NorFor – The Nordic feed evaluation system

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Chapters 1-3

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1. Introduction

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Feed is one of the major expenses in modern cattle production. In addition to feed prices, its overall costs are affected by the efficiency of feed utilization and the output of animal products to be marketed. Hence, there is a clear need to evaluate feed quality in order to maximise profitability. This requires information on both animal requirements and nutrient supply, since formulation of an appropriate ration involves balancing available feeds in proportions that match the amounts of nutrients supplied to the animals' nutrient requirements as closely as possible. There are two principal methods used to describe animal nutrition: those based on mechanistic approaches, which describe responses to nutrients from chemical and physiological processes in the gastrointestinal tract and intermediary, and empirical approaches describing simple relationships between nutrient intakes and production responses. The challenge in the development of new feed evaluation systems is to accurately predict responses to nutrients so that any difference in product income and feed costs can be maximized, while improving overall feed efficiency. Feed efficiency is also of great importance due to its impact on enteric methane emission to the atmosphere and nitrogen and phosphorus passing into the environment.

Feed evaluation for cattle has long traditions. Important milestones are introductions of the Weende analysis by Henneberg and Stohmann (1864), and the starch equivalent system by Kellner (1912). In the Nordic countries the introduction of the milk production value by Hansson (1913) and the Scandinavian feed unit by Møllgaard (1929) were of great magnitude for modern cattle production. Extensive research in the 1950's and 60's further improved our knowledge in feed evaluation, and in the period from 1970 to 1990 most countries introduced new systems for energy based either on metabolizable energy (ME) or net energy for lactation (NEL) or growth (NEG) (Van der Honing and Alderman, 1988). Also the knowledge of protein evaluation for cattle have increased considerably during the last 40 years, from use of total or digestible crude protein to the protein evaluation systems that predict the host animal amino acid (AA) supply from dietary protein escaped ruminal degradation and from microbial protein synthesized in the rumen (Madsen, 1985; NRC, 1985; Vérité *et al.*, 1987; AFRC, 1992; Tamminga *et al.*, 1994).

Traditional feed evaluation systems are additive and generally do not take into account interactions in digestion and nutrient metabolism. When interactions and non-linear relationships are considered, in attempts to describe feed metabolism, individual feeds will no longer have fixed values. Hence, the value of a given feedstuff will depend on how the feed is used. This means that the feed value cannot be determined until we know which feed ration will be used and the production situation in which it will be applied. Therefore, the development of a new feed evaluation system must consist of a ration evaluation system which can be used to optimize nutrient supply and production responses, rather than a system that can predict individual feed values. Development of new feed evaluation systems (Russell *et al.*, 1992; Sniffen *et al.*, 1992; Fox *et al.*, 1992; NRC, 2001) and mechanistic models (Baldwin, 1995; Danfær *et al.*, 2006), which describe nutrient supply and the nutritional requirements of cattle, are important for understanding ruminant nutrition and constitute an important step towards implementing more sophisticated nutritional strategies to optimize production responses in cattle. The use of non-linear semi-mechanistic feed evaluation systems for ration optimization requires powerful computing tools. Recent improvements in non-linear optimization tools and algorithms enable the development of more complex feed evaluation systems that can also be used in practice.

The aim of this book is to provide a detailed description of the semi-mechanistic feed evaluation system NorFor, which has already been implemented by advisory services in four Nordic countries, i.e. Denmark, Iceland, Norway and Sweden.

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2. Overall model description

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The NorFor system is a semi-mechanistic, static and science-based model, which predicts nutrient supply and requirements for maintenance, milk production, growth and pregnancy in cattle. The model can be divided into five parts: (1) an input section describing characteristics of the animal and feeds available; (2) a module simulating processes in the digestive tract and the intermediary metabolism, termed the feed ration calculator (FRC); (3) a module predicting feed intake; (4) a module predicting the physical structure of the diet; and (5) an output section describing nutrient supply, nutrient balances and production responses (Figure 2.1).

