbourn, D.F., 1978. Principles governing the use of chemical methods for asessing the nutritive value of forages: a review. Anim. Feed Sci. Techn. 3:265.
Osbourn, D.F. & R.A. Terry, 1977. In-vitro techniques for the evaluation of ruminant feeds. Proc. Nutr. Soc. 36:219.
Osbourn, D.F., R.A. Terry, G.E. Outen & S.B. Cammell, 1974. The significance of a determination of cell walls as the rational basis for the nutritive evaluation of forages. Proc. XII. Int. Grassld. Congr.:514.
Osbourn, D.F., D.J. Thomson & R.A. Terry, 1966. The relationship between voluntary intake and digestibility of forage crops, using sheep. Proc. X Int. Grassld. Congr.:363.
Otsokovic, S. & I. Velotchkovic, 1977. Effect of concentrate upon green herbage consumption, assimilation of nutrients and milk production on high-quality low-land pasture in Yugoslavia. Stocarstvo 31:453.
Owen, J.B., E.L. Miller & P.S. Bridge, 1968. A study of the voluntary intake of food and water and the lactation performance of cows given diets of varying roughage content ad libitum. J. Agric. Sci. 70:223.
Pain, B.F. & D.M. Broom, 1978. The effects of injected and surface-spread slurry on the intake and grazing behaviour of dairy cows. Anim. Prod. 26:75.
Pain, B.F., J.D. Leaver & D.M. Broom, 1974. Effects of cow slurry on herbage production, intake by cattle and grazing behaviour. J. Br. Grassld. Soc. 29:85.
Payne, W.J.A., 1966. Nutrition of ruminants in the tropics. Nutr. Abstr. Rev. 36:653.
Pearce, G.R., J.E. Vercoe & M. Freer, 1962. The establishment of faecal nitrogen - digestibility regressions for animals grazing irrigated pasture. J. Agric. Sci. 59:397.
Penning, P.D. & J. Valderrabano, 1979. The influence of level of feed intake on digestive efficiency. Proc. III European Grazing Workshop.
Penzhorn, E.J. & J.P. Meintjes, 1972. Influence of pregnancy and lactation on the voluntary feed intake of Afrikaner heifers and cows. Agroanimalia 4:83.
Petersen, R.G., H.L. Lucas & G.O. Mott, 1965. Relationship between rate of stocking and per animal and per acre performance on pasture. Agron. J. 57:27.
Raymond, W.F., 1969. The nutritive value of forage crops. Advances Agron. 21:1.
Raymond, W.F., 1970. The utilization of grass and forage crops by cutting and grazing. Proc. XI. Int. Grassld. Congr.:A95.
Raymond, W.F., C.D. Kemp, A.W. Kemp & C.E. Harris, 1954. Studies in the digestibility of herbage. IV. The use of faecal collection and chemical analysis in pasture studies (b) faecal index methods. J. Br. Grassld. Soc. 9:69.
Raymond, W.F. & D.J. Minson, 1955. The use of chromic oxide for estimating the faecal production of grazing animals. J. Br. Grassld. Soc. 10:282.

Raymond, W.F., D.J. Minson & C.E. Harris, 1959. Studies in the digestibility of herbage. VII. Further evidence on the effect of level of intake on the digestive efficiency of sheep. J. Br. Grassld. Soc. 14:75.
Reardon, T.F., 1977. Effect of herbage per unit area and herbage allowance on dry matter intake by steers. Proc. N.Z. Soc. Anim. Prod. 37:58.
Reed, K.F.M., 1978. The effect of season of growth on the feeding value of pasture. J. Br. Grassld. Soc. 33:227.
Reid, D., 1966. Studies on the cutting management of grass-clover swards. IV. The effects of close and lax cutting on the yield of herbage from swards cut at different frequencies. J. Agric. Sci. 66:101.
Reid, G.W., J.F.D. Greenhalgh & J.N. Aitken, 1972. The effects of grazing intensity on herbage consumption and animal production. IV. An evaluation of two methods for avoiding the rejection of fouled herbage by dairy cows. J. Agric. Sci. 78:491.
