482. Beretning fra Statens Husdyrbrugs forsøg

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Strategies for concentrate feeding to attain optimum feeding level in high yielding dairy cows

An interdisciplinary study based on a Danish long term experiment 1972–76 on input-output relationships in milk production

Kraftfoderstrategier til opnåelse af optimalt foderniveau til højtydende malkekøer

Med dansk sammendrag

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Foreword

The present work was carried out as an interdisciplinary study during the years 1970–78 at the National Institute of Animal Science, Department of Research in Cattle and Sheep, Copenhagen. The planning of the research project was started when studying at Michigan State University, U.S.A. (1969–70).

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Copenhagen, July 1978

Vagn Østergaard

CONTENTS

Key-words supplementing the title: experimental design; food intake; persistency; body tissue; fertility.

I. Introduction, problem definition and formulation of the hypothesis

Most dairy farmers aim to maximize their income or the profit per cow or man-hour. This means that the input of food must be optimized within herd and system of production. For many milk producers, however, the optimum level of food intake has to be planned and regulated without the possibility of individual feeding with roughage. This is the case in several of the older, and in most of the newer systems, of housing cows and handling feed. As a consequence, individual feeding according to standards of requirements is not practicable.

On this background it is pertinent to formulate the following important problem for the dairy farmer:

> Which strategy, i.e. level and pattern of concentrate feeding during lactation, secures optimum feeding under current prices of milk, roughage and concentrates, when the roughage, e.g. grass silage, is fed ad libitum?

In accordance with this problem, the aim of the present study was to provide the necessary data for the estimation of the technical functions (i.e. response productions) from which the optimum level of concentrates during the lactation can be calculated with various prices of feeds (concentrates and roughage) and products (milk and body tissue gain). Therefore the study also has involved the economical aspects and has been planned primarily as an interdisciplinary study.

According to Blaxter (1956 and 1966), Burt (1957), Conrad et al. (1964), Armstrong and Prescott (1970) and others, many trials and feeding experiments show that the chemical composition and physical structure of the total ration has a great influence on the voluntary intake of food and the level and composition of the production. The further development of the relevant literature will be presented at the appropriate places in the thesis. Initially the following working hypothesis was formulated:

> »Even when the main roughage is fed ad libitum, it is possible by means of the concentrate feeding to regulate within certain limits the total food intake and the composition of the ration and thereby to influence the level and composition of production at a given stage of lactation«.

As the primary use of the experimental data has been (by means of the input/output relationships) to optimize the input of food, the hypothesis was tested for the following economically important variables:

Input:

Total food intake
Intake of grass silage

Output:

Milk yield (including solids, butterfat and protein)
Body tissue gain
Allied »products«: fertility and incidence of disease.

II. Experimental design and recording of data

2.1. Experimental design

Since the aim of the experiment was to obtain data for the estimation of milk production functions under circumstances where the level of concentrates was the only input to be controlled directly, concentrate feeding or the strategy for allowance of concentrates was the independent variable of the experiment.

This is in contrast to the classic situation, where the animals are fed according to the current milk yield. In this latter case the food intake is in reality a function of the yield, as illustrated in Figure 2.1, where the total food allowances (u) depend on the standard (b_H, b_M or b_L) fed per kg of 4% fat corrected milk (FCM), and the standard fed for maintenance (m). When feeding according to the current yield of the cow, the total food intake is, for each standard (High, Medium or Low), a linear function of the milk yield.

Feeding the highest standard, the food intake, if accepted by the cow, follows the upper line in Fig. 2.1. When feeding the medium (M) or low (L) standard, food intake follows the two lower lines for changing milk yields of the cows, even with an accidental change. It can be concluded from Fig. 2.1 that the resultant milk yield difference between two treatments depends very much on the length of the experimental period, the frequency of adjusting the food to milk yield and the stage of lactation. It should be noted that the difference in body tissue change has not been taken into consideration.

These types of experiments, do not therefore allow a reliable estimation of the long-term (i.e. whole lactation) response of cows to any specific level of intake of energy (Jensen, 1961, Claesson, 1965). Similarly, the classic studies by Armsby (1917), Mølgaard (1929) and Frederiksen et al. (1931) provide only data for the estimation of the day to day energy requirements for maintenance, milk production and body gain. However, it is possible to conclude that one feeding standard, under certain conditions, gives a better or poorer economic result than another one (Arbrandt, 1971).

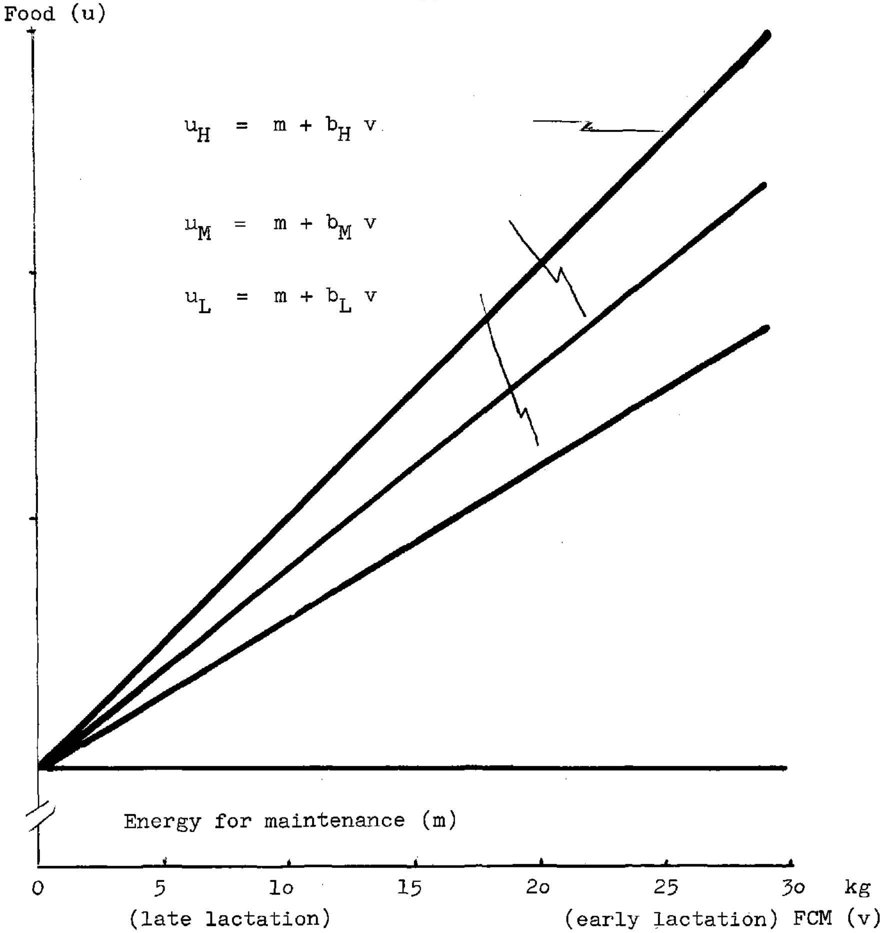

Fig. 2.1. The relation between milk yield and food offered when feeding according to yield using different standards.

In the following, the treatments are described, and the background for these is given. Furthermore, it is appropriate to define the concentrates, which in accordance with the discussion above have to be the independent variable of the experiment.

Dairy cow rations very often include feeds which are as high in digestibility of the organic matter as the commonly used concentrates, such as oilcakes, grains and these in combination (grain mix). Consequently in the present study, it is appropriate to define concentrates as feeds high in digestibility, these including grain mix, roots, molasses and dried sugar beet pulp mixed with molasses. However, only the grain mix feeding was planned to be different between strategies.

The choice of treatments (i.e. strategies of grain mix feeding plus a fixed amount of other concentrates) was based on present knowledge of milk yield and food intake of the high yielding dairy cow during the various phases of lactation (Flatt et al., 1969a, b and Broster et al., 1969). This is illustrated in schematic form in Fig. 2.2. It is seen that the cow in early lactation is in a phase of mobilization, there being a deficit in energy intake. In late lactation energy intake exceeds the requirements for milk production and maintenance, and the cow is in a phase of deposition (i.e. the body reserves are being reestablished).

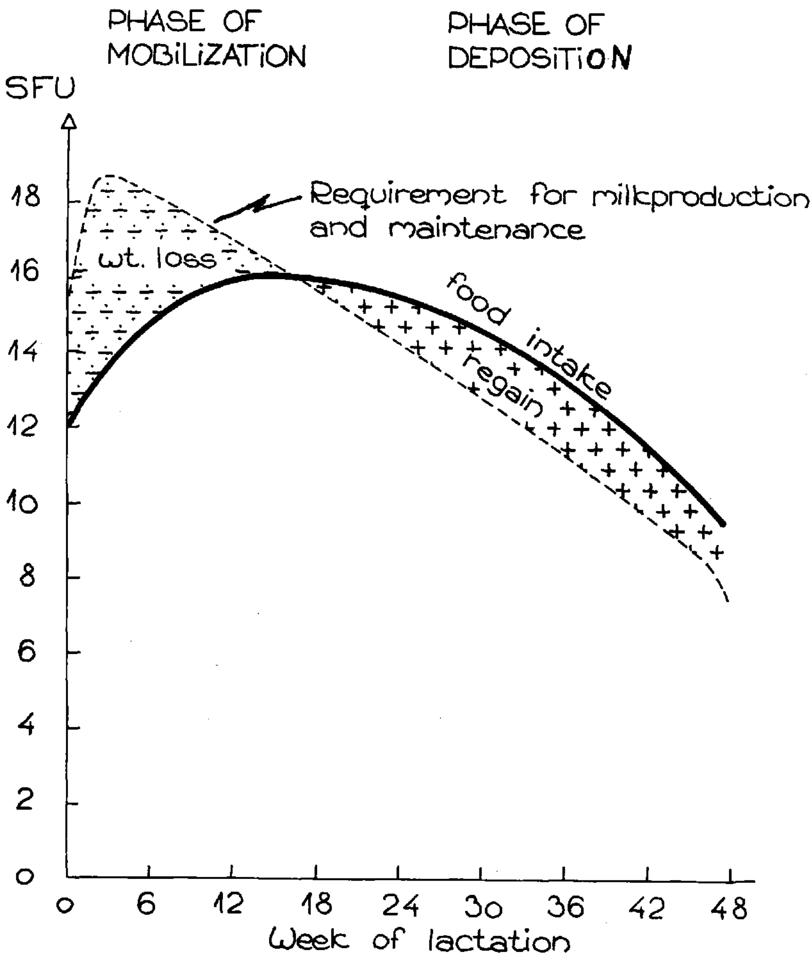

Fig. 2.2. Schematic illustration of voluntary foodintake and food requirements through lactation for a cow with a high potential for milk production.

These phases are characteristic for cows with a high potential for milk yield. Another fact of importance for the planning of the present experiment is that the highest milk yield, kg milk and kg FCM, is not always obtained with rations very high in concentrate, but rather with rations containing approximately 60 and 40% of concentrates, respectively, as shown by Flatt et al., (1969a).

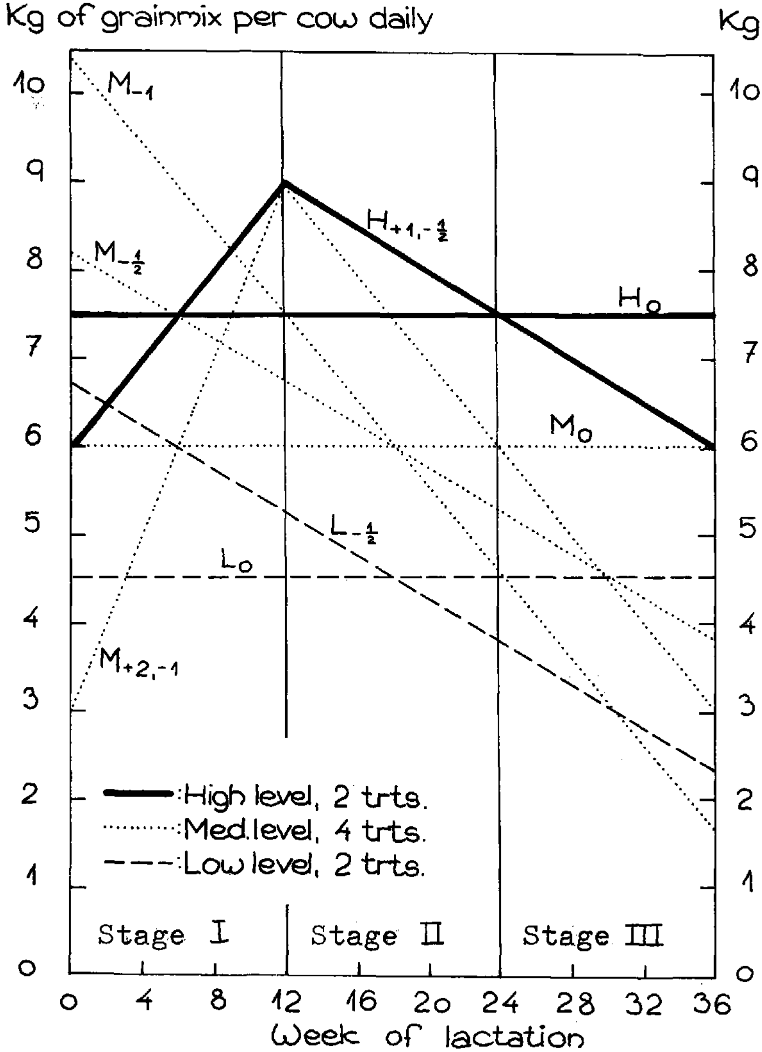

Fig. 2.3. Treatments: 8 strategies for feeding grain mix throughout lactation.

On basis of these findings and typical lactation curves for cows of the larger Danish breeds (Mygind-Rasmussen, 1970), the strategies chosen involved a variation in both the level of grain mix fed and in the pattern of feeding the grain mix allowances during lactation. All together 8 experimental strategies were tested. In each of these the grain mix was fed independently of the current milk yield, and grass silage were offered ad libitum.

The strategies are presented in graphical form in Fig. 2.3, and they are described in detail in Tables 2.1 and 2.2. As will be seen there were two strategies with an equal, but low level of grain mix: one in which the same amount of grain mix was given from day to day throughout the first 36 weeks of lactation (L_0), and one in which the amount was reduced by 0.5 kg per 4 weeks ($L_{-½}$). There were four strategies with an equal, but medium level of grain mix: one with constant daily allowances (M_0), one in which the amount was reduced by 0.5 kg per 4 weeks ($M_{-½}$), one in which the amount was reduced by 1.0 kg per 4 weeks (M_{-1}) and one in which the daily allowances were increased over the first 12 weeks, and thereafter reduced ($M_{+2,-1}$). There were finally two strategies with an equal, but high level of grain mix: one with constant daily allowances (H_0), and one with increasing daily allowances over the first 12 weeks and followed by a constant reduction ($H_{+1,-½}$). It was expected that the strategy $H_{+1,-½}$ might lead to an almost constant ratio between concentrates and roughages through a great part of the lactation, because of the increasing food intake during the first 3 months after parturition (Johnson et al., 1966).

In order to compare the eight strategies involving grain mix fed independent of milk yield with the traditional »feeding to standard«, a ninth treatment, Norm, was included. In this treatment the Danish feeding standard (Frederiksen et al., 1931) of 0.40 Scandinavian feed unit (SFU) per kg of 4% fat corrected

Table 2.1 The elements (variables) of the 9 different treatments

Level of	Level of grain mix	Change in allowances, kg per 4 weeks			
Stages of lactation	I–III	I	II	III	
Weeks of lactation	1–36	1–12	13–24	25–36	
	Kg				**Strategy**
Low	1134	0	0	0	Lo, o, o = Lo
Low	1134	–½	–½	–½	L–½, –½, –½ = L–½
Medium	1512	0	0	0	Mo, o, o = Mo
Medium	1512	–½	–½	–½	M–½, –½, –½ = M–½
Medium	1512	+2	–1	–1	M+2, –1, –1 = M+2, –1
Medium	1512	–1	–1	–1	M–1, –1, –1 = M–1
High	1890	0	0	0	Ho, o, o = Ho
High	1890	+1	–½	–½	H+1, –½, –½ = H+1, –½

Feeding according to yield: 0.40 SFU per kg FCM: Norm.

Table 2.2 Treatments, kg of grain mix per cow daily

Stage of lactation	Week of lactation	Treatment: Strategy of grain mix feeding								
		Lo	L–½	Mo	M–½	M+2,–1	M–1	Ho	H+1,–½	Norm
	1	4.5	6.5	6.0	8.0	3.0	10.5	7.5	6.0	
	2	4.5	6.5	6.0	8.0	3.5	10.0	7.5	6.5	
	3	4.5	6.5	6.0	8.0	4.0	10.0	7.5	6.5	
	4	4.5	6.5	6.0	8.0	4.5	9.5	7.5	7.0	
	5	4.5	6.0	6.0	7.5	5.0	9.5	7.5	7.0	
I	6	4.5	6.0	6.0	7.5	5.5	9.0	7.5	7.5	
	7	4.5	6.0	6.0	7.5	6.5	9.0	7.5	7.5	
	8	4.5	6.0	6.0	7.5	7.0	8.5	7.5	8.0	
	9	4.5	5.5	6.0	7.0	7.5	8.5	7.5	8.0	
	10	4.5	5.5	6.0	7.0	8.0	8.0	7.5	8.5	
	11	4.5	5.5	6.0	7.0	8.5	8.0	7.5	8.5	
	12	4.5	5.5	6.0	7.0	9.0	7.5	7.5	9.0	
	13	4.5	5.0	6.0	6.5	9.0	7.5	7.5	9.0	
	14					8.5	7.0			
	15	4.5	5.0	6.0	6.5	8.5	7.0	7.5	8.5	
	16					8.0	6.5			
II	17	4.5	4.5	6.0	6.0	8.0	6.5	7.5	8.5	
	18					7.5	6.0			
	19	4.5	4.5	6.0	6.0	7.5	6.0	7.5	8.0	
	20					7.0	5.5			
	21	4.5	4.0	6.0	5.5	7.0	5.5	7.5	8.0	
	22					6.5	5.0			
	23	4.5	4.0	6.0	5.5	6.5	5.0	7.5	7.5	
	24					6.0	4.5			
	25	4.5	3.5	6.0	5.0	6.0	4.5	7.5	7.5	
	26					5.5	4.0			
	27	4.5	3.5	6.0	5.0	5.5	4.0	7.5	7.0	
	28					5.0	3.5			
III	29	4.5	3.0	6.0	4.5	5.0	3.5	7.5	7.0	
	30					4.5	3.0			
	31	4.5	3.0	6.0	4.5	4.5	3.0	7.5	6.5	
	32					4.0	2.5			
	33	4.5	2.5	6.0	4.0	4.0	2.5	7.5	6.5	
	34					3.5	2.0			
	35	4.5	2.5	6.0	4.0	3.5	2.0	7.5	6.0	
	36					3.0	1.5			
Total, kg	1–36	1134	1134	1512	1512	1512	1512	1890	1890	Var.
Accepted, kg	1–36	1134	1132	1510	1500	1510	1495	1877	1888	Var.

milk (FCM) was applied. During the first 6 weeks of lactation the cows were given 1 kg of grain mix in addition for »lead feeding« (Table 2.3). The Scandinavian feed unit is defined by the net energy (NE) of 1.00 kg barley (85% dry matter) corresponding to 11.92 MJ of metabolizable energy (ME) according to Larsen (1969), (1 Mcal = 4.184 MJoule). Assuming the ME : GE (Gross energy) ratio to be 0.61 the SFU also corresponds to 7.26 MJ_{NE1} (NE_l = net energy for lactation according to van Es (1975)). Kg FCM = 15 × kg butterfat + 0.4 × kg milk.

It should be noted that week 1 of lactation started on average 7 days after parturition, as the first days were used for adjusting the animal to the treatment.

Table 2.3 Plan of feeding on the Norm treatment: standard feeding with 0.40 SFU per kg of FCM. Food per cow daily

Feed	DM, kg		First lactation SFU	Second and following lactations SFU
Roots, beet[1])	2.7		2.5	2.5
Molasses	1.0	Basal	1.0	1.0
Silage of beet tops[2])	1.0	ration	0.8	0.8
Barley straw	0.7 5.4		0.2 4.5	0.2 4.5
Grass silage			3.0	4.5
Total food excl. grain mix			7.5	9.0
For maintenance and gain			5.5	5.0
Residual for milk production			2.0	4.0

[1]) Summer: Equivalent food in molasses and dried pulp of sugar beet.
[2]) Grass cobs during a few months.

Details of feeding plan

Dry period or FCM, kg	Molasses SFU	Roots beet SFU	Grass silage SFU 1	Grass silage SFU 2	Beet top sil. SFU	Straw SFU	Grain mix SFU 1	Grain mix SFU 2	Total SFU 1	Total SFU 2
4–2 weeks pre calv.	1.0	2.0*)	2.8	2.8*)	–	0.2	1.0–3.0*)	1.0–3.0*)	7.0–	7.0–
14–4 days pre calv.	1.0	2.0	2.8	2.8	–	0.2	1.5	1.5	7.5	7.5
4–0 days pre calv.	1.0	1.0	1.8	1.8	–	0.2	1.0	1.0	5.0	5.0
31.3–32.5	1.0	2.5	3.0	4.5	0.8	0.2	–	9.0	–	18.0
30.1–31.2	1.0	2.5	3.0	4.5	0.8	0.2	–	8.5	–	17.5
28.8–30.0	1.0	2.5	3.0	4.5	0.8	0.2	10.0	8.0	17.5	17.0
27.6–28.7	1.0	2.5	3.0	4.5	0.8	0.2	9.5	7.5	17.0	16.5

Details of feeding plan

Dry period or FCM, kg	Molasses SFU	Roots beet SFU	Grass silage SFU 1	Grass silage SFU 2	Beet top sil. SFU	Straw SFU	Grain mix SFU 1	Grain mix SFU 2	Total SFU 1	Total SFU 2
16.3–27.5	1.0	2.5	3.0	4.5	0.8	0.2	9.0	7.0	16.5	16.0
25.1–26.2	1.0	2.5	3.0	4.5	0.8	0.2	8.5	6.5	16.0	15.5
23.8–25.0	1.0	2.5	3.0	4.5	0.8	0.2	8.0	6.0	15.5	15.0
22.6–23.7	1.0	2.5	3.0	4.5	0.8	0.2	7.5	5.5	15.0	14.5
21.3–22.5	1.0	2.5	3.0	4.5	0.8	0.2	7.0	5.0	14.5	14.0
20.1–21.2	1.0	2.5	3.0	4.5	0.8	0.2	6.5	4.5	14.0	13.5
18.8–20.0	1.0	2.5	3.0	4.5	0.8	0.2	6.0	4.0	13.5	13.0
17.6–18.7	1.0	2.5	3.0	4.5	0.8	0.2	5.5	3.5	13.0	12.5
16.3–17.5	1.0	2.5	3.0	4.5	0.8	0.2	5.0	3.0	12.5	12.0
15.1–16.2	1.0	2.5	3.0	4.5	0.8	0.2	4.5	2.5	12.0	11.5
13.8–15.0	1.0	2.5	3.0	4.5	0.8	0.2	4.0	2.0	11.5	11.0
12.6–13.7	1.0	2.5	3.0	4.5	0.8	0.2	3.5	1.5	11.0	10.5
11.3–12.5	1.0	2.5	3.0	4.5	0.8	0.2	3.0	1.0	10.5	10.0
10.1–11.2	1.0	2.5	3.0	4.5	0.8	0.2	2.5	0.5	10.0	9.5
8.8–10.0	1.0	2.5	3.0	4.5	0.8	0.2	2.0	0	9.5	9.0
7.6– 8.7	1.0	2.5	3.0	4.0	0.8	0.2	1.5	0	9.0	8.5
6.3– 7.5	1.0	2.5	3.0	3.5	0.8	0.2	1.0	0	8.5	8.0
5.1– 6.2	1.0	2.5	3.0	3.0	0.8	0.2	0.5	0	8.0	7.5

1: 1st lactation (heifers); 2: 2nd and following lactations.

*) The level depended on the condition (flesh) of the cow. Thin cows were fed to a normal condition before calving.

2.2. Livestock and management

On basis of the theory for sample size in experiments on milk yield (Gill, 1969), the number of animals/lactations per treatment was planned to be approximately 10 per year through a period of 4 years. With this it should be possible to test a treatment difference of 1 kg of milk per cow daily with a high level of significance.

All experimental animals were Black and White Danish Dairy Cattle (SDM), and the experiment was carried out with commercial dairy herds. Variation in the yield potential of the cows within a herd was from a conventional significance point of view unwanted, but from an economic point of view the typical variation within a commercial herd helps to get more usable data for estimation of milk production functions. A private farm, A/S Søvang (H 901), with 120 cows was chosen as the site of the experiment, and the study on this farm included a total of 298 lactations (heifers and cows). To increase the amount of data relating to fertility, 3 treatments (L-½, M-½ and H-½) were carried out at Bannerslund (H 731) farm. The experimental design, feeds etc. were the same on the two farms. However, the period of the experimental treatment was shortened to weeks 1–24 of lactation at Bannerslund. This length was assumed to be sufficient for the particular purpose, a test of fertility. Herd H 731 will be discussed only in relation to fertility (Section 6.2.5).

The animals were divided into two groups according to parity (heifers and cows), and the assignment of animals to the respective experimental treatments was done randomly within these two groups. It should be noted that each animal, through all lactations, stayed on the treatment to which it was assigned at the start of the experiment. All animals were subjected to their respective treatments after parturition.

All cows on the nine treatments were fed the same amount of a basal ration almost equivalent to the requirements (energy and protein) for maintenance (Table 2.3). In the Norm treatment grass silage was fed in a fixed amount, adjusted to heifers and cows, respectively. In all other treatments grass silage was fed ad libitum, i.e. if no refusals were present in the morning there was fed 3 kg extra (approx. 10%) at the following feeding. The grass silage fed in the early afternoon was available for approximately 15 hours. Consequently, grass silage and grain mix competed in these eight treatments, as planned. To eliminate variation in protein level per SFU above maintenance, the composition of the grain mix was fixed at 160 g of digestible crude protein and 60 g of crude fat per SFU, this being similar to the content of a typical quality of grass silage.

The composition of the grain mix was:

35% oilcake mix (composition (%): cotton-seed (30), sunflower (20), soya (22), linseed (7), rape-seed (10), animal fat (4), molasses (5), dicalciumphosphate (1,5) and sodium chloride (0,5)).
35% rolled barley
18% rolled oats
6% wheat bran
6% molasses

Content per kg: 1.01 SFU; 160 g digestible crude protein and 60 g crude fat.

A mineral- and vitamin supplement was fed individually to cover the common standard for the total diet, which with the test feeds is very like the most common diets used in Danish dairy herds.

Table 2.3 shows in detail how the cows on the Norm treatment were fed. The cows on the other eight treatments differed only in level of grain mix (Tables 2.1 and 2.2) during week 1–36 of lactation since grass silage was fed ad libitum.

At the end of the lactation, from week 37 to the dry period (stage IV of lactation), all cows on the respective treatments were fed according to yield and condition. The condition was adjusted through the feeding to be good (score 4), but not fat (score 5). In this way all cows were fed alike during the dry period of 6 weeks (Table 2.3) and in good condition at calving, as planned.

Management of the feeding: Within all treatments each animal was fed the respective feeds separately in individual standings, and the following feeding sequences were practised:

Morning:	Grain mix, roots, minerals + vitamins, silage of beet tops and barley straw.
Afternoon:	Grain mix, grass silage, molasses and barley straw.

Feeding after calving on the Norm treatment: During 1–2 weeks the amount of feeds was increased slowly up to the planned level according to yield. However, during the first 6 weeks of lactation the animals were given 1 kg of grain mix per day in addition, and at least 6 kg per cow daily, independent of the milk yield. 6 weeks post partum the grain mix was fed according to yield, but the weekly decrease was not allowed to be greater than 0.5 SFU. If the basal ration and the grass silage was not consumed according to the plan, the refused feed was substituted by grain mix on a net energy basis (SFU). If a cow was thin (score 1–2) 12 weeks after calving, 1 kg of grain mix extra was fed daily in order to bring the cow into medium condition (score 3). At the end of lactation, i.e. after week 36 of lactation, all cows were fed to be in a good condition (score 4), before they were dried off. The Norm treatment (standard feeding) may thus be said to have been practised in an idealized way.

In the other eight treatments, the strategy of grain mix feeding was practised as soon as possible after calving. The amount of grass silage was increased and fed ad libitum as described, according to the current appetite of the individual animal. The fixed amounts of feeds representing the basal ration were accepted by all animals during lactation.

The cows were kept in individual standings in a shed (stanchion barn, insolated, ventilated) all the year round, except for a few of them during the first part of the dry period. Water was available from drinking bowls at all times. The cows were milked twice daily during lactation, but once a day during the week when they were dried off.

2.3. Recording the input and output

The intake of feeds (feed offerings minus feed refusals) by the individual cow was recorded daily. Samples of grass silage were taken weekly for chemical analyses and in vitro digestibility. For grain mix, molasses etc. the chemical composition was determined in each delivery and homogeneous lot.

Milk yields were recorded every second week, but not earlier than 4 days after parturition. The milk was analyzed for the content of butterfat, protein and solids. The body weight was recorded at the end of week 0, 12, 24, 36 and at the end of lactation by weighing all animals twice. On basis of these weighings the live weight change of the animals through the different stages of lactation were estimated. For all animals the chest girth was measured twice every 4 weeks through the lactation, and the condition of the animals was scored (independently) by two technicians according to the following numerical scale: very thin: 1; thin: 2; normal condition: 3; good condition: 4 and very fat: 5.

Each incidence of disease was recorded by the veterinarians and technicians. Reproduction status of the animals was also carefully checked, and inseminations were initiated at the first estrus subsequent to 50 days post partum. Performance at calving and the weight of the calf were recorded. If the animal was seriously injured by calving it did not enter the experiment. The policy of culling cows was defined by detailed rules for minimum yield at different stages of lactation. These rules were based on pre-determined lactation curves and are presented in Appendix A.

III. Material

3.1. Experimental animals, characteristics and season of calving

Each cow lactation was considered as a separate experimental unit, since equal condition of all animals was planned at drying off and at parturition independent of the treatments during weeks 1–36 of lactation. Furthermore, analyses showed in weeks 1–12 daily yields of 23.3 ang 23.6 kg FCM for cows irrespective of being in the experiment the previous lactation. The correlations between subsequent lactations from the same cow were also found to be small (see Table 6.18, Chapter VI).

The time of calving in alle treatments were spread throughout the year. However, small deviations for a specific treatment form the average distribution of the calvings did not effect the milk yield. The statistical analysis (Chapter IV) showed that animals calving during the winter and the spring produced approximately 0.5% less, while animals calving during the summer and the autumn produced approximately 0.5% more milk than the average of all animals.

During the years 1972–76 a total number of 298 experimental animals performed at least 36 weeks of lactation in herd H 901. These included 128 heifers and 170 cows distributed between the different treatments as shown in Table 3.1. Throughout the experimental period, a total number of 30 animals was culled as a consequence either of illness or the rules for culling because of low yield. In both cases culling of the animals could not be explained by the treatment, since analysis did not show significant differences between treatments.

The characteristics of the animals immediately after calving, as expressed by the live weight, chest girth and condition are shown in Table 3.1 for the respective treatments and parities, heifers and cows.

Table 3.1. Experimental animals (units) and their characteristics post partum

Treatment/Strategy	Lo	L–½	Mo	M–½	M+2,–1	M–1	Ho	H+1,–½	Norm
Heifers, number	13	13	17	15	14	14	13	14	15
Live weight,									
average, kg	480	481	477	473	473	479	485	484	466
s.d.	35	41	26	33	28	25	44	41	39
Chest girth,									
average, mm	1858	1851	1835	1844	1850	1826	1857	1854	1821
s.d.	59	76	51	56	54	37	69	69	74
Condition,									
average, score	3.25	3.11	3.23	3.08	3.40	3.00	3.20	3.30	3.09
s.d.	0.46	0.33	0.44	0.29	0.52	0.00	0.63	0.48	0.30
Cows, number	19	21	14	17	18	19	20	21	21
Live weight,									
average, kg	547	540	530	538	547	537	537	529	535
s.d.	43	49	33	36	47	48	46	37	54
Chest girth,									
average, mm	1906	1895	1895	1913	1924	1885	1908	1879	1883
s.d.	62	71	57	88	56	53	77	65	86
Condition,									
average, score	3.35	3.33	3.33	3.40	3.67	3.24	3.06	3.11	3.37
s.d.	0.61	0.59	0.65	0.63	0.49	0.56	0.56	0.58	0.50
Total number of animals (298):	32	34	31	32	32	33	33	35	36

3.2. Feeds, chemical composition and nutritive value

The feeds were of the same type each year, but due to the fact that the grass silage was made from several cuttings comprehensive analyses had to be made. These included: Dry matter, crude fibre, crude protein, true protein, ash, in vitro digestibility of organic matter, pH, NH_3-N, lactic acid, acetic acid, butyric acid, alcohol and the minerals: Ca, P and Mg. The grass silage was made in clamps from different grass species, and the raw material was unwilted or slightly wilted, as commonly practised.

The chemical analyses were made by the Department of Animal Physiology and Chemistry, National Institute of Animal Science, Copenhagen. The dry matter content, content of crude ash, crude protein, true protein, crude fat and crude fibre were determined as described in Chemistry of Feedstuffs and Animals (Jacobsen and Weidner, 1973). The determination of the in vitro digestibility was made by Vestergaard Thomsen, Department of Cattle and Sheep Experiments, by means of the method described by Tilley and Terry (1963) and modified by Frederiksen (1966).

Contents of lactic acid, acetic acid, butyric acid and NH_3-N were determined on fresh silage by the methods described by Pedersen (1966). The Ca and Mg content was determined by atomic absorption, and the content of P was determined colometrically. Content of alcohol was determined by an unpublished method by J. O. Andersen, The Department of Animal Physiology and Chemistry.