The input variables for the model are animal and feed characteristics. For dairy cows, the main input variables are body weight (BW), stage of lactation, pregnancy day and planned or potential daily milk production. For growing animals (bulls, steers and heifers) input variables are BW and average daily weight gain (ADG). The feed dry matter (DM) is separated into ash, crude protein (CP), crude fat (CFat), neutral detergent fibre (NDF), starch (ST), sugar (SU), fermentations products (FPF) such as organic acids and alcohols, and a residual fraction (RestCHO). The CP is divided into soluble (sCP), potentially degradable (pdCP), indigestible (iCP) and ammonia (NH_3N). The NDF is divided into a total indigestible (iNDF) and a potentially degradable (pdNDF) fraction. The ST is divided into soluble (sST), potentially degradable (pdST) and indigestible (iST) fractions. The FPF are separated into lactic acid (LAF), volatile fatty acids (VFA) and alcohols. Fractional degradation rates (kd) of the soluble and potentially degradable feed fractions are also required for the model.

The FRC consists of four sections: (1) the rumen, (2) the small intestine, (3) the large intestine and (4) metabolism (Figure 2.2). Feed organic matter (OM) entering the rumen is either fermented and used for microbial production, or it escapes from the rumen for further digestion in the lower digestive tract. Ruminal degradation of CP, ST and NDF in concentrate feeds are assumed to follow first-order single-compartment kinetics, while degradation of NDF in roughage is modelled as a

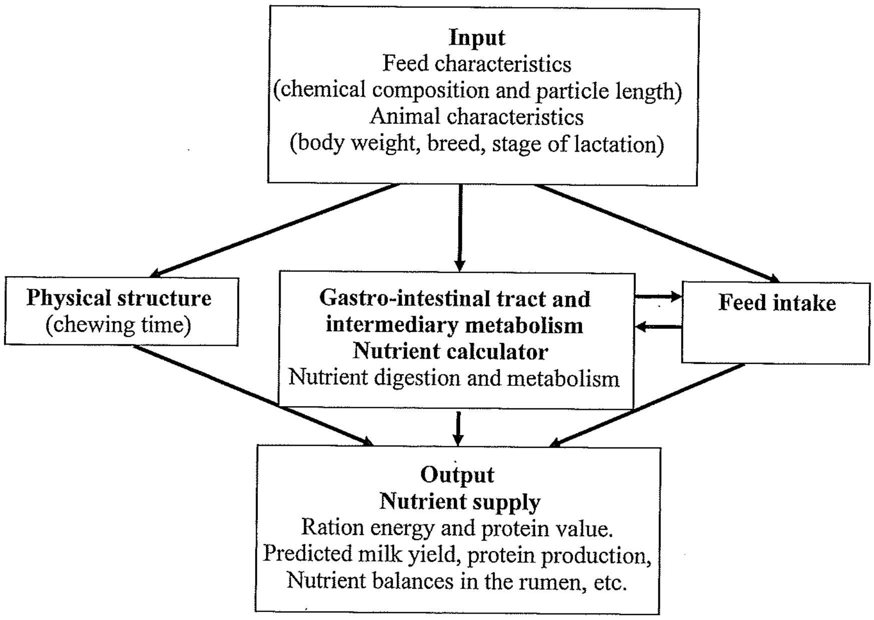

Figure 2.1. Overview of the NorFor model.