Reid, J.T., 1962. Indicator methods in herbage quality studies. In: American society of agronomy and others (Eds.). Pasture and range research techniques. Comstock publishing associates. Ithaca, U.S.A. p.45.
Reid, J.T., P.G. Woolfolk, W.A. Hardison, C.M. Martin, A.L. Brundage & R.W. Kaufman, 1952. A procedure for measuring the digestibility of pasture forage under grazing conditions. J. Nutr. 46:255.
Reid, J.T., P.G. Woolfolk, C.R. Richards, R.W. Kaufman, J.K. Loosli, K.L. Turk, J.I. Miller & R.E. Blaser, 1950. A new indicator method for the determination of digestibility and consumption of forages by ruminants. J. Dairy Sci. 33:60.
Reid, R.L., & G.A. Jung, 1965. Factors affecting the intake and palatability of forages for sheep. Proc. IX Int. Grassld. Congr.:863.
Reid, R.L., G.A. Jung & S.J. Murray, 1966. Nitrogen fertilization in relation to the palatability and nutritive value of orchardgrass. J. Anim. Sci. 25:636.
Rigg, J.C. & B.F. Visser, 1979. Nomenclature of derived quantities. Review and recommendations 1979. International union of pure and applied chemistry.
Rijpkema, Y.S., 1974. Estimating the faecal output of grazing animals. Proc. I European Grazing Workshop.
Rodriguez, J.M., 1973. The herbage intake of young grazing cattle. Ph.D. Thesis, University of Reading.
Rodriguez, J.M. & J. Hodgson, 1974. The influence of sward characteristics on the herbage intake of young grazing cattle in tropical and temperate climates. Proc. XII Int. Grassld. Congr.:87.
Rohr, K., 1972. Untersuchungen über die Futteraufnahme und Futterverwertung bei Milchkühen verschiedener Rassen unter besonderer Berücksichtigung des Grünfutters. Kieler Milchwirtschaft. Forsch. Ber. 24:23.
Rohr, K., 1976. Futteraufnahme und Nährstoffversorgung von Milchkühe bei Weidegang bzw. Grünfutterung. Übers. Tierernähr. 4:133.
Rohr, K., 1977. Die Verzehrsleistung des Wiederkäuers in Abhängigkeit von verschiedenen Einflussfactoren. Übers. Tierern. 5:75.
Rohr, K. & W. Kaufmann, 1967. Untersuchungen zur Trockensubstanzaufnahme von Milchkühe bei Weidegang. Das Wirtsch. eig. F. 13:85.
Roth, F.X. & M. Kirchgessner, 1972. Zum Einfluss der chemischen Zusammensetzung des Weidegrases auf die Futteraufnahme von Milchkühen. Das Wirtsch. eig. F. 3:194.
Runcie, K.V., 1960. The utilization of grass by strip grazing and zero grazing with dairy cows. Proc. X Int. Grassld. Congr.:644.
Sarker, A.B. & W. Holmes, 1974. The influence of supplementary feeding on the herbage intake and grazing behaviour of dry cows. J. Br. Grassld. Soc. 29:141.
Scales, G.H., C.L. Streeter, A.H. Denham & G.M. Ward, 1974a. A comparison of indirect methods of predicting in-vivo digestibility of grazed forage. J. Anim. Sci. 38:192.
Scales, G.H., C.L. Streeter, A.H. Denham & G.M. Ward, 1974b. Effect of mastication, salivary contamination and leaching on the chemical composition of forage samples collected via oesophageal fistulae. J. Anim. Sci. 38:1278.
Sidahmed, A.E., J.G. Morris, W.C. Weir & D.T. Torell, 1977. Effect of the length of fasting on intake, in-vitro digestibility and chemical composition of forage samples collected by oesophageal fistulated sheep. J. Anim. Sci. 46:885.
Smetham, M.L., 1976. The influence of herbage utilization on pasture production and animal performance. Proc. N.Z. Grassl. Ass. 37:91.
Smith, N.E. & R.L. Baldwin, 1974. Effects of breed, pregnancy and lactation on weight of organs and tissues in dairy cattle. J. Dairy Sci. 57:1055.