The nutritive value of the feeds expressed as SFU per kg, was estimated on the basis of the chemical analyses. The nutritive value of grain mix was calculated by means of the method given by Andersen et al. (1970), using the chemical analyses for dry matter, ash, crude fat, crude protein and crude fibre. The digestibility coefficients of the organic components in the grain mix were calculated on the basis of tabulated values of the single components (barley, cotton seed cake etc.). The nutritive value of barley straw was calculated in the

Table 3.2. Chemical composition, in vitro digestibility and nutritive value of feeds

	Num. of samp.	Dry matter content % DM	% of dry matter			Dig. coef. org. matter in vitro	Per kg of DM	
			Crude fibre	Crude protein	Ash		SFU	Dig. crude protein, g
Grain mix								
Average	(24)	87.0	8.3	23.7	4.9	82.3	1.11	179
s.d.		0.9	1.2	2.2	0.5	1.1	0.01	29
Grass silage								
Average	(162)	22.2	31.8	13.8	13.3	65.7	0.69	96
s.d.		3.5	3.5	2.4	3.4	6.4	0.04	23
Beet-top silage								
Average	(39)	19.1	14.8[1]	16.5	19.3	–	0.75	112
s.d.		2.4	–	1.7	4.0	–	0.04	13
Grass cobs								
Average	(7)	91.0	25.9	13.6	9.9	72.7	0.61	79
s.d.		1.0	1.2	1.0	0.8	2.7	0.03	9
Dried sugar beet pulp + molasses								
Average	(10)	89.1	17.1	12.0	7.9	–	0.94	83
s.d.		5.7	0.1	0.2	0.3	–	–	–
Molasses								
Average	(14)	74.7	0	13.6[1]	10.3[1]	–	1.00[1]	97[1]
s.d.		4.1	–	–	–	–	–	–
Fodder beets								
Average	(6)	16.2	6.2[1]	7.4[1]	6.8[1]	–	0.90[1]	36[1]
s.d.		1.5	–	–	–	–	–	–
Barley straw								
Average	(4)	91.5	33.6	6.1	8.9	–	0.28	11
s.d.		0.8	3.4	1.4	0.7	–	0.01	3

[1]) Standard-values (Andersen et al., 1970).

same way, and on the basis of the content of dry matter, ash, crude protein and crude fibre (Andersen et al., 1970).

The nutritive value of grass cobs was calculated on the basis of the content of dry matter, crude fibre, crude protein and insoluble ash. Roots, molasses and dried sugar beet pulp were only analysed for the dry matter content, and calculation of the nutritive values was based on the respective standard nutritive values of the dry matter, also given by Andersen et al. (1970).

The nutritive value of grass silage and beet-top silage was determined by the method given by Frederiksen (1969). The method for grass silage was based on the contents of dry matter, ash, crude protein and crude fibre, and that of beet-top silage was based on the contents of dry matter, crude protein and ash.

The different feeds are described in Table 3.2. The largest relative variation in chemical composition, digestibility and nutritive value was found for grass silage. This variation is unwanted from a conventional significance point of view, but desirable for practical application aspects.

Table 3.3. shows some quality characteristics of the grass silage.

Table 3.3. Quality characteristics of the grass silage

	Number of samples	Mean	s.d.
Lactic acid, % of dry matter	26	1.2	0.9
Acetic acid, % of dry matter	25	1.3	0.5
Butyric acid, % of dry matter	20	0.8	0.9
Alcohol, % of dry matter	11	0.3	0.3
NH_3-N % of total N	27	16	10
pH	160	4.3	0.5

The relative low content of organic acids especially lactic acid is probably due to the use of approcimately 1 litre of formic acid per ton green-mass for the ensiling.

IV. Statistical Procedures

4.1. Introduction

The design of the present experiment (Chapter II), made it possible to analyze the data with the amount of concentrates fed as the independent variable and intake of grass silage (fed ad libitum), total food intake and size and composition of production as dependent variables. Furthermore, different characteristics of the cows used, such as size, parity and yielding capacity, could be included in the analysis as independent variables, in order to investigate possible differences and interactions in the response to concentrate feeding.

The statistical procedures used for analyzing the experiment are briefly discussed in the following. The discussion is mainly based on Snedecor and Cochran (1967) and Draper and Smith (1966). The analyses are computed with procedures from Statistical Analysis System (Barr et al., 1976). The discussion is written in close co-operation with stud. lic. agro. I. Thysen, who carried out the computations.

4.2. Analysis of treatment effects

The effect of treatments (strategies) on the above mentioned dependent variables was analyzed with the following model:

(1) $$Y_{ijk} = \mu + \beta \cdot W_{ijk} + \alpha_i + \gamma_j + (\alpha\gamma)_{ij} + \varepsilon_{ijk}$$

where Y_{ijk} = any dependent variable observed on the k'th cow in the i'th lactation number and the j'th strategy,

μ = location parameter common to alle observations,

W_{ijk} = weight of the ijk'th cow at the beginning of the period analyzed,

β = coefficent of regression of dependent variable Y on weight W,

α_i = effect of the i'th lactation,

γ_j = effect of the j'th strategy,

$(\alpha\gamma)_{ij}$ = effect of interaction between the i'th lactation and j'th strategy,

ε_{ijk} = residual term.

The following comments are given on model (1):

a) Weight and parity are cow characteristics measuring size and age. Model (1) has two classes of parity (1: First lactation; 2: Second and following lactations) as cows were assigned randomly to strategies within these two classes. In the early stages of data analysis transformation of weight to metabolic weight (kg ¾), and interactions between weight and parity, and between weight and strategy were found to be non-important.

b) The independence of the residuals (ε_{ijk}) was investigated for two possible sources of dependence: i) seasonal variation in the environment, where no systematic trends could be detected, and ii) correlations between subsequent lactations from the same cow. The latter were found to be rather small (see Table 6.18), and furthermore the cows had at most 3 and on average 1.5 complete lactations (36 weeks) during the experiment. For these reasons, dependence of the residuals for the above mentioned reasons was not considered to affect the validity of the analysis.

The null-hypothesis of no effects of weight, parity, strategy and interaction were tested with F-tests, where F = effect mean square divided by error mean square.

Differences between treatment means were tested with the 95% least significant difference (Snedecor and Cochran 1967, p. 272):

$$(2) \qquad \mathrm{LSD} = t \cdot s \cdot \sqrt{\frac{2}{n}}$$

where t = the 97.5% point of the Student-Fisher t-distribution with d.f. equal to the error d.f. of the analysis of variance,

s = standard deviation obtained in the analysis of variance,

n = number of replications (cows) per treatment.

It should be noted that when several mean values are tested with the t-test, as is the case when the LSD value is used, the level of significance is connected with each single t-test. The probability of declaring at least one difference significant by mistake is therefore considerably larger than the significance level used. This possibility of error can be controlled by other test criteria (Snedecor and Cochran, 1967), but at the expense of fewer detections of real significant differences. For this reason the LSD-test was chosen; it should be used as a general reference for the variability between treatment means and used with care, when the F-test for treatment effects is non-significant.

4.3. Estimation of response functions

The major objective of the experiment was to quantify the response in voluntary intake of grass silage and milk yield to the input of concentrates. These response functions were estimated by means of regression analysis. It should be noted that »concentrates« refer to grain mix alone or grain mix plus other concentrates used.

4.3.1. Statistical models

Two aspects of the analysis described in the previous section were considered in deciding on the regression model.

Firstly, if interaction between strategy and parity was present, the two classes of parity were analyzed separately. If interaction was not present, analysis of co-variance was used with both classes simultaneously. Secondly, the treatments consisted of two components, the amount of concentrates and the pattern of giving the concentrates. In the estimation of response functions, it was supposed that the way of giving the concentrates did not affect the response. From the results from model (1) it can be seen if a strategy disagrees with this hypothesis and therefore should be deleted from the regression analysis.

The regression models were also based on studies of information from sources other than the present experiment (see Sections 5.1 and 6.1). It was concluded that the response functions could be represented by parabolas, leading to model (3), and, furthermore, that the parabolas have a maximum at an input of X_m units of concentrates, leading to model (4):

$$(3) \qquad Y_{ik} = \beta_o\ [+\ \alpha_i] + \beta_1 X_{ik} + \beta_2 X^2{}_{ik} + \varepsilon_{ik}$$

$$(4) \qquad Y_{ik} = \beta_3\ [+\ \alpha_i] + \beta_4 (X_{ik} - X_m)^2 + \varepsilon_{ik}$$

where Y_{ik} = silage intake or milk yield of the k'th cow in the i'th lactation,

X_{ik} = amount of concentrates to the k'th cow in the i'th lactation,

$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$ = regression parameters to be estimated

α_i = effect of the i'th lactation (used only when the two classes of parity were analyzed simultaneously) and

ε_{ik} = random variable.

4.3.2. Test of the adequacy of the models

On each treatment the food intake and milk yield have been measured for a number of cows. Each X-value is therefore connected to several Y-values. The deviation of the Y-value estimated by the model from the observed Y-value can consequently be partionated into two parts: The deviation from the curve to the treatment mean and the deviation from the treatment mean to the individual Y-value. The first part is due to lack of fit of the model to the data and the second part is due to the individual variation between the cows, and is pure error, as this part does not depend on the model.

The residual sum of squares (SS) of the regression analysis can be partionated in a similar way into lack of fit SS and pure error SS (Draper and Smith, 1966, p. 26–32). The partionating can be obtained by combining the regression analysis with an analysis of the treatment effects in the following way:

Regression analysis	Adequacy test	Analysis of treatment effects
Regression SS	= Regression SS	= Between treatments SS
Residual SS =	Lack of fit SS	
	Pure error SS	= Within treatment SS

The degrees of freedom are obtained in a similar manner.

The corresponding pure error mean square (MS), is an unbiased estimate of the true variance. The lack of fit MS is an estimate of the true variance + a bias term, which is due to the departure from the curve to the treatment means. If the model is correct, then the bias term is equal to zero and the lack of fit MS equal to the pure error MS. The adequacy of the model can therefore be tested with a F-test of the null-hypothesis: lack of fit MS > pure error MS. When the F-test does *not* show significance then, in the words of Draper and Smith (1966), »there appears to be no reason for doubting the adequacy of the model«.

4.3.3. Confidence intervals

The regressions equations obtained can be regarded as estimates of the population functions, and they can, as such, be used in the planning of dairy feeding. The equations can then be used a) to estimate the size of production to a given input of concentrates and b) to estimate the change in response associated with a change in the amount of concentrates, i.e. in optimizing the input of concentrates economically.

It is, naturally, important to know the precision of such estimates. In the following will be given formulas for the above mentioned estimates and their confidence intervals.

It should be noted that the term α_i is defined as follows: α_1 = mean of first lactation minus mean of second and following lactations, and α_2 = o. The residual variance (s^2) is assumed to be equal for both parity groups. The variances of β_1, β_2 and β_4 are denoted s_1^2, s_2^2 and s_4^2. The covariance between β_1 and β_2 is denoted s_{12}.

a) The expected mean response of a group of m cows, of which m_1 is in first lactation, to an input of X_0 units of concentrates is, for model (3) and (4) respectively, given by:

(5):

$$\hat{Y} = \hat{\beta}_0 + \frac{m_1}{m}\hat{\alpha}_1 + \hat{\beta}_1 X_0 + \hat{\beta}_2 X_0^2$$

and

$$\hat{Y} = \hat{\beta}_3 + \frac{m_1}{m}\hat{\alpha}_1 + \hat{\beta}_4 (X_0 - X_m)^2$$

with 100 (1-q) per cent confidence intervals:

(6):

$$\pm\, t_{½q,f} \times \sqrt{\frac{s^2}{m} + \frac{s^2}{N} + s^2\frac{m_1}{m}\left(\frac{1}{n_1} - \frac{1}{N-n_1}\right) + s_1^2(X_0-\bar{X})^2 + s_2^2(X_0^2-\overline{X^2})^2 + s_{12}(X_0-\bar{X})(X_0^2-\overline{X^2})}$$

and

$$\pm\, t_{½q,f} \times \sqrt{\frac{s^2}{m} + \frac{s^2}{N} + s^2\frac{m_1}{m}\left(\frac{1}{n_1} - \frac{1}{N-n_1}\right) + s_4^2((X_0-X_m)^2 - \overline{(X - X_m)^2})^2}$$

where $t_{½q,f}$ = the ½q point of the Student-Fisher t-distribution with d.f. equal to the error d.f. in the regression analysis

N = the total number of cows in the regression analysis

n_1 = the number of cows in first lactation in the regression analysis.

In (6) $(X_0-\bar{X})$ is used instead of X_0 in order to avoid co-variances between the intercept (β_0 or β_3) and the regression coefficients in the formulas. The terms containing m_1 are excluded when separate equations for the two parity classes are used, and when $m_1 = o$.

b) In optimizing the concentrate input, interest is placed on the marginal response given by the derivatives of the equations:

(7):

$$\frac{dY}{dX_0} = \hat{\beta}_1 + 2\hat{\beta}_2 X_0$$

and

$$\frac{dY}{d(X_0 - X_m)} = 2\hat{\beta}_4 (X_0 - X_m)$$

with 100(1–q) per cent confidence intervals.

(8):

$$\pm t_{\frac{1}{2}q,f}\sqrt{s_1^2 + 4s_2^2X_0^2 + 4s_{12}X_0}$$

and

$$\pm t_{\frac{1}{2}q,f}\sqrt{4s_4^2(X_0-X_m)^2}$$

The estimates of the marginal response and their confidence intervals thus depend solely on the regression coefficients and their standard deviations.

c) When model (3) is used, the input giving maximum response is given by:

$$(9) \quad X_m = \frac{\hat{\beta}_1}{2\hat{\beta}_2}$$

with confidence interval (Bliss, 1970, p. 49):

$$(10) \quad C\,X_m - K \pm \sqrt{(C-1)\,CX_m{}^2 + \frac{s_1^2}{4s_2{}^2} + K(K - 2CX_m)}$$

$$\text{with } C = \frac{\hat{\beta}_2{}^2}{\hat{\beta}_2{}^2 - s_2{}^2 \cdot t^2_{\frac{1}{2}q,f}}$$

$$\text{and } K = \frac{-s_{12}\,(C-1)}{2s^2{}_{22}}$$

4.4. Analysis of models of lactation curves of food intake and milk yield

In the experiment, measurements of food intake and milk yield were taken daily (summed for the week) and each second week, respectively. In Section 2 of this chapter was discussed the analysis of mean values for a specific period of time during lactation. In this section will be discussed a more extensive analysis that also includes the shape of the curves formed by all measurements during lactation. This analysis will be performed by fitting the measurement from each cow to a hypothetical underlying model, the »within individual model«, and then analyse the estimated parameters with a »between individuals model«, as for example model (1). Attention must be paid, however, to possible correlations between the estimated parameters of the within individuals model. If these are present, a multi-variate technique should be used in the analysis of the across individuals model (see e.g. Morrison, 1976).

4.4.1. Models of intake of grass silage

Curves of the voluntary intake of grass silage during lactation are shown in the Fig. 5.3–5.6, the daily intake increasing in the first 12–16 weeks after parturition and remaining more or less constant thereafter.

Different algebraic models were fitted to the intake during lactation, for example a three-degree polynomium and Wood's (1967) model for the milk yield curve. None of these were satisfactory.

A new model was then constructed. It was assumed that the increasing part of the curve could be described by the asymptotic function (Snedecor and Cochran,1967, p. 448).

$$(11) \quad Y_t = a - b \cdot e^{-c \cdot t} + \varepsilon_t$$

where Y_t = intake in week t
e = the base of the natural logarithm and
a, b, c are parameters to be estimated.

To allow for a positive or negative trend in the latter part of lactation, a linear term was added to model (11):

$$(12) \quad Y_t = a - b \cdot e^{-c \cdot t} + d \cdot t + \varepsilon_t$$

This function is non-linear in its parameters. Least-squares estimates of the parameters were found by means of the NLIN-procedure in the SAS-system using a modified Gauss-Newton method (Barr et al., 1976). A curve was fitted for each strategy/parity-group on the basis of mean weekly values of daily intake for the respective groups.

The model showed a good fit to the data. The residual sums of squares were less than 1% of the total between weeks-sums of squares and about 5–30% of between weeks-sums of squares corrected for the mean (the latter percentage is comparable to 100–R^2 in linear regression). The average deviation from the estimated intake to the observed intake was approximately 0.2 kg (Table 5.10, Chapter V).

In Fig. 4.1. are shown observed and estimated intakes for three groups. The first curve is typical for most of the strategy/parity-groups, while the two other curves are more specific, showing, respectively, a pronounced increase and decrease in intake in the latter part of lactation. This can be explained by the pattern of feeding concentrates.

4.4.2. Models of milk yield

Curves of the daily milk yield during lactation are given in Fig. 4.2. These curves showed an almost linearly decreasing yield in most cases, suggesting the following within individual model:

(13) $Y_t = \bar{Y} + b_1 (t-\bar{t}) + \varepsilon_t$

where Y_t = yield in week t

$\bar{Y}$ = mean yield

b_1 = regression coefficient or persistency of yield.

The goodness of fit of model (13) was tested by a technique modified after Grizzle and Allen (1969): A complete description of the 18 observations of yield from each cow can be supplied by a regression model containing terms of o'th degree through 17'th degree. If model (13) is correct, then all coefficients of degrees higher than 1 have expected values equal to zero and the adequacy of the model can therefore be tested by testing this hypothesis.

The regression coefficient of all degrees for each cow were calculated by means of orthogonal polynomials (see e.g. Snedecor and Cochran, 1967, p. 460). The mean values of the coefficients are calculated for each strategy/parity-group and by means of t-tests it is tested whether these means are significantly different from zero.

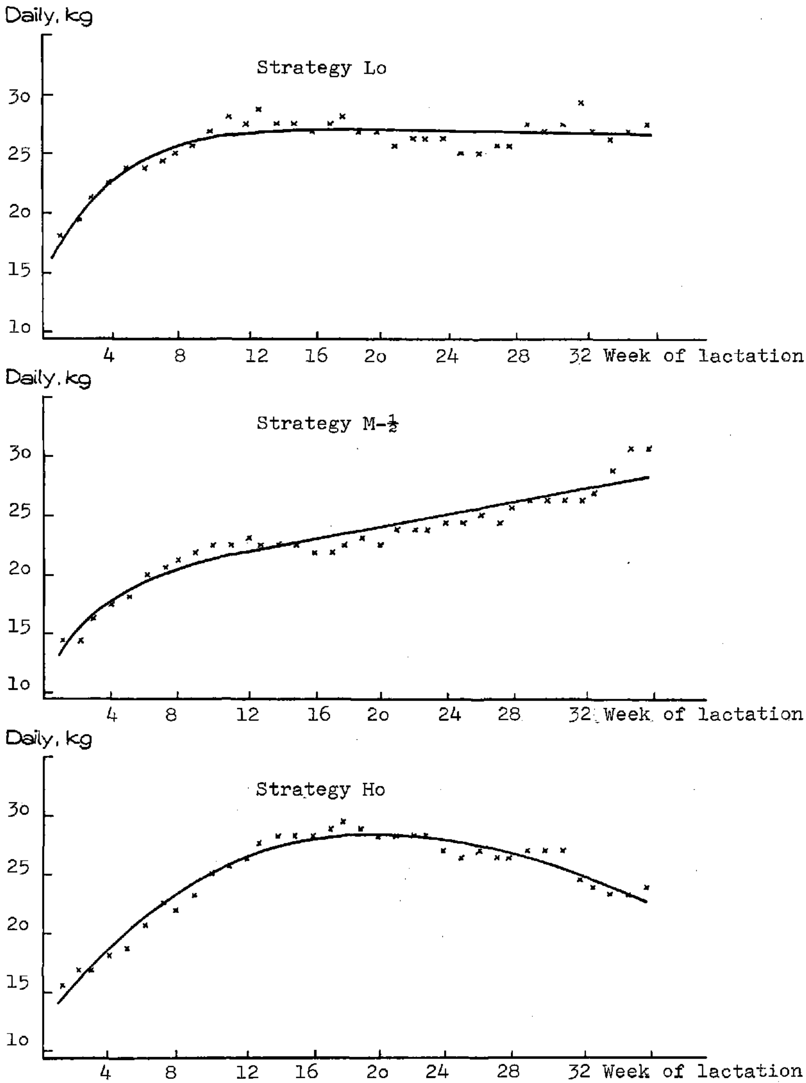

Fig. 4.1. Daily intake of grass silage of heifers on certain strategies during weeks 1–36 after parturition: observed intake (x) and intake estimated from model (12)

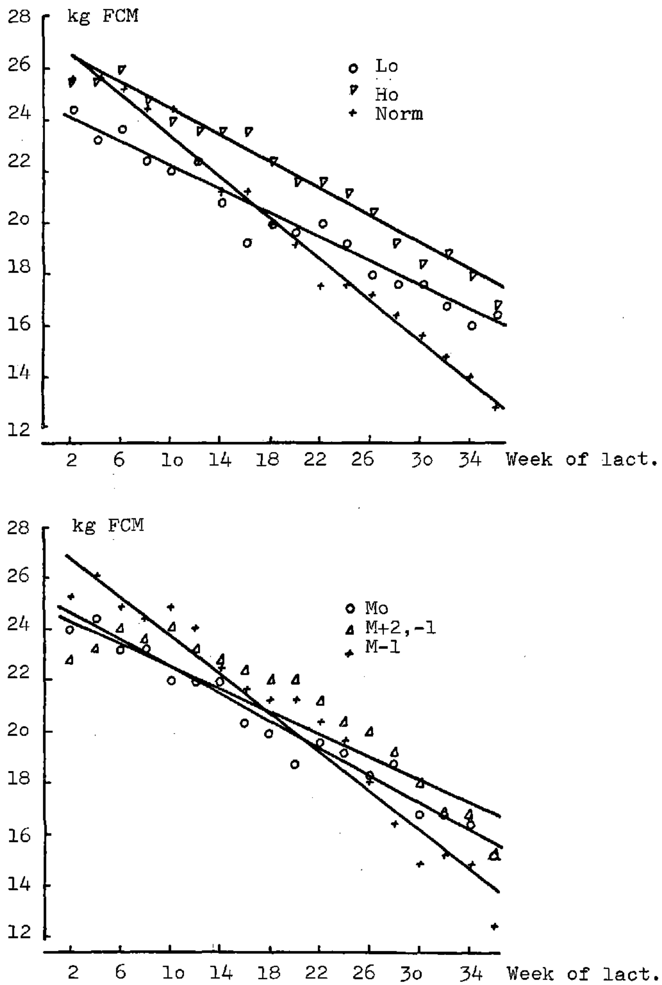

Fig. 4.2. Daily milk yield of cows during weeks 1–36 after parturition: observed and estimated (the lines) for certain strategies from model (13)

In Table 4.1. is given the mean values of the coefficients of quadratic and cubic terms along with the t-tests. Coefficients of higher orders were not of great interest as the curve is known to be nearly a straight line. An exception to this in strategy M+2, and M–1, which show considerable curvature (Table 4.1).

The next step in the analysis was to examine the effects of body weight, lactation number and strategy on mean yield ($\bar{Y}$) and persistency (b_1) by model (1).

Table 4.1. Mean value and probability of zero mean value of quadratic and cubic coefficients of regression of FCM on lactation week (kg × 10^{-3})

Strategy	First lactation				Second + following lactations			
	Quadratic		Cubic		Quadratic		Cubic	
	Mean	P	Mean	P	Mean	P	Mean	P
L_0	–0.2	0.96	1.0	0.18	2.5	0.40	–0.2	0.81
$L_{-½}$	–2.7	0.47	0.5	0.49	–6.0	0.040	0.2	0.75
M_0	2.3	0.49	1.4	0.037	–1.4	0.71	–0.4	0.62
$M_{-½}$	–5.6	0.11	0.5	0.47	–1.1	0.74	0.2	0.71
$M_{+2,-1}$	–15.1	0.0001	2.0	0.0065	–19.4	0.0001	0.6	0.36
M_{-1}	–14.0	0.0001	1.4	0.058	–13.1	0.0001	0.6	0.31
H_0	–6.5	0.079	–0.5	0.50	–6.3	0.037	0.1	0.85
$H_{+1,-½}$	–7.5	0.035	0.1	0.93	–7.0	0.018	0.1	0.88
Norm	2.7	0.44	1.3	0.065	–1.6	0.59	0.3	0.62

A point of interest was whether the deviation of each individual's curve from the mean curve of its group could be described by a characteristic on the individual, for example the yield capacity. In order to make such a model usable for the estimation of the full lactation curve from a few milk recordings in the beginning of the lactation, the average yield in the first 4 weeks of the experimental period was taken as an estimate of the yielding capacity. However, as this initial yield is affected by strategy and parity, the yielding capacity has to be estimated as the deviation of the individual's initial yield from the mean of its group.

The initial yield defined as above was computed as the residuals from an analysis with model (1) on the yield in weeks 1–4. The initial yield was then used as a co-variate in the analysis on mean yield and persistency.

The effect of the treatments could possibly depend on the yielding capacity of the cow and, therefore, interactions between initial yield and treatment were also analysed.

4.5. Analysis of incidence of disease

Data on incidence of disease consisted of qualitative (discrete) variables and special statistical methods were needed for the analysis. In this experiment a method developed by Grizzle, Starmer and Koch (1969) was adapted. For an application of the method to experiments in animal husbandry, see Thysen (1978).

To analyse the incidence of a disease or a class of diseases in a given period of the lactation, the cows were divided into two categories on the basis of daily inspections: 1) cows having the disease or diseases in question at least once during the period and 2) cows not having the disease or diseases.

Since the hypothesis was that parity and treatment might affect the incidence of the disease, the following linear model was used:

(14) $$p_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$$

where p_{ij} = the relative frequency of cows with the diseases on the i'th parity and the j'th treatment
μ = mean
α_i = effect of the i'th parity
β_j = effect of the j'th treatment
ε_{ij} = residual term

However, if the relative frequency is close to 0 or 1, then it is not reasonable to expect a linear model to fit well. In these cases were used the logit transformation (Snedecor and Cochran, 1967, p. 494).

(15) $$Y_{ij} = \ln \frac{p_{ij}}{1-p_{ij}} \quad \text{and} \quad \text{Var.}\,(Y_{ij}) \approx \frac{1}{p_{ij}(1-p_{ij})N_{ij}}$$

and model (16):

(16) $$Y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$$

Grizzle, Starmer and Koch (1969) have shown that when models similar to (14) and (16) are analysed with a weighted least squares procedure (the weights being the reciprocals of variances of p_{ij} or Y_{ij}) then the sums of squares computed are identical to the minimum – Neyman – chi-square statistic

(17) $$\chi^2 = \Sigma \frac{(\text{observed rel. freq.} - \text{expected rel. freq.})^2}{\text{observed rel. freq.}}$$

which can be used in a way similar to the well-known Pearson-chi-square.

A standard weighted regression computer program can therefore be used in the analysis of model (14) and (16). The sums of squares computed are then chi-square statistics and a table of the chi-square-distribution is used as reference to judge significance. The degrees of freedom produced are correct.

The error SS can be interpreted as a measure of the variation due to interaction between parity and treatment. The SS of the effects of parity and treatment, respectively, give the difference in χ^2 when these effects are included and not included in the model, and can be used to test the influence of parity and treatment on the incidence of the diseases.

V Food intake

5.1. Literature and introduction

The voluntary intake of food has been studied in many experiments, but few data are available in the literature from which to estimate the total food intake as a function of the level of concentrates when feeding forage ad libitum and feeding the concentrates independent of the daily milk yield. The reason for this is that most published studies have been of a physiological nature, the aim of which was to define the physiological factors which regulate food intake (Balch and Campling, 1969; Bines, 1976; Journet and Remond, 1976; Kaufmann, 1976).

To understand how the voluntary food intake can be regulated*) by means of the level of concentrates, the regulating factors should be noted. Balch and Campling (1969) emphasize the following factors: 1) physical factors [a) size of reticulo-rumen, b) amount of digesta, c) digestibility of the food, d) rate of passage, e) rate of flow and f) oropharyngeal factors] and 2) the thermostatic as well as 3) the chemostatic regulation.

On the basis of experiments in mid-lactation in which grass silage was fed ad libitum (Lingvall, 1977; Rohr et al., 1974; Ekern, 1972 III; Mather et al., 1960) a calculation can be made of the change in intake of silage per unit of change in the level of concentrates, when the latter is changed from one level to another (Fig. 5.1). Using published data this relationship was calculated on a dry-matter basis. As the silage was rich in protein, it was assumed that the marginal change in silage intake was zero when no concentrates were fed. The following function was then obtained for the marginal silage intake (MSI) (Note: The term »function« refers to the regression equation based on given empirical data. The term »model« is used in the statistical discussion):

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*) »to regulate« is here and on the following pages used – as in the working hypothesis (Chapter I) – in the sense of: »to adjust the quantity of feeds eaten to the amount desired in the feeding plan set up by the dairy farmer«.

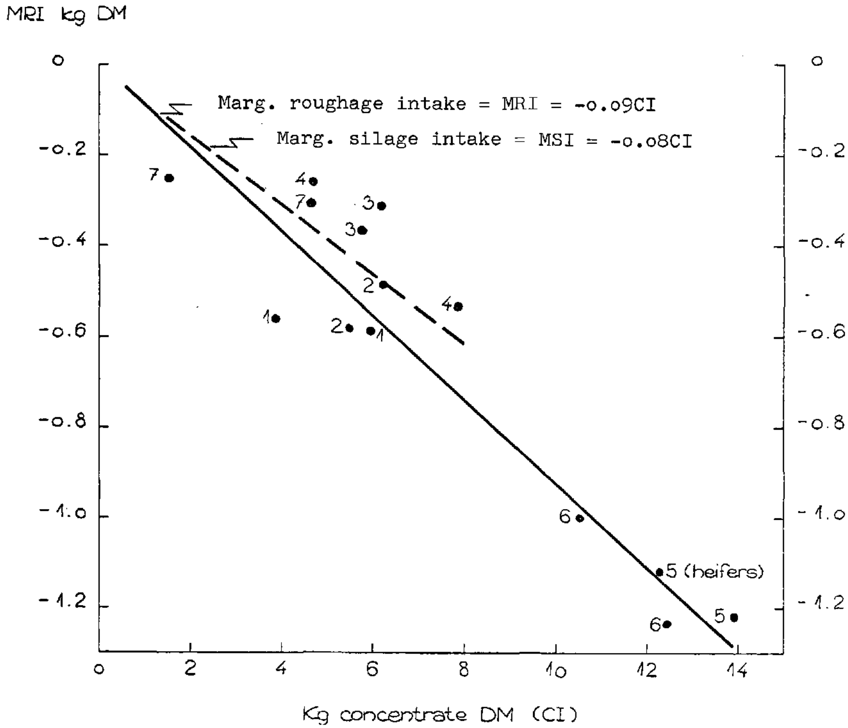

Fig. 5.1. Relationship between »marginal« change in intake of roughages (mainly grasssilage) fed ad lib. and level of concentrate intake.

Sources:

1. Lingvall,	1977.	Grass silage. Week 12–26.
2. Ekern,	1972 III.	Grass silage. Week 13–18[1])
3. Ekern,	1972 III.	Grass silage. Week 19–26.[1])
4. Rohr et al.,	1974.	Grass silage. Mid-lactation.
5. Bines,	1976.	Forage: Hay. Data at peak intake. Week 10–18.
6. Kesler & Spahr,	1964.	Forage: 50% alfala-grasshay and 50% corn silage.
7. Mather et al.,	1960.	Grass silage; main roughage.

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[1]) Concentrates fed at two levels according to yield.

(18) $MSI = -0.077CI$,

where CI = kg concentrates DM intake daily.

The silage intake (SI) thus becomes:

(19) $SI = \text{constant} -0.038CI^2$.

To obtain functions for higher levels of concentrates it was necessary to include experiments, in which the concentrates were mixed with hay (Bines, 1976; Kesler and Spahr, 1964). The results are shown in Figure 5.1, and on the basis of all the data the following functions were calculated for marginal roughage intake (MRI) and roughage intake (RI):

(20) $MRI = -0.09CI$

(21) $RI = \text{constant} -0.045CI^2$

These relationships are in agreement with observations from physiological studies, which show that higher levels of starch have a depressing influence on fibre digestion (Head, 1953; Zeremski, 1965; Conrad et al., 1966; Lonsdale et al., 1971; Tayler and Aston, 1976). A reduced rumen pH is unfavourable to the cellulolytic bacteria (Kaufmann, 1972), and consequently the time of digestion and the filling effect of the food is increased. Furthermore, higher levels of concentrates cause higher levels of energy intake which may reduce the voluntary food intake through chemostatic regulation (Balch and Campling, 1969).

Using function (21) above, the voluntary dry matter intake (VDM) of grass silage and total food, as well as the intake of net energy (SFU) were calculated for increasing levels of concentrates, and depicted in Fig. 5.2. The intake was based on well conserved silage (digestibility of organic matter 65–70%) with a total intake, at zero concentrates to a cow of 550 kg live weight, of 14 kg DM of grass silage, (= the constant in function (21)) according to estimates of Østergaard (1973). Despite reservations about the compilation in Fig. 5.1, it may reasonably be concluded that these functions demonstrate how food intake can vary with the level of concentrates. The dry matter intake reaches a maximum at a concentrate level equal to 11 kg of DM (= approximately 60% of total dry matter), while the calculated net energy (SFU) is still increasing, but at a slower rate for reaching a maximum possible just above 70% concentrate dry matter.

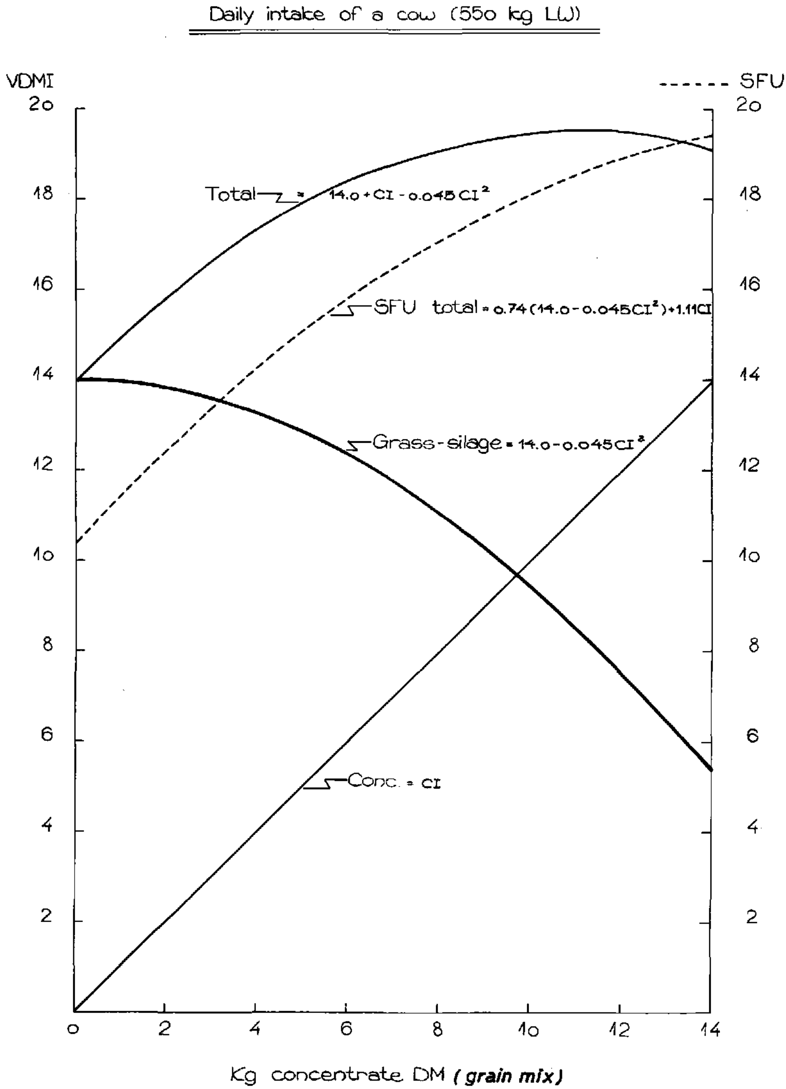

Fig. 5.2. Functions for voluntary dry matter intake (VDMI) of a high producing dairy cow for increased level of concentrates.