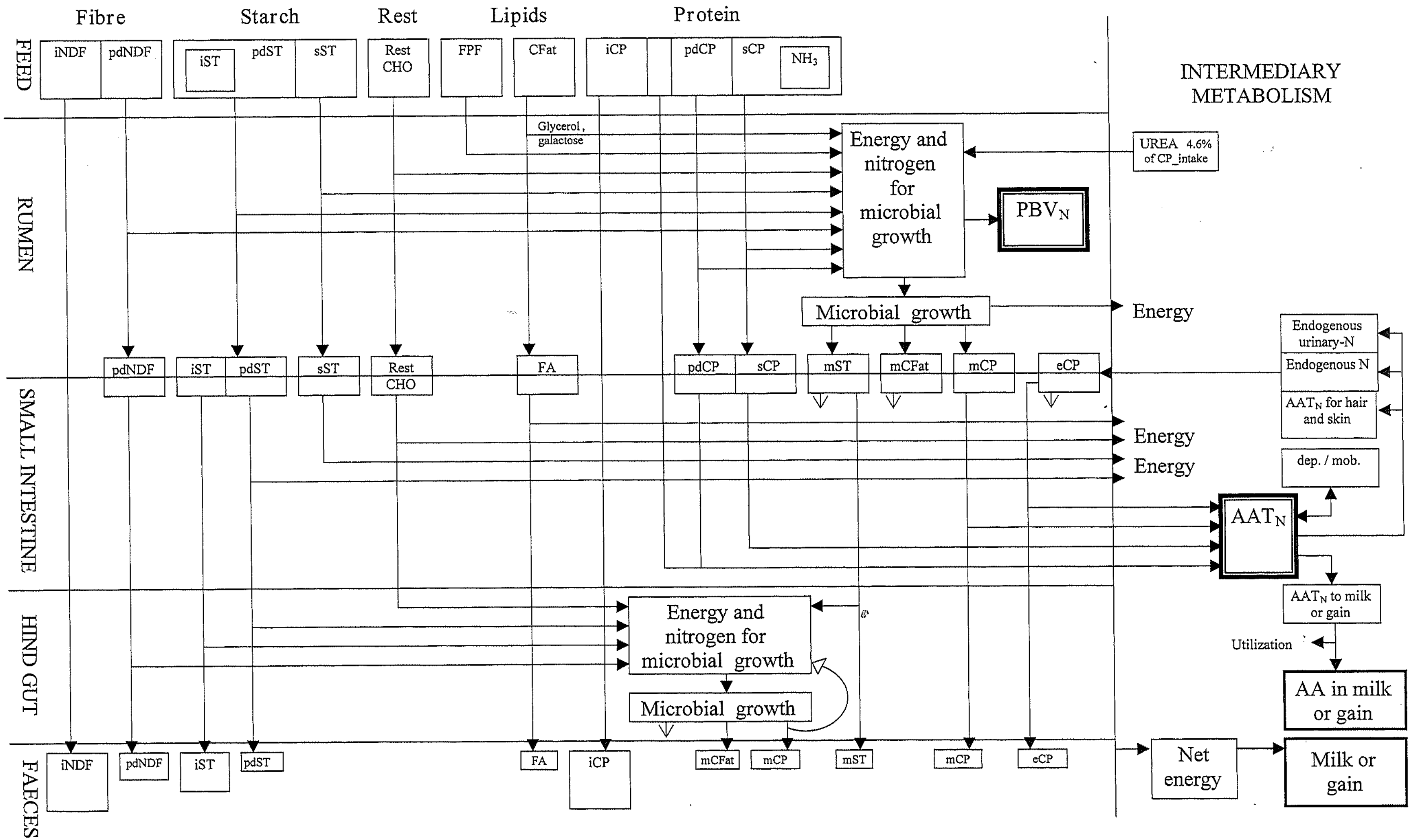

Figure 2.2. Flow diagram of the gastrointestinal tract and intermediary compartments of the NorFor feed evaluation system. For all abbreviations check the abbreviation list.

two-compartment system, with a non-escapable and an escapable pool. The nutrients available for microbial growth come from ruminally degraded NDF, ST, RestCHO, glycerol, CP and LAF. The efficiency of microbial synthesis depends on the level of feed intake and diet composition. The input to the small intestine consists of OM from microbes, unfermented feed fractions escaping from the rumen and endogenous secretions. These components are partly digested in the small intestine and are either metabolised or enter the large intestine. The OM passing into the large intestine is subjected to microbial fermentation, and the digested OM not used for microbial synthesis is absorbed and metabolised. Faecal excretion consists of OM from microbes synthesised in the large intestine, feed that has escaped previous digestion and undigested rumen microbial material. The intermediary metabolism section yields ME calculated from total tract digestible OM. Net energies for maintenance, lactation, growth and pregnancy are predicted from the ME. Different coefficients are used to calculate NE for maintenance, lactation, and growth. Net energy for lactation is used for dairy cows, while NEG is used as the energy measurement for growing cattle.