Smith, T.M., A.L. Lesperance & V.R. Bohman, 1967. Drying methods related to changes in chemical composition. Proc. West Sec. Am. Soc. Anim. Sci. 18:285.
Soest, P.J. van, 1963. Use of detergents in the analyses of fibrous feeds. II. A rapid method for the determination of fiber and lignin. J.Assn. Official Agr. Chem. 46:829.

Soest, P.J. van, 1964. Symposium on nutrition and forage and pasture: New chemical procedures for evaluating forages. J. Anim. Sci. 23:838.
Soest, P.J. van, 1965a. Symposium on factors influencing the voluntary intake of herbage by ruminants: voluntary intake in relation to chemical composition and digestibility. J. Anim. Sci. 24:834.
Soest, P.J. van, 1965b. Use of detergents in analysis of fibrous feeds. III Study of effects of heating and drying on yield of fiber and lignin in forages. J. Assn. Official Agr. Chem. 48:785.
Soest, P.J. van & J.B. Robertson, 1977. What is fibre and fibre in food. Nutr. Rev. 35:12
Soest, P.J. van & R.H. Wine, 1968. Determination of lignin and cellulose in acid-detergent fiber with permanganate. J. Assn. Official Agr. Chem. 51:780.
Soest, P.J. van, R.H. Wine & L.A. Moore, 1966. Estimation of the true digestibility of forages by the in-vitro digestion of cell walls. Proc. X Int. Grassld. Congr.:438.
Soni, B.K., F.R. Murdock, A.S. Hodgson, T.H. Blosser & K.C. Mahanta, 1954. Diurnal variation in the estimates of digestibility of pasture forage using plant chromogens and faecal nitrogen as indicators. J. Anim. Sci. 13:474.
Sonneveld, A. 1965a. Dry matter intake of cattle fed on grass. Technical Report no.1. Grassld. Res. Inst. Hurley.
Sonneveld, A., 1965b. Waarnemingen over het opnemen van vers gras door het rundvee. Veeteelt & Zuivelber. 8:409.
Spahr, S.L., E.M. Kessler, J.W. Bratzler & J.B. Washko, 1961. Effect of stage of maturity at first cutting on quality of forages. J. Dairy Sci. 44:503.
Spedding, C.R.W., R.V. Large & D.D. Kydd, 1966. The evaluation of herbage species by grazing animals. Proc. X Int. Grassld. Congr.:474.
Steger, H., B. Piatkowski & F. Püschel, 1962. Methodische Untersuchungen zur Bestimmung der Verdaulichkeit des Weidegrases mit Hilfe der Chromogen methode. Arch. für Tierernähr. 12:121.
Stehr, W. & M. Kirchgessner, 1975. Zum Einfluss von Angebot and Nährstoffgehalt des Grases auf die Futteraufnahme von Milchkühen auf der Weide. Bayer. Landw. Jahrbuch 52:285.
Stehr, W. & M. Kirchgessner, 1976. The relationship between the intake of herbage grazed by dairy cows and its digestibility. Anim. Feed Sci. Techn. 1:53.
Stevenson, A.E., 1962. Some observations on the accuracy of the chromic oxide technique for the estimation of faeces output of dairy cattle. N.Z. J. Agric. Res. 5:339.
Stobbs, T.H., 1973a. The effect of plant structure on the intake of tropical pastures I. Variation in the bite size of grazing cattle. Aust. J. Agric. Res. 24:809.
Stobbs, T.H., 1973b. The effect of plant structure on the intake of tropical pastures. II. Differences in sward structure, nutritive value, and bite size of animals grazing Setaria Anceps and Chloris Gayana at various stages of growth. Austr. J. Agric. Res. 24:821.
Stobbs, T.H. & L.J. Cooper, 1972. Automatic measurement of the jaw movements of dairy cows during grazing and rumination. Trop. Grassld. 6:107.
Streeter, C.L., 1969. A review of techniques used to estimate the in-vivo digestibility of grazed forage. J. Anim. Sci. 29:757.
Sullivan, J.T., 1955. Cellulose and lignin in forage grasses and their digestion coefficients. J. Anim. Sci. 14:710.