5.2. Own investigations

5.2.1. Total food intake

The relationships in Fig. 5.2 support the hypothesis formulated in chapter I, viz: »Even when the main roughage is fed ad libitum, it is possible by means of the concentrate feeding to regulate within certain limits the total food intake«.

This hypothesis was tested on the data of the present experiment (Chapter II), by means of an analysis of variance on total food intake (SFU per cow daily). The result of the analysis on the 9 treatments for various stages of lactation is shown in Table 5.1. Model (1), which includes the effects of the weight of the cow, parity, strategy, and the interaction between strategy and parity, explains 56–60% of the total variation (R^2) in total food intake, independent of the stage of lactation. Among the sources of variation in total food intake the strategy x parity interaction was not significant.

The strategy effect was highly significant for all stages of lactation ($P < 0.001$). The first part of the hypothesis was therefore accepted. The effect of parity was also significant for all stages of lactation except stage III. The effect of live weight at the beginning of each stage of lactation was significant, except for stage III, where P was 0.69. One reason for this could be the variation in body condition of the cows at this late stage of lactation.

Table 5.2 shows the least squares estimates of the effects of weight with the regression coefficient for the various stages of lactation, these being 0.53, 0.43, 0.07, 0.48 and 0.42 SFU, respectively, per 100 kg change in the initial live weight. The average live weight of all animals at calving was 512 kg. The above figures are rather low but can be explained by the nutritive value and the quality of the grass silage (Chapter III) as well as the amount of the daily basal ration (4.4 SFU) and the grain mix (average 6 SFU during weeks 1–36 (Table 2.2)).

Table 5.1 Analysis of variance on total food intake (SFU per cow daily)

Stage of lactation		I		II		III		I–II		I–III	
Weeks of lactation		1–12		13–24		25–36		1–24		1–36	
Source	d.f.	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Model	18	299.3	16.63	443.8	24.66	571.5	31.75	277.3	15.41	262.3	14.57
Error	279	229.3	0.82	335.2	1.20	389.2	1.40	205.8	0.74	205.5	0.74
R^2 (%)		56.6		57.0		59.5		57.4		56.1	
Source	d.f.	SS	P	SS	P	SS	P	SS	P	SS	P
Weight[1)]	1	13.0	0.0001	7.8	0.011	0.2	0.69	10.7	0.0002	8.1	0.0010
Parity	1	12.9	0.0001	6.9	0.017	0.2	0.68	9.0	0.0006	3.3	0.035
Strategy	8	214.8	0.0001	380.7	0.0001	517.7	0.0001	212.7	0.0001	222.2	0.0001
Strat. × parity	8	10.5	0.12	15.3	0.13	17.1	0.15	11.5	0.053	8.2	0.20

1) Initial live weight of the cow for the respective stages of lactation.

Table 5.2 Least squares estimates of the effects of weight (regression coefficient), parity and strategy (adjusted means) on total food intake, SFU per cow daily

Stage of lactation Weeks of lactation	I 1–12	II 13–24	III 25–36	I–II 1–24	I–III 1–36
Source					
Live weight (SFU per 100 kg)	0.53	0.43	0.07	0.48	0.42
Parity, Heifers	14.12	14.26	13.60	14.30	14.07
Cows	14.97	15.08	13.70	15.03	14.60
Strategy[1]) L_0	12.92	13.63	13.67	13.29	13.41
$L_{-½}$	14.29	13.89	12.45	14.09	13.55
M_0	13.87	14.64	14.85	14.26	14.47
$M_{-½}$	15.03	14.43	13.35	14.74	14.28
$M_{+2,-1}$	14.47	16.09	13.61	15.31	14.75
M_{-1}	16.26	14.68	12.15	15.49	14.38
H_0	14.96	15.41	15.89	15.55	15.67
$H_{+1,-½}$	15.20	16.58	15.20	15.90	15.68
Norm	14.40	13.25	11.76	13.82	13.14
LSD[2])	0.44	0.53	0.57	0.41	0.41
Overall mean[1])	14.60	14.87	13.66	14.72	14.37

[1]) 43% first lactation (heifers). [2]) LSD = least significant differences.

The difference between cows and heifers in average daily food intake decreased from 0.85 (14.97–14.12) in weeks 1–12 to 0.10 SFU in weeks 25–36 of lactation, when the live weight post partum was 538 and 477 kg respectively (Table 5.2.).

The mean food intake, adjusted for live weight and parity (the different treatments have equal percentage of heifers (43%) and cows (57%) respectively), for the 9 strategies is shown in Table 5.2. By studying weeks 1–12 of the lactation for example, the difference in food intake is clearly evident. The intake of SFU varied from 12.92 for strategy Lo to 16.26 for strategy M-1.

The figures in the last column of Table 5.2 show by means of the least significant differences (LSD) that there was no significant difference between total food intake during weeks 1–36 within the same total input of grain mix. This was so even with quite different patterns of feeding of the grain mix within the three levels L, M and H, except between M-½ and M+2, -1. There was however a clear significant difference in total food intake between these three levels of grain mix.

5.2.2. Voluntary intake of grass silage

A second part of the hypothesis was that »Even when the main roughage is fed ad libitum the composition of the ration can be regulated by means of the level of concentrates«. This hypothesis was verified by testing the voluntary intake of grass silage with the same model (Model (1)) and independent variables as was used with total food intake (SFU). The analysis of variance, which does not include the Norm treatment because of the standard feeding with a fixed amount of grass silage, is shown in Table 5.3.

Table 5.3 Analysis of variance on intake of grass silage fed ad libitum (kg per cow daily)

Stage of lactation Weeks of lactation		I 1–12		II 13–24		III 25–36		I–II 1–24		I–III 1–36	
Source	d.f.	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Model	16	3012	185.25	2790	174.37	1794	112.14	2763	172.67	2382	148.89
Error	245	6155	25.12	9761	39.84	13287	54.23	6072	24.78	6547	26.72
R^2 (%)		32.9		22.2		11.9		31.3		26.7	
Source	d.f.	SS	P	SS	P	SS	P	SS	P	SS	P
Weight[1])	1	288	0.0008	301	0.0065	19	0.56	367	0.0002	399	0.0001
Parity	1	253	0.0017	160	0.046	148	0.10	155	0.013	69	0.11
Strategy	7	1267	0.0001	817	0.0059	1004	0.012	861	0.0001	757	0.0004
Strat. × parity	7	231	0.24	719	0.014	365	0.46	437	0.016	377	0.053

[1]) Initial live weight for the respective stages of lactation.

Contrary to the total food intake, Model (1) explains a relatively small part of the total variation in intake of grass silage fed ad libitum, the R^2 for the respective stages of lactation being 33, 22, 12, 31 and 27%. This shows that there were marked individual differences, which cannot be explained by the three independent variables included in the model. Nevertheless, the influence of the three variables on the voluntary intake of grass silage was significant for nearly all stages of lactation. Weight in weeks 25–36 and parity in weeks 25–36 and 1–36 are exceptions. The interaction strategy x parity, had a significant influence only in weeks 13–24 and 1–24. The strategy effect was highly significant and the voluntary intake of grass silage decreased with increasing level of grain mix. The second part of the hypothesis was therefore accepted.

The dependence of daily intake of grass silage (kg) on the initial live weight, parity and strategy is described by least squares estimates in Table 5.4. The estimates of the effect of weight on intake of grass silage were 2.72, 2.87 and 0.68 kg respectively per 100 kg change in initial live weight for stages I, II and III. The live weight at the beginning of stage III had very little effect, due to differences in condition, as pointed out in Section 5.2.1.

Table 5.4 Least squares estimates of the effects of weight (regression coefficient), parity and strategy (adjusted means) on intake of grass silage fed ad libitum, kg per cow daily

Stage of lactation Weeks of lactation	I 1–12	II 13–24	III 25–36	I–II 1–24	I–III 1–36
Source					
Weight (kg/100 kg)	2.72	2.87	0.68	3.08	3.21
Party, Heifers	21.61	25.49	26.75	23.68	24.65
Cows	25.77	29.17	29.23	27.51	28.12
Strategy¹) L_0	26.64	29.82	29.63	28.30	28.74
$L_{-½}$	26.39	31.01	30.08	28.71	29.53
M_0	23.43	27.44	27.94	25.42	26.33
$M_{-½}$	22.29	25.85	27.63	24.16	25.39
$M_{+2,-1}$	27.07	27.32	29.72	27.34	27.45
M_{-1}	21.13	26.97	29.80	24.23	26.14
H_0	22.01	26.87	24.90	24.52	24.69
$H_{+1,-½}$	22.86	25.43	25.61	24.22	24.77
LSD	2.41	3.04	3.55	2.40	2.49
Overall mean¹)	23.98	27.59	28.16	25.86	26.63

¹) 43% heifers.

The effect of parity (excluding any interaction with strategy) is evident from a comparison of the values for the different stages of lactation (Table 5.4). In stage I was found a difference of 25.77 – 21.61 = 4.16 kg between cows and heifers for their respective weights (538 and 477 kg live weight). Of the total difference in silage intake, 1.66 kg was caused by the difference in live weight and the last 2.50 kg was caused by the difference in maturity. The differences decreased during lactation, as shown by the values for stages II and III.

The effect of strategy in the different stages of lactation is clearly described by the data in Table 5.4, where the LSD-value is also given. The maximum difference between two strategies is seen for M+2, – 1 and M – 1 and was almost 6 kg silage in weeks 1–12. Compared to the LSD-value of 2.41 this difference was highly significant. The difference is caused by the level of grain mix and the pattern of feeding. In weeks 1–12 there was also a significant difference between strategy Mo and M+2,–1. This difference might be explained by the pattern of feeding of the grain mix. Almost the same difference was found between Mo and L-½ (same level of grain mix in weeks 1–12), which to some extent might be explained by a slightly different capacity of food intake of the cows on those two strategies (Table 5.5). The three strategies M-½, Ho and H+1,-½ had equal levels of grain mix and a slightly different pattern of feeding during weeks 1–12. Nevertheless an almost equal intake of silage was seen (Table 5.4).

Table 5.5 Least squares means of intake of grass silage (fed ad libitum) on the different strategies and the two parities, kg per cow daily

Stage of lactation	I		II		III		I–II		I–III	
Weeks of lactation	1–12		13–24		25–36		1–24		1–36	
Parity[1]	1	2	1	2	1	2	1	2	1	2
Strategy										
L_0	23.75	28.81	26.55	32.28	26.37	32.09	25.34	30.53	25.73	31.01
$L_{-1/2}$	23.63	28.47	28.90	32.59	28.39	31.35	26.31	30.53	27.82	30.81
M_0	22.51	24.13	27.74	27.21	28.53	27.49	25.01	25.72	26.22	26.41
$M_{-1/2}$	19.50	24.40	22.59	28.31	26.58	28.43	21.28	26.34	23.16	27.07
$M_{+2,-1}$	25.58	28.18	25.67	28.56	28.25	30.83	25.94	28.40	25.17	29.18
M_{-1}	16.58	24.57	21.32	31.24	26.33	32.41	19.06	28.12	21.53	29.62
H_0	20.75	22.96	27.65	26.29	24.96	24.86	24.36	24.64	24.58	24.77
$H_{+1,-1/2}$	20.53	24.61	23.52	26.87	24.62	26.36	22.12	25.81	22.98	26.13
Mean	21.61	25.77	25.49	29.17	26.75	29.23	23.68	27.51	24.65	28.12

[1]) Parity 1 = Heifers. Parity 2 = Cows.

Strategy M-1 represented the highest level of grain mix in weeks 1–12 and showed the lowest intake of grass silage.

The data for weeks 1–36 in the last column of Table 5.4 clearly show differences between the strategies with the lowest and the highest level of grain mix, but within the three levels of grain mix (L, M and H) the silage intake was almost equal. The reason for strategy M+2,–1 showing the highest intake of silage among the medium levels of grain mix might be the pattern of feeding of the total amount of grain mix fed.

Interaction between strategy and parity was discovered in mid-lactation by means of the analysis of variance (Table 5.3). For this reason the mean intake was calculated separately for the different strategies and parities (Table 5.5). A comparison of strategy M+2,–1 and M-1, which, throughout the lactation were quite different strategies, shows differences in the silage intake of heifers and cows. Table 5.6 shows the differences in intake of grass silage between cows and heifers during the first 9 periods of 4 weeks of lactation. The marked difference between the data for strategy M+2,–1 and M-1 is possibly caused by the high level of grain mix fed in strategy M-1 during stage I of the lactation leading to a rumen fermentation that depressed the intake of silage, particularly for the heifers. Furthermore, the level of net energy intake led to better condition of the animals on M-1. This may have caused a reduction in food intake during stages II and III of the lactation compared to strategy M+2,–1.

The intake of grass silage expressed as dry matter, was analysed with the same model (Model (1)) as the intake expressed in kg of silage. The data are given in Tables 5.7, 5.8 and 5.9, and show the same levels of significance. It should be noted that the rather low values for dry matter intake of grass silage in the respective main stages of lactation can be explained by the quality of the silage, as well as by the daily amount of the basal ration given, viz.:

Roots, molasses and dried sugar beet pulp: 3.7 kg DM
Silage of beet leaves, grass cobs and straw: 1.7 kg DM

Furthermore the amounts of grain mix ranged from 2.6 to 7.7 kg DM per cow daily.

Table 5.6 Differences in voluntary food intake between cows and heifers in the different stages of lactation, kg of grass silage daily

Weeks of lactation	1–4	5–8	9–12	13–16	17–20	21–24	25–28	29–32	33–36
Strategy									
L_0	3.00	6.23	5.94	5.03	4.62	6.35	6.03	5.81	4.50
$L_{-½}$	3.01	5.03	6.49	5.44	3.03	2.27	1.77	0.52	–0.68
M_0	3.23	2.33	–0.69	–1.63	0.61	0.42	1.01	–0.88	–2.65
$M_{-½}$	3.98	6.11	4.64	6.14	6.00	3.55	3.16	1.65	–0.03
$M_{+2,-1}$	3.08	1.55	3.17	3.18	1.03	2.75	2.72	2.27	0.93
M_{-1}	4.96	9.63	9.39	9.13	10.63	10.60	8.74	5.51	4.22
H_0	2.58	3.50	0.53	–1.07	–2.34	–1.58	–0.95	–0.90	1.86
$H_{+1,-½}$	2.54	4.92	4.80	4.40	3.01	2.52	1.75	2.23	2.23
MSD[1])	4.04	6.04	6.59	6.76	6.51	7.11	7.35	7.64	8.25
Mean	3.30	4.92	4.28	3.83	3.33	3.36	3.03	2.03	1.29

[1]) MSD = minimum significant difference between 2 strategies (5% level) ≈S.E. × 1.96.

Table 5.7 Analysis of variance on dry matter intake of grass silage fed ad libitum (kg per cow daily)

Stage of lactation Weeks of lactation		I 1–12		II 13–24		III 25–36		I–II 1–24		I–III 1–36	
Source	d.f.	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Model	16	169.2	10.57	163.9	10.24	81.1	5.07	150.7	9.42	118.3	7.39
Error	245	314.7	1.28	553.3	2.26	690.5	2.82	318.5	1.30	345.5	1.41
R^2 (%)		35.0		22.9		10.5		32.1		25.5	
Source	d.f.	SS	P	SS	P	SS	P	SS	P	SS	P
Weight[1])	1	17.7	0.0003	21.2	0.0024	1.0	0.55	20.3	0.0001	15.7	0.0010
Parity	1	13.5	0.0013	7.8	0.065	5.9	0.15	9.1	0.0087	5.4	0.052
Strategy	7	69.3	0.0001	50.4	0.0031	46.4	0.024	44.7	0.0001	38.8	0.0005
Strat. × parity	7	15.2	0.11	34.3	0.037	17.4	0.52	23.1	0.016	19.2	0.063

[1]) Initial live weight for the respective stages of lactation.

Table 5.8 Least squares estimates of the effects of weight (regression coefficient) parity and strategy (adjusted means) on intake of grass silage fed ad libitum, kg dry matter per cow daily

Stage of lactation Weeks of lactation		I 1–12	II 13–24	III 25–36	I–II 1–24	I–III 1–36
Source						
Weight (kg/100 kg)		0.68	0.76	0.16	0.72	0.64
Parity,	Heifers	4.82	5.70	6.11	5.30	5.57
	Cows	5.81	6.59	6.55	6.21	6.32
Strategy[1])	L_0	5.96	6.79	6.63	6.40	6.40
	$L_{-½}$	5.89	7.06	7.03	6.48	6.67
	M_0	5.25	6.08	6.26	5.66	5.87
	$M_{-½}$	5.05	5.76	6.25	5.43	5.72
	$M_{+2,-1}$	6.17	5.97	6.61	6.12	6.30
	M_{-1}	4.74	6.17	6.65	5.50	5.90
	H_0	4.91	6.14	5.71	5.55	5.61
	$H_{+1,-½}$	5.08	5.66	5.74	5.39	5.52
	LSD	0.55	0.73	0.81	0.55	0.57
Overall mean[1])		5.38	6.20	6.36	5.82	6.00

[1]) 43% heifers.

Table 5.9 Least square means of intake of grass silage (fed ad libitum) on the different strategies and the two parities, kg dry matter per cow daily

Stage of lactation Weeks of lactation	I 1–12		II 13–24		III 25–36		I–II 1–24		I–III 1–36	
Parity[1])	1	2	1	2	1	2	1	2	1	2
Strategy										
L_0	5.34	6.43	5.82	7.52	5.81	7.26	5.63	6.98	5.63	6.99
$L_{-½}$	5.30	6.34	6.58	7.41	6.98	7.07	5.96	6.88	6.30	6.95
M_0	5.09	5.37	6.09	6.07	6.27	6.24	5.56	5.73	5.81	5.92
$M_{-½}$	4.32	5.60	5.21	6.18	6.19	6.30	4.82	5.89	5.30	6.03
$M_{+2,-1}$	5.81	6.45	5.57	6.27	6.41	6.76	5.78	6.37	6.02	6.50
M_{-1}	3.61	5.60	4.91	7.13	6.01	7.13	4.29	6.42	4.87	6.67
H_0	4.60	5.14	6.22	6.09	5.75	5.67	5.46	5.62	5.57	5.65
$H_{+1,-½}$	4.48	5.53	5.17	6.03	5.42	5.97	4.86	5.79	5.06	5.87
Mean	4.82	5.81	5.70	6.59	6.11	6.55	5.30	6.21	5.57	6.32

[1]) Parity 1 = Heifers. Parity 2 = Cows.

5.2.3. Pattern of the voluntary intake of grass silage and total food through lactation

Before discussing the intake of grass silage as a function of the daily allowances of grain mix during lactation, it is relevant to describe the variation through lactation. For this purpose the daily intake of grass silage during each week was fitted to a function describing the pattern of voluntary silage intake for each strategy and parity. As a suitable function was, among several, chosen (see Chapter IV):

$$(22)\ SI = a - b \times e^{cx} + dx$$

where x = week number of lactation and SI = silage intake.

The estimates of parameters, maximum intake (week number and kg grass silage), mean daily intake in weeks 1–36 of lactation and the efficiency of the model, are shown in Table 5.10. The data in the two columns to the right show clearly that the model fitted well. This means that the model provides an efficient description of the relation between voluntary intake of grass silage and week of lactation for each strategy.

The intake of silage increased throughout the 36 weeks of lactation (i.e. no maximum intake) for heifers on strategies L-½, Mo, M-½, M+2,–1, M-1 and H+1,–½ and for cows on strategies Mo and M+2,–1. For the other strategies there was a maximum within the observed period indicating that the appetite of the cow decreased in the later part of lactation. The reason for the maxima occurring in mid-lactation, may, according to Balch and Campling (1969) and Bines (1976), be the effect of excess food relative to the requirements for milk production and maintenance. Furthermore, pregnancy will start to influence food intake in the later stages of lactation.

In all cases there was a marked increase in early lactation (weeks 1–12) and a very small change (decrease or increase depending on strategy) in late lactation (weeks 25–36) for heifers as well as cows. The strategies with constant daily allowances of grain mix illustrates directly the week of lactation in which the appetite of the animal was maximum. Table 5.10 shows that heifers on Lo and Ho had maximum silage intakes in weeks 18 and 20, and, consequently, maximum food intake and maximum appetite in these weeks. For the cows on strategy Lo and Ho the maximum food intake and appetite was found in weeks 15 and 16. On Strategy Mo the heifers as well as the cows did not achieve maximum silage intakes within weeks 1–36 according to the functions, but the increase in late lactation was very small. Therefore appetite was almost unchanged through weeks 20–36, and the maximum may be in that period.

Table 5.10 Estimates of parameters, maximum intake of grass silage (week-no. and kg), mean daily intake weeks 1–36 and the efficiency of the model, SI = a – b · e^cx + dx.

Parameters etc.	a	b	c	d	Max. intake Week	Max. intake kg[1])	Mean, wks. 1–36, kg	Av. diff. from observed data	R^2 %
Strategy									
Heifers									
L_0	28.0	13.5	–0.234	–0.045	18	27	25.2	0.17	83
$L_{-½}$	28.7	13.1	–0.154	0.077	–	–	27.3	0.13	96
M_0	26.7	15.5	–0.228	0.065	–	–	25.6	0.14	94
$M_{-½}$	18.5	7.9	–0.396	0.266	–	–	22.4	0.17	92
$M_{+2,-1}$	25.2	16.1	–0.789	0.101	–	–	26.1	0.21	73
M_{-1}	15.1	4.6	–0.287	0.370	–	–	21.0	0.24	91
H_0	108.8	96.0	–0.035	–1.657	20	28	24.3	0.13	95
$H_{+1,-½}$	22.5	9.1	–0.262	0.084	–	–	22.6	0.14	88
Cows									
L_0	34.2	21.2	–0.298	–0.066	15	33	30.6	0.16	91
$L_{-½}$	37.7	21.9	–0.188	–0.207	16	33	30.2	0.13	95
M_0	26.7	12.1	–0.287	0.025	–	–	25.5	0.22	75
$M_{-½}$	28.6	15.8	–0.265	–0.004	26	28	26.5	0.15	90
$M_{+2,-1}$	28.5	12.4	–0.656	0.074	–	–	28.7	0.17	74
M_{-1}	33.2	21.4	–0.163	–0.012	35	33	28.9	0.15	96
H_0	28.5	14.7	–0.213	–0.111	16	26	24.2	0.08	96
$H_{+1,-½}$	27.6	14.7	–0.307	–0.035	16	27	25.2	0.15	86

[1]) *Mean values of grass silage:* 22% DM, 32% fibre, 14% crude protein and 66% in vitro digestibility.

[2]) $R^2\ (\%) = 100 - \dfrac{\text{Residual SS}}{\text{Corr. total SS}} \times 100.$

Compared to the cows, the heifers generally achieved maximum intake later in lactation, due to their growth.

The intake of grass silage for some »key-weeks« is calculated and shown in Table 5.11.

For further illustration, the intake of grass silage throughout the lactation, for heifers and cows separately, is given in Figs. 5.3, 5.4, 5.5 and 5.6. These figures clearly demonstrate the effect of the various strategies as well as the inborn characteristics of the cow. The curves were constructed by means of Function (22), and the parameters in Table 5.10. It should be noted from Figs. 5.3 and 5.5 that animals on Norm treatment did not eat the fixed level of grass silage planned until approximately 12 weeks post partum.

Table 5.11 Intake of grass silage in particular weeks of lactation, kg dry matter per cow daily[1])

	Heifers					Cows				
	Week 1	Week 6	Week 12	Week 24	Week 36	Week 1	Week 6	Week 12	Week 24	Week 36
Strategy										
L_0	3.82	5.38	5.87	5.92	5.82	4.05	6.66	7.22	7.18	7.01
$L_{-½}$	3.86	5.27	6.06	6.64	6.91	4.24	6.45	7.23	7.14	6.64
M_0	3.17	5.09	5.82	6.20	6.39	3.89	5.43	5.86	6.00	6.07
$M_{-½}$	2.96	4.27	4.77	5.49	6.19	3.62	5.58	6.13	6.26	6.26
$M_{+2,-1}$	3.96	5.65	5.82	6.09	6.35	4.86	6.30	6.45	6.65	6.85
M_{-1}	2.65	3.64	4.27	5.28	6.26	3.30	5.51	6.60	7.14	7.19
H_0	3.17	4.66	5.75	6.16	4.91	3.63	5.22	5.73	5.66	5.39
$H_{+1,-½}$	3.43	4.65	5.08	5.39	5.61	3.68	5.52	5.90	5.89	5.80

[1]) Calculated by function (22), $SI = a - b \cdot e^{cx} + dx$, the parameters a, b, c and d and the average grass silage quality shown in table 5.10.

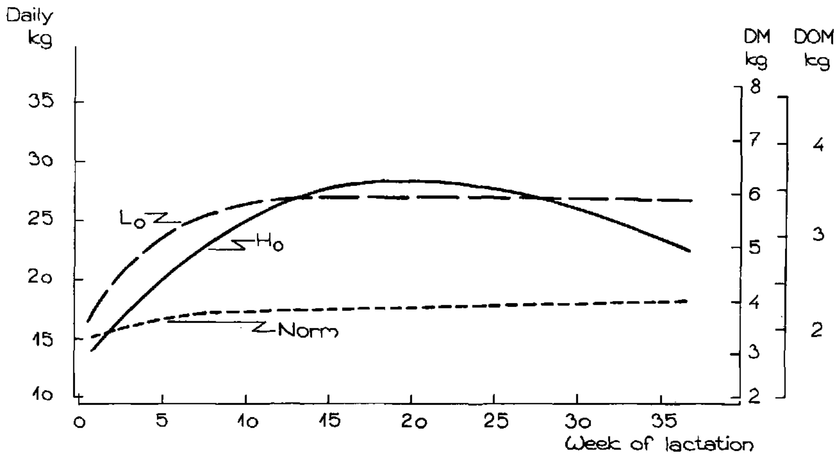

Fig. 5.3. Grass silage intake throughout lactation. Heifers on 3 different strategies of feeding grain mix.

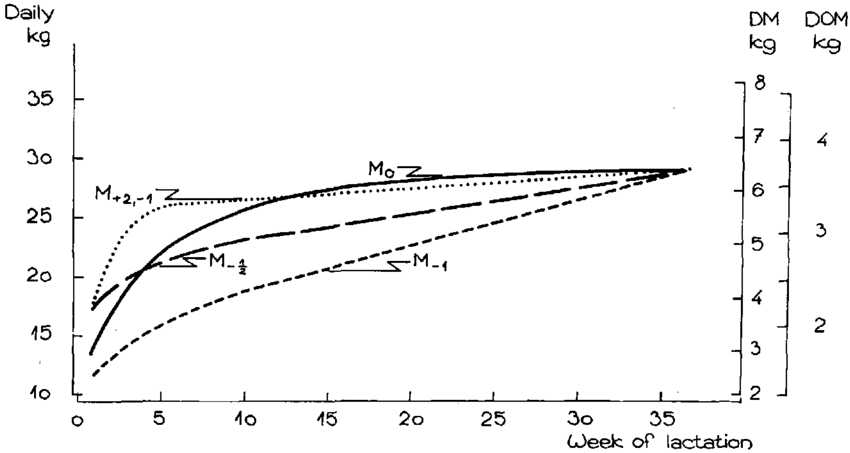

fig. 5.4. Grass silage intake throughout lactation. Heifers on 4 different strategies of feeding grain mix.

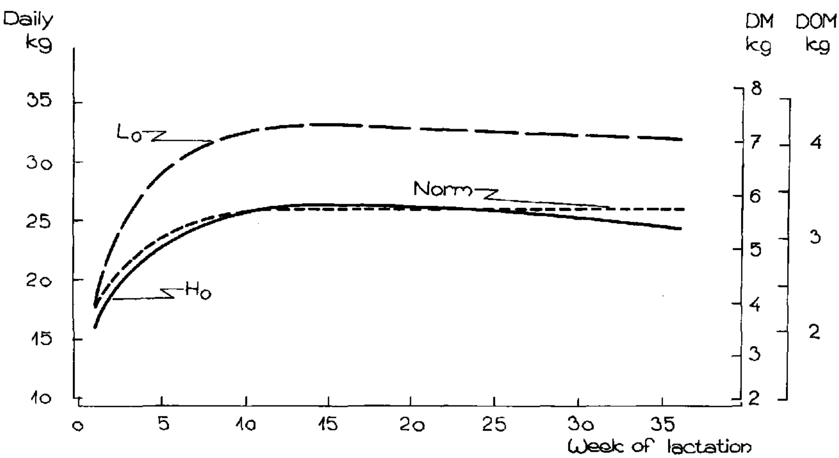

Fig. 5.5. Grass silage intake throughout lactation. Cows on 3 different strategies of feeding grain mix.

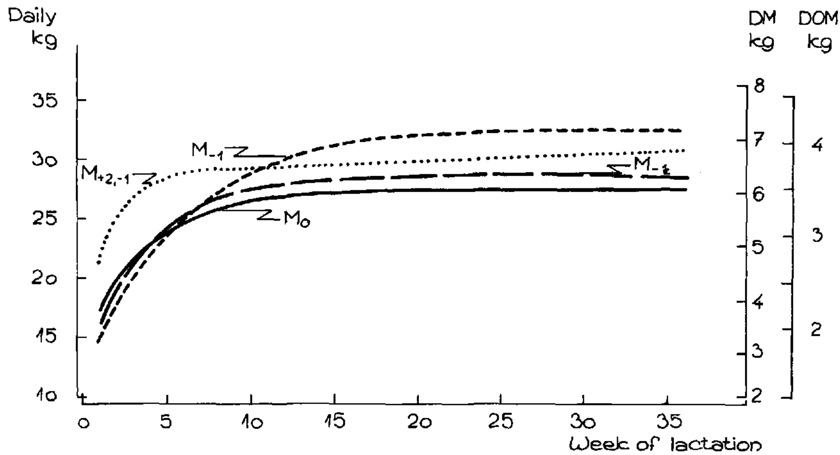

Fig. 5.6. Grass silage intake throughout lactation. Cows on 4 different strategies of feeding grain mix.

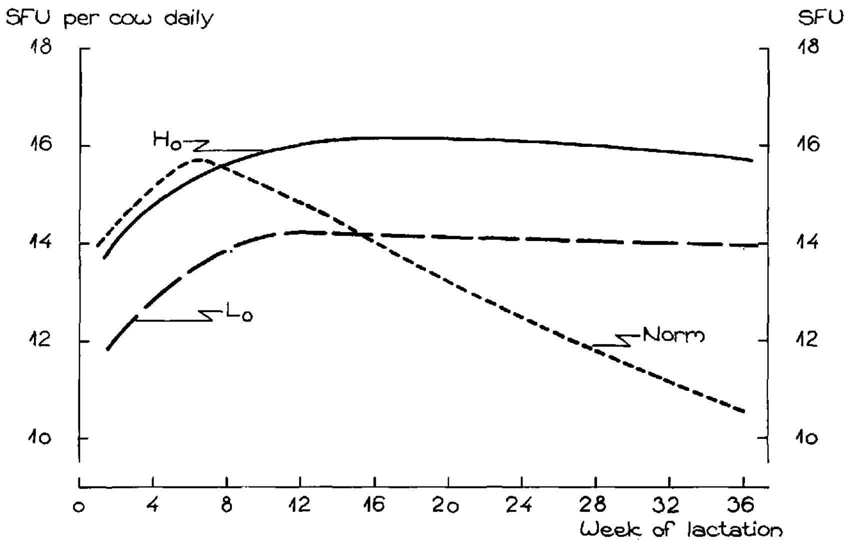

Fig. 5.7. Total food intake of cows on 3 different strategies of feeding grain mix.

The total food intake, expressed as net energy (SFU), throughout lactation is given for cows on strategies Lo, Ho, Norm in Fig. 5.7 and Mo, M-½, M+2,–1, M-1 in Fig. 5.8 as a visual illustration of the effect of the treatments. The curves were constructed from the basic data, but use of the functions for silage intake (Table 5.10) led to the same picture. These figures then illustrate how the strategy of grain mix feeding regulated the total food intake efficiently. The intakes were equal for strategies Mo, M-½ and M-1 following week 18, when the allowances of grain mix were also equal.

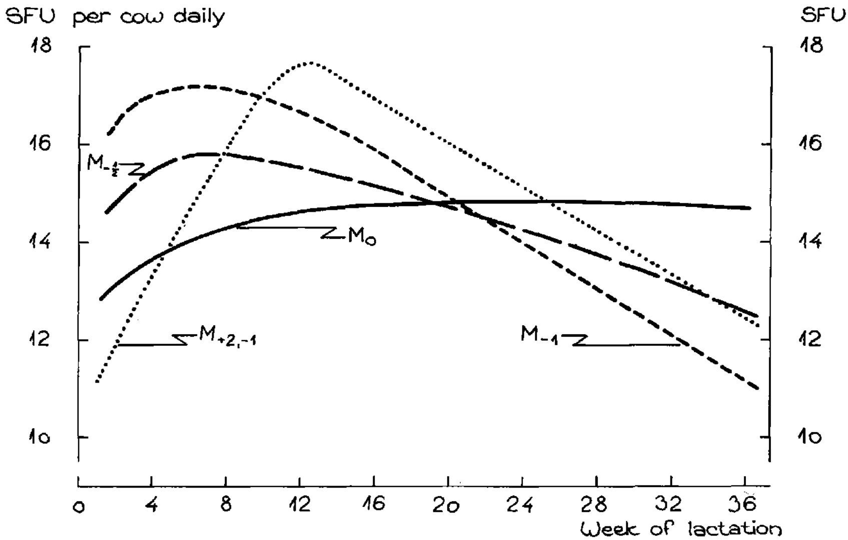

Fig. 5.8. Total food intake of cows on 4 different strategies of feeding grain mix.

5.2.4. Pattern of the ration composition through lactation

The composition of the ration was significantly influenced in the main stages of lactation by the level of grain mix (Section 5.2.2). The composition of the total ration during any week of lactation was calculated on dry matter basis, and is presented for different strategies for heifers and cows in Figs. 5.9, 5.10, 5.11 and 5.12. The concentrates consisted of grain mix, roots, molasses and sugar beet pulp. The reason for adding roots, molasses and dried sugar beet pulp to the grain mix is their almost identical effect on rumen pH (Kaufmann, 1972), and consequently on fibre digestion. Furthermore, these feeds have a digestibility , which is almost equal to that of grain mix.