The nitrogen (N) fractions entering the intermediary metabolism consist of NH_3N absorbed from the rumen, dietary, microbial and endogenous amino acids (AA) absorbed from the small intestine, and NH_3N from the large intestine. The absorbed AAs are utilized for maintenance, growth, pregnancy and milk production. The efficiency of AA utilization is specific for each production/process. The metabolizable protein available for animal production is assigned as amino acids absorbed from the small intestine (AAT_N). The N which is not used for maintenance or production is excreted in the urine.

Predicting nutritive value is only one part of ration formulation as formulation involves both the selection of feed ingredients and the prediction of feed intake. Therefore, the NorFor system contains a module to predict the intake of feeds. For prediction of feed intake dietary fill values (FV) and animal intake capacity (IC) are applied. In roughages, FV is calculated from OM digestibility (OMD) and NDF content, and in ensiled forages the basic FV is also corrected for content of VFA, LAF and NH_3N. Animal IC is dependent on BW, milk yield, stage of lactation, lactation number, ADG and physical activity. The model uses a combination of dietary physical effects and metabolic factors to impact feed intake, and the effect of easily fermentable carbohydrates on roughage intake is accounted for by using a substitution rate factor (SubR).

A minimum amount of large particles is essential for optimal rumen function. Hence, a module to evaluate the physical structure of the diet is included in NorFor. The dietary physical effect is described by a total chewing index (CI), which is calculated as the sum of an eating (EI) and ruminating (RI) index for each individual feed. The EI value reflects the associated chewing activity as feed is consumed and is calculated from the particle length and NDF content of the feed. The RI value is calculated from particle length, NDF content and a hardness factor, which is dependent on the iNDF content of the feed. The hardness factor reflects the lignification of the structural fibre of the feed and the associated physical force required for the comminution of large particles.

The output from a model calculation in NorFor describes the intake of the individual feeds in the total ration. It consists of variables describing efficiencies of digestion and nutrient utilization, production (milk, ADG), N excretion, nutrient balances, energy (NEL or NEG) and protein (AAT_N) values of the ration.

3. Animal input characteristics.

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Animal characteristics are needed for calculation of nutrient requirements and IC for both cows and growing cattle. Information on animal parameters, such as BW, is also needed when calculating ruminal variables, such as passage rates of feed fractions out of the rumen and efficiency of microbial protein synthesis. Moreover, the physical activity of the animal (simply classified according to whether it is loose or tied up) will affect the IC and energy requirements.

3.1 Input data for cows

All required input data for cows are listed in Table 3.1 and default values for different breeds are compiled in Table 3.2. The information needed for cows in the system is breed, lactation number, BW, stage of lactation (days in milk) and milk production. Pregnancy and whether the cow is dry or lactating are also factors required for determining IC and requirements for gestation. When calculating energy and protein requirements for gestation, information on mature body weight (BW_mat) is needed since this variable is breed-specific (see Table 3.2 and Sections 9.1.3 and 9.2.5). BW_mat is also needed to determine protein requirements for growth in primiparous cows (Section 9.2.3).

Animal weight changes can be estimated as changes in body condition score (BCS), where the BW per condition scores depends on the breed. The BCS in NorFor uses a scale from 1 to 5, where 1 is thin and 5 is fat (Gillund *et al.*, 1999). One unit of BCS corresponds to 60 kg BW except for Jersey which is set to 45 kg BW; these values are based on data from several previous studies (e.g. Enevoldsen and Kristensen,1997; Gillund *et al.*, 1999; Nielsen *et al.*, 2003; Bossen, 2008).

Table 3.1 Input data for cows in NorFor.