Tainton, N.M., 1974. Effects of different grazing rotations on pasture production. J. Br. Grassld. Soc. 29:191.
Taparia, A.L. & A.W.F. Davey, 1970. The effect on food intake and milk production of adding concentrates to the ration of pasture-fed cows. N.Z.J. Agric. Res. 13:616.
Tayler, J.C., 1959. A relationship between weight of internal fat 'fill' and the herbage intake of grazing cattle. Nature 184:2021.
Tayler, J.C., 1966. Relationship between the herbage consumption or carcass energy increments of grazing beef cattle and the quantity of herbage on offer. Proc.X Int. Grassld. Congr. :463.
Tayler, J.C. & R.E. Deriaz, 1963. The use of rumen fistulated steers in the direct determination of nutritive vale of ingested herbage in grazing experiments. J. Br. Grassld. Soc. 18:29.
Tayler, J.C. & J.E. Rudman, 1965. Height and method of cutting or grazing in relation to herbage consumption and live weight gain. Proc. IX Int. Grassld. Congr. :609.
Tayler, J.C. & J.E. Rudman, 1966. The distribution of herbage at different heights in 'grazed' and 'dung-patch' areas of a sward under two methods of grazing management. J. Agric. Sci. 66:29.
Tayler, J.C. & J.M. Wilkinson, 1972. The influence of level of concentrate feeding on the voluntary intake of grass and on live weight gain by cattle. Anim. Prod. 14:85.

Thill, N., E. Francois, A. Thewis & M. Thielemans, 1978. Comparison chez le mouton de l'oxyde de chrome-papier et du radio-cerium, marqueurs de la phase solide des digesta. Ann. Zootech. 27:363.
Thomas, S. & R.C. Campling, 1976. Relationship between digestibility and faecal nitrogen in sheep and cows offered herbage ad libitum. J. Br. Grassld. Soc. 31:69.
Thompson, G.E., 1973. Climatic physiology of cattle. J. Dairy Res. 40:441.
Thye, F.W., R.G. Warner & P.D. Miller, 1970. Relationship of various blood metabolites to voluntary feed intake in lactating ewes. J. Nutr. 100:565.
Tilley, J.M.A. & R.A. Terry, 1963. A two-stage technique for the in-vitro digestion of forage crops. J. Br. Grassld. Soc. 18:104.
Torell, D.T., 1954. An esophageal fistula for animal nutrition studies. J. Anim. Sci.13: 878.
Troelsen, J.E. & J.B. Campbell, 1969. The effect of maturity and leafiness on the intake and digestibility of alfalfas and grasses fed to sheep. J. Agric. Sci. 73:145.
Tulloh, N.M., 1966. Physical studies of the alimentary tract of grazing cattle. III. Seasonal changes in capacity of the reticulo-rumen of dairy cattle. N.Z. J. Agric. Res. 9:252.
Ulyat, M.J., 1971. Studies on the causes of the differences in pasture quality between perennial ryegrass, short-rotation ryegrass, and white clover. N.Z. J. Agric.Res.14: 352.
Umoh, J.E. & W. Holmes, 1974. The influence of type and level of supplementary feed on intake and performance of beef cattle on pasture. J. Br. Grassld. Soc. 29:301.
Vercoe, J.E. & G.R. Pearce, 1962. The estimation of the intake of grazing sheep.I. Establishment of faecal nitrogen regressions. J. Agric. Sci. 59:343.
Vérité, R. & M. Journet, 1970. Influence de la teneur en eau et de la déshydration de l'herbe sur la valeur alimentaire pour les vaches laitières. Ann. Zootech. 19:255.
Visser, H. de & A.A.M. de Groot, 1980. The influence of the starch and sugar content of concentrates on feed intake, rumen fluid, production and composition of milk. Proc. IV. Intern. Conf. on production diseases in farm animals.
Voigtländer, G. & W. Kühbauch, 1978. Factors constraining animal production in grazing management. Proc. VII. Gen. Meeting Eur. Grassld. Fed.:43.
Waddington, J. & A. Cooke, 1971. The influence of sample size and number on the precision of estimates of herbage production and consumption in two grazing experiments. J. Br. Grassld. Soc. 26:95.