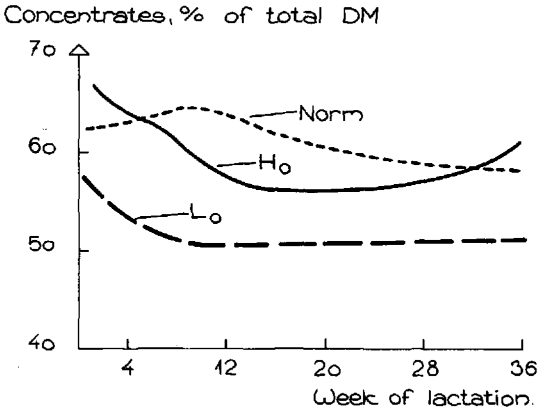

Fig. 5.9. Ration composition. Heifers on strategy Lo, Ho and Norm.

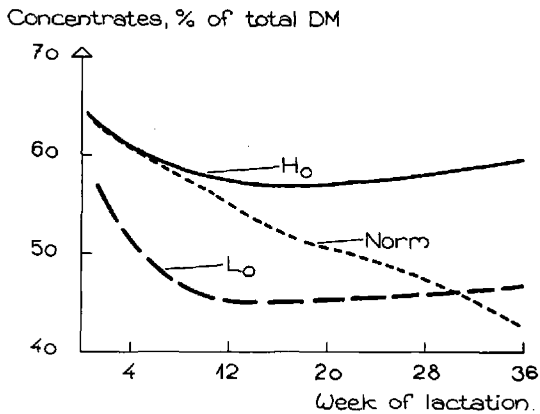

Fig. 5.10. Ration composition. Cows on strategy Lo, Ho and Norm.

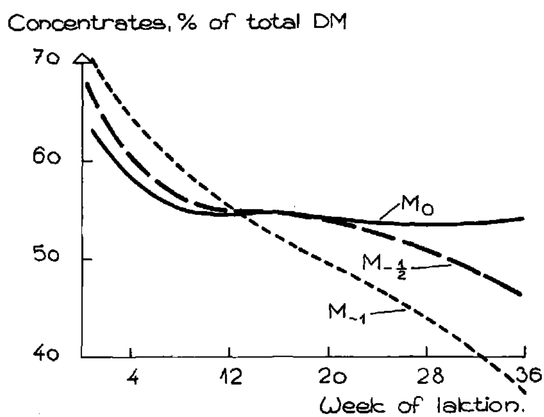

Fig. 5.11. Ration composition. Cows on strategy Mo, M–½ and M–1.

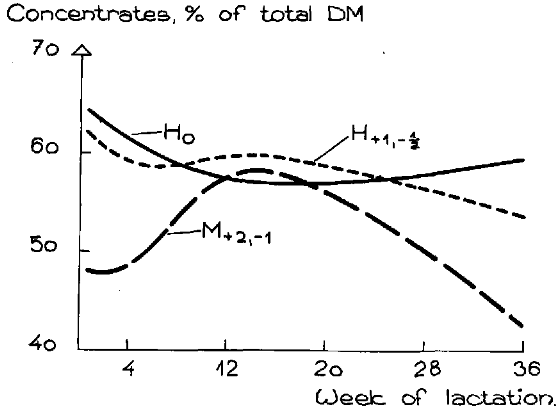

Fig. 5.12. Ration composition. Cows on strategy M+2,–1, Ho and H+1,–½.

The curves in Fig. 5.9 concern heifers on strategies Lo and Ho, and show the highest percentage of concentrates at the beginning of the lactation in accordance with the low level of silage intake (Fig. 5.3). Norm treatment in heifers produced an almost constant percentage of concentrates (60–65) throughout lactation, due to the high persistency of lactation and the constant level of silage.

For cows on Norm treatment, the picture was different (Fig. 5.10) because of a lower persistency compared to the heifers (Section 6.2.2).

Fig. 5.11 shows for cows the effect of 3 different patterns of feeding the same total amount of concentrates during the first 36 weeks of lactation. The greatest change throughout lactation is seen for Strategy M-1, with the range of 70% in early lactation to approximately 35% in week 36.

By comparing all the curves it is seen from Fig. 5.12 that the H+1,–½ strategy caused a very constant percentage of concentrates (62–58) through the first 24 weeks of lactation. Consequently, this strategy on average for weeks 1–24 can be representative for a complete ration with approximately 60% of concentrates.

5.2.5. Intake of grass silage and total food as a function of level of concentrate feeding

To optimize the level of concentrates it is necessary to estimate the quantitative relation between the inputs of grass silage (dependent variable) and concentrates (grain mix, roots, molasses, dried pulp (independent variables)). For this purpose the basal ration of roots, molasses and dried pulp was added to the grain mix because, as pointed out in Section 5.2.4, they produce an almost identical effect on the rumen pH and consequently on fibre digestion. There is furthermore an almost identical effect on the total intake of energy. In a pre-study (1971–72), an equal voluntary intake of alfalfa hay (7.5 kg DM daily at digestibility 62%) fed ad libitum was found when feeding o, 2.5 and 5.0 SFU of roots (fodder beets) per cow daily instead of the same net energy in grain. The protein level in the roots was supplemented with oil cakes to equal that in the grain (50% barley + 50% oats) on a net nergy basis. Findings of Mäkelä (1956) and Ekern (1972 III) with two levels of roots and silage ad libitum show a similar effect of roots on roughage intake.

Based on the theory discussed in Section 5.1, the parameters of function (21) were estimated. The strategy M+2,–1 was not included in these computations as the intake of grass silage and total food (Tables 5.8 and 5.2) differed significantly from Strategy Mo, weeks 1–12. The Norm treatment was not useable for two reasons the intake of grass silage should be the dependent variable and the level of concentrates fed the independent variable. (For the statistical procedure see Section 4.3.1).

The estimated parameters and analysis of variance of regression of grass silage intake on kg^2 DM in grain mix are shown in Tables 5.12, 5.13 and 5.14.

Table 5.12 Estimated parameters and analysis of variance of regression of silage intake, kg DM per cow daily on kg^2 DM in grain mix, roots, molasses and pulp. Model (4)

Parameters estimated for weeks 1–12 of lactation

	First lactation		Sec. + follow. lact.		All lactations	
Parameter	Estimate	s.e.	Estimate	s.e.	Estimate	s.e.
Intercept	6.693	0.462	6.858	0.482	7.199	0.346
Effect of parity[1])					–0.971	0.154
Coefficient of regression	–0.022	0.005	–0.013	0.005	–0.017	0.003

Analysis of variance Source	d.f.	SS	P	d.f.	SS	P	d.f.	SS	P
Parity							1	53.19	0.0001
Regression	1	21.93	0.0001	1	11.09	0.0086	1	31.07	0.0001
Residual	97	101.99		129	200.72		227	304.66	
Lack of fit	5	4.89	0.45	5	32.28	0.0005	5	16.49	0.029
Pure error	92	97.10		124	168.44		222	288.17	
R^2 (%)		17.7			5.2			21.6	

[1]) First lactation minus Sec. + follow. lactations.

The CI-values range between 7.7 and 11.4 (incl. 3.7 kg DM of roots, molasses and dried sugar beet pulp).

Table 5.13 Estimated parameters and analysis of variance of regression of silage intake, kg DM per cow daily on kg² DM in grain mix, roots, molasses and pulp. Model (4)

Parameters estimated for weeks 1–24 of lactation

Parameter	First lactation			Sec. + follow. lact.			All lactations		
	Estimate		s.e.	Estimate		s.e.	Estimate		s.e.
Intercept	6.930		0.482	7.869		0.532	7.850		0.374
Effect of parity¹)							–0.892		0.154
Coefficient of regression	–0.020		0.005	–0.020		0.006	–0.020		0.004
Analysis of variance Source	d.f.	SS	P	d.f.	SS	P	d.f.	SS	P
Parity							1	44.91	0.0001
Regression	1	13.36	0.0003	1	20.37	0.0006	1	33.72	0.0001
Residual	97	91.13		129	211.47		227	302.60	
Lack of fit	5	16.34	0.0023	5	18.75	0.18	5	8.64	0.26
Pure error	92	74.79		124	192.71		222	293.96	
R^2 (%)		12.8			8.8			20.5	

¹) First lactation minus Sec. + follow. lactations.
The CI-values range between 7.7 and 10.6.

Table 5.14 Estimated parameters and analysis of variance of regression of silage intake, kg DM per cow daily on kg² DM in grain mix, roots, molasses and pulp. Model (4)

Parameters estimated for weeks 1–36 of lactation

Parameter	First lactation			Sec. + follow. lact.			All lactations		
	Estimate		s.e.	Estimate		s.e.	Estimate		s.e.
Intercept	6.515		0.506	8.307		0.505	7.889		0.369
Effect of parity¹)							–0.737		0.158
Coefficient of regression	–0.013		0.006	–0.026		0.006	–0.021		0.004
Analysis of variance Source	d.f.	SS	P	d.f.	SS	P	d.f.	SS	P
Parity							1	30.61	0.0001
Regression	1	5.27	0.030	1	31.01	0.0001	1	33.30	0.0001
Residual	97	105.10		129	210.39		227	318.47	
Lack of fit	5	16.93	0.0060	5	9.84	0.30	5	5.59	0.60
Pure error	92	88.17		124	200.55		222	312.88	
R^2 (%)		4.8			12.8			16.8	

¹) First lactation minus Sec. + follow. lactations.
The CI-values range between 7.7 and 10.3.

The analysis of variance showed significant P-values for the regression coefficient for the different stages of lactation. However, less than 25% of the total variation was explained by the model. Partitioning the residual variation into lack of fit (deviation from the curve to the treatment means) and pure error (variation between individuals within treatment) showed that the low R^2-values were, to a large degree, caused by the individual variation (s.d.: 1.0–1.3). The test of lack of fit (see Section 4.3) was not significant in most cases. The significant lack of fit for heifers in weeks 1–24 was mainly due to the fact that the function overestimatd the intake on the M-1 strategy by 0.6 kg DM, and underestimated the intake on the Ho strategy by 0.6 kg DM, the two treatments having equal average amounts of concentrates in that period. In weeks 1–36 the intake on M-1 was again overestimated. When both parity groups were analysed together, the lack of fit was non-significant.

The model (4) outlined in Section 4.3, which led to the function (21) in Section 5.1, seems therefore to fit well to the data on a group basis. The individual variation, however, shows that the food intake for an individual cow cannot be predicted with great accuracy, when the genetic capacity for food intake compared to average is not known.

Furthermore new calculations, based on grain mix, were made. The parameters for predicting the intake of grass silage as a function of the allowances of grain mix alone were also estimated on the basis of Model (4), in a similar way to the estimation of these parameters for the total input of concentrates as the independent variable. The parameters, as well as the basal ration for heifers and cows at different stages of lactation are shown in Table 5.15. The derived functions give the relation between intake of silage and allowances of grain mix with the same accuracy as do the functions based on the grain mix plus roots, molasses and dried sugar beet pulp, (Tables 5.12–5.14).

The data on silage intake were analysed for interaction between live weight and allowance of grain mix. No interaction was found, and therefore the estimated functions for the independent variable, expressed as kg grain mix (DM) per kg of metabolic weight ($W^{3/4}$), were not improved and therefore not presented. The reason might be the relative small range of live weight (407 to 659 kg) and therefore of metabolic weight (91 to 130 kg).

Table 5.15 Estimated parameters of the intercept and the coefficient of regression of grass silage intake (SI, kg DM per cow daily) on kg² of grain mix (GI²) Model (4). Basal ration (BI)

Weeks of lactation	Intercept (b_0)		Coefficient of regression (b_1)		Basal ration (fixed) kg DM daily (BI)	
	Heifers	Cows	Heifers	Cows	Heifers	Cows
1–12	5.94	6.37	–0.036	–0.021	5.18	5.23
1–24	6.26	7.17	–0.033	–0.034	5.27	5.31
1–36	6.06	7.44	–0.022	–0.047	5.36	5.40

The effect of initial live weight on dry matter intake of grass silage during weeks 1–12 and 1–24 was 0.7–0.8 kg DM per 100 kg deviation from 477 kg (heifers) and 538 kg (cows), respectively (Table 5.8). The grain mix intake for the above mentioned main stages of lactation varied between 4.0 and 7.7 respective 4.0 and 6.9 kg DM per animal daily.

On basis of the estimated parameters (b_0 and b_1 in Table 5.15), the fixed basal ration (BI), and the amount of grain mix (GI) fed, it was possible for any given period of the lactation to use function (21) for the estimations of the average voluntary intake of grass silage (SI, kg DM per animal daily).

For example, the silage intake of heifers during weeks 1–24 of lactation is:

$$SI = 6.26 - 0.033 GI^2 = 5.07 \text{ for } GI = 6.$$

The total dry matter intake (kg TDMI per animal daily) was calculated by means of:

$$(23)\ TDMI = BI + GI + SI$$

For example, the total food intake of heifers during weeks 1–24 of lactation is:
$TDMI = 5.27 + GI + (6.26 - 0.033 GI^2) = 16.34$ kg for $GI = 6$.

The functions of TDMI are transformed to total energy intake (TEI) e.g. expressed in SFU, by multiplying the dry matter intake of the feeds by their nutritive values. Expressed in this way the present study led to the following function:

$$(24)\ TEI_{SFU} = 0.84\ BI_{DM} + 1.11\ GI_{DM} + 0.69\ SI_{DM}$$

Using the above functions and the parameters in Table 5.15, the average daily food intake for different levels of grain mix fed to heifers or cows were calculated, and the results are shown in Table 5.16. Among the levels of grain mix in Table 5.16 only 8 kg of DM during weeks 1–24 and 1–36 of lactation differed markedly from the range of the experimental data (Chapter II). The predictive efficiency of the functions (21) and (24) is also seen by comparing the figures in Table 5.16 and in Tables 5.2 and 5.9.

The following example also shows the good agreement between the experimental figures and the estimates by the pooled functions for heifers and cows for weeks 1–24,

$$TEI_{SFU} = 9.11 + 1.11\ GI - 0.0235\ GI^2:$$

Strategy	Lo	L–½	Mo	M–½	M–1	Ho	H+1,–½
Grain mix, kg DM/day ..	3.95	4.60	5.25	5.87	6.50	6.52	6.90
TEI, SFU/day							
By function above	13.13	13.72	14.29	14.82	15.33	15.35	15.65
From Table 5.2	13.29	14.09	14.26	14.74	15.49	15.55	15.90
Rel. to est. by fct.	101	103	100	99	101	101	102

Table 5.16 Estimates of daily food intake for different levels of grain mix per cow[1])

Weeks of lactation		1–12			1–24			1–36		
Grain mix (GI) kg DM		Grass Silage kg DM	Total food[3]) kg DM	Total food[3]) SFU	Grass Silage kg DM	Total food[3]) kg DM	Total food[3]) SFU	Grass Silage kg DM	Total food[3]) kg DM	Total food[3]) SFU
4	Heifers[2])	5.37	14.55	12.46	5.73	15.00	12.81	5.70	15.07	12.84
	Cows	6.04	15.27	12.97	6.62	15.93	13.46	6.68	16.08	13.53
5	Heifers	5.04	15.22	13.38	5.43	15.70	13.72	5.51	15.87	13.81
	Cows	5.85	16.08	13.99	6.32	16.63	14.36	6.26	16.66	14.35
6	Heifers	4.65	15.83	14.22	5.07	16.34	14.58	5.26	16.62	14.75
	Cows	5.62	16.85	14.94	5.94	17.25	15.21	5.74	17.14	15.10
7	Heifers	4.18	16.36	15.00	4.64	16.91	15.39	4.98	17.34	15.66
	Cows	5.34	17.57	15.85	5.50	17.81	16.02	5.13	17.53	15.79
8	Heifers	3.64	16.82	15.74	4.14	17.41	16.16	4.65	18.01	16.55
	Cows	5.03	18.26	16.75	4.99	18.30	16.77	4.43	17.83	16.42

1) Based on the parameters of silage intake (SI) shown in Table 5.15.
2) Average live weight at beginning of the periods: Heifers: 477 kg. Cows: 538 kg.
3) Nutritive value, SFU/kg DM: Grain mix: 1.11, grass silage: 0.69 and basal ration: 0.84.

5.3. Discussion and conclusion

In the present studies it has been shown that under circumstances where grass silage is fed ad libitum, the total food intake as well as the ration composition during the respective stages of lactation can be regulated through the amount of concentrate fed (Table 5.2, Fig.'s 5.7–5.8 and Fig.'s 5.9–5.12). This is so because the strategy effect was highly significant for the three main stages of lactation.

The average intake of total food per animal daily varied from 12.9 to 16.3 SFU when changing the grain mix allowances from 4.5 kg (Strategy Lo) to 9.0 kg (Stragegy M-1) as the daily average during weeks 1–12 of lactation (Table 5.2). Similar but smaller effects were found for the other main stages of lactation, weeks 13–24 and 25–36. Heavier feeding with grain mix (digestibility of organic matter, 82%) in competition with grass silage (digestibility of organic matter, 66% on average) fed ad libitum thus leads to a larger food intake, expressed as net energy, SFU.

The dependent variable, the voluntary intake of grass silage, was also highly significantly influenced by the 8 different strategies of feeding grain mix (the Norm treatment was not included). The average dry matter intake of grass silage during weeks 1–12 of the lactation was 4.8 kg for the heifers per animal daily and 5.8 kg for the cows. During weeks 13–24 the intakes are 5.7 and 6.6, and during weeks 25–36, 6.1 and 6.6 kg per heifer and cow, respectively. The standard deviation of approximately 1.2 within treatment and within the different stages of lactation was almost equal for heifers and cows.

The rather low average intake of grass silage was caused by the basal ration of 5.3 kg DM, the allowances of grain mix (average 5–6 kg DM) and the quality of the silage. The latter is described in Tables 3.2 and 3.3.

According to the findings of Campling and Murdoch (1966) and Andersen et al. (1972) and the estimates of Østergaard (1973), the quality of the silage does influence the intake to a great extent. The analysis and discussion of this important subject is outside the scope of the present work, but is given in a separate report by Hermansen (1979) based on the present experimental data. However, a few values should be given. The daily voluntary intake of organic matter in well conserved grass silage to cows of 550 kg body weight can be roughly described by the following simplified function, when no supplement is fed (Østergaard, 1973):

(25) $OMI = -4.2 + 0.25\ DC_{OM}$ (for $55 < DC_{OM} < 75$)

where OMI = kg organic matter intake
and DC_{OM} = digestibility coefficient of organic matter.

This relationship which is valid for mid-lactation, is in extremely good agreement with the findings of Walters (1971), and with recent French observations on sheep by Demarquilly and Jarrige (1974).

The voluntary dry matter intake (for a typical ash content of 10%) is shown in Table 5.17.

Table 5.17 Estimates of the daily voluntary dry matter intake (VDMI) of well conserved grass silage to lactating cows in mid-lactation for various coefficients of organic matter digestibility (DC_{OM})

DC_{OM}:	55	60	65	70	75
VDMI, kg per cow (550 kg)	10.6	12.0	13.4	14.8	16.2
VDMI, kg per 100 kg live weight	1.9	2.2	2.4	2.7	2.9
Filling effect (relative to DC_{OM} = 60) per kg of DM	1.13	1.00	0.90	0.81	0.74

In planning a particular food intake at ad libitum feeding a useful tool is the filling effect. This is defined by how much a feed does fill relative to a standard feed, e.g. grass silage with DC_{OM} = 60, which is chosen here.

The filling effect of a feed depends on the chemical composition and physical structure, as is also shown by the experiments of Mäkelä (1956). The intake of converted dry matter, (CDM = sum of filling effect x kg DM in the respective feeds (Hyppölä and Hasunen, 1970)) is, per definition, equal in the 5 different cases in Table 5.17, 12.0 kg daily per cow (550 kg body weight). This estimate is almost equal to that of Hyppölä and Hasunen (1970) 12.4 kg of a mixed ration to cows of the same weight. The daily intake of cows (538 kg body weight) was 11.8 kg CDM in the present experiment during weeks 13–24, when 4 kg DM of grain mix was fed and the filling effect of the concentrates (grain mix, roots etc.) was assumed to be 0.5 according to Mäkelä (1956), Ekern (1972 III) and own pre-experimental results (Section 5.2.5).

The above food intake data relating to mid-lactation (weeks 10–26) and analysed as described in the Tables 5.1 and 5.2 depended on the stage of lactation, live weight, parity and allowances of concentrates.

Within the classes of heifers and cows, respectively, the live weight of the animal influenced the DM-intake in the grass silage and therefore the total food. According to the results presented in Section 5.2.2 (Table 5.9) the effect of live weight was, for the different stages of lactation:

Weeks of lactation:	1–12	13–24	25–36	1–24	1–36
kg DM/100 kg change	0.68	0.76	0.16	0.72	0.64

Different estimates were found by Huth (1968), Andersen et al. (1972) and Krohn and Konggaard (1976) and might be explained by differences in the following sources of variation: stage of lactation, feeding principle (i.e. feeding concentrates according to versus independent of daily yield), quality of grass silage, parity, condition of the cow and number of animals (great genetic variation exists).

It can be concluded that on average the relationship between live weight and the voluntary intake of silage intake in the different stages of lactation, excluding weeks 25–36, almost corresponds to the change in the requirement of net energy for maintenance. Consequently, within the range of weight in the present experiment the heavier animal has the same amount of energy left for production (milk and body tissue gain).

The voluntary intake of grass silage (kg) throughout lactation can be described efficiently by means of the following function:

$$SI = a - b \times e^{cx} + dx \quad (x = \text{week of lactation}).$$

The parameters for the 8 strategies, for heifers as well as cows, are given in Table 5.10. Table 5.11 shows the estimated silage intake during particular weeks. Maximum intake took place in mid- or late-lactation depending on the strategy of the grain mix feeding.

The voluntary intake of grass silage and total food throughout lactation, when feeding grass silage ad libitum, is described by curves in Figs. 5.3 to 5.8. The food intake increased markedly during the early stage of lactation. This is in agreement with findings of Johnson et al. (1966), Ekern (1972 III) and Journet and Remond (1976). Furthermore these curves show that it is possible, even under ad libitum feeding, to attain a certain food intake for a group of cows at various stages of lactation. Because of the variation in silage intake between individual cows, caused by genetic differences, it is not possible in practise (i.e. in a commercial herd) to predict the intake of individuals very precisely. Even knowledge of the intake in particular weeks (e.g. in early lactation) does not make it possible to make a precise estimate of the food intake of the individual cow during later weeks as seen of Table 5.18. The coefficients of correlation are influenced by the uniformity and the quality of the silage and this question should be subject to further research.

The voluntary intake of grass silage and the total food intake was estimated as a function of the level of the concentrate feeding. An increasing level of concentrates (grain mix, roots, molasses and dried sugar beet pulp) or of grain mix alone gave a reduced intake of grass silage, and the marginal intake decreased (Tables 5.12–5.15 and 5.19–5.20). The marginal intake of grass silage ranged on a DM-basis between –0.27 and –0.54 per extra kg grain mix-DM,

Table 5.18 Within-class correlations of Model (1) between daily intake of silage in different periods of lactation. Kg per cow daily above diagonal and kg DM per cow daily below diagonal

Weeks of lactation	1–4	5–8	9–12	13–16	17–20	21–24	25–28	29–32	33–36
1– 4	1	0.65	0.45	0.25	0.16	0.11	0.14	0.15	0.14
5– 8	0.65	1	0.78	0.57	0.41	0.27	0.24	0.29	0.28
9–12	0.35	0.68	1	0.80	0.61	0.45	0.40	0.39	0.38
13–16	0.15	0.44	0.75	1	0.76	0.56	0.49	0.44	0.41
17–20	0.13	0.30	0.53	0.76	1	0.78	0.61	0.60	0.50
21–24	0.08	0.24	0.40	0.49	0.70	1	0.81	0.69	0.59
25–28	0.08	0.24	0.38	0.42	0.51	0.76	1	0.78	0.62
29–32	0.13	0.26	0.38	0.47	0.56	0.62	0.74	1	0.81
33–36	0.08	0.23	0.29	0.36	0.51	0.58	0.54	0.75	1

when the grain mix level varied from 4 to 8 kg DM per animal daily for weeks 1–24 of lactation. These values were the same for heifers and cows, but during weeks 1–12 they were numerical 10% higher for heifers and 40% lower for cows. However, for weeks 1–36 the values were almost 40% lower for the heifers and almost 40% higher for the cows than for weeks 1–24. The reason for the difference between heifers and cows in weeks 1–12 and weeks 1–36 might be explained to a great extent by the growth of the heifers throughout lactation and the higher energy requirement of cows than heifers in early lactation, while in late lactation the reverse is the case and activates the chemostatic regulation in the cows (Balch and Campling, 1969).

The estimated values of the marginal change in silage intake for increasing allowances of grain mix (Table 5.20) were close to those estimated on the basis of data from the experiments of Lingvall (1977), Rohr et al. (1974), Ekern (1972 III) and Mather et al. (1960). (See Section 5.1).

The total food intake, kg dry matter and SFU, could be calculated quite precisely for a group of heifers or cows by means of the functions based on the parameters in Table 5.15. The estimates of total daily food intake for different levels of grain mix, 4 to 8 kg per animal, are given in Table 5.16. The values show for heifers an average daily intake of 14.55 kg DM (12.46 SFU) at 4 kg DM of grain mix, but 16.36 kg DM (15.00 SFU) at 7 kg DM of grain mix daily fed at a fixed daily level during weeks 1–12 of the lactation. The average intake was higher for weeks 1–24 and highest for weeks 1–36.

For cows the total food intake was estimated higher than for heifers, except for 8 kg DM allowances of grain mix during weeks 1–36 (Table 5.16). This is in agreement with the conclusion, which can be drawn from experiments carried out by Mäkelä (1956), Mather et al. (1960), Huth (1968) and Krohn and Konggaard (1976).

Table 5.19 Marginal grass silage intake at different levels of concentrates, kg DM per cow daily[1])

Level of conc., kg DM daily (including grain mix, kg DM)		7 (3.3)	8 (4.3)	9 (5.3)	10 (6.3)	11 (7.3)	12 (8.3)
Weeks of lactation:							
	Heifers[2])	(–0.31)	–0.35	–0.40	–0.44	–0.48	–0.53
1–12	Cows	(–0.18)	–0.21	–0.23	–0.26	–0.29	–0.31
	All lact.	(–0.24)	–0.27	–0.31	–0.34	–0.37	–0.41
	Heifers	(–0.24)	–0.28	–0.32	–0.36	–0.40	(–0.44)
1–24	Cows	(–0.24)	–0.28	–0.32	–0.36	–0.40	(–0.44)
	All lact.	(–0.24)	–0.28	–0.32	–0.36	–0.40	(–0.44)
	Heifers	(–0.18)	–0.21	–0.23	–0.26	(–0.29)	(–0.31)
1–36	Cows	(–0.36)	–0.42	–0.47	–0.52	(–0.57)	(–0.62)
	All lact.	(–0.29)	–0.34	–0.38	–0.42	(–0.46)	(–0.50)

[1]) The parameters of the functions are given in Table 5.12–5.14.
[2]) Average live weight at the beginning of the periods: Heifers: 477 kg. Cows: 538 kg.

Note: Estimates in brackets are not within the range of the experimental data.

Table 5.20 Marginal grass silage intake at different levels of grain mix, kg DM per cow daily[1])

Level of grain mix, kg DM daily		3	4	5	6	7	8
Weeks of lactation:							
	Heifers	(–0.22)	–0.29	–0.36	–0.43	–0.50	–0.58
1–12	Cows	(–0.13)	–0.17	–0.21	–0.25	–0.29	–0.34
	All lact.	(–0.16)	–0.22	–0.27	–0.32	–0.38	–0.43
	Heifers	(–0.20)	–0.26	–0.33	–0.40	–0.46	(–0.53)
1–24	Cows	(–0.20)	–0.27	–0.34	–0.41	–0.48	(–0.54)
	All lact.	(–0.20)	–0.27	–0.34	–0.41	–0.48	(–0.54)
	Heifers	(–0.13)	–0.18	–0.22	–0.26	(–0.31)	(–0.35)
1–36	Cows	(–0.28)	–0.38	–0.47	–0.56	(–0.66)	(–0.75)
	All lact.	(–0.22)	–0.29	–0.36	–0.43	(–0.50)	(–0.58)

[1]) The parameters of the functions are given in Table 5.15.

The experimental data have shown that even quite different patterns of feeding a given amount of grain mix led to almost the same voluntary intake of grass silage (Table 5.8). The functions are therefore valid for feeding the grain mix in different strategies, e.g. with a constant, daily amount as well as a decreasing or increasing amount, except for extreme strategies such as Strategy M+2,–1.

The estimates of total daily dry matter intake of allowances as a function of grain mix to grass silage fed ad libitum, are shown in Table 5.21.

From the data in Table 5.21 it is seen that for a particular amount of grain mix the intake of dry matter in relation to live weight, metabolic weight and requirement for maintenance was almost equal for heifers and cows. However, it was lowest for the cows mainly due to a slightly lower percentage of concentrate DM in the ration, caused by the higher intake of silage. The dry matter intake per 100 kg live weight varied in the present study from 2.8 to 3.8 kg, which is high compared to the values of 1.9 to 2.9 given in Table 5.17 relating to feeding different qualities of grass silage without any supplement.

It can be concluded that the voluntary dry matter intake of high yielding dairy cows can be regulated within 1.9 to 3.8 kg DM per 100 kg live weight during weeks 1–36 of lactation by ad libitum feeding with grass silage of various digestibility and with a fixed daily supplement ranging from zero to almost 12 kg DM of concentrates (8.0 kg of grain mix and 3.7 kg of roots, molasses and sugar beet pulp). On a net energy basis the regulation is higher, as the total daily food intake, for the above mentioned conditions, ranges within approximately 1.0 to 3.0 SFU per 100 kg initial live weight of the cows. The intake of the heifers per

Table 5.21 Estimates of total daily food intake for different levels of grain mix feeding. Grass silage is fed ad libitum

Grain mix feeding kg DM daily[1]		Total daily food, kg DM per 100 kg live weight and (g DM per kg live weight$^{3/4}$)						
		Weeks 1–12		Weeks 1–24			Weeks 1–36	
4	Heifers[2])	3.05	(143)	3.14	(147)	2.7[3])	3.16	(148)
	Cows[2])	2.84	(137)	2.96	(143)	2.6	2.99	(144)
6	Heifers	3.32	(155)	3.43	(160)	3.1	3.48	(163)
	Cows	3.13	(151)	3.21	(154)	2.9	3.19	(153)
8	Heifers	3.53	(165)	3.65	(171)	3.4	3.78	(176)
	Cows	3.39	(163)	3.40	(164)	3.2	3.31	(160)

[1]) Other concentrates are: roots, molasses and dried pulp of sugar beets fed in fixed amount, 3.7 kg DM daily.

[2]) Initial live weight (metabolic weight): Heifers: 477 kg (102.1 kg). Cows: 538 kg (111.7 kg).

[3]) Net energy as a multiple of maintenance requirement.

100 kg initial live weight is slightly higher when feeding the same amounts of concentrates. Furthermore it seems reliable to conclude that for practical application valuable predictions of the food intake can be made by means of the presented functions, even when the composition of the concentrates is higher respective lower in oilcakes, grain, roots, pulp or molasses than was the case in the present study. However, the physical structure of the ration should be so that the rumen fermentation is not disturbed, and the dry matter in concentrates should not amount to more than approximately 70 percentages of the total dry matter in the ration (Section 5.1 and Fig. 5.2).

VI Production

6.1. Literature and introduction

The literature relating to the feeding of dairy cows is rich in reports on experiments in which different levels of energy are fed according to the actual milk yield. These studies by Frederiksen et al. (1931), Hansson et al. (1954), Hvidsten (1955), Larsen and Larsen (1956), Holmes et al. (1957), Burt (1957), Broster et al. (1958), Nordfeldt and Ruudvere (1963), Larsen et al. (1967), Dijkstra (1969), Wiktorsson (1971) and Ekern (1972 I) cannot form the basis for estimating response functions, however, as explained in Chapter II. Furthermore, for the estimation of response functions more than two levels of the independent food input are needed, and therefore the experiments of Broster et al. (1969) and Johnson (1977) with two yield-independent food allowances cannot be used either. However, these important studies do show clearly how the use of different standards changes the partition of the food intake between milk and body tissue production. Blaxter (1956 and 1966), Burt (1957) and Flatt et al. (1969 a and 1969 b), among others, found in their studies that a greater part of the energy intake was used for body gain when the concentrate allowance was increased.

The above mentioned studies also show the possibility of changing milk composition. In association with higher levels of energy feeding per kg milk or per kg of 4% fat corrected milk (FCM), the percentage of milk fat is usually decreased, while the percentage of protein is increased or unchanged. Consequently the ratio of protein:fat is increased. This is demonstrated by the following results of studies on ration effect on milk composition (Flatt et al., 1969 a):

Ration, % of DM		Fat	Protein	SNF	Protein
Hay	Grain mix	%	%	%	: Fat ratio
60	40	3.5	3.1	8.3	0.89
40	60	3.0	3.2	8.3	1.07
20	80	2.7	3.1	8.0	1.15

This picture is a general one and is therefore valid for the different stages of lactation. A recent Danish experiment involving different levels of energy and protein, fed independently of daily milk yield in early lactation (week 1–9) also stresses this picture (Krohn and Andersen, 1978).

From an economical point of view it is primarily the total daily amount of butterfat, protein and other milk components produced and secondly the chemical composition which is of interest. If only one parameter of milk output should be taken into account, the best one is kg of FCM, which with the present breed expresses the monetary equivalence accurately under Danish market conditions (Østergaard et al., 1977). FCM also expresses the energy equivalence of milk production efficiently, when the fat percentage is not lower than 3.00 (Tyrrell and Reid, 1965). This was the case in the present experiment.

Studying the effect of increasing the allowances of grain mix, Neimann-Sørensen (1971) concluded that maximum milk yield (FCM) is attained when the grain mix dry matter amounts to approximately 60% of total dry matter of the ration. In some experiments relating to this question, the optimum percentage has been found to be lower, even 40–50, indicating that the effect of the percentage of grain mix depends on the type and quality of the roughages fed as well as the chemical composition and physical structure of the grain mix.

In most short term feeding experiments attention has been focused on the milk yield as well as on the marginal yield, while the response in body tissue gain has not been examined. When balance trials cannot be carried out, as was the case in the present study the change in body tissue can be measured and expressed by: a) live weight change, b) chest girth change and c) residual net energy, defined as the difference in net energy between the intake and the requirements for milk production and maintenance.

Because of changes in rumen fill in early lactation and changes in body composition (Moe and Flatt, 1969), method c) is considered to be the best to describe changes in body tissue.