Input data	Unit
Dry cow	none[1]
Lactation number	No.
Days in milk	days
Daily milk yield	kg/day
Protein content in milk	g/kg
Fat content in milk	g/kg
Lactose content in milk	g/kg
Yield level of the herd	kg ECM
Body weight, current	kg
Body weight, mature[2]	kg
Weight gain in primiparous cows	kg/day
Days of gestation	days
Daily change in body condition score	BCS/day
Weight per unit body condition score[2]	kg/BCS
Activity	none[1]
Breed[3]	none[1]

[1] No unit.

[2] Default values can be taken from Table 3.2.

[3] Abbreviations for breeds are explained in Table 3.2.

Table 3.2. Default values for mature body weight (BW_mat) and the weights corresponding to a body condition score unit (BCS_kg) for dairy cows of different breeds.

Abbr.	Dairy breed	BW_mat kg	BCS_kg kg/BCS
DH	Danish Holstein	640	60
IB	Icelandic breed	470	60
JER	Jersey	440	45
NR	Norwegian Red	600	60
RD	Danish Red	660	60
SH	Swedish Holstein	640	60
SR	Swedish Red	620	60

The energy requirement for milk production is based on the production of energy corrected milk (ECM), which can be calculated from either of two equations (Sjaunja *et al.*, 1990) depending on whether information on milk lactose content is available:

$$ECM = MY \cdot \left(0.01 + 0.122 \cdot \frac{f\_milk}{10} + 0.077 \cdot \frac{p\_milk}{10} + 0.053 \cdot \frac{l\_milk}{10}\right) \quad 3.1$$

$$ECM = MY \cdot \left(0.25 + 0.122 \cdot \frac{f\_milk}{10} + 0.077 \cdot \frac{p\_milk}{10}\right) \quad 3.2$$

where ECM is the energy corrected milk, kg/day; MY is the daily milk yield, kg/day; and f_milk, p_milk and l_milk are the contents of fat, protein and anhydrous lactose in milk, respectively, g/kg.

When formulating feed rations for groups of cows, the daily ECM yield (ECMherd) can be estimated from breed-specific lactation curves:

$$ECMherd = a + b \cdot YHerd - c \cdot DIM + \ln(DIM) \cdot d \quad 3.3$$

where ECMherd is the daily estimated ECM yield, kg/d; YHerd is the herd's average ECM yield per cow, kg/305 d; DIM is days in milk; a, b, c and d are regression coefficients presented in Table 3.3 for primiparous and multiparous cows of different breeds.

Standard lactation curves are available for different dairy breeds and lactation numbers. The ECMHerd value refers to the herd's 305-d lactation yield, which is based on national herd recording data. Danish cow recording data (Danish Cattle Association) have been used to parameterize the standard lactation curves for the dairy breeds Jersey, Danish Holstein and Danish Red. Icelandic, Norwegian and Swedish national herd recording data are the basis for the standard lactation curves for the Icelandic breed, Norwegian Red, Swedish Holstein and Swedish Red cattle, respectively (Farmers Association of Iceland; Tine Dairies in Norway; Swedish Dairy Association).

Daily milk protein yield is calculated from milk yield and milk protein content according to Equation 3.4. Protein production is essential for calculating the AA requirement for milk production:

$$MPY = MY \cdot p\_milk \quad 3.4$$

where MPY is the milk protein yield, g/day; MY is the milk yield, kg/day; and p_milk is the milk protein content, g/kg.

Table 3.3. The multiple regression coefficients a, b, c and d is used to predict daily ECM yield from standardised lactations curve in Equation 3.3.

Breed[1]	Lactation	a	b	c	d
DH	primiparous	-3.10	0.00325	0.01685	1.140
DH	multiparous	3.17	0.00338	0.06040	1.025
IB	primiparous	0.88	0.00288	0.04009	1.627
IB	multiparous	6.34	0.00269	0.06234	1.569
JER	primiparous	-8.15	0.00324	0.02810	2.654
JER	multiparous	-2.98	0.00335	0.05630	2.305
NR	primiparous	-7.09	0.00314	0.06440	3.741
NR	multiparous	-0.59	0.00310	0.09100	3.378
RD	primiparous	-6.20	0.00335	0.02138	1.750
RD	multiparous	1.45	0.00330	0.06973	1.844
SH	primiparous	-4.05	0.00299	0.03560	2.591
SH	multiparous	2.93	0.00299	0.06100	1.997
SR	primiparous	-4.46	0.00304	0.03970	2.677
SR	multiparous	-0.21	0.00317	0.06920	2.520

[1] The abbreviations of the different breeds are shown in Table 3.2.