Waite, R., W. Holmes & J. Boyd, 1952. Studies in grazing managament. V. Further determination of the nutrient intake of dairy cows under close-folding and rotational methods of grazing. J. Agric. Sci. 41:314.
Waite, R., W. Holmes, J.I. Campbell & D.L. Fergusson, 1950. Studies in grazing management. II. The amount and chemical composition of herbage eaten by dairy cattle under close folding and rotational methods of grazing. J. Agric. Sci. 40:392.
Waite, R., M.J. Johnston & D.J. Armstrong, 1964. The evaluation of artificially dried grass as a source of energy for sheep. I. The effect of stage of maturity on the apparent digestibility of ryegrass, cocksfoot and timothy. J. Agric. Sci. 62:391.
Wallace, L.R., 1961. Nutritional requirements of dairy cattle. Proc. N.Z. Soc. Anim. Prod. 21:64.
Wallace, J.D. & A.H. Denham, 1970. Digestion of range forage by sheep collected by esophageal fistulated cattle. J. Anim. Sci. 30:605.
Wallace, J.D. & G.M. van Dyne, 1970. Precision of indirect methods for estimating digestibility of forage consumed by grazing cattle. J. Range Mangmt. 23:424.
Walters, R.J.K., 1971. Variation in the relationship between in-vitro digestibility and voluntary dry matter intake of different grass varieties. J. Agric. Sci. 76:243.
Walters, R.J.K., 1973. Variation between grass species and varieties in voluntary intake. Proc. V Gen. Meeting Eur. Grassld. Fed.:184.
Walters, R.J.K. & E.M. Evans, 1979. The evaluation of a sward sampling technique for estimating herbage intake by grazing sheep. Grass and Forage Sci. 34:37.
Weeda, W.C., 1965. The effects of frequency and severity of grazing by cattle on the yield of irrigated pasture. N.Z. J. Agric. Res. 8:1060.
Weir, W. & D.T. Torell, 1959. Selective grazing by sheep as shown by a comparison of the chemical composition of range and pasture forage obtained by hand-clipping and that collected by esophageal-fistulated sheep. J. Anim. Sci. 18:641.
Weisbach, F., 1970. Über die Nährstoffverluste bei der Grünfuttersilierung. Intern. Zeitschr. Landwirtsch. :72.
Weston, R.H. & J.P. Hogan, 1973. Nutrition of herbage-fed ruminants. In: Alexander, G. & O.B. Williams (Eds.). The pastoral industries of Australia. Sydney University Press. Sydney.

Wieling, H., A.H. Koops, L.E.M. Rompelberg & S. de Jong, 1977. Normen voor de voedervoorziening. Rapport nr. 57 P.R.
Wilkinson, J.M. & J.H.D. Prescott, 1970. Beef production from grass and silage with autumn-born calves. I. The influence of grazing intensity on efficiency of herbage utilization and live-weight gain of cattle. Anim. Prod. 12:433.
Wilson, G.F., 1966. Ryegrass varieties in relation to dairy cattle performance II. The influence of ryegrass varieties on intake, digestibility, and on some characteristics of rumen fermentation. N.Z.J. Agric. Res. 9:1053.
Wilson, R.K. & R.B. McGarrick, 1966. Apparent dry-matter digestibility, voluntary food-intake and yields of dry-matter of mixed swards, conserved as artificially dried grass and tetrapod hay, at progressive stages of maturity. Proc. X. Int. Grassld. Congr. 371
Witt, M. & F.W. Huth, 1966. Untersuchungen über den Weidegrasverzehr von Milchkühen bei Stallhaltung. Das Wirtsch. eig. F. 12:84.
Wolton, K.M., 1972. Producing grass for summer milk. J. Br. Grassld. Soc. 27:93.
Zeeb, K., 1972. Eine neue Methode der Aktivitätserfassung beim Rind. Tierärzl. Umschau 5:1.
Zemmelink, G., 1980. Effect of selective consumption on voluntary intake and digestibility of tropical forages. Agric. Res. Rep. (Versl. Landbk. Onderz.) 896.