The above mentioned residual net energy (SFU) is calculated by subtracting from the total food intake the requirements for milk production (0.40 x kg FCM) and maintenance (4.9 + 0.007 (live weight –500)). These requirements for milk production and maintenance are based on the estimates of Frederiksen et al. (1931) and Moe and Flatt (1969) respectively, because of the high level of food intake used. These standard lead to the same total requirements at approximately 20 kg of FCM per cow daily, as those suggested by van Es (1975). However, the older standard chosen is about 7% lower for milk production and about 10% higher for maintenance.

If the residual net energy attained by larger allowances of grain mix is estimated only by means of the conventional formulas (Chapter III), an overestimation will be the case, as these formulas for the calculation of the nutritive value of the respective feeds do not take regard to the size and composition of the diet.

The raised question is answered by the studies of van Es (1975 and 1976), who concluded: »Energy losses from the diet in faeces, methane and urine in dairy cattle increase by about 1.8% per multiple of maintenance feeding level. Higher losses occur, especially at higher feeding levels, when the diet lacks physical structure (i.e. less than 30% long forage on a dry matter basis), or if the diet is very rich in protein or fat«. This was not the case in the present experiment. However, when the residual net energy grows the surplus of protein raises as the protein requirement for body tissue gain is lower than for milk production. According to estimates by Østergaard (1973) the direct calculated amount of SFU's in diets rich in protein is overestimated in net energy by 0.7 SFU per kg of digestible crude protein in surplus compared to the requirements of the total production and maintenance. By means of these findings and the figures in Tables 5.16 and 5.21 the correction factors for the total daily diet to all animals in the present study were calculated to be about –0.1, –0.2, –0.3 and –0.4 SFU when feeding 5, 6, 7 and 8 kg DM of grain mix, respectively. It was assumed that no correction should be made to the balanced food level attained by feeding 4 kg DM of grain mix or less as the latter food intake is comparable to the one used in the experiments for estimating the nutritive value of various feeds.

The following examples for heifers during weeks 1–24 of lactation show the calculation of the correction of the calculated net energy intake, only by means of –1.8 percentage per multiple of maintenance feeding level (MMF), (Tables 5.16 and 5.21):

Grain mix kg DM	Daily food intake per heifer: Total concentrates kg DM	Total concentrates %	Total SFU	MMF[1] a)	MMF[1] b)	Change from low food intake: MMF	Change from low food intake: –0.018 MMF × SFU, total
4	7.7	51	12.81	2.70	3.0	–	–
5	8.7	55	13.72	2.89	3.2	0.2	–0.05
6	9.7	59	14.58	3.08	3.4	0.4	–0.11
7	10.7	63	15.39	3.25	3.6	0.6	–0.17
8	11.7	67	16.16	3.41	3.8	0.8	–0.23

[1]) Maintenance requirements based on studies of: a) Moe and Flatt (1969) and b) van Es (1975).

Similar calculations for cows lead to almost the same correction in the intake of net energy.

Assuming maximum milk yield with about 65% concentrates in the total dry matter of the ration, a surplus of digestible crude protein will be found at the higher food intake. The increase, from the lowest food intake, i.e. at 4 kg of grain mix daily, in the allowances of protein can easily be calculated on basis of the figures in Tables 3.2 and 5.16. When feeding 5, 6, 7 and 8 kg of grain mix daily to heifers and cows during weeks 1–24 of lactation, this increase can be calculated to 150, 294, 430 and 561 g digestible crude proteing per animal, respectively. The surplus of protein, which depends on the marginal milk yields and gain, may range from about zero to about 0.3 kg. This corresponds to an overestimation of the net energy, calculated by the formulas referred to in Chapter III, by up to about 0.2 SFU, when multiplying the above possible protein-surplus by 0.7 SFU per kg of digestible crude protein.

The conclusion of these calculations is the suggestion of the above mentioned correction factors, –0.1, –0.2, –0.3 and –0.4 SFU on an average basis, when feeding 5, 6, 7 and 8 kg DM of grain mix per animal daily, respectively.

In the present long term experiment, the fertility as well as the incidences of diseases will be looked upon as a part of the output, i.e. the production.

6.2. Own investigations

6.2.1. Milk yield

The result of the analysis of variance on kg FCM per cow daily is shown in Table 6.1. Model (1), which includes the effects of weight of the cow, parity, strategy and of the interaction between strategy and parity, explains 52% for weeks 1–12, and 48% for weeks 1–24 of the total variation (R^2) in the milk yield. These values were close to those found in the analysis of total food intake. However, the values for the other stages of lactation were smaller.

Among the sources of variation in milk yield (FCM) the strategy x parity interaction was not significant, while the strategy effect was highly significant in all stages of lactation, as was also the case for the parity effect except for weeks 25–36 of the lactation. The effect of weight was highly significant except for weeks 13–24 and 25–36, this being explained by a highly negative correlation between milk yield and live weight change for weeks 1–12.

Table 6.1 Analysis of variance on milk yield (kg FCM per cow daily)

Stage of lactation Weeks of lactation		I 1–12		II 13–24		III 25–36		I–II 1–24		I–III 1–36	
Source	d.f.	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Model	18	1814	100.78	699	38.86	424	23.54	1133	62.97	672	37.33
Error	279	1664	5.97	1353	4.85	1648	5.91	1229	4.41	1130	4.05
R^2 (%)		52.2		34.1		20.4		48.0		37.3	
Source	d.f.	SS	P	SS	P	SS	P	SS	P	SS	P
Weight[1])	1	277	0.0001	1	0.70	7	0.28	136	0.0001	72	0.0001
Parity	1	352	0.0001	279	0.0001	11	0.17	235	0.0001	109	0.0001
Strategy	8	186	0.0002	242	0.0001	308	0.0001	166	0.0001	173	0.0001
Strat. × parity	8	52	0.37	46	0.32	80	0.099	40	0.34	43	0.22

[1]) Initial live weight for the respective stages of lactation.

Table 6.2 shows the least squares estimates of the effects of weight, parity and strategy. The regression coefficient of yield on weight is seen to be 2.4 kg FCM daily per 100 kg initial live weight in weeks 1–12, but for the following two stages the coefficients were negative as mentioned above.

The analyses of variance on daily milk yield expressed as kg milk, kg milk solids, kg butterfat, kg milk protein and kg solids-not-fat show a picture similar to that for kg FCM. In all cases a highly significant strategy (treatment) effect was obtained (Tables 6.3, 6.5, 6.7, 6.9 and 6.11). Consequently the hypothesis concerning level of production (Chapter I) can be accepted.

The corresponding least square estimates of the effects of weight, parity and strategy are shown in the Tables 6.4, 6.6, 6.8, 6.10 and 6.12. The composition of the milk, expressed by the milk protein:butterfat ratio, was changed significantly by strategy during weeks 1–12. However, the initial weight of the animal had a significant effect for weeks 1–12, 1–24 and 1–36, respectively (Table 6.13). Table 6.14 shows the least square estimates of the effect of weight, parity and strategy, and Table 6.15 shows the chemical composition of the milk.

Table 6.2 Least squares estimates of the effects of weight (regression coefficient), parity and strategy (adjusted means) on milk yield, kg FCM per cow daily

Stage of lactation Weeks of lactation	I 1–12	II 13–24	III 25–36	I–II 1–24	I–III 1–36
Source					
Weight (kg/100 kg)	2.432	–0.129	–0.381	1.705	1.238
Parity, Heifers	19.87	18.60	16.92	19.21	18.43
Cows	24.11	20.92	17.15	22.55	20.71
Strategy[1]) L_0	20.71	18.54	16.54	19.59	18.53
$L_{-1/2}$	22.07	19.38	16.04	20.72	19.13
M_0	22.41	19.66	17.59	21.07	19.90
$M_{-1/2}$	22.23	19.61	16.93	20.94	19.58
$M_{+2,-1}$	21.19	20.39	17.14	20.78	19.52
M_{-1}	22.91	20.19	15.88	21.55	19.62
H_0	23.09	21.35	18.63	22.21	20.98
$H_{+1,-1/2}$	23.04	21.26	18.78	22.17	21.01
Norm	22.94	18.89	15.93	20.96	19.29
LSD	1.18	1.06	1.17	1.01	0.97
Overall mean[1])	22.29	19.92	17.05	21.11	19.73

[1]) 43% heifers.

Table 6.3 Analysis of variance on milk yield (kg milk per cow daily)

Stage of lactation Weeks of lactation		I 1–12		II 13–24		III 25–36		I–II 1–24		I–III 1–36	
Source	d.f.	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Model	18	1909	106.08	760	42.20	395	21.95	1208	67.12	663	36.82
Error	279	1711	6.13	1749	6.27	1812	6.49	1456	5.22	1338	4.80
R^2 (%)		52.7		30.3		17.9		45.3		33.1	
Source	d.f.	SS	P	SS	P	SS	P	SS	P	SS	P
Weight[1])	1	169	0.0001	5	0.36	12	0.17	98	0.0001	57	0.0006
Parity	1	495	0.0001	329	0.0001	1	0.65	300	0.0001	116	0.0001
Strategy	8	253	0.0001	244	0.0001	267	0.0001	196	0.0001	175	0.0001
Strat. × parity	8	58	0.30	68	0.21	86	0.11	52	0.28	51	0.23

[1]) Initial live weight for the respective stages of lactation.

Table 6.4 Least squares estimates of the effects of weight (regression coefficient), and strategy (adjusted means) on milk yield, kg per cow daily

Stage of lactation Weeks of lactation		I 1–12	II 13–24	III 25–36	I–II 1–24	I–III 1–36
Source						
Weight (kg/100 kg)		1.90	–0.36	–0.51	1.44	1.11
Parity,	Heifers	20.69	19.14	16.91	19.89	18.87
	Cows	25.12	21.52	16.75	23.32	21.13
Strategy[1])	L_0	21.51	19.13	16.00	20.27	18.98
	$L_{-½}$	22.85	19.98	16.12	21.39	19.60
	M_0	23.12	20.33	17.41	21.75	20.30
	$M_{-½}$	23.37	20.13	16.50	21.75	19.97
	$M_{+2,-1}$	21.89	20.97	17.23	21.39	19.93
	M_{-1}	24.14	20.50	15.64	22.29	20.03
	H_0	24.44	21.93	18.36	23.16	21.51
	$H_{+1,-½}$	23.92	21.97	18.42	22.95	21.40
	Norm	23.71	19.54	15.70	21.67	19.69
	LSD	1.19	1.21	1.23	1.10	1.05
Overall mean[1])		23.22	20.50	16.82	21.85	20.16

[1]) 43% heifers.

Table 6.5 Analysis of variance on milk solids (kg per cow daily)

Stage of lactation		I		II		III		I–II		I–III	
Weeks of lactation		1–12		13–24		25–36		1–24		1–36	
Source	d.f.	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Model	18	33.141	1.8412	12.995	0.7219	7.290	0.4050	20.760	1.1532	11.737	0.6521
Error	278	30.439	0.1091	28.153	0.1009	31.620	0.1133	24.114	0.0864	22.472	0.0805
R^2 (%)		52.1		31.6		18.7		46.3		34.3	
Source	d.f.	SS	P	SS	P	SS	P	SS	P	SS	P
Weight[1])	1	3.669	0.0001	0.0	0.98	0.098	0.35	1.988	0.0001	1.651	0.0004
Parity	1	7.823	0.0001	4.906	0.0001	0.079	0.40	4.878	0.0001	2.133	0.0001
Strategy	8	4.072	0.0001	4.298	0.0001	5.218	0.0001	3.181	0.0001	3.092	0.0001
Strat. × parity	8	0.709	0.59	1.040	0.25	1.459	0.12	0.686	0.44	0.704	0.37

[1]) Initial live weight for the respective stages of lactation.

Table 6.6 Least squares estimates of the effects of weight (regression coefficient), parity and strategy (adjusted means) on milk solids, kg per cow daily

Stage of lactation		I	II	III	I–II	I–III
Weeks of lactation		1–12	13–24	25–36	1–24	1–36
Source						
Weight (kg/100 kg)		0.028	–0.001	–0.045	0.206	0.150
Parity,	Heifers	2.639	2.441	2.202	2.539	2.422
	Cows	3.220	2.759	2.212	2.990	2.728
Strategy[1])	L_0	2.760	2.436	2.156	2.594	2.442
	$L_{-1/2}$	2.933	2.559	2.085	2.744	2.522
	M_0	2.949	2.587	2.285	2.771	2.608
	$M_{-1/2}$	2.999	2.584	2.200	2.793	2.592
	$M_{+2,-1}$	2.787	2.682	2.207	2.732	2.551
	M_{-1}	3.105	2.621	2.045	2.863	2.586
	H_0	3.115	2.822	2.432	2.967	2.783
	$H_{+1,-1/2}$	3.040	2.809	2.412	2.926	2.751
	Norm	3.041	2.498	2.049	2.774	2.533
	LSD	0.159	0.153	0.162	0.142	0.137
Overall mean[1])		2.970	2.622	2.208	2.796	2.596

[1]) 43% heifers.

Table 6.7 Analysis of variance on butterfat (kg per cow daily)

Stage of lactation Weeks of lactation		I 1–12		II 13–24		III 25–36		I–II 1–24		I–III 1–36	
Source	d.f.	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Model	18	2.864	0.1591	1.082	0.0601	0.755	0.0419	1.753	0.0974	1.094	0.0608
Error	278	3.417	0.0122	2.267	0.0081	2.911	0.0104	2.173	0.0078	1.927	0.0069
R^2 (3)		45.6		32.3		20.6		44.6		36.2	
Source	d.f.	SS	P	SS	P	SS	P	SS	P	SS	P
Weight[1])	1	0.583	0.0001	0.001	0.95	0.007	0.42	0.265	0.0001	0.132	0.0001
Parity	1	0.433	0.0001	0.398	0.0001	0.037	0.059	0.313	0.0001	0.166	0.0001
Strategy	8	0.256	0.0001	0.392	0.0001	0.552	0.0001	0.238	0.0003	0.276	0.0001
Strat. × parity	8	0.084	0.56	0.062	0.47	0.135	0.12	0.058	0.49	0.068	0.28

[1]) Initial live weight for the respective stages of lactation.

Table 6.8 Least squares estimates of the effects of weight (regression coefficient), parity and strategy (adjusted means) on butterfat, kg per cow daily

Stage of lactation Weeks of lactation		I 1–12	II 13–24	III 25–36	I–II 1–24	I–III 1–36
Source						
Weight (kg/100 kg)		0.112	0.001	–0.012	0.075	0.053
Parity,	Heifers	0.774	0.729	0.675	0.752	0.725
	Cows	0.938	0.821	0.694	0.880	0.817
Strategy[1])	L_0	0.808	0.725	0.660	0.766	0.729
	$L_{-1/2}$	0.863	0.759	0.639	0.810	0.753
	M_0	0.878	0.769	0.708	0.824	0.785
	$M_{-1/2}$	0.860	0.771	0.688	0.816	0.772
	$M_{+2,-1}$	0.830	0.801	0.683	0.815	0.769
	M_{-1}	0.884	0.799	0.641	0.842	0.774
	H_0	0.888	0.839	0.752	0.863	0.825
	$H_{+1,-1/2}$	0.899	0.832	0.761	0.866	0.830
	Norm	0.898	0.738	0.643	0.820	0.761
	LSD	0.053	0.043	0.049	0.043	0.040
Overall mean[1])		0.868	0.781	0.686	0.825	0.778

[1]) 43% heifers.

Table 6.9 Analysis of variance on milk protein (kg per cow daily)

Stage of lactation Weeks of lactation		I 1–12		II 13–24		III 25–36		I–II 1–24		I–III 1–36	
Source	d.f.	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Model	18	1.892	0.1051	0.753	0.0418	0.506	0.0281	1.167	0.0648	0.662	0.0368
Error	278	2.067	0.0074	2.359	0.0085	2.605	0.0093	1.828	0.0066	1.780	0.0064
R^2 (%)		47.8		24.2		16.3		39.0		27.1	
Source	d.f.	SS	P	SS	P	SS	P	SS	P	SS	P
Weight¹)	1	0.152	0.0001	0.002	0.65	0.008	0.37	0.064	0.0020	0.024	0.053
Parity	1	0.473	0.0001	0.280	0.0001	0.008	0.36	0.336	0.0001	0.167	0.0001
Strategy	8	0.368	0.0001	0.251	0.0004	0.378	0.0001	0.238	0.0001	0.213	0.0001
Strat. × parity	8	0.032	0.82	0.039	0.80	0.097	0.25	0.025	0.87	0.035	0.71

¹) Initial live weight for the resepctive stages of lactation.

Table 6.10 Least squares estimates of the effects of weight (regression coefficient), parity and strategy (adjusted means) on milk protein, kg per cow daily

Stage of lactation Weeks of lactation		I 1–12	II 13–24	III 25–36	I–II 1–24	I–III 1–36
Source						
Weight (kg/100 kg)		0.057	0.006	–0.013	0.037	
Parity,	Heifers	0.685	0.649	0.599	0.667	0.643
	Cows	0.821	0.729	0.604	0.775	0.717
Strategy¹)	L_0	0.709	0.655	0.595	0.682	0.652
	$L_{-½}$	0.756	0.677	0.569	0.716	0.667
	M_0	0.750	0.689	0.622	0.720	0.687
	$M_{-½}$	0.787	0.699	0.603	0.743	0.696
	$M_{+2,-1}$	0.702	0.698	0.597	0.700	0.665
	M_{-1}	0.813	0.699	0.556	0.756	0.668
	H_0	0.800	0.747	0.664	0.774	0.736
	$H_{+1,-½}$	0.775	0.732	0.653	0.753	0.719
	Norm	0.769	0.658	0.558	0.714	0.662
	LSD	0.042	0.044	0.047	0.039	0.038
Overall mean¹)		0.763	0.695	0.602	0.729	0.686

¹) 43% heifers.

Table 6.11 Analysis of variance on solids-not-fat (kg per cow daily)

Stage of lactation Weeks of lactation		I 1–12		II 13–24		III 25–36		I–II 1–24		I–III 1–36	
Source	d.f.	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Model	18	16.922	0.9401	6.699	0.3722	3.505	0.1947	10.540	0.5856	5.715	0.3175
Error	278	18.342	0.0657	16.636	0.0596	16.900	0.0606	13.967	0.0501	12.607	0.0452
R^2 (%)		48.0		28.7		17.2		43.0		31.2	
Source	d.f.	SS	P	SS	P	SS	P	SS	P	SS	P
Weight[1]	1	1.326	0.0001	0.001	0.95	0.054	0.35	0.801	0.0001	0.437	0.0021
Parity	1	4.575	0.0001	2.510	0.0001	0.008	0.72	2.721	0.0001	1.108	0.0001
Strategy	8	2.495	0.0001	2.141	0.0001	2.416	0.0001	1.716	0.0001	1.546	0.0001
Strat. × parity	8	0.326	0.76	0.655	0.21	0.764	0.13	0.365	0.51	0.357	0.45

[1]) Initial live weight for the respective stages of lactation.

Table 6.12 Least squares estimates of the effects of weight (regression coefficient), parity and strategy (adjusted means) on solids-not-fat, kg per cow daily

Stage of lactation Weeks of lactation		I 1–12	II 13–24	III 25–36	I–II 1–24	I–III 1–36
Source						
Weight (kg/100 kg)		0.168	–0.002	–0.034	0.131	0.097
Parity,	Heifers	1.865	1.711	1.525	1.800	1.697
	Cows	2.282	1.938	1.518	2.110	1.911
Strategy[1])	L_0	1.952	1.710	1.496	1.828	1.713
	$L_{-1/2}$	2.071	1.800	1.446	1.981	1.769
	M_0	2.071	1.818	1.577	1.947	1.823
	$M_{-1/2}$	2.139	1.813	1.512	1.977	1.820
	$M_{+2,-1}$	1.957	1.881	1.524	1.918	1.782
	M_{-1}	2.221	1.821	1.404	2.021	1.812
	H_0	2.226	1.983	1.680	2.103	1.959
	$H_{+1,-1/2}$	2.141	1.977	1.652	2.060	1.921
	Norm	2.143	1.760	1.406	1.955	1.772
	LSD	0.124	0.118	0.119	0.108	0.102
Overall mean[1])		2.102	1.840	1.522	1.977	1.819

[1]) 43% heifers.

Table 6.13 Analysis of variance on milk protein:butterfat ratio

Stage of lactation Weeks of lactation		I 1–12		II 13–24		III 25–36		I–II 1–24		I–III 1–36	
Source	d.f.	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Model	18	0.384	0.0213	0.069	0.0039	0.128	0.0071	0.165	0.0092	0.128	0.0071
Error	278	3.157	0.0113	2.156	0.0077	1.986	0.0071	1.891	0.0068	1.371	0.0049
R^2 (%)		10.8		3.1		6.0		8.0		8.5	
Source	d.f.	SS	P	SS	P	SS	P	SS	P	SS	P
Weight[1])	1	0.096	0.0038	0.001	0.77	0.001	0.75	0.055	0.0047	0.043	0.0033
Parity	1	0.012	0.30	0.001	0.88	0.013	0.18	0.011	0.21	0.004	0.37
Strategy	8	0.235	0.0094	0.037	0.78	0.050	0.53	0.085	0.14	0.056	0.19
Strat. × parity	8	0.062	0.70	0.032	0.84	0.061	0.39	0.033	0.78	0.031	0.62

[1]) Initial live weight for the respective stages of lactation.

Table 6.14 Least squares estimates of the effects of weight (regression coefficient), parity and strategy (adjusted means) on milk protein:butterfat ratio

Stage of lactation Weeks of lactation		I 1–12	II 13–24	III 25–36	I–II 1–24	I–III 1–36
Source						
Weight (kg/100 kg)		–0.045	0.000039	–0.000039	–0.00034	–0.00030
Parity,	Heifers	0.90	0.90	0.89	0.89	0.89
	Cows	0.88	0.90	0.87	0.89	0.88
Strategy[1])	L_0	0.88	0.91	0.91	0.89	0.90
	$L_{-½}$	0.89	0.89	0.89	0.89	0.89
	M_0	0.87	0.90	0.88	0.88	0.88
	$M_{-½}$	0.93	0.91	0.88	0.91	0.90
	$M_{+2,-1}$	0.86	0.87	0.87	0.86	0.86
	M_{-1}	0.93	0.88	0.87	0.90	0.90
	H_0	0.92	0.92	0.89	0.90	0.90
	$H_{+1,-½}$	0.87	0.89	0.86	0.88	0.87
	Norm	0.86	0.89	0.87	0.87	0.87
	LSD	0.05	0.04	0.04	0.04	0.03
Overall mean[1])		0.89	0.90	0.88	0.89	0.88

[1]) 43% heifers.

Table 6.15 Chemical composition of the milk produced on the different strategies

Strategy	Milk-comp. % Wks. 1–12				Milk-comp. % Wks. 13–24				Milk-comp. % Wks. 25–36			
	Solids	Fat	Prot.	SNF	Solids	Fat	Prot.	SNF	Solids	Fat	Prot.	SNF
L_0	12.83	3.76	3.30	9.07	12.73	3.79	3.42	8.94	13.48	4.13	3.72	9.35
$L_{-½}$	12.84	3.78	3.31	9.06	12.81	3.80	3.39	9.01	12.93	3.96	3.53	8.97
M_0	12.76	3.80	3.24	8.96	12.72	3.78	3.39	8.94	13.12	4.07	3.57	9.05
$M_{-½}$	12.83	3.68	3.37	9.15	12.84	3.83	3.47	9.01	13.33	4.17	3.65	9.16
$M_{+2, -½}$	12.73	3.79	3.21	8.94	12.79	3.82	3.33	8.97	12.81	3.96	3.46	8.85
M_{-1}	12.86	3.66	3.37	9.20	12.78	3.90	3.41	8.88	13.08	4.10	3.55	8.98
H_0	12.75	3.63	3.27	9.12	12.87	3.83	3.41	9.04	13.25	4.10	3.62	9.15
$H_{+1, -½}$	12.71	3.76	3.24	8.95	12.79	3.79	3.33	9.00	13.09	4.13	3.55	8.97
Norm	12.83	3.79	3.24	9.04	12.78	3.78	3.37	9.00	13.05	4.10	3.55	8.95
Overall mean	12.79	3.74	3.29	9.05	12.79	3.81	3.39	8.98	13.13	4.08	3.58	9.05

6.2.2. Persistency of milk yield

Knowledge of persistency of milk yield is a useful measure for the prediction of the milk yield, and for the planning of the feeding.

Table 6.16 shows by analysis of variance that initial live weight, parity and strategy of grain mix allowances all have a highly significant effect on kg of FCM in most of the mentioned nine 4-weeks periods of lactation. The within-class correlations between daily yield in different periods of the lactation were, for subsequent periods, not very high in early lactation, but higher in mid and late lactation (Table 6.17).

An estimation of the within-class correlations of milk yield in subsequent lactations of the same cows was also made (Table 6.18). Very low values were found in early lactation, while the values in late lactation were 0.4 to 0.6, showing a fairly good correlation in the later stage of lactation.

Table 6.19 shows the least squares means of daily yield in the respective 4 weeks-periods for heifers and cows as well as the strategy. It should be noted that the LSD-value and the overall standard deviation (s) was almost the same in the different stages of lactation.

The analysis of the curvature of the lactation curve (Chapter IV) showed for all the different strategies that a straight line efficiently described the relation between week of lactation and kg FCM daily, except for the two strategies M+2,–1 and M-1. Persistency is therefore defined as the coefficient of regression of milk yield on week of lactation (i.e. weeks after parturition minus one, according to the design of the experiment (Chapter II)). By use of Model (13) the expected yield in week »t« for the respective strategies and periods of lactation can be described by the function on the following general form:

(26) $Y_t = \bar{y} + b_1\,(t-\bar{t})$

Table 6.16 Analysis of variance on daily yield in 4-weeks periods: Partial sums of squares of Model (1), (kg FCM)

Weeks of lactation		1–4	5–8	9–12	13–16	17–20	21–24	25–58	29–32	33–36
Source	d.f.	SS	SS	SS	SS	SS	SS	SS	SS	SS
Model	18	2577	1876	1219	937	756	654	513	417	525
Error	279	2492	2063	1974	1508	1631	1646	1675	1891	2214
Total	297	5069	3939	3193	2445	2387	2300	2188	2308	2739
R^2 (%)		50.8	47.6	38.2	38.3	31.7	28.4	23.4	18.1	19.2
Weight	1	411***	305***	150***	67***	60***	17	15	6	0.2
Parity	1	482***	346***	248***	205***	112***	114***	46***	2	8
Strategy	8	272***	192***	167***	239***	240***	282***	299***	289***	348***
Strat. × parity	8	66	51	64	29	65	63	59	90	119

***: $P < 0.0001$

Table 6.17 Within-class correlations of Model (1) between daily yield in different periods of lactation

Weeks of lactation	1–4	5–8	9–12	13–16	17–20	21–24	25–28	29–32	33–36
1– 4	1	0.67	0.56	0.46	0.40	0.40	0.35	0.27	0.20
5– 8		1	0.73	0.60	0.50	0.48	0.42	0.34	0.26
9–12			1	0.73	0.60	0.58	0.52	0.43	0.35
13–16				1	0.70	0.70	0.65	0.54	0.50
17–20					1	0.79	0.68	0.63	0.57
21–24						1	0.80	0.72	0.64
25–28							1	0.84	0.72
29–32								1	0.83
33–36									1

Least significant difference between two correlation coefficients on 5% and 1% level is 0.17 and 0.22 respectively.

Table 6.18 Within-class correlations of milk yield in subsequent lactations of the same cows

Weeks of lactation	1–4	5–8	9–12	13–16	17–20	21–24	25–28	29–32	33–36
1st vs. 2nd lact. (n = 50)	0.16	–0.05	–0.06	0.24	0.29	0.41	0.49	0.56	0.61
2nd vs. follow. lact. (n = 55)	–0.05	0.16	0.17	0.37	0.26	0.40	0.46	0.57	0.48

Table 6.19 Least squares means of daily yield in 4 weeks-periods, kg FCM

Weeks of lactation	1–4	5–8	9–12	13–16	17–20	21–24	25–28	29–32	33–36
Heifers	19.71	19.95	19.98	19.24	18.55	17.94	17.27	17.00	16.13
Cows	24.75	24.24	23.38	22.07	20.79	19.87	18.61	17.01	15.67
Strategy									
L_0	21.17	20.68	20.34	18.94	17.41	17.99	16.91	16.45	15.83
$L_{-½}$	22.65	22.32	21.26	20.38	19.21	18.43	17.01	16.09	14.77
M_0	22.94	22.46	21.85	20.54	19.49	19.09	18.58	17.42	16.69
$M_{-½}$	22.66	22.36	21.70	20.95	19.36	18.56	17.79	17.14	15.62
$M_{+2,-1}$	20.59	21.39	21.63	21.09	20.51	19.42	18.28	16.94	15.73
M_{-1}	22.96	22.94	22.86	21.20	20.12	19.16	17.56	15.62	14.39
H_0	23.58	23.26	22.47	22.15	21.15	20.62	19.44	18.59	17.46
$H_{+1,-½}$	23.23	23.12	22.78	22.10	21.22	20.51	19.79	18.66	17.60
Norm	24.47	23.04	22.34	20.34	18.98	17.55	16.93	16.15	14.74
LSD	1.44	1.31	1.28	1.12	1.16	1.17	1.18	1.25	1.36
Mean	22.58	22.40	21.91	20.85	19.83	19.04	18.03	17.01	15.87
s.d.	2.99	2.72	2.66	2.33	2.42	2.43	2.45	2.60	2.82

Function (26) neglects the description of the increasing yield just after parturition, but it is acceptable in the present long term study because of the short period of increasing yield and the fact that the milk yield was recorded only every second week.

In Chapter IV some curves of lactation are presented in Fig. 4.2. Mean yield and persistency were found to be uncorrelated on a between cow basis (r was –0.13 and 0.04 for weeks 1–24 and weeks 1–36, respectively). Therefore the analysis of the lactation curve can be performed as two independent analyses of the two parameters describing the curve.

The mean yield, $\bar{y}$, to use in Function (26) is shown in Table 6.2.

The analysis of variance (Model (1)) on persistency of milk yield (b_1) showed highly significant effects of treatment as well as of initial live weight and parity (Table 6.20). Table 6.21 shows for weeks 1–24 and 1–36 the estimates of the change in kg FCM over a 4 weeks period (slope). It is seen that the slope was steeper for the »–½« – and »–1«-strategies and the Norm treatment than for the »0«-strategies. The strategies M +2, –1 and H+1, –½ had the flattest slope, apparently caused by the low and increasing level of grain mix during early lactation. The overall means shows a great difference in persistency between heifers and cows.

A study was made of the influence of the initial yield, defined as the deviation from average daily yield (kg FCM) within strategies during weeks 1–4 of the lactation, on persistency. Initial yield, average of the two records during weeks 1–4, was preferred to peak yield, as the latter is not considered an appropriate tool for predictions because the date or week of its appearance is hardly ever known in commercial herds. The result of the analysis is given in Table 6.22. It appears from this that the initial yield as well as the live weight, parity and strategy had a highly significant effect both on the mean yield and on the persistency. The interaction terms, initial yield x weight, initial yield x parity and initial yield x strategy, were not significant, as the P-values were in between 0.18–0.95.

The isolated effect of initial yield on the mean yield and the persistency was estimated, and a comparison made of observed and estimated means. The results are given in Table 6.23 and show that one kg FCM extra in initial yield increases the average daily yield by 0.52 and 0.42 kg for weeks 1–24 and 1–36 of lactation, respectively. However, the persistency is lowered by 0.125 and 0.081, respectively, for the same weeks.

How well Model (1), expanded with the effect of initial yield, can predict the average daily yield and persistency for weeks 1–24 and 1–36 is seen in Table 6.23 by comparing the observed experimental data with the estimated. An extremely good agreement was found for the averages of the three equal-sized groups of cows.

Table 6.20 Analysis of variance on persistency (the slope of the curve of lactation, kg FCM per 4 weeks)

Weeks of lactation		1–24		1–36	
Source	d.f.	SS	MS	SS	MS
Model	18	61.3	3.41	49.8	2.77
Error	279	98.9	0.35	51.4	0.18
R^2 (%)		38.3		49.2	
Source	d.f.	SS	P	SS	P
Weight	1	10.6	0.0001	6.1	0.0001
Parity	1	5.5	0.0001	9.1	0.0001
Strategy	8	18.4	0.0001	8.3	0.0001
Strat. × parity	8	3.0	0.41	2.1	0.18

Table 6.21 Least squares means of the slope of the lactation curve for different strategies and parity, kg FCM per 4 weeks, (b_1 in Function (26))

Weeks of lactation		1–24			1–36	
Parity	Heif.	Cows	Mean	Heif.	Cows	Mean
Strategy						
L_0	–0.37	–0.93	–0.69	–0.39	–0.93	–0.70
$L_{-½}$	–0.70	–1.04	–0.90	–0.74	–1.21	–1.01
M_0	–0.53	–1.08	–0.84	–0.47	–1.05	–0.80
$M_{-½}$	–0.34	–1.26	–0.87	–0.48	–1.22	–0.90
$M_{+2,-1}$	–0.06	–0.41	–0.26	–0.43	–0.88	–0.69
M_{-1}	–0.39	–1.16	–0.83	–0.67	–1.51	–1.15
H_0	–0.26	–0.88	–0.61	–0.39	–1.06	–0.77
$H_{+1,-½}$	–0.19	–0.86	–0.57	–0.35	–1.01	–0.73
Norm	–0.73	–1.65	–1.25	–0.58	–1.59	–1.15
LSD	–	–	0.29	–	–	0.21
Mean	–0.40	–1.03	–0.76	–0.50	–1.16	–0.88

Table 6.22 Analysis of variance on the influence of initial yield on mean and persistency of daily yield (kg FCM)[1])

Variate:		Mean yield		Persistency	
Weeks of lactation		1–24	1–36	1–24	1–36
Source	d.f.	P	P	P	P
Weight	1	0.0001	0.0001	0.0001	0.0001
Parity	1	0.0001	0.0001	0.0001	0.0001
Strategy	8	0.0001	0.0001	0.0001	0.0001
Strat. × parity	8	0.013	0.027	0.095	0.035
Initial yield	1	0.0001	0.0001	0.0001	0.0001

[1]) Initial yield is kg FCM per day during weeks 1–4 of lactation.

Table 6.23 The effect of initial yield on the average daily yield and persistency. Comparison of observed and estimated means (FCM)

Initial yield (wks. 1–4)		Average daily yield, kg		Persistency (kg FCM per 4 weeks)	
Effect of ± 1 kg FCM		Wks. 1–24 ±0.52	Wks. 1–36 ±0.42	Wks. 1–24 ±0.125	Wks. 1–36 ±0.081
Low (–3.1 kg*)	Observed	19.5	18.4	–0.42	–0.66
	Estimated	19.5	18.4	–0.38	–0.63
Medium (0*)	Observed	21.2	19.9	–0.66	–0.83
	Estimated	21.1	19.7	–0.76	–0.88
High (+3.3 kg*)	Observed	22.8	21.0	–1.25	–1.19
	Estimated	22.8	21.1	–1.17	–1.15

* Devitations from expected initial yield (average 22.6 kg FCM).

6.2.3. Body tissue gain

The changes in body tissue were measured in three different ways: a) Live weight change, b) chest girth change and c) residual net energy.

The analysis of variance on live weight change (kg per cow) showed significant effects of initial weight and stragegy for weeks 1–12, 1–24 and 1–36 of lactation (Table 6.24). The working hypothesis (Chapter I) can therefore also be accepted with respect to gain.

However, the variation in live weight change between strategies were from –3 to 12 kg (overall mean 5 kg) for weeks 1–12, from 5 to 35 kg (overall mean 22 kg) for weeks 1–24, and from 35 to 60 kg (overall mean 50 kg) for weeks 1–36 (Table 6.25). Between animals, within the strategies, parities and initial live weights, there was found a large variation. This must be attributed to random effects and genetic differences with respect to mobilization and deposition of body tissue.

Table 6.24 Analysis of variance on live weight change (kg per cow)

Stage of lactation Weeks of lactation		I 1–12		II 13–24		III 25–36		I–II 1–24		I–III 1–36	
Source	d.f.	SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Model	18	42436	2358	14064	781	15110	839	79124	4396	88114	4895
Error	279	146935	527	75922	272	131539	471	229387	822	289641	1038
R^2 (%)		22.4		15.6		10.3		25.6		23.3	
Source	d.f.	SS	P	SS	P	SS	P	SS	P	SS	P
Weight[1])	1	25985	0.0001	251	0.34	3347	0.0082	35158	0.0001	37179	0.0001
Parity	1	2616	0.027	1817	0.010	1153	0.12	265	0.57	596	0.45
Strategy	8	8786	0.037	7670	0.0007	8342	0.027	25831	0.0002	27166	0.0014
Strat. × parity	8	4747	0.35	3112	0.18	3360	0.52	7750	0.31	13417	0.12

[1]) Initial live weight for the respective stages of lactation.

Table 6.25 Least squares estimates of the effects of live weight (regression coefficient), parity and strategy (adjusted means) on live weight change, kg/cow

Stage of lactation Weeks of lactation		I 1–12	II 13–24	III 25–36	I–II 1–24	I–III 1–36
Source						
Weight (kg/100 kg)		–23.54	–2.44	–8.38	–27.38	–28.15
Parity:	Heifers	9.00	21.70	29.77	30.38	57.41
	Cows	2.15	14.08	29.26	16.06	43.80
Strategy[1])	L_0	7.84	19.05	35.88	26.72	59.84
	$L_{-½}$	2.52	12.06	27.57	14.46	40.48
	M_0	–3.01	15.85	33.94	12.71	45.65
	$M_{-½}$	5.80	15.70	26.37	21.21	45.72
	$M_{+2,-1}$	11.99	23.54	26.09	35.19	58.00
	M_{-1}	12.49	15.53	17.95	27.61	43.05
	H_0	6.68	21.93	33.74	28.38	59.42
	$H_{+1,-½}$	4.75	23.72	34.08	28.20	59.86
	Norm	–3.21	8.85	29.65	5.47	34.83
	LSD	11.06	7.94	10.45	13.81	15.52
Overall mean[1])		5.09	17.36	29.48	22.21	49.65

[1]) 43% heifers.

The analysis of variance on change in chest girth also showed significant treatment effects, as there was a high, positive correlation between live weight change and change in the chest girth (Table 6.26). The table also shows that there were found low correlations between live weight change and residual net energy as well as between chest girth change and residual net energy, particularly during weeks 13–24.

The result of the third method, c) residual net energy (Section 6.1), for measuring the body tissue gain is presented in Section 6.2.4, due to its dependence on food intake and milk yield.

Table 6.26 Correlation between live weight change (LWC) and chest girth change (CGC) and between these and the estimated residual net energy (RNE). Coefficients for all animals

Weeks of lactation	LWC (kg), CGC (mm)	LWC (kg), RNE (SFU)	CGC (mm), RNE (SFU)
1–12	0.67	0.54	0.42
13–24	0.33	0.12	0.19
25–36	0.57	0.31	0.22
1–24	0.78	0.41	0.38
1–36	0.77	0.39	0.37

6.2.4. Milk yield and body tissue gain as a function of level of grain mix

The analyses of variance were made in order to investigate on possible differences and interactions in the milk yield response to grain mix feeding. There was found highly significant treatment effect of the allowances of grain mix and it is possible to estimate reliable response functions. Furthermore, since no significant effect of pattern of feeding the same amount of grain mix was found, (Section 6.2.1), all the animals and strategies except M+2, –1, and Norm treatment were used in the computations. By means of Model (3) (Chapter IV) the milk yield was estimated as a function of the allowances of grain mix. In Table 6.27 are shown the estimated parameters of the functions representing the output of milk or the components of milk. The parameters are b_0, b_1 and b_2 and the functions can be written as follows:

$$(27) \quad Y = b_0 + b_1 \cdot GI + b_2(GI)^2$$

where Y = kg of milk or the respective components per cow daily

and GI = kg DM of grain mix daily.

Table 6.27 Estimated parameters of regression of milk yield (milk, solids, butterfat, milk protein and solids-not-fat, kg per cow daily) on kg DM in grain mix per cow daily

Trait	Weeks of lactation	b_0	b_1 (b_2 if noted) est.	b_1 (b_2 if noted) s.d.	t-test $b = 0$ P-value	Residual s.d.
1. Function (27)						
Milk, kg						
	1–12	13.72				2.599
		b_1 :	2.656	1.369	0.054	
		b_2 :	–0.167	0.117	0.15	
Solids, kg						
	1–12	2.017				0.340
		b_1 :	0.246	0.171	0.17	
		b_2 :	–0.013	0.015	0.38	
Butterfat, kg						
	1–12	0.537				0.118
		b_1 :	0.099	0.063	0.11	
		b_2 :	–0.007	0.005	0.19	
2. Function (27) for $b_2 = 0$						
Milk, kg						
	1–12	19.18	0.705	0.150	0.0001	2.605
	1–24	17.43	0.805	0.151	0.0001	2.345
	1–36	16.02	0.815	0.145	0.0001	2.197
Solids, kg						
	1–12	2.452	0.091	0.020	0.0001	0.340
	1–24	2.238	0.102	0.019	0.0001	0.293
	1–36	2.054	0.107	0.018	0.0001	0.277
Butterfat, kg						
	1–12	0.765	0.018	0.007	0.011	0.119
	1–24	0.672	0.028	0.006	0.0001	0.092
	1–36	0.613	0.032	0.006	0.0001	0.083
Milk protein, kg						
	1–12	0.607	0.028	0.005	0.0001	0.085
	1–24	0.586	0.027	0.005	0.0001	0.076
	1–36	0.551	0.027	0.005	0.0001	0.075
Solids-not-fat, kg						
	1–12	1.686	0.073	0.015	0.0001	0.258
	1–24	1.566	0.074	0.014	0.0001	0.219
	1–36	1.441	0.075	0.014	0.0001	0.206

Correlation between b_1 and b_2 for weeks 1–12: –0.9940 (for use in (6) page 28)

Range of GI-values:	Wks. 1–12	4.0 – 7.7
	Wks. 1–24	4.0 – 6.9
	Wks. 1–36	4.0 – 6.6

In Table 6.27 (upper part) is shown only the functions for which the t-test showed the lowest P-values, when testing the b_1- and b_2-parameters. Consequently the probability of the existence of curvilinear relationships within the range of the present experimental data is low. However, linear relationships may exist within the range of GI-values, as highly significant b_1-parameters were found (Table 6.27, lower part). In no cases there was found significant difference between the b_1's for weeks 1–12, 1–24 and 1–36 within the functions concerning milk or one of the milk components (traits), although larger b_1-values are seen for the longer periods of lactation than of weeks 1–12.

Under circumstances where the milk protein:butterfat ratio was not changed markedly, as was the case in the present experiment, it is appropriate to express the milk output in kg FCM. By using Model (3) the following functions were estimated on the GI-values ranging from 3.3 to 8.1:

Heifers		t-test for $b_2 = 0$	$Y_{max.}$ for:
Wks. 1–4	$Y = 6.88 + 4.37GI - 0.349GI^2$,	P: 0.0011	GI = 6.3
Wks. 1–8	$Y = 5.83 + 4.56GI - 0.352GI^2$,	P: 0.011	GI = 6.5
Cows			
Wks. 1–4	$Y = 16.16 + 2.49GI - 0.164GI^2$,	P: 0.071	GI = 7.6
Wks. 1–8	$Y = 15.56 + 2.49GI - 0.158GI^2$,	P: 0.24	GI = 7.9

Curvilinear relationships were detected and the maximum yields were found with about 65%-concentrates (grain mix, roots, molasses, dried sugar beet pulp) in the total dry matter of the ration. On the basis of these findings and the observations discussed in the introduction (Section 6.1), the level of total concentrates which gives maximum daily yield is assumed to be 65% of the total DM in the ration. Using this as a restriction on Model (4), the parameters of the Function (27) for heifers and cows in three periods of lactation were estimated (Table 6.28).

The agreement between the estimates by Function (27) using the parameters in Table 6.28 and the strategy-figures in Table 6.2 is seen of the following daily yields of kg FCM during weeks 1–24 of lactation of heifers and cows on the respective strategies: (pooled function: kg FCM daily = $12.57 + 2.45GI - 0.158GI^2$):

Weeks 1–24:

Strategy:	L_0	$L_{-½}$	M_0	$M_{-½}$	M_{-1}	H_0	$H_{+1,-½}$
GI, kg DM/day	3.95	4.60	5.25	5.87	6.50	6.52	6.90
By Function (27)	19.78	20.50	21.08	21.51	21.82	21.83	21.95
From Table 6.2	19.59	20.72	21.07	20.94	21.55	22.21	22.17
Relative to est. by Fct. (27)	99	101	100	97	99	102	101

The body tissue gain, for increasing allowances of grain mix, is best described by the residual, defined as the net energy intake minus the requirements for maintenance and milk production. When calculating in SFU this difference is reduced by 0.1 SFU per extra kg of grain mix-DM above 4 (see Section 6.1). The transformation of the residual net energy, SFU, to body tissue gain (BTG = kg of standardized gain) is made by multiplying with the factor 0.2, corresponding to 5.1 SFU per kg of gain. The latter factor is based on the net energy per kg of gain containing 75% fat, 5% protein and 20% water. This corresponds to 30.99 MJ_{NE} and $\frac{30.99}{7.26} = 4.3$ SFU. To this is added 0.8 SFU, the calculated extra maintenance requirement, on a full lactation basis, for body tissue deposited in mid-lactation instead of late-lactation. The latter calculation is based on a time-difference in deposition of 4 months.

According to Moe et al. (1971) the efficiency in use of food for deposition during the dry period was found to be 0.59 compared to 0.73 during lactation. Consequently, the requirements of SFU per kg of gain are 4.3 :(0.59:0.73) = 5.3 during the dry period. Deposition during lactation is therefore from an energy utilization point of view preferable to the dry period. This being the reason for the estimation of functions describing the relationship between the allowances of grain mix and the body tissue gain during lactation.

For weeks 1–12 and 1–24 the response functions were the following, when the body tissue gain (BTG) is expressed in kg per day (Range of GI-values: 4.0 to 7.7, respective 4.0 to 6.9). The BTG is also given for two allowances of grain mix:

		BTG at GI, kg	
		4	8
Heifers			
Wks. 1–12	$BTG = 0.104 - 0.068GI + 0.015GI^2$	0.07	0.52
Wks. 1–24	$BTG = 0.114 - 0.028GI + 0.011GI^2$	0.18	0.59
Cows			
Wks. 1–12	$BTG = -0.511 + 0.036GI + 0.0073GI^2$	–0.25	0.24
Wks. 1–24	$BTG = -0.258 + 0.032GI + 0.0057GI^2$	–0.04	0.36

The following is an example of the calculation of the total energy intake in SFU (TEI_{SFU}), the requirements (SFU) for maintenance and milk production, the residual SFU, the corrected residual SFU and the BTG. Cows in weeks 1–24 with initial live weight 538 kg. (See also Tables 5.15 and 6.28).

$$\begin{aligned}
\text{TEI}_{\text{SFU}} &= 4.46 + 1.11\text{GI} + 0.69(7.17 - 0.034\text{GI}^2) \\
\text{Maint. + Milk}_{\text{SFU}} &= 5.17 + 0.40(14.82 + 2.13\text{GI} - 0.130\text{GI}^2) \\
\text{Residual}_{\text{SFU}} &= -1.690 + 0.258\text{GI} + 0.0285\text{GI}^2 \\
\text{Corrected res.}_{\text{SFU}} &= -1.290 + 0.158\text{GI} + 0.0285\text{GI}^2 \\
\text{BTG}_{\text{kg}} &= 0.2(\text{Cor.res.}_{\text{SFU}}) = -0.258 + 0.032\text{GI} + 0.0057\text{GI}^2
\end{aligned}$$

The BTG-function for heifers and cows in weeks 1–36 can be calculated in the same way and lead to functions very close to those for weeks 1–24, as the estimated parameters (Table 6.28) were almost equal for weeks 1–24 and 1–36 for heifers and cows respectively. It should be noted – also for the milk yield – that the experimental data, GI, during weeks 1–36 ranged between only 4.0 and 6.6.

The pooled functions for heifers and cows for weeks 1–24 are the following:

$$\begin{aligned}
\text{TEI}_{\text{SFU}} &= 9.11 + 1.11\text{GI} - 0.0235\text{GI}^2 \\
\text{BTG}_{\text{kg}} &= -\,0.098 + 0.006\text{GI} + 0.008\text{GI}^2
\end{aligned}$$

The estimates by means of those functions can also be used for comparison to the strategy-figures in Tables 5.2 and 6.25. As seen of the following figures the agreement is good for TEI_{SFU}, but bad for BTG_{kg} as expected according to the discussion in Section 6.1 and the figures of correlation in Table 6.26.

Weeks 1–24:

Strategy:	L_0	$L_{-1/2}$	M_0	$M_{-1/2}$	M_{-1}	H_0	$H_{+1,-1/2}$
Grain mix, kg DM/day	3.95	4.60	5.25	5.87	6.50	6.52	6.90
TEI, SFU/day							
By function above	13.13	13.72	14.29	14.82	15.33	15.35	15.65
From Table 5.2	13.29	14.09	14.26	14.74	15.49	15.55	15.90
Rel. to est. by fct.	101	103	100	99	101	101	102
BTG, kg[1])	8.5	16.6	25.9	35.8	46.9	47.2	54.5
LWC, kg (T.6.25)	26.7	14.5	12.7	21.2	27.6	28.4	28.2
Rel. to est. by fct.	(314)	(87)	(49)	(59)	(59)	(60)	(52)

[1]) By function above multiplied by 168 (days)

Table 6.28 Estimated parameters of the intercept and the coefficients of regression of kg FCM (Y) on kg DM in grain mix (GI). Kg per cow daily. By Model (4)

Parity and weeks	Intercept b_0	Coeff. of regress. b_1	b_2	$Y_{max.}$ for GI:	($Y_{max.}$)
Heifers					
Wks. 1–12	8.97	3.38	–0.245	6.9	(20.6)
Wks. 1–24	9.59	2.87	–0.194	7.4	(20.2)
Wks. 1–36	9.89	2.51	–0.157	8.0	(19.9)
Cows					
Wks. 1–12	16.43	2.08	–0.127	8.2	(24.9)
Wks. 1–24	14.82	2.13	–0.130	8.2	(23.5)
Wks. 1–36	13.24	2.22	–0.142	7.8	(21.9)

Table 6.29 Weight of the calves at birth, kg

Strategy:	L0	L–½	M0	M–½	M+2,–1	M–1	H0	H+1,–½	Norm	Mean
Heifers	39	39	36	36	39	39	40	40	37	38
Cows	41	41	42	44	44	40	43	43	42	42
Mean	40	40	39	41	42	40	42	42	40	41

The weight of the calves at birth is shown in table 6.29, and no marked differences between the strategies were found.

6.2.5. Fertility and health

The fertility of the cows is important for normal reproduction and the economy of production. The analysis on the fertility was based on 419 cows, animals from the supplementary station, H 731, being included to increase the numbers. These numbers were necessary to obtain a reliable answer to the question: »Does the strategy of feeding grain mix influence fertility?«. The results are shown in Table 6.30. Although the percentage of cows in calf after the first or the first plus the second insemination was larger for the two highest than for the two lowest levels of grain mix, there was no significant strategy effect on fertility when examined with the chi-square test (Section 4.5). The reason might be the plane of nutrition, which was neither very low nor very high, as the range was narrowed by feeding the grass silage ad libitum. It is in accordance with this, that no extreme variations in the condition occured. Only one cow (strategy H+1, –½) was scored to 1 (very thin) and none to 5 (very fat) during weeks 8–12 of lactation.

Table 6.30 Fertility of 419 cows on which insemination is started. Stations H 901 and H 731

Grain mix, kg daily wks. 1–12	4.5	6.0	Norm (7.1)	7.5	9.0
No. of cows	33	139	35	146	66
Time of first insem., days after calving	64	69	58	71	72
Percent in calf after first insem.	30	30	34	40	43
Time of second insem., days after calving	106	108	105	106	111
Percent in calf after first + sec. insem.	73	68	80	66	80

Table 6.31 The health expressed by cases of diseases for all animals on H 901

	Ketosis[1]	Mastitis, cases per cow[2]			All diseases, cases per cow[3]	
Strategy	Number of cows	Weeks 1–12	Weeks 13–24	Weeks 25–36	Weeks 1–24	Weeks 1–36
L_0	0	0.19	0.05	0.09	0.66	0.75
$L_{-½}$	2	0.16	0.07	0	0.71	0.74
M_0	0	0.27	0.05	0.13	0.90	1.23
$M_{-½}$	0	0.18	0.11	0.06	1.09	1.31
$M_{+2,-1}$	0	0.28	0.10	0.09	0.75	0.94
M_{-1}	2	0.19	0.12	0.18	1.00	1.24
H_0	1	0.14	0.05	0.08	0.88	1.06
$H_{+1,-½}$	1	0.34	0.08	0.14	1.20	1.40
Norm	3	0.11	0.08	0.03	1.03	1.11
Overall mean	1	0.21	0.08	0.09	0.92	1.09

[1]) In weeks 0–4 of lactation. Further 1 case in week 25 was reported.

[2]) Ratio between number of cows infected with mastitis during the period and number of cows at the beginning of the period.

[3]) Among 298 cows that fulfilled weeks 1–36.

The health of the animals throughout the experiment is seen from the incidence of diseases in Table 6.31. Number of culled animals and the main reasons are given in Table 6.32. Chi-square tests detected in no case significant differences between the strategies during the respective stages of lactation. The body condition of the cows changed throughout the lactation, but not very much, as only 9 cows in week 36 received a score of 5 (very fat). None of these cows were on the Norm treatment and Strategy Mo, but on both Lo and M–½ there were two fat animals, the remainder being distributed over the remaining 5 strategies.

6.3. Discussion and conclusion

In the present study it has been shown that even when grass silage is fed ad libitum the milk yield can, within certain limits, be efficiently regulated through the amount of concentrates fed. This is so because the strategy effect was highly significant for the three main stages of lactation (weeks 1–12, 13–24 and 25–36), as well as for the long term (for weeks 1–24 or 1–36 of lactation). This was the case for the yield expressed in different ways, as in kg FCM, milk, solids, butterfat, milk protein and solids-not-fat (Tables 6.1 to 6.12).

High, average yields ranging from 19.8 to 22.1 kg 4% FCM per animal (43% heifers) daily during weeks 1–24 of lactation were found, when feeding a fixed daily amount of 4 to 8 kg dry matter of grain mix or about 8 to 12 kg dry matter in total concentrates (including roots, molasses and dried pulp). During weeks 1–36 of lactation the corresponding yields range from 18.8 to 21.1 kg. When feeding the Danish standard, 0.40 SFU per kg of FCM, the corresponding yields for weeks 1–24 and weeks 1–36 were 21.0 and 19.2, respectively. The standard deviation, which corresponds to these mean yields, is 2.1 for weeks 1–24 and 2.0 for weeks 1–36.

The general picture of these results is in agreement with other well documented findings presented, for example in the review article by Broster (1972). However, it is not possible to make direct comparisons between the present study and the large number of published studies in which different allowances of energy have been fed according to the current milk yield (see Sections 2.1 and 6.1). In the present study the strategy effect was also significant with respect to body tissue gain (Tables 6.24 and 6.25).

The published studies, discussed in Section 6.1, also show how milk composition can be influenced by the level of feeding of grain mix. They have shown that at very high intakes of grain mix, the protein:fat ratio is increased. This was also the case in the present study, but only for weeks 1–12, when the highest level of grain mix plus roots, molasses and pulp exceeded 65% of the total dry matter intake (Tables 6.13 to 6.15).

Table 6.32 Specification of the main reasons for culled animals

Weeks of lactation	Number of culled animals during weeks 1–36							
	1–12		13–24		25–36		1–36	
Strategy	Ill-ness	Milk yield	Ill-ness	Milk yield	Ill-ness	Milk yield	Ill-ness	Milk yield
L_0	1	–	–	–	1	–	2	0
$L_{-½}$	1	–	2	–	–	1	3	1
M_0	–	–	2	4	1	–	3	4
$M_{-½}$	–	–	–	1	1	–	1	1
$M_{+2,-1}$	1	–	2	2	–	1	3	3
M_1	–	–	1	1	–	1	1	2
H_0	–	–	1	–	–	1	1	1
$H_{+1,-½}$	–	–	1	1	–	–	1	1
Norm	–	–	–	2	–	–	0	2
Total	3	0	9	11	3	4	15	15

The long-term study by Rakes and Davenport (1971) with 2 different patterns for feeding the same total amount of grain mix in equal versus decreasing daily amounts throughout the whole lactation, together with roughage ad libitum, showed no difference in kg FCM per cow yearly. The same was the case in the study by Johnson (1977), in which three different patterns of grain mix feeding were used for weeks 1–20 together with fixed amounts of roughage. The results of the present study are in agreement with those findings.

The present study has shown that the persistency, defined as the slope of the lactation curve, depended significantly on the strategy, i.e. the pattern of feeding a specific amount of grain mix for a particular period (i.e. weeks 1–36), while different levels led to almost the same slope (Table 6.21). This is in agreement with Broster et al. (1969) and Johnson (1977), but the higher persistency in the present experiment may be explained by feeding the main roughage, grass silage, ad libitum. The initial yield within the strategies was found to influence the slope significantly and markedly (see Tables 6.22 and 6.23). The effect of initial yield or peak yield (as a measure of the individuality of the cow) on persistency has been pointed out by Blaxter (1966), Broster (1974) and Madsen (1975).

When M+2, –1 and H+1, –½ Strategies are not included, the Norm treatment led to the lowest persistency, while the fixed allocation of grain mix throughout lactation led to the highest persistency (Table 6.21). This can be explained by the fact that on Lo, Mo and Ho Strategy a fall in yield did not lead to a reduced plane of nutrition as was the case with the Norm treatment.

However, the reduction in the daily amount of grain mix did not exceed 0.5 kg per week on the Norm treatment (Chapter II) to eliminate the effect of random falls in the milk yield.

The existence of random falls (changes) in daily milk yield is demonstrated by Fig. 6.1 in which the histogrammes show the distribution of the changes in kg FCM for two successive records throughout the lactation. Each column represents the range of the shown figure ± 1 kg.

When feeding a standard the random changes in some cases lead to underfeeding. Such mistake leads to greater yield fall. Feeding a constant amount of concentrates does not lead to such mistake. After the first 12 to 24 weeks of lactation there is a good basis for yield prediction, although random changes occur. The prediction of yield (FCM for the individual cow or a group of cows) for a following 4-weeks period can be made with sufficient accuracy by means of the persistency (estimated from the previous yield records) and the milk yield of last preceding period, as the coefficients of within class correlations between daily yield in two successive periods are very high, viz. 0.7 to 0.8 throughout lactation (Table 6.17). Even the prediction of the milk yield for a following 12-weeks period can be made with great accuracy on basis of the persistency and mean yield during the past 12-weeks period. The predicted milk yield within e.g. Strategy Lo, Mo or Ho has in absolute terms deviated from the actual yield only 0.1 to about 1 kg FCM per animal daily for 12-weeks periods throughout lactation. The maximum deviation therefore has been only about 5%. Within other strategies a corresponding accuracy in prediction of the milk yield was found.

The frequent question: »Does it pay to feed low yielders as heavily as high yielding cows«?, has been studied in relation to the allowance of grain mix in the present study. The cow potential was expressed by the initial yield, that is, kg of FCM during weeks 1–4 of lactation.

Analysis of variance on milk yield (FCM during weeks 1–24 and 1–36) did not show any effect of the interaction between initial yield and strategy (P = 0.95 and 0.93, respectively), when the model also included the terms initial live weight, parity, strategy and initial yield (as the deviation from average within the strategies). The latter terms all showed highly significant effects on kg FCM during weeks 1–12, 1–24 and 1–36 (Table 6.22). Consequently , the cows with the higher yields during weeks 1–4 did not give a larger marginal output than cows with lower yields when feeding the grain mix within the range 4 to 8 kg DM daily. The reason for this might be, as found in the present study, that the animals with the higher initial yields have a greater ability to mobilize body reserves and to eat more silage (fed ad libitum). This is seen of the following figures, showing positive correlations within strategies between intake of silage and milk yield (FCM) of 0.08, 0.11 and 0.18 for weeks 1–12, weeks 1–24 and weeks 1–36, respectively. For the same periods of lactation the analysis also

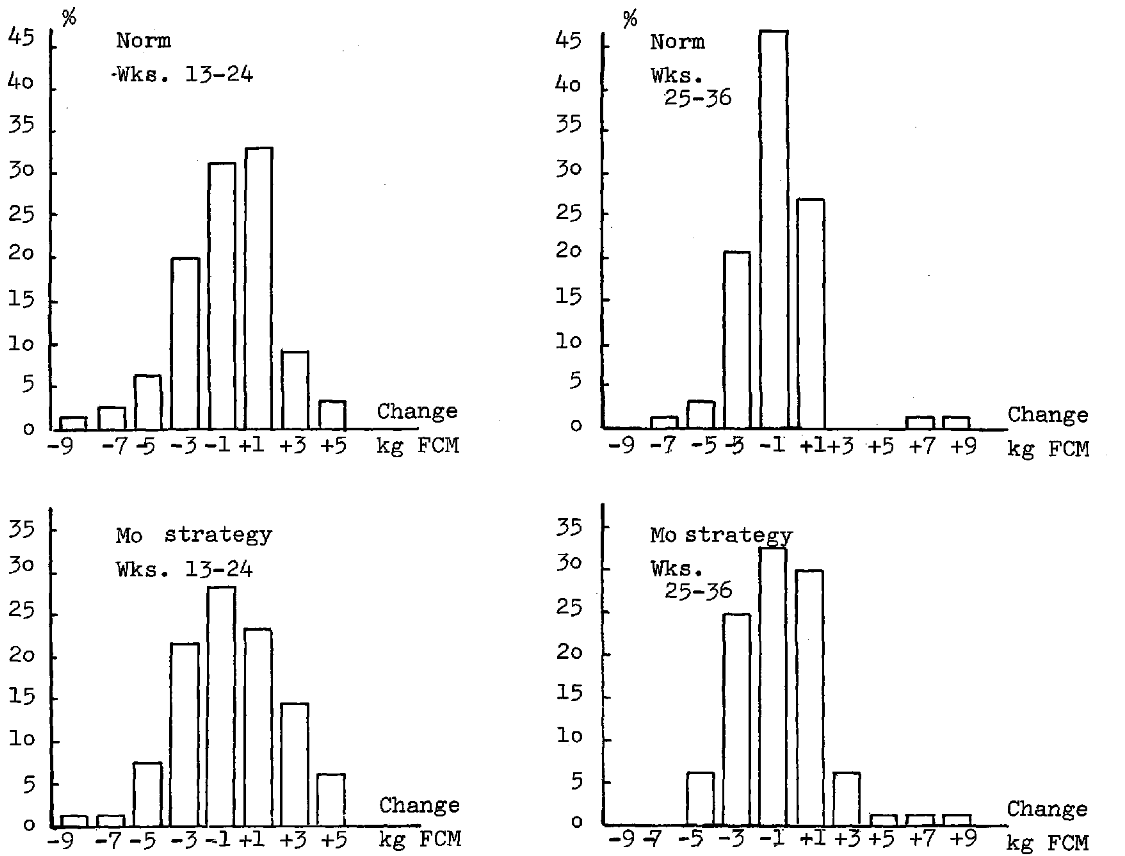

Fig. 6.1. Histogrammes showing the distribution in percentage of the yield changes from one record to the following within different stages of lactation. Norm (Standard feeding) and Mo strategy (Cows).

detected that the intake of grass silage changed by 0.04, 0.06 and 0.11 kg of DM per kg of FCM, the yield deviated from the mean within strategies. Broster and Alderman (1977) reported a corresponding coefficient of regression to be 0.16 and stressed that intake will be affected by e.g. diet composition and stage of lactation. It is seen that the voluntary food intake was found to vary with the milk yield, but not sufficiently to secure energy balance in the different stages of lactation. Consequently, the cows with higher potentials for milk yield have also higher potentials for food intake and mobilization/deposition leading to energy balance on the long term, but not the short term. This may be an answer to the age-old question: »Do dairy cows produce because they eat or do they eat because they produce?« (Baumgardt, 1970).

The above statement concerning cows of various potential and the long term effects of feeding makes it easy in practice to feed the optimum level of grain mix to cows at the same stage of lactation because equal daily allowances of grain mix to all the cows is the pattern of feeding giving the highest milk yield, when grass silage is fed ad libitum (in average a medium quality). This conclusion seems to be in disagreement with Jensen et al. (1942), Blaxter (1966), Broster et al. (1975) and Johnson (1977). However, their findings of greater marginal outputs by cows with higher potential may be due to several causes, such as output in kg milk (rather than FCM or the milk components), short-term experiments, feeding according to current yield, restrictive feeding of roughages, no correction for effect of initial live weight within parity, and smaller numbers of experimental animals, perhaps with a larger genetic variation than the commercial herd used in the present study.

However, the total yield during lactation was found to depend very much on the cow potential (initial yield) (see Tables 6.22 and 6.23), in agreement with findings reported by e.g. Jensen et al., (1942), Jensen (1961), Broster (1974) and Johnson (1977). The findings in the present study lead only to different intercept values for the milk production functions for cows with lower or higher yield potentials (Table 6.28).

Another important question often raised, »Does the marginal milk output change from one stage of lactation to another?«, has also been studied. The answer is given by the estimates of the coefficients of regression in Table 6.27, lower part. From these it can be concluded that when feeding grass silage ad libitum, the marginal output of milk, solids, butterfat and fat-corrected milk for a certain allowance of grain mix is almost the same, but larger, although not significant, for weeks 1–36 than for weeks 1–24, and the latter is larger than for weeks 1–12. However, the marginal output of milk protein and solids-not-fat was not found to increase from stage I to stage II of lactation.

The reasons for these findings being in contrast to those reported by e.g. Jensen et al. (1942), Burt (1957), Blaxter (1966) and Broster (1972), may be that the grass silage was fed ad libitum (the intake increased markedly during weeks

1–12) and that the grain mix and the other concentrates (roots etc.) were fed independent of the current yield. Thus the food was not a function of yield, but the reverse was the case as planned (see Section 2.1). Furthermore the narrowed range of grain mix throughout lactation (Table 6.28) may also have an influence, due to the computations.

Estimation of milk production functions were made for various parts of lactation. In the early part of lactation, weeks 1–4 and weeks 1–8, were found curvilinear relationships between the input of grain mix and the output of milk. The maximum yield of the heifers respective the cows were found with about 65%-concentrates (grain mix, roots, molasses, dried sugar beet pulp) in the total dry matter of the ration. The highest input of concentrates was above 70% on a dry matter basis, as the allowances of concentrates ranged from 7 to 12 kg DM per animal daily. The curvilinear relationships may be due to the increased allowances of grain mix plus other concentrates, which lead to increased food intake, but at a decreasing rate, and also may lead to a change of the fermentation in the rumen (Sections 5.1 and 6.1). These curvilinear relationships are in agreement with findings reported by e.g. Heady et al. (1956 and 1964), Hoover et al. (1967) and correspond also to findings reported by Jensen et al. (1942), Jensen (1961), Nekby (1965) and van Boven (1965) in their attempts to make econometric analyses of the results of experiments in which feeding according to current yield was the case (Section 6.1). Broster (1976) also stressed on the curvilinear relationships between input of food and output of milk.

During later stages of lactation the range of feeding grain mix was narrowed, and the percentages of total concentrates in the the dry matter of the rations decreased (see Figures 5.9 to 5.12, Section 5.2.4). Consequently the maximum milk yield was not within the experimental data and only linear functions were detected (Table 6.27). In order to estimate reliable milk production functions, Model (4) was used, and it was assumed that maximum milk yield (FCM) was attained, when the concentrates equaled 65% of the total dry matter intake (see Sections 6.1 and 6.2.4).

The estimated parameters of the intercept and the coefficients of regression of kg FCM on kg DM in grain mix per animal daily are given in Table 6.28. On basis of the figures in Table 6.28 and the estimated functions for body tissue gain (Section 6.2.4), the marginal outputs of kg FCM and kg body tissue gain for animals at different allowances of grain mix were calculated and are given in Table 6.33. These are important in the calculation of the optimum allowances of feed. Further discussion in Chapter VII.

The figures in Table 6.33 demonstrate the curvilinear response, which for the milk yield (FCM) leads to decreasing marginal output and for the body tissue gain (BTG) leads to increasing marginal output, when the allowances of grain mix are increased and grass silage is fed ad libitum. It is seen from the marginal values of FCM for weeks 1–12 that the production of the heifers is more

Table 6.33 Marginal output of fat corrected milk (FCM) and body tissue gain (BTG) at different levels of grain mix in different stages of lactation[1])

Level of grain mix kg DM daily		0	4	6	8
Other concentrates kg DM daily		3.7	3.7	3.7	3.7
Wks. 1–12 of lactat.					
Heifers	FCM, kg	(3.38)	1.42	0.44	–0.54
	BTG, kg	(–0.07)	0.05	0.11	0.17
Cows	FCM, kg	(2.08)	1.06	0.56	0.05
	BTG, kg	(0.04)	0.09	0.12	0.15
All lact.	FCM, kg	(2.64)	1.21	0.51	–0.20
	BTG, kg	(–0.01)	0.08	0.12	0.16
Wks. 1–24 of lactat.					
Heifers	FCM, kg	(2.87)	1.32	0.54	(–0.23)
	BTG, kg	(–0.03)	0.06	0.10	(0.15)
Cows	FCM, kg	(2.13)	1.09	0.57	(0.05)
	BTG, kg	(0.03)	0.08	0.10	(0.12)
All lact.	FCM, kg	(2.45)	1.19	0.56	(–0.07)
	BTG, kg	(0.01)	0.07	0.10	(0.13)

[1]) Estimates in the brackets are not within the range of the experimental data.

sensitive for small and large quantities of grain mix than is the production of the cows. This might to a great extent be explained by differences in maturity and stomach capacity. The latter is demonstrated by a larger change in the marginal intake of grass silage for heifers than for cows, when the allowances of grain mix are increased (Table 5.20).

However, at a medium level of grain mix around 6 kg DM, the marginal outputs of FCM and BTG are almost equal for heifers and cows. Since the strategy x parity interaction (Model (1)) was not significant (Table 6.1), the data can be pooled. The functions for all animals have fitted well as seen of a comparison between estimates by Function (27) and experimental data presented in Table 6.2.

An analysis of the correlation between the three different measurements for body tissue gain was made. The correlation between live weight change and residual net energy, as well as between chest girth change and residual net energy was estimated to 0.1 to 0.5 (Table 6.26). These low correlations might be explained by changes in body composition and rumen fill, as stressed by Moe and Flatt (1969). The estimated coefficients were so low, particularly during weeks 13–24, that the body tissue gain was measured with greater accuracy by using the estimated residual net energy corrected by the factor of –0.1 SFU per kg of extra grain mix DM within the range of 4 to 8 kg. This factor was calculated on basis of published findings of van Es (1975 and 1976) and Østergaard (1973) (See Section 6.1).

The fertility of the animals on the different treatments was not found to be significantly different. This is in agreement with studies in which the animals have received moderate to generous planes of nutrition (Broster, 1973), as was the case in the present experiment. From and experiment, similar in many ways to the present one, Johnson (1977) reported that there was no significant difference between treatments in the average number of inseminations to achieve conceptions.

The health of the cows was good throughout the experiment, as seen from the incidence of diseases in Table 6.31. Chi-square tests detected no significant differences between the strategies during the respective stages of lactation. The reason for the low incidence of ketosis for example, might be the relatively high intakes of food as designed in the experiment. The rate of culling was not influenced significantly by the treatments either.

It can be concluded that, when feeding forage of a medium quality grass silage ad libitum, at the smaller allowance of grain mix (4 kg DM) or total concentrates (7.7 kg DM) the marginal milk output (FCM) for all animals is almost equal during weeks 1–12 and weeks 1–24 of lactation (Table 6.33). However, at larger allowances of grain mix (6 and 8 kg DM) or total concentrates (9.7 and 11.7 kg DM) the marginal outputs decrease and are negative at the largest allowance but they are higher for weeks 1–24 than for weeks 1–12 of lactation, particularly for the heifers. Contrarily, for the body tissue gain increased marginal outputs occur, when the total food intake is increased. Furthermore, increased food intake leads to increased energy losses, and maximum daily milk yield (FCM) is attained with about 65%-concentrates in the total dry matter of the ration. Consequently the amount of concentrates in the total ration fed in practise to high yielding dairy cows should not, from a technical point of view, exceed 65% on a dry matter basis. Next the most profitable pattern of feeding the larger amounts during lactation (weeks 1–24 or weeks 1–36) is by equal daily allowances.

VII Optimum strategy of feeding concentrates through lactation

7.1. Introduction

As pointed out in Chapter I, most dairy farmers aim to maximize their income per cow (short run) or per man-hour (long run). Therefore, the input of food must be optimized within herd and system of production. Although the economic aspects of milk production are complex (Østergaard, 1970 and 1972), involving many resources or variables, the present economic analysis has involved only feeds, veterinarian service and labour as variables. The other resources, e.g. buildings and machinery, are assumed »fixed«.

In accordance with the general agricultural production economics, the optimum level of feeding is attained, when the income from the physical output (milk, gain and health) of the last unit of food input equals the costs of this. The condition for that statement (marginal income = marginal costs) is diminishing returns to the independent factor: food. Consequently, the process of optimization involves the technical data describing the input-output relationship (production function) as well as the prices of the products and the factors (Heady, 1964, Bradford and Johnson, 1967, Vincent, 1962).

7.2 Optimum strategy of concentrate feeding

The strategy of feeding concentrates involves two elements: The level and the pattern of feeding concentrates during the different stages of lactation. The separate effect of these two elements were analysed and evaluated by calculating the economic result per cow and year for the nine treatments. The calculations included also the post-experimental period (weeks 37–46 of lactation) during which all the animals were fed according to milk yield and condition. The economic calculations were based on equal fertility and health as no significant differences were found between the strategies (Section 6.2.5).

The milk yield kg FCM per animal, during the post-experimental period was estimated to the following for the respective treatments:

Lo	L–½	Mo	M–½	M+2,–1	M–1	Ho	H+1,–½	Norm
987	913	1047	972	980	886	1101	1111	911

The main result, technically and economically, was calculated per complete lactation and year, and is shown in Table 7.1. High yields per cow are seen, ranging from 5657 kg of FCM on Strategy Lo, 6062 on Strategy Mo and 6388 on Strategy Ho to 6406 kg on Strategy H+1, –½. The latter strategy is characterized by an almost equal ratio between concentrates and roughages during most of the lactation even with the silage fed ad libitum (Fig. 5.12). It should be noted that the higher yield of 232 kg FCM on Strategy Mo than on Strategy M–1 was to a great extent due to the residual effect during the post-experimental period caused by a higher persistency of the cows on Strategy Mo than on Strategy M–1 (Table 6.21). The Norm treatment has given almost the same yield as Strategy L–½, but about 100 kg more than Strategy Lo, the strategy with the lowest yield.

The net income to labour input per cow and year was calculated as the total income minus all other costs except labour costs. The variables, including prices of milk, grain mix and grass silage are shown in Table 7.1. It should be noted that the expression of the food input in kg DM makes the calculation independent of the various systems of feed evaluation. Similarly, the use of the relative prices (100 – 90 – 50) makes the calculation independent of the various currencies from country to country.

The milk income was based on the recorded yield multiplied by 0.96 as the difference between recorded yield and deliveries to the dairies has been found to be approximately 4 percentages (Østergaard, 1971 b). The »fixed« inputs do not affect the absolute differences between the results of the nine treatments, but do affect the relative figures. Therefore, it should be noted that the costs of the basal ration (1857 kg of DM: 69% roots, molasses and dried sugar beet pulp, 17% beet top silage, 5% grass cobs and 9% straw) incl. minerals and vitamines (130 kr.) were 1300 kr. per cow and year. The fixed costs (buildings, livestock etc.) and miscellaneous costs were also equal for all treatments, 2275 kr. The value of the gain (cow and calf) were estimated to 275 kr. pr. cow and year, when the depreciation of the cow is included. For this calculation an average gain per cow of 50 kg per year was taken, according to Table 6.25.

Table 7.1 shows that the net income to labour per cow and year ranged between 1460 kr. (Strategy M–1) and 1897 kr. (Strategy H+1, –½). Strategy Ho has given a net income of 1880 kr., only 1 percentage less than the latter strategy. The Norm treatment has given a net income of 1664 kr., which is 4–10 percentages higher than the net income of the strategies Lo, L–½, M–½ and M+2, –1, but 3 percentages lower than that of Strategy Mo.

Table 7.1 Total food input and milk output per cow and year. Net income per cow and man-hour for nine different treatments of concentrates

Strategy of grain mix feeding	Lo	L-½	Mo	M-½	M+2,-1	M-1	Ho	H+1,½	Norm
Grain, mix, kg DM	1161	1234	1585	1537	1491	1517	1841	1860	1441
Grass silage, kg DM	2246	2312	2110	2072	2219	2117	2045	2022	1870
Milk, kg FCM	5657	5734	6062	5906	5899	5830	6388	6406	5772
Net income to labour, kr. per cow and year[1])	1594	1557	1707	1576	1517	1460	1880	1897	1664
Man-hours per cow and year	37	38	37	38	38	38	37	38	40
Net income per man-hour, relative[2])	104	99	111	100	96	92	122	120	100

[1]) *Prices per unit:* Milk: 100 (1.50 kr. per kg FCM). Grain mix: 90 (1.35 kr. per kg DM). Grass silage: 50 (0.75 kr. per kg DM of a medium quality).

[2]) Net income 100 = 41.60 kr. per man-hour.

It is important to note that these comparisons to the Norm treatment are only valid for circumstances where the individual feeding is based on known quantities and qualities of all feeds, available in the herd, to which the planning of the optimum feeding is applied. When individual feeding is possible, e.g. in small herds and when labour requirements can be met with, the following question becomes pertinent: How much should the prices in Table 7.1 change to make the standard feeding (Norm) more economic than the most profitable strategies (Ho and H+1, -½), when looking at the short run? By changing one price at a time, the answers are:

a. An increase in the price of grain mix of at least 40%. The price of 1 kg DM of grain mix is then almost 30% higher than the price of 1 kg of FCM,

or b. An increase in the price of grass silage of at least 180%,

or c. A fall in the price of milk (FCM) of at least 24%.

Such marked changes of the common price relations given in Table 7.1 occur very seldom, if at all. However, smaller changes of all prices in an unfavourable direction give the same result. If the prices change in the opposite direction than those mentioned in items a, b and c, the profitability of using strategies Ho and H+1, –½ raises further compared to the Norm treatment.

It can be concluded that in general it is more profitable to practise strategies Ho or H+1, –½ followed by feeding according to yield and body condition in late lactation, than to practise the Norm treatment. This is the case when looking at the short run, where the goal is to maximize the net income per cow and year.

Strategy Ho is, like strategies Lo and Mo, characterized by the fixed daily allowances of grain mix. This pattern of feeding a particular total amount of concentrates (grain mix etc.) during most of the lactation, combined with the feeding of forages ad libitum, can be described as a new simplified feeding principle. It comprises strategies for feed allowances, which are very easy and labour-economic to apply in practise.

Strategy H+1, –½ is characterized by the increasing allowances of grain mix during weeks 1–12 of lactation followed by decreasing allowances. As shown in Fig. 5.12 this leads to an almost constant concentrates: roughages ratio of 60:40 during a great part of the lactation. Consequently, this strategy corresponds closely to a complete mixed diet of the same average composition as the ration fed on this strategy. A complete diet will then be to prefer, if the use of a feed mixer can make the daily feeding work as cheap as feeding the feeds separately.

In the long run, i.e. when the dairy farmer can adjust the number of cows to the amount of labour available, the maximum net income per man-hour makes the highest net income to the farmer for the input of a specific number of hours. Therefore, the labour consumption should also be involved in the calculations of the economical results under these circumstances.

The input of man-hours per cow and year in a typical stanchion barn-herd was for the respective treatments estimated on basis of studies made in Denmark under practical conditions (Pedersen, 1974 and Østergaard et al., 1975).

Table 7.1 shows that the net income per man-hour relative to Norm (100) is 92 for Strategy M–1 and 96 for Strategy M+2, –1, the only two strategies which results in a markedly poorer result than the Norm treatment. Within the treatments with equal total amount of grain mix during weeks 1–36 of lactation, Strategy Lo, Mo and Ho has given the best economical results, viz. respective 104, 111 and 122 relative to the Norm treatment. The Norm treatment during the whole lactation was found to be less competitive to strategies Ho and H+1, –½, when the net income was calculated per man-hour instead of per cow and year.

It can be concluded that feeding of grain mix or concentrates independent of the daily milk yield has given a higher or an almost equal income per man-hour compared to the Norm treatment. Furthermore, an equal daily distribution of a specific amount of grain mix for weeks 1–36 of lactation was more profitable than three other patterns tested, although Strategy H+1, –½ has given almost the same net income per man-hour as Strategy Ho did.

The results (Strategy H+1, –½) indicate that also in the long run, a mix of all the feeds to a complete diet with approximately 60% of concentrates (grain mix, roots, molasses etc.) will give results comparable to those of the simplified feeding principle. Which of these two feeding principles to apply in practise depends on the costs for making and feeding a homogenous mix. As the rations used in the present experiment have been composed of several common feeds, a rather broad validity of the conclusions may be expected.

7.3. Estimation of the optimum input of grain mix, total dry matter and Scandinavian feed units

Within each dairy herd the optimum input of grain mix depends on the actual prices of grain mix, grass silage, milk and gain. If Strategy Lo (4.0 kg DM of grain mix) is practised under circumstances, where Strategy Ho with 6.6 kg DM of grain mix per cow daily is the optimum input, the relative net income per man-hour will be 104 compared to 122 (Ho). As the difference is 17 percentages, the calculation and the use of the optimum level of grain mix is of great economic importance.

The estimation of the optimum level of the controlling factor, grain mix intake (GI), involves the following response functions for weeks 1–24 of lactation (Sections 5.2.5 and 6.2.4):

grass silage intake:	kg DM	$= 6.77 - 0.034GI^2$
Total food intake:	kg DM	$= 12.07 + GI - 0.034GI^2$
	SFU	$= 9.11 + 1.11GI - 0.0235GI^2$
Milk yield:	kg FCM	$= 12.57 + 2.45GI - 0.158GI^2$
Body tissue (residual–E):	kg gain	$= -0.098 + 0.006GI + 0.008GI^2$

The total food intake is a function of GI, and therefore not regarded as a variable directly involved in the process of optimization. The function of total food intake is mentioned here because of its great biological influence on the production of milk and body tissue and because a generalized use of the data in estimation the optimum level of feeding also involves the total food intake (see later).

Only the functions for weeks 1–24 of lactation are brought into use for the estimation of the optimum feeding level, as most of the animals at about week 24 of lactation, have filled up their body reserves after the period of mobilization (Sections 6.2.3 and 6.2.4). Consequently, at this stage of lactation the level of grain mix should be reduced slowly in such a way that the loss in milk-output is economically balanced by the savings in food-input.

Data for the heifers and the cows were pooled as the marginal inputs and outputs were almost equal for these two classes at the medium level of allowances of grain mix (Tables 5.19 and 6.33).

The optimization is simplied by transformation of the marginal output of body tissue gain to units of »milk« as the main output. The size of the factor for the transformation of kg body tissue gain (BTG) to kg FCM depends on the price ratio, BTG:FCM. Under common Danish market conditions this is approximately 5:1 (Østergaard, 1971 b, Hindhede and Petersen, 1973, Østergaard et al., 1974, 1975, 1976, 1977), and therefore the multiplier for the transformation is 5. Under extreme market conditions the latter figure can vary from 4 to 6, but recalculation with any actual figure is easily made. The marginal output of body tissue gain, (0.006 + 0.016GI) kg, is multiplied by 5 and added to the marginal output of milk, (2.45–0.316GI) kg, and the total marginal output in kg of »FCM« is then (2.48–0.236GI) kg. The latter value will be (2.47–0.252GI) and (2.49–0.220GI) for the BTG:FCM price ratios of 4:1 and 6:1, respectively.

For the farm in question it is important to emphasize the price ratio expected. However, it is less important to discuss different price ratios from one cow to another as a consequence of the cow being subject for slaughtering or not in the lactation concerned. The reason for this is the risk of culling as well as the profitability of bringing the cow in a good condition before drying off.

By means of the above response functions and considerations the estimates of the above response functions and considerations the estimates of the dependent variables were calculated for 5 actual levels of GI (Table 7.2).

Table 7.2 Daily food intake, milk yield and body tissue gain. Average and marginal values at different levels of grain mix during weeks 1–24 of lactation. 43% heifers and average initial live weight of all animals, 512 kg

		Independent inputs, kg DM per cow daily				
	Grain mix (GI)	4	5	6	7	8
Dependent variables:	Basal diet: Concentrates	3.7	3.7	3.7	3.7	3.7
	Forage	1.6	1.6	1.6	1.6	1.6
Silage intake,	Average	6.2	5.9	5.5	5.1	4.6
kg DM	Marginal	–0.27	–0.34	–0.41	–0.48	–0.54
Total food	DM, kg	15.5	16.2	16.8	17.4	17.9
intake	SFU	13.2	14.1	14.9	15.7	16.5
Milk yield,	Average	19.8	20.9	21.6	22.0	22.1
kg FCM	Marginal	1.19	0.87	0.56	0.24	–0.07
Body tissue,	Average	0.054	0.132	0.226	0.336	0.462
kg gain	Marginal	0.070	0.086	0.102	0.118	0.134

When feeding a medium-quality grass silage ad libitum under various price relations, the optimum fixed daily allowances of grain mix to cows and heifers can be calculated from the equations mentioned above. The optimum allowance of grain mix is found where:

The marginal physical output x price per unit equals the marginal physical input x price per unit.

The marginal input involves grain mix and grass silage. For BTG:FCM price ratio of 5:1 the equation for the estimation of the optimum daily allowances of grain mix (GI) is:

(28) $(2.48 - 0.236GI)P_{FCM} = P_{Grain} - (0.068GI)P_{Silage}$

or

(28) $\text{GI, kg DM}_{opt.} = 10.51 - 4.24 \dfrac{P_{Grain} - (0.068GI)\, P_{Silage}}{P_{FCM}}$

or

(28) $\text{GI, kg DM}_{opt.} = \dfrac{P_{Grain} - 2.48\, P_{FCM}}{0.068P_{Silage} - 0.236\, P_{FCM}}$

P_{Grain} = price per kg DM of grain mix
P_{Silage} = price per kg DM of grass silage
P_{FCM} = price per kg of FCM

In the short run, i.e. the optimization of the ration is made after harvesting the grass, the price of grass silage is the value determined from use in the best alternative production (opportunity costs). In the long run, i.e. before the grass is grown and silage made, the »internal price of production« should be used. The definition and the method of the calculation of the latter price is given by Østergaard (1969 and 1971 a).

The results of optimizing the daily input of grain mix per cow at various prices is given in Table 7.3. In the table the optimum input is found to range from 6.13 to 9.25 kg DM of grain mix depending on the price combination. The level of 6.13 kg DM of grain mix, which gives a total daily food intake of 16.9 kg DM and 15.0 SFU, is found at a very high price of grain mix (120% per kg DM of the price per kg of FCM) in combination with a very low price of grass silage (40% per kg DM of the price per kg of FCM). The level of 9.25 kg DM of grain mix, which gives a total daily food intake of 18.4 kg DM and 17.4 SFU, is found at a very low price of grain mix in combination with a very high price of grass silage. In the latter case the level of grain mix plus 3.7 kg DM of roots, molasses and pulp is beyond 65% of the total intake of dry matter, which was found to be the level giving maximum of milk yield, termed by FCM. In this case the level

Table 7.3 Optimum fixed allowances of grain mix during weeks 1–24 of lactation for various prices of the feeds relative to the price per kg of FCM (100). Kg DM per cow daily[1])

Relative price per kg DM of:	Grass silage (medium quality)		
Grain mix	40	60	80
80	8.05 (17.9 & 16.5)	8.61 (18.2 & 16.9)	9.25 (18.4 & 17.4)
100	7.09 (17.5 & 15.8)	7.58 (17.7 & 16.2)	8.15 (18.0 & 16.6)
120	6.13 (16.9 & 15.0)	6.56 (17.2 & 15.4)	7.05 (17.4 & 15.8)

[1]) Figures in brackets are the estimated total daily food intake expressed by kg DM and SFU, respectively.

should therefore be reduced or the grain mix should be fed by 3–4 feedings together with smaller amounts of roughage to avoid rumen disturbances (Kaufmann, 1976).

If the value of one kg of body tissue gain (BTG) is 4 or 6 relative to the price of one kg of FCM instead of 5 as assumed in Table 7.3, the optimum level of grain mix is approximately 0.5 kg lower or higher, respectively.

Within the range of the live weights in the present experiment, the optimum level of grain mix is independent of the weight of the cow. The reason for this is that a deviation from the average in the weight of the cow leads to a change in the intake of silage that corresponds to the change in maintenance requirement.

It is of interest to develop a general description of the relation between the total food intake and the production of milk and body tissue. For that purpose reliable production functions can be estimated from the data in Table 7.2. These functions are as follows for kg of total daily dry matter intake, TDMI, and for the total daily net energy intake, SFU, as the indenpendent variables:

TDMI as the independent variable:

(29) $\text{kg FCM} = -102.5 + 13.9\text{TDMI} - 0.388\,(\text{TDMI})^2$

(30) $\text{kg gain} = 6.93 - 0.975\text{TDMI} + 0.0343(\text{TDMI})^2$

The optimum level of total dry matter intake per cow daily can be calculated by means of the following equations, one for each BTG:FCM price ratio:

(31) $\text{kg TDMI} = 19.92 - 1.99 \dfrac{P_{DM}}{P_{FCM}}$ for BTG:FCM price ratio = 4:1

(32) $\text{kg TDMI} = 20.81 - 2.30 \dfrac{P_{DM}}{P_{FCM}}$ for BTG:FCM price ratio = 5:1

(33) kg TDMI = 22.12 – 2.75 $\frac{P_{DM}}{P_{FCM}}$ for BTG:FCM price ratio = 6:1

P_{DM} = price per kg of DM (marginal).

SFU as the indepentent variable:

(34) kg FCM = –38.7 + 7.41SFU – 0.226(SFU)^2

(35) kg gain = 1.48 – 0.293SFU + 0.0140(SFU)^2

The optimum allowances of total SFU per cow daily can in a similar way be calculated as follows:

(36) SFU_{total} = 18.35 – 2.94 $\frac{P_{SFU}}{P_{FCM}}$ for BTG:FCM price ratio = 4:1

(37) SFU_{total} = 19.07 – 3.21 $\frac{P_{SFU}}{P_{FCM}}$ for BTG:FCM price ratio = 5:1

(38) SFU_{total} = 19.89 – 3.52 $\frac{P_{SFU}}{P_{FCM}}$ for BTG:FCM price ratio = 6:1

P_{SFU} = price per SFU (marginal)

The optimization of the food input can be based on other outputs than kg of FCM and kg of body tissue. The milk output can be described by milk, solids, butterfat, milk protein or solids-not-fat. How these outputs are related to the grain mix input is illustrated in Table 6.27. If the relation is described by a linear function, the marginal output is constant and from a theoretical point of view the optimum input will be the minimum or the maximum input. However, the ad libitum intake of silage was found to vary curvilinearly with the input of grain mix. Consequently, the linearity of the whole production is not present, and the equations for the optimization of the grain mix input can be constructed similar to the equation based on the daily output of FCM.

7.4. Practical application of the simplified feeding principle

Since 1974 the simplified feeding principle, feeding fixed daily amount of concentrates and forages ad libitum, has been used on 20 pilot farms with approximately 1400 cows. The technical and economical results based on current and regular control and registration of all inputs and outputs have shown benefits of the change from the traditional standard feeding to the simplified feeding principle. This was the case independent of the system of housing (stanchion barn versus loose housing) and the size of herd. The persons, who took care of the cows, were the same both years (Østergaard et al., 1976). The average yield of the 20 herds was raised with 2 kg of butterfat per month to 253 kg of butterfat per cow and year during the first year after change.

The economy was also improved markedly, as the feed efficiency and the culling rate was unchanged. It should be noted that this demonstration lacks adequate treatments for scientific comparison, as only one treatment (feeding principle) has been planned and practised within year and herd.

The different main types of rations recommended for winter- and summerfeeding of high yielding dairy cows by means of the simplified feeding principle have been published by Østergaard and Neimann-Sørensen (1976).

In the practical application of the simplified feeding principle the optimum fixed daily allowances of grain mix (concentrates), in the individual herd, was found by means of the current prices and figures shown in Table 7.3. The level of the concentrates fed was adjusted to the quantity and quality of the forage, if the latter was below medium quality, additional 1–2 kg of DM was fed, and if over medium, less 1–2 kg of DM was fed (Østergaard, 1976).

If the yield of an individual cow remained on a low level several months after parturition, then the cow was culled. In spite of this practise, the rate of culling was the same after the change to the simplified feeding principle, as it was before (Østergaard et al., 1976).

The reduction of the allowances of concentrates fed was started about 24 weeks after parturition and was made according to:

a. Expected milk yield based on the last milk recordings.
b. Pregnancy, i.e. number of weeks to the next parturition.
c. Condition and necessary gain in late lactation to attain good and equal condition of the cows before drying off.

When practising the simplified feeding principle the risk of incorrect feeding of the individual cow was lowered, the reasons being 1) the same daily amount of concentrates was fed to a great part of the cows within a herd or to all cows within a group, 2) all cows have, even in early lactation, the ability to consume the moderate amount of concentrates during the restricted time in the milking parlour, and 3) random errors (e.g. random falls in yield) in milk recording do not affect the daily concentrate feeding.

The estimation of the optimum level of TDMI under ad libitum conditions should be made on basis of current prices. The price of the marginal food intake should be used. This price depends on two factors, firstly the marginal forage intake for a changed level of grain mix fed, secondly on the prices of forage and grain mix. This dependence is by the relative prices illustrated in Table 7.4, which is calculated on basis of the following equation:

(39) Marginal price per kg of extra DM =

$$\frac{\text{Grain mix price per kg DM} + (\text{marg. forage intake (DM)} \times \text{forage price})}{1.0 \text{ kg DM of grain mix} + \text{marg. forage intake, kg DM}}$$

Table 7.4 Marginal price per kg of extra DM-intake by means of grain mix fed in competition with forage fed ad libitum. Relative to grain mix (100)

Price ratio:	Marginal price per kg of DM, when marginal forage intake, for a change of 1 kg of DM of grain mix, is					
Forage : Grain mix[1]	-0.3	-0.4	-0.5	-0.6	-0.7	-0.8
40 : 100	126	140	160	190	240	340
60 : 100	117	127	140	160	193	260
80 : 100	109	113	120	130	147	180
100 : 100	100	100	100	100	100	100

[1]) The prices per unit are the value in the best alternative use (opportunity costs) or the price at purchase.

In table 7.5 is for different price ratios given the optimum feeding level in kg of TDMI. These various levels of total dry matter should be composed so that each level leads to ad libitum feeding, as the response functions are estimated under ad libitum feeding of the forage included.

Table 7.5 The optimum level of total daily dry matter intake at various price ratios, kg TDMI per cow during weeks 1–24 of lactation

Price ratio:[1])	Price ratio, BTG : FCM		
DM : FCM	4.0	5.0	6.0
1.0	17.9	(18.5)	(19.4)
1.2	17.5	(18.1)	(18.8)
1.4	17.1	17.6	(18.3)
1.6	16.7	17.1	17.7
2.0	15.9	16.2	16.6
2.4	15.1	15.3	15.5

[1]) The price per kg of marginal input of DM should be used.

The estimation of the optimum feeding level, expressed in terms of net energy, SFU, is calculated in a similar way. The marginal prices per SFU relative to grain mix can for different marginal forage intake also be seen of Table 7.4, as only »kg of DM« should be substituted by SFU.

In Table 7.6 the optimum feeding level in SFU per cow daily is shown for different price ratios.

Table 7.6 The optimum feeding level in net energy at various price ratios, SFU per cow daily during weeks 1–24

Price ratio:[1])	Price ratio, BTG : FCM		
SFU : FCM	4.0	5.0	6.0
0.7	16.3	(16.8)	(17.4)
0.8	16.0	16.5	(17.1)
0.9	15.7	16.2	(16.7)
1.0	15.4	15.9	16.4
1.1	15.1	15.5	16.0
1.2	14.8	15.2	15.7

[1]) The price per SFU of the marginal input should be used.

In Fig. 7.1 the simplified feeding principle is shown in schematical form.

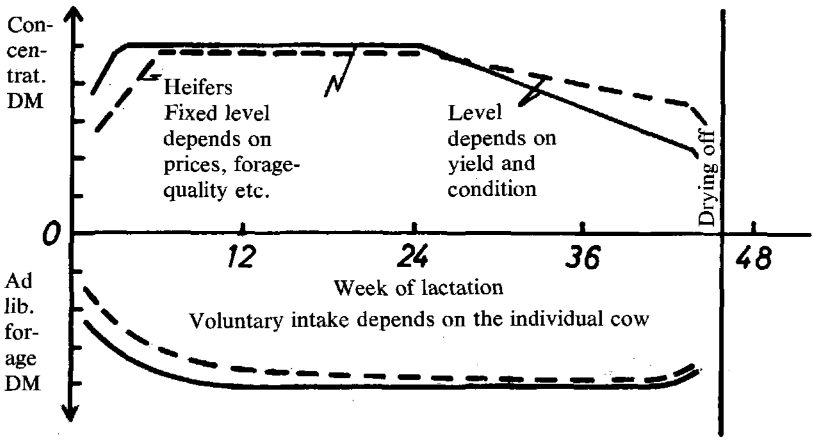

Fig. 7.1. The simplified feeding principle. Schematically.

The greatest effect of the practical application of the simplified feeding principle superior to other principles tested in the present long term experiment can be expected, if the planning of feeding the cows within herds having very great potential for yield (roughly 7.000 kg of 4% FCM per lactation), includes about additional 1 kg DM of concentrates per cow daily during weeks 1–24 of lactation. But the cows within a herd with low potential for yield (roughly 5.000 kg of 4% FCM per lactation) should be fed less about 1 kg DM of concentrates per cow daily compared to the optimum level estimated by equations based on the data of the present experiment. It should also be noted that it is advantageous, if the daily fixed amount of concentrates is adjusted to possible variation in the quality of the ad libitum fed forage. The daily food intake per cow should therefore be controlled regularly.

VIII Final conclusion

The present long term experiment permits the following conclusions:

1. The voluntary intake of grass silage increases markedly during the first twelwe weeks of lactation, the rate depending on the strategy of feeding grain mix (concentrates) and on the parity. Heifers and cows reach maximum intake at about week 20 and week 16 of lactation, respectively.
2. The total intake of food during the successive stages of lactation can be regulated by means of the allowance of grain mix or total concentrates, even when grass silage is fed ad libitum.
3. When feeding 6 kg DM of grain mix the addition of 1 further kg DM of grain mix reduces the intake of a medium quality grass silage with 0.4 kg DM. At larger or smaller allowances of grain mix the marginal change of silage intake, in absolute terms is greater and smaller, respectively.
4. The daily yield, expressed in FCM, is increased, but with diminishing marginal output, when feeding more grain mix. This is due to the above mentioned decreasing marginal intake of grass silage and the change of rumen fermentation.
5. Different patterns (2–4) of feeding the same amount of grain mix give rise to almost the same total milk yield during weeks 1–36 of lactation. Due to greater persistency, however, the yield after week 36 is higher on the strategies with equal daily allowances of grain mix during lactation than on the strategies with decreasing daily allowances.
6. The persistency depends to a great extent on the pattern of feeding the grain mix through the lactation, as well as on the initial yield, initial live weight and parity.
7. The body tissue gain is increased, but at an increasing marginal output, when the grain mix allowances are increased.
8. Within the range of 4–8 kg DM of grain mix, the marginal output of FCM per kg DM of grain mix can be expected to be independent of the yield potential of the animal under circumstances similar to those of the experiment, i.e. good forage fed ad libitum and supplemented with 4 kg DM of other concentrates.

9. The fertility and health of the animals are not influenced significantly by the strategy of feeding the grain mix within the range of 4 to 8 kg DM per animal daily.
10. The simplified feeding principle: Fixed daily allowance of grain mix (concentrates) and grass silage fed ad libitum during the first 24 weeks of lactation followed by feeding according to expected yield and wanted gain before drying off, leads to the highest net income per man-hour, when compared to the strategies with decreasing daily allowances or feeding according to yield (0.40 SFU per kg of 4% FCM).
11. The optimum allowance of concentrates depends on the prices of the competing feeds, on the prices of the milk and gain. At common prices the optimum fixed allowance of grain mix is 6 to 8 kg DM per cow daily during the first 24 weeks of lactation.

In general the optimum feeding level to high yielding dairy cows (live weight: 500–600 kg) is within 15 and 17 SFU per cow daily during the first 24 weeks of lactation. This feeding level corresponds to 17–18 kg DM at ad libitum conditions. As the ad libitum food intake can be regulated by means of the quality of the forage and the concentrate feeding, the optimum level of concentrates is lowered or increased when feeding good respectively poor quality forage ad libitum.

IX Summary

Chapter I. Introduction, problem definition and formulation of hypothesis

In most systems of housing dairy cows and handling feed, the possibility of feeding specific amounts of roughage to individual cows is not present. As a consequence, individual feeding according to standards of requirements is not practicable. When the roughage, e.g. grass silage, is fed ad libitum, the concentrates therefore have to be fed according to a strategy, which conveniently can be described by the level and the pattern of daily concentrate allowances during lactation. The dairy farmer will then need to know the optimum pattern of allowances and a tool for optimizing the level of concentrates.

Therefore, the aim of the study was to provide the necessary data for testing different patterns of concentrate feeding and for the estimation of response functions. As the formulated problem also included the economical aspects, the study was primarily planned as an interdisciplinary study.

A working hypothesis was formulated as a further basis for the study, and the hypothesis was tested for the following economically important variables: Total food intake, intake of grass silage, milk yield (including 4% FCM, solids, butterfat and milk protein), body tissue gain, fertility and incidence of disease. The working hypothesis was:

»Even when the main roughage is fed ad libitum, it is possible by means of the concentrate feeding to regulate within certain limits the total food intake and the composition of the ration and thereby to influence the level and composition of production at a given stage of lactation«.

Chapter II. Experimental design and recording of data

Since the aim of the study was to obtain data for the estimation of response functions under circumstances when the allowance of concentrates is the only input under direct control, concentrate feeding or the strategy for allowance of concentrates had to be the independent variable of the experiment.

This is in contrast to the classic situation, where the animals are fed according to the current milk yield. It is discussed how the food intake, in the latter case, in reality is a function of the milk yield (Fig. 2.1).

A basis of the study was formed by an experiment with 8 treatments, i.e. 8 fixed strategies of feeding concentrates independent of the current yield. The strategies were characterized by different patterns of feeding 3 different total amounts of concentrates throughout lactation (Fig. 2.3 and Tables 2.1 and 2.2). In order to compare these 8 strategies with the traditional »feeding to standard« a Norm treatment was included (Table 2.3). In this treatment the Danish feeding standard of 0.40 Scandinavian feed unit (SFU) per kg of 4% fat corrected milk (FCM) was applied.

The experimental animals were Black and White Danish Dairy Cattle (SDM) and a total of about 300 lactations (experimental units) were planned. This made it possible to detect, with high significance, even small differences in the observed data.

Among the feeds, the grain mix (the independent variable) was fed according to the design of the experiment. Grass silage (an independent variable) was fed ad libitum. Concentrates other than grain mix (roots, molasses and dried sugar beet pulp) were fed in equal daily amounts during lactation and for all strategies. Most feeds were fed twice a day.

The animals were kept in individual standings in a shed (stanchion barn, insolated, ventilated) throughout the year. The animals were milked twice daily during lactation. All the input and output data were recorded for the individual cow.

Chapter III. Material

During the years 1972–76 a total number of 298 experimental animals performed at least 36 weeks of lactation. The characteristics of the animals post partum as expressed by the live weight, chest girth and body condition were almost equal for the respective treatments within parities, heifers and cows (Table 3.1).

The feeds were of the same type each year, but due to the fact that the grass silage was from several cuttings comprehensive analyses had to be made. These included: Dry matter, crude fibre, crude protein, ash, in vitro digestibility of organic matter, lactic acid, acetic acid, butyric acid, alcohol, NH_3–N and pH (Tables 3.2 and 3.3).

Chapter IV. Statistical procedures

The design of the present experiment and the formulation of the working hypotheses (Chapter I) made it possible to analyse the data, with the amount of concentrates fed as the independent variable and intake of grass silage, total food intake and size and composition of production as dependent variables. Furthermore, different characteristics of the animals used, such as size, parity and yielding capacity, could be included in the analysis as independent variables, in order to investigate possible differences and interactions in the response to concentrate feeding.

The statistical procedures used for analysing the experimental data are discussed in Chapter IV. These procedures concerned estimation and test of treatment effects by analysis of variance, estimation and test of response functions by regression analysis, fitting and analysis of curves of food intake and milk yield throughout lactation and analysis of incidence of disease.

Chapter V. Food intake

The hypothesis, »Even when the main roughage is fed ad libitum, it is possible by means of the concentrate feeding to regulate the total food intake and the composition of the ration«, was tested by means of analyses of variance on total food intake (SFU per cow daily) and voluntary intake of grass silage (kg and kg DM). The tests showed that the treatment (strategy of grain mix feeding) effect in both cases were highly significant for all stages of lactation (Tables 5.1, 5.3 and 5.7). The above hypothesis was therefore accepted, and the basis of the estimation of response functions was present.

The pattern of the voluntary intake of grass silage and total food during lactation was examined. The result showed a marked increase in intake during the first 12 weeks of lactation. The maximum intake was reached at about week 20 and week 16 of lactation for heifers and cows, respectively (Tables 5.10–5.11 and Figures 5.3–5.8).

The ration composition (described by the percentage of total dry matter in grain mix, roots, molasses and dried sugar beet pulp) varied during the lactation in a way that depended on the strategy (Figures 5.9–5.12).

The experimental data showed that quite different patterns of feeding a given total of grain mix led to almost the same intake of silage fed ad libitum. The intake of grass silage could therefore be estimated as a function of the level of the concentrate feeding on strategies others than Lo, Mo and Ho. A curvilinear function was fitted to the data. An increasing level of concentrates reduced the silage intake at an increasing rate (Tables 5.12–5.15 and 5.19–5.20). For weeks 1–24 of lactation the marginal intake was –0.27 and –0.54 kg DM per extra kg grain mix-DM at 4 and 8 kg grain mix-DM, respectively.

The total food intake, kg dry matter or SFU, can be estimated by means of the parameters of the intake functions (Table 5.15). The estimates are of sufficient precision for optimizing and planning rations for a group of heifers or cows.

It is concluded that the voluntary intake by dairy cows with high yield potentials can be regulated within 1.9 to 3.8 kg DM per 100 kg live weight during weeks 1–36 of lactation by ad libitum feeding with grass silage of various digestibility and with a fixed daily supplement ranging from zero to almost 12 kg DM of concentrates (8.0 kg of grain mix and 3.7 kg of roots, molasses and sugar beet pulp). On a net energy basis the regulation is higher, as the total daily food intake, for the above mentioned conditions, ranges within approximately 1.0 to 3.0 SFU per 100 kg initial live weight of the cows.

Chapter VI. Production

The working hypothesis did also include influence of the strategy of feeding concentrates on the level and composition of production at a given stage of lactation. Analysis of variance on the production variables showed a highly significant treatment effect. This was the case for the milk yield expressed in different ways, kg of 4% FCM, milk, solids, butterfat, milk protein and solids-not-fat (Tables 6.1–6.12). The treatment effect was also significant with respect to body gain (Tables 6.24 and 6.25), while significant treatment effects on fertility, incidence of disease and rate of culling was not detected. The above hypothesis was therefore accepted, and the basis for the estimation of response functions was present.

The experimental data also showed that quite different patterns of feeding a given total of grain mix led to almost the same milk yield and body tissue gain through weeks 1–24 or weeks 1–36 of lactation. The milk yield and body tissue gain could therefore be estimated as a function of the level of grain mix on strategies others than Lo, Mo and Ho.

The milk yield as a function of level of grain mix was found to be curvilinear. The estimates of the parameters of the intercept and the coefficients of regression of milk yield on kg DM in grain mix are shown in Tables 6.27 and 6.28. It was concluded that at the smaller allowance of grain mix (4 kg DM) or total concentrates (7.7 kg DM), the marginal milk output for all animals (1.2 kg FCM) is almost equal when analysing the mean yield of weeks 1–12 and weeks 1–24 of lactation (Table 6.33).

However, at larger allowances of grain mix (6 and 8 kg DM) or total concentrates (9.7 and 11.7 kg DM) the marginal outputs are smaller and negative at the largest allowance, but they are higher for weeks 1–24 than for weeks 1–12 of lactation, particularly for the heifers. Contrarily, for the body tissue gain increased marginal outputs occur, when the total food intake is increased by means of heavier feeding of grain mix and other concentrates. Maximum daily milk yield (FCM) was found at about 65%-concentrates in the total dry matter of the ration. However, this proportion of concentrates was only reached in the beginning of lactation.

High, average yields can be expected, ranging from 19.8 to 22.1 kg 4% FCM per animal (43% heifers) daily during weeks 1–24 of lactation, when feeding a fixed daily amount of 4 to 8 kg dry matter of grain mix or about 8 to 12 kg dry matter in total concentrates (including roots, molasses and dried pulp). During weeks 1–36 of lactation the corresponding yields range from 18.8 to 21.1 kg. When feeding the Danish standard, 0.40 SFU per kg of FCM, the corresponding yields for weeks 1–24 and weeks 1–36 can be expected to be 21.0 and 19.2, respectively.

Chapter VII. Optimum strategy of feeding concentrates through lactation

Since most dairy farmers aim to maximize their income per cow in the short run (fixed number of cows per man) and per man-hour in the long run (number of cows can be adjusted to the labour on hand), the economy of using the different strategies was calculated and analysed.

The net income to labour for the respective strategies was found to be the following, kr. per cow and year:

Lo	L–½	Mo	M–½	M+2,–1	M–1	Ho	H+1,–½	Norm
1594	1557	1707	1576	1517	1460	1880	1897	1664

The prices per unit were: Milk 100 (1.50 kr. per kg FCM), grain mix 90 (1.35 kr. per kg DM) and grass silage 50 (0.75 kr. per kg DM of a medium quality). The variables, inputs of feeds and output of milk, are shown in Table 7.1.

The standard feeding (Norm treatment), which needs individual feeding of all feeds with known quality and quantity, is only superior to the most profitable strategies (Ho and H+1, –½), if one of the following price changes, compared to the typical prices, occurs:

a. An increase in the price of grain mix of at least 40%. The price of 1 kg DM of grain mix is then almost 30% higher than the price of 1 kg of FCM,

or b. An increase in the price of grass silage of at least 180%,

or c. A fall in the price of milk (FCM) of at least 24%.

Strategy Ho is, like strategies Lo and Mo, characterized by the fixed daily allowances of concentrates. This pattern of feeding a particular total amount of concentrates (grain mix etc.) during most of the lactation combined with the feeding of forages ad libitum makes the definition of »Simplified feeding principle«. This new feeding principle comprises strategies for feed allowances, which are very easy and labour economic to apply in practise.

It is concluded that in general it is more profitable to practise Ho or H+1, –½ Strategy followed by feeding according to yield and body condition in late lactation, than to practise the Norm treatment. This is the case when looking at the short run, where the goal is to maximize the net income per cow and year.

In the long run, when the number of cows is adjusted to the amount of labour available, the highest net income per man-hour makes maximum net income to the farmer. With the same prices as above and with the labour consumption included,the following relative net income per man-hour was found for the respective strategies (The Norm treatment = 100 = 41.60 kr. per hour):

Lo	L–½	Mo	M–½	M+2,–1	M–1	Ho	H+1,–½	Norm
104	99	111	100	96	92	122	120	100

It is concluded that feeding of the grain mix or concentrates independent of the daily milk yield was found to give a higher or an almost equal income per man-hour compared to the Norm treatment, when the main roughage (e.g. grass silage) was fed ad libitum. Furthermore, an equal daily distribution of a specific amount of grain mix (concentrates) for weeks 1–36 of lactation was more profitable than three other patterns tested, although Strategy H+1, –½ has given almost the same net income per man-hour as Strategy Ho did.

In the long run, a mix of all the feeds to a complete diet including approximately 60% of concentrates (grain mix, roots, molasses etc.) is also competitive to the simplified feeding principle, if there are no extra costs for making a homogenous mix. As the rations used in the present experiment have been composed of several common feeds, a rather broad validity of the conclusions may be expected.

Within each dairy herd, the optimum input of grain mix depends on the actual prices of grain mix, grass silage (or a similar forage), milk and live weight gain. In Section 7.3 the tools (Equations 28, 31, 32, 33, 36, 37 and 38) for optimizing the input of the fixed daily allowance of grain mix during weeks 1–24 of lactation are presented, and in Table 7.3 the optimum amount is shown for various prices. The total input of concentrates is kg DM of grain mix added 3.7 kg DM of roots, molasses and dried sugar beet pulp. The equations concerning the optimum input of total dry matter (TDMI) and Scandinavian feed units (SFU) are also presented. In Tables 7.5 and 7.6 the optimum input for various prices is shown for TDMI and SFU, respectively.

A consequence of great importance of the dairy farmer, is that the risk of incorrect feeding is lowered, when the simplified feeding principle is used. In Fig. 7.1 this principle is shown in schematical form.

Chapter VIII. Final conclusion

The conclusions of greatest importance for the dairy farmer are presented in 11 items, which by words descripe the following quantitative relationships, which are needed for the optimization of the input of concentrates:

		Voluntary				Milk yield
Allowance of	→	intake of	→	Total	→	Body gain
concentrates		roughage		food intake		Fertility
						Health

The dairy farmer has the following main feeding principles as alternatives:

1. Standard feeding according to the daily milk yield (e.g. 0.40 SFU per kg of 4% FCM).
2. Simplified feeding principle (in late lactation followed by feeding according to expected yield and wanted live weight gain).
3. Complete diet fed ad libitum.

According to the actual conditions on the individual dairy farm, one of these feeding principles is the most profitable to practise. In general, the simplified feeding principle is superior to standard feeding and complete diet feeding. Depending on the costs of making homogenous complete diets, feeding complete diets may however be the most profitable principle to practise in herds, where grouping of the cows easily can be made as follows: One group for cows in the first part of lactation, a second group for cows in late lactation and a third group for dry cows.

X Dansk sammendrag

Kapitel I. Introduktion, problemstilling og hypoteseformulering

Idet de fleste staldindretninger og udfodringssystemer for malkekøer ikke giver mulighed for at fodre en bestemt mængde grovfoder til den enkelte ko, bliver fodring efter norm ikke praktisk gennemførlig. Det kan derfor være hensigtsmæssigt, at grovfoderet, f.eks. græsensilage, fodres ad libitum, medens kraftfoderet fodres efter en på forhånd fastlagt plan (strategi), som beskrives ved mængde og fordeling af kraftfoderet over laktationen. Mælkeproducenten må derfor kende den optimale fordeling samt have et værktøj til optimering af kraftfodermængden.

Det foreliggende arbejde har derfor som mål at fremskaffe de nødvendige data dels til at vurdere forskellige måder at tildele kraftfoderet på og dels til at danne grundlag for bestemmelse af produktionsfunktioner. Idet problemstillingen også inddrager de økonomiske aspekter, blev det foreliggende studium planlagt til at være interdisciplinært, d.v.s. dækkende flere specialområder.

Der blev formuleret en arbejdshypotese som grundlag for studiet, og denne blev undersøgt og vurderet på følgende økonomisk vigtige variable: ialt foderforbrug, forbrug af græsensilage, mælkeydelse (incl. 4% målemælk, tørstof, smørfedt og mælkeprotein), tilvækst, frugbarhed og sundhed (udtrykt ved sygdomsforekomst). Arbejdshypotesen var følgende:

»Selv når hovedgrovfoderet fodres efter ædelyst, er det muligt ved hjælp af kraftfodertildelingen at regulere inden for visse grænser den totale foderoptagelse og sammensætningen af rationen og derved påvirke niveauet og sammensætningen af produktionen i et givet laktationsstadium«.

Kapitel II. Forsøgsplan og dataregistrering

Da studiets mål var fremskaffelsen af data til bestemmelse af produktionsfunktioner under fodringsbetingelser, hvor alene kraftfodertildelingen kan foretages individuelt, må denne tildeling eller kraftfoderstrategien være den uafhængige variable i forsøget. Dette er det modsatte af fremgangsmåden i de klassiske forsøg, hvor der fodres efter den daglige mælkeydelse. Der diskuteres, hvorledes fodertildelingen i sidstnævnte tilfælde i realiteten bliver en funktion af mælkeydelsen (fig. 2.1).

Grundlaget for studiet udgøres bl.a af et forsøg med 8 på forhånd fastlagte kraftfoderstrategier, som er uafhængige af den daglige ydelse. Kraftfoderstrategierne blev karakteriseret ved tildelingsforløbet over laktationen af 3 forskellige totalmængder (fig. 2.3 og tabellerne 2.1 og 2.2). For at kunne sammenligne disse 8 strategier med den traditionelle »fodring efter ydelse« blev der også inddraget forsøgsbehandlingen »Norm« (tabel 2.3). I denne forsøgsbehandling blev der fodret efter den danske norm med 0.40 f.e. pr. kg 4% mælk.

Forsøgsdyrene var SDM-køer, og der blev planlagt ialt ca. 300 laktationer for på et højt signifikans-niveau at kunne afsløre selv små forskelle i forsøgsdata.

Lavprocentigt kraftfoder, med 16% fordøjeligt råprotein og 6% råfedt, der var forsøgets uafhængige variabel, blev fodret efter den lagte plan, medens græsensilagen (afhængig variabel) blev fodret efter ædelyst, undtagen ved normfodringen. Øvrige kraftfodermidler (fodersukkerroer, melasse og tørret sukkerroeaffald) blev fodret i ens og konstante daglige mængder over laktationen på alle forsøgsbehandlinger. De fleste fodermidler blev udfodret 2 gange dagligt.

Forsøgsdyrene stod på stald hele året i en isoleret og ventileret bindestald med krybbeskillevægge, der muliggjorde individuel fodring. Køerne blev malket 2 gange dagligt, og alle input- og output-data blev registrert for den enkelte ko. Således blev eksempelvis alle fodermidler registreret dagligt, idet der i forsøget blev fodret individuelt.

Kapitel III. Materiale

Forsøget, der gennemførtes i årene 1972–76, omfattede ialt 298 laktationer af mindst 36 ugers varighed. Forsøgsdyrenes karakteristika, udtrykt ved vægt, brystmål og huld, var lige efter kælvning næsten ens for de respektive forsøgsbehandlinger. Dette gjaldt såvel 1. kalvs køerne som de øvrige køer (tabel 3.1). De samme fodermidler indgik i forsøget i alle årene, men da græsensilagen blev fremstillet af flere slæt, blev der foretaget omfattende analyser, således tørstof, træstof, råprotein, aske, in vitro fordøjelighed af organisk stof, mælkesyre, eddikesyre, smørsyre, alkohol, NH_3–N og pH (tabellerne 3.2 og 3.3).

Kapitel IV. Statistiske metoder

Den lagte forsøgsplan og den opstillede arbejdshypotese gjorde det muligt at analysere resultaterne med kraftfodertildelingen som den uafhængige variable og foderoptagelsen (græsensilage og ialt foder) samt produktionens størrelse og sammensætning som de afhængige variable. Yderligere kunne de forskellige karakteristika af dyrene (størrelse, laktationsnummer og ydelseskapacitet) inddrages i analysen som uafhængige variable for at klarlægge eventuelle vekselvirkninger samt forskelle i udbyttet af kraftfodertildelingen.

De statistiske metoder, der er blevet benyttet i analysen, er beskrevet nærmere i kapitlet og har omfattet estimering og test af behandlingseffekter ved variansanalysen, estimering og test af produktionsfunktioner ved regressionsanalysen, analyse af kurver beskrivende foderoptagelse og mælkeydelse over laktationen samt analyse af sygdomsforekomst.

Kapitel V. Foderoptagelse

Hypotesen, »Selv når hovedgrovfoderet fodres efter ædelyst, er det ved hjælp af kraftfodertildelingen muligt at regulere den totale foderoptagelse og sammensætningen af foderet«, blev testet ved variansanalyse på total foderoptagelse (f.e. pr. ko dagligt) og ad libitum optagelsen af græsensilage (kg og kg tørstof). Analyserne viste stærkt signifikante effekter af forsøgsbehandlingen (forskellige kraftfoderstrategier) i de respektive laktationsstadier (tabellerne 5.1, 5.3 og 5.7). Ovennævnte hypotese kunne derfor accepteres, og grundlaget for fastlægning af produktionsfunktioner var dermed også til stede.

Analysen af forløbet over laktationen og optagelsen af græsensilage fodret ad libitum og ialt foder viste en betydelig stigning i laktationens første 12 uger. Den største foderoptagelse blev nået omkring laktationsuge 20 og 16 for 1. kalvs køer henholdsvis øvrige køer (tabellerne 5.10–5.11 og figurerne 5.3–5.8).

Foderrationens sammensætning, beskrevet ved andelen af lavprocentigt kraftfoder, roer, melasse og tørret roeaffald i procent af ialt tørstof, ændrede sig, afhængig af kraftfoderstrategien, over laktationen (Figurerne 5.9–5.12).

Forsøgsresultaterne viste, at forskellige måder at tildele en given mængde lavprocentigt kraftfoder på, førte til næsten den samme ad libitum foderoptagelse af ensilage. Optagelsen af græsensilagen kunne derfor fastlægges som en funktion af mængden af kraftfoder også ved strategier med forskelligt forløb af kraftfodertildelingen over laktationen. Denne sammenhæng blev fastlagt til at være krumlinet, idet et stigende kraftfoderniveau formindskede ensilageoptagelsen med tiltagende styrke (tabellerne 5.12–5.15 og 5.19–5.20). I laktationsperioden 1–24 uger efter kælvning fandtes den marginale ensilageoptagelse at være –0.27 og –0,54 kg tørstof pr. kg tørstof i lavprocentigt kraftfoder tildelt ved 4 henholdsvis 8 kg kraftfodertørstof.

Den samlede foderoptagelse, kg tørstof eller f.e., kan beregnes ved hjælp af optagelsesfunktionernes parametre (tabel 5.15). Estimaterne, den beregnede foderoptagelse, for en gruppe af 1. kalvs køer og øvrige køer er tilstrækkeligt præcise for optimering og planlægning af foderrationer.

Det konkluderes, at foderoptagelsen hos køer med gode ydelsesanlæg kan reguleres inden for 1,9 til 3,8 kg tørstof pr. 100 kg levende vægt over laktationsugerne 1–24 og 1–36 ved hjælp af ad libitum fodring med græsensilage af forskellig fordøjelighed og med et konstant dagligt tilskud varierende fra 0 til næsten 12 kg kraftfodertørstof (8,0 kg i lavprocentigt kraftfoder og 3,7 kg i roer, melasse og sukkerroeaffald). Nævnte regulering er højere udtrykt ved nettoenergi, da den daglige foderoptagelse under ovennævnte forudsætninger varierer fra ca. 1,0 til 3,0 f.e. pr. 100 kg levende vægt lige efter kælvning.

Kapitel VI. Produktion

Den opstillede hypotese inkluderede også, at kraftfoderstrategien påvirker såvel produktionens størrelse som sammensætning i et givet laktationsstadium. Variansanalysen på de fundne produktionsdata viste stærkt signifikante behandlingseffekter. Dette var således tilfældet for mælkeydelsen udtrykt på følgende måder i kg: 4% mælk, mælk, mælketørstof, smørfedt, mælkeprotein og fedtfrit tørstof (tabellerne 6.1–6.12). Forsøgsbehandlingens indflydelse på tilvæksten var også signifikant (tabellerne 6.24–6.25), medens dette ikke var tilfældet m.h.t. frugtbarhed, sygdomsforekomst og udskiftning. Ovennævnte hypotese kunne derfor accepteres, og grundlaget for fastlægning af produktionsfunktioner forelå dermed også.

Forsøgsresultaterne viste også, at forskellige måder at tildele en given totalmængde kraftfoder på, førte til næsten den samme mælkeydelse og tilvækst over laktationsugerne 1–24 eller 1–36. Mælkeydelsen og tilvæksten kunne derfor fastlægges som en funktion af kraftfodermængden, også ved strategier med forskelligt forløb af kraftfodertildelingen over laktationen. Mælkeydelsens afhængighed af kraftfodermængden kunne beskrives ved en krumlinet funktion med aftagende marginaludbytte. Parametrene for interceptværdierne (konstantleddet i funktionen) og regressionskoefficienterne for mælkeydelse på kg tørstof i lavprocentigt kraftfoder er angivet i tabellerne 6.27 og 6.28.

Det blev – under forudsætning af ad libitum fodring med græsensilage af en middelgod kvalitet eller med et tilsvarende foder – konkluderet, at den marginale ydelse for alle køer næsten er ens (ca. 1,2 kg 4% mælk), når der ses på den gennemsnitlige ydelse i ugerne 1–12 og 1–24 efter kælvning, og når kraftfoderniveauet samtidig er 7,7 kg tørstof (heraf 4,0 kg i lavprocentigt kraftfoder) pr. ko daglig. Ved større kraftfodertildeling, f.eks. ca. 10 og 12 kg tørstof pr. ko daglig, aftager marginaludbytterne og bliver negative ved den største tildeling. Marginaludbytterne findes under sidstnævnte forudsætninger at være større for ugerne 1–24 efter kælvning end for ugerne 1–12 og tydeligst for 1. kalvs køerne, men dog ikke signifikant større. I modsætning til ovennævnte findes der tiltagende marginaludbytter på tilvæksten, når den samlede foderoptagelse øges ved hjælp af kraftigere fodring med lavprocentigt kraftfoder. Maksimumydelse fandtes, når det samlede kraftfoder på tørstofbasis udgør ca. 65% af den totale ration. Denne andel af kraftfoder i rationen blev dog kun opnået i begyndelsen af laktationen.

Der kan forventes opnået høje gennemsnitsydelser, varierende fra 19,8 til 22,1 kg 4% mælk pr. ko (43% 1. kalvs) daglig i de første 24 uger af laktationen, når græsensilage fodres efter ædelyst, og der samtidig fodres fra 8 til 12 kg tørstof i kraftfoder (lavprocentigt kraftfoder, roer, melasse og tørret roeaffald) pr. ko daglig. I laktationsstadiet omfattende ugerne 1–36 varierer de tilsvarende ydelser fra 18,8 til 21,1 kg 4% mælk. Ved fodring efter den danske norm, 0,40 f.e. pr. kg 4% mælk, kan ydelsen i ugerne 1–24 og 1–36 forventes at blive 21,0 henholdsvis 19,2 kg 4% mælk pr. ko daglig.

Kapitel VII. Optimal kraftfoderstrategi over laktationen

De økonomiske virkninger af at anvende de forskellige kraftfoderstrategier er beregnet og analyseret ud fra den forudsætning, at de fleste mælkeproducenters mål er at opnå den størst mulige arbejdsfortjeneste, dels pr. ko ved betragtning af det korte sigt (konstant antal køer pr. mand) og dels pr. mandtime ved betragtning af det lange sigt. I sidstnævnte tilfælde kan antallet af køer tilpasses mængden af arbejdskraft, der er til rådighed. Arbejdsaflønningen, d.v.s. ialt udbytte ÷ alle omkostninger excl. arbejdsindsats, blev på de respektive kraftfoderstrategier følgende i kr. pr. årsko:

Lo	L-½	Mo	M-½	M+2,-1	M-1	Ho	H+1,-½	Norm
1594	1557	1707	1576	1517	1460	1880	1897	1664

De relative priser samt enhedspriserne var følgende: Mælk 100 (1,50 kr. pr. kg 4% mælk), lavprocentigt kraftfoder 90 (1,35 kr. pr. kg tørstof) og græsensilage 50 (0,75 kr. pr. kg tørstof af en middelgod kvalitet). De variable størrelser, bl.a. indsatsen af foder og udbyttet af mælk, er vist i tabel 7.1.

Det udledes, at normfodring, der forudsætter individuel fodring med alene fodermidler af kendt kvalitet og mængde, kun er mere fordelagtig end de bedst afkastende strategier (Ho og H+1, ÷ ½), hvis der indtræder én af følgende prisændringer i forhold til udgangspunktet med typiske priser:

a. En stigning i prisen på lavprocentigt kraftfoder på mindst 40%. Prisen pr. kg tørstof er da næsten 30% højere end prisen pr. kg 4% mælk,

eller b. En stigning i prisen på græsensilage på mindst 180%,

eller c. Et fald i mælkeprisen på mindst 24%.

Strategierne Lo, Mo og Ho er karakteriseret ved den konstante daglige tildeling af lavprocentigt kraftfoder. Dette forløb, tildelingen af en bestemt totalmængde af kraftfoder over det meste af laktationen og samtidig fodring med grovfoder efter ædelyst, fører til definitionen på et nyt fodringsprincip: »Forenklet fodringsprincip«. Dette princip omfatter kraftfoderstrategier, der er lette at anvende i praksis.

Det konkluderes, at det i almindelighed er mere fordelagtigt at anvende strategi Ho eller H+1, ÷ ½ efterfulgt af fodring efter ydelse og huld i sidste del af laktationen end at anvende normfodring. Dette er tilfældet ved det korte sigt, hvor målet er at maksimere arbejdsaflønningen pr. årsko.

På det lange sigt medfører den største aflønning pr. mandtime også den største aflønning til landmanden, når der forudsættes indsat et bestemt antal mandtimer. Under forudsætning af de samme priser som ovenfor, blev arbejdsaflønningen pr. mandtime på de respektive strategier beregnet til følgende relative værdier, idet normfodringens aflønning på 41,60 kr. pr. mandtime ansættes til 100:

Lo	L-½	Mo	M-½	M+2,-1	M-1	Ho	H+1,-½	Norm
104	99	111	100	96	92	122	120	100

Det kan konkluderes, at inden for forsøgets rammer fandtes fodring med lavprocentigt kraftfoder og dermed ialt kraftfoder, uafhængig af den daglige ydelse, at give en større eller tilsvarende aflønning pr. mandtime sammenlignet med normfodring, når hovedgrovfoderet (f.eks. græsensilage) blev fodret ad libitum. Yderligere fandtes, at en konstant tildeling, d.v.s. ens daglig fordeling af en given mængde lavprocentigt kraftfoder i laktationsugerne 1–36 var mere fordelagtig end 3 andre undersøgte tildelingsforløb. Strategi H+1, ÷ ½ gav dog næsten samme arbejdsaflønning pr. mandtime som strategi Ho.

Ved fortsat betragtning af det lange sigt, vil fodring med et fuldfoder, der på tørstofbasis indeholder ca. 60% kraftfodermidler (oliekager, korn, roer, melasse m.m.) også være konkurrencedygtig overfor det forenklede fodringsprincip, hvis der ikke er ekstra omkostninger forbundet med at fremstille og udfodre en homogen blanding af alle aktuelle fodermidler.

Da de i nærværærende forsøg anvendte fodermidler repræsenterer de typiske for en alsidig sammensat foderration, er det forsvarligt at generalisere ud fra ovennævnte konklusioner.

I den enkelte besætning afhænger den optimale mængde kraftfoder af dettes pris samt prisen på såvel det konkurrerende foder, græsensilage eller tilsvarende, som på mælk og tilvækst. I afsnit 7.3 er anført det værktøj (ligningerne 28, 31, 32, 33, 36, 37 og 38), der skal anvendes ved optimering af indsatsen af den konstante daglige kraftfodermængde i laktationens første 24 uger. I tabel 7.3 er vist den optimale mængde lavprocentigt kraftfoder for forskellige prissæt. Den samlede tildeling af kraftfoder fås ved at tillægge 3,7 kg tørstof i roer, melasse og tørret sukkerroeaffald. Ligninger til optimering af indsatsen af ialt tørstof (TDMI) og ialt foderenheder (SFU) er også anført i afsnit 7.3. I tabellerne 7.5 og 7.6 er vist den optimale indsats under forskellige prisforudsætninger.

Det er af væsentlig økonomisk betydning for mælkeproducenten, at risikoen for forkert fodring af den enkelte ko som følge af bl.a. tilfældige fejl ved ydelseskontrollen, for kort opholdstid i malkestalden til at æde stor kraftfodermængde eller fejlidentifikation, formindskes, når det forenklede fodringsprincip anvendes.

Kapitel VIII. Sammenfattende konklusion

Konklusionerne af største interesse for mælkeproducenten er anført i 11 punkter, som i ord beskriver de følgende kvantitative sammenhænge, der er nødvendige for optimering af kraftfodertildelingen:

		Ad libitum				Mælkeydelse
Tildeling af	→	optagelse af	→	Samlede foder-	→	Tilvækst
kraftfoder		grovfoder		optagelse		Frugtbarhed
						Sundhed

Mælkeproducenten kan vælge imellem følgende alternative hovedprincipper for fodringen:

1. Normfodring på grundlag af den daglige mælkeydelse ved f.eks. 0,40 f.e. pr. kg 4% mælk.
2. Forenklet fodringsprincip, der i sidste del af laktationen inkluderer fodring efter forventet ydelse og ønsket tilvækst.
3. Fodring med fuldfoder efter ædelyst.

Under hensyntagen til de aktuelle forudsætninger i den enkelte bedrift vil et af disse fodringsprincipper være mest fordelagtigt at anvende. I de fleste tilfælde vil det forenklede fodringsprincip være mere fordelagtigt at anvende end de øvrige to. Fodring med fuldfoder vil – afhængig af omkostningerne ved at lave et homogent foder – kunne være det mest fordelagtige princip at anvende i besætninger, hvor dyrene (1. kalvs og/eller øvrige køer) let kan grupperes i følgende 3 grupper: køer i første del af laktationen, køer i sidste del af laktationen og goldkøer.

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Appendix A. Culling of cows

1. Conditions for culling

Culling of cows during the experimental period (weeks 1–36 after parturition) took place, when one of the following conditions was fulfilled:

1.1. Low yield capacity

Low yielding cows were culled when their milk records were below the pre-determined minimum lactation curves given in Tables A.1 and A.2. The conditions for culling were 1) 3 subsequent records of descending yields below the minimum lactation curve *or* 2) a total of eight records below the minimum curve.

1.2. Serious injuries

Injuries that seriously and/or permanently affect the cow's mobility or production ability (compared to the minimum curve).

1.2.1. Severe infectious diseases

1.2.2. Long-term diseases

Diseases that cause a long-term or permanent reduction of the production ability (compared to the minimum curve).

1.2.3. Short-term diseases

Short-term diseases did not cause a culling (but maybe a deletion of a single milk record). If, however, the disease occured repeatedly, then the cow was culled when the disease occured the third time in the same lactation.

1.2.4. Loss of teats

Cows with less than 3 secreting teats were culled.

2. Effectuation of culling

The culling was effectuated immediately after a condition for culling was fulfilled. The cow was weighed before culling (if possible). The data registration was ceased by the end of the last complete week of the experiment.

3. Replacement of culled cows

New cows were entered into the experiments in rounds during which one cow was assigned to each group (see Chapter II). Replacements of culled cows took place in between these rounds in the same order as culling. When all second and following lactation cows in the herd had entered the experiment, then all replacements were done with first lactation cows.

Table A.1 Minimum yields (kg FCM per day) for non-pregnant cows

Week after parturition	TREATMENT/STRATEGY: L0, L-½, Norm Lactation 1	L0, L-½, Norm Lactation 2	L0, L-½, Norm Lactation 3 and over	M0, M-½, M+2,-1, M-1 Lactation 1	M0, M-½, M+2,-1, M-1 Lactation 2	M0, M-½, M+2,-1, M-1 Lactation 3 and over	H0, H+1,-½ Lactation 1	H0, H+1,-½ Lactation 2	H0, H+1,-½ Lactation 3 and over
1–16	12.0	14.0	15.0	13.5	15.5	16.5	15.0	17.0	18.0
17	11.9	13.8	14.7	13.4	15.3	16.3	14.9	16.8	17.7
18	11.8	13.5	14.4	13.3	15.1	16.0	14.8	16.5	17.4
19	11.6	13.3	14.1	13.3	14.9	15.8	14.6	16.3	17.1
20	11.5	13.1	13.8	13.2	14.7	15.5	14.5	16.1	16.8
21	11.4	12.8	13.6	13.1	14.5	15.3	14.4	15.8	16.6
22	11.3	12.6	13.3	13.0	14.3	15.0	14.3	15.6	16.3
23	11.1	12.4	13.0	12.9	14.1	14.8	14.1	15.4	16.0
24	11.0	12.1	12.7	12.8	13.9	14.5	14.0	15.1	15.7
25	10.9	11.9	12.4	12.8	13.8	14.3	13.9	14.9	15.4
26	10.8	11.7	12.1	12.7	13.6	14.0	13.8	14.7	15.1
27	10.7	11.4	11.8	12.6	13.4	13.8	13.7	14.4	14.8
28	10.5	11.2	11.5	12.5	13.2	13.5	13.5	14.2	14.5
29	10.4	11.0	11.2	12.4	13.0	13.3	13.4	14.0	14.2
30	10.3	10.7	11.0	12.3	12.8	13.0	13.3	13.7	14.0
31	10.2	10.5	10.7	12.3	12.6	12.8	13.2	13.5	13.7
32	10.0	10.3	10.4	12.2	12.4	12.5	13.0	13.3	13.4
33	9.9	10.0	10.1	12.1	12.2	12.3	12.9	13.0	13.1
34	9.8	9.8	9.8	12.0	12.0	12.0	12.8	12.8	12.8
35	9.8	9.8	9.8	12.0	12.0	12.0	12.8	12.8	12.8
36	9.8	9.8	9.8	12.0	12.0	12.0	12.8	12.8	12.8

Table A.2 Minimum yields (kg FCM per day) for pregnant cows

Weeks to next parturition	Strategy: L0, L-½, Norm	M0, M-½, M+2,-1, M-1	H0, H+1,-½
32–24	9.8	12.0	12.8
23	9.2	11.4	12.1
22	8.6	10.7	11.4
21	8.1	10.1	10.8
20	7.5	9.4	10.1
19	6.9	8.8	9.4
18	6.3	8.1	8.7
17	5.7	7.5	8.0
16	5.2	6.8	7.4
15	4.6	6.2	6.7
14	4.0	5.5	6.0
13-parturition	0.0	0.0	0.0

Noteringer

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