3.2 Input data for growing cattle

When calculating nutrient requirements and the IC for growing cattle, information on BW, ADG, sex, breed and activity are needed, and for heifers the days of gestation are also required (Table 3.4).

Table 3.4. Input data for growing cattle.

Parameter	Unit
Sex	none[1]
Breed[2]	none[1]
Activity	none[1]
Body weight[3]	kg
Average daily gain[3]	g/day
Days of gestation (heifers)	days
Body weight, birth[4]	kg
Body weight, start[4]	kg
Body weight, end[4]	kg
Body weight, mature[4]	kg
Age, start[4]	days
Age, current[4]	days
Age, end[4]	days

[1] No unit.

[2] The classifications of different breeds are shown in Table 3.5.

[3] Body weight and daily gain are required parameters and can be estimated from the parameters that are marked by [4].

[4] These parameters are required if current body weight and average daily gain data are not available.

3.2.1 Estimation of body weight and daily weight gain from a growth function

When planning feed rations for animals of different ages, data of BW_mat, age and BW at the start of the rearing period and planned age and BW at the end of the rearing period are needed. Expected BW and ADG can be estimated from the following logistic growth equation based on:

$$BW\_calc = BW\_start \cdot e^{(A\cdot(1-e(-B\cdot(Age-Age\_start))))} \quad 3.5$$

where BW_calc is the estimated BW for the current age, kg; BW_start is the BW at the start, kg; A is described in Equation 3.7; B is described in Equation 3.8; Age is the current age, days; Age_start is the age at start, days. If Age_start is 0 the BW_start is the same as BW_birth.

$$ADG\_calc = \left(BW\_start \cdot e^{(A\cdot(1-e(-B\cdot(Age-Age\_start+1))))} - BW\_start \cdot e^{(A\cdot(1-e(-B\cdot(Age-Age\_start))))}\right) \cdot 1000 \quad 3.6$$

where ADG_calc is the estimated average daily gain for the current age, g/day; BW_start is the BW at the start, kg; A is described in Equation 3.7; B is described in Equation 3.8; Age is the current age, days; Age_start is the age at start, days. If Age_start is 0 the BW_start is the same as BW_birth.

Factor A and B in Equations 3.5 and 3.6 are calculated as:

$$A = \ln\left(\frac{BW\_mat \cdot 1.1}{BW\_start}\right) \quad 3.7$$

$$B = \frac{\ln\left(\frac{\ln(BW\_mat \cdot 1.1 / BW\_start)}{\ln(BW\_mat \cdot 1.1 / BW\_end)}\right)}{Age\_end - Age\_start} \quad 3.8$$

where A and B are factors used in Equations 3.5 and 3.6; BW_mat is the mature body weight, kg; BW_start is the body weight at start or at birth, kg; BW_end is the body weight at the end of the feeding period; Age_start is the age at start, days; and Age_end is the age at the end of the feeding period, days. If Age_start is 0 days, the BW_start is the same as BW_birth.

An example of the logistic growth function of ADG and BW during the rearing period is shown in Figure 3.1.

The end of the feeding period depends on whether the animal will be sold, slaughtered or used for replacement. Default values for birth weights (BW_birth) and BW_mat that can be used for estimating BW and ADG for different breeds and gender are shown in Table 3.5. BW_birth values for beef breeds were collected from Danish, Norwegian and Swedish national recording data compiled by the Danish Cattle Association, Norwegian Meat and Poultry Research Centre and Cattle statistics (2007), respectively. Values for BW_mat were taken from Danish, Norwegian and Swedish slaughter data for animals over 4 years of age over the last 10 years supplied by the Danish Cattle Association; Norwegian Meat and Poultry Research Centre and Swedish Dairy Association, respectively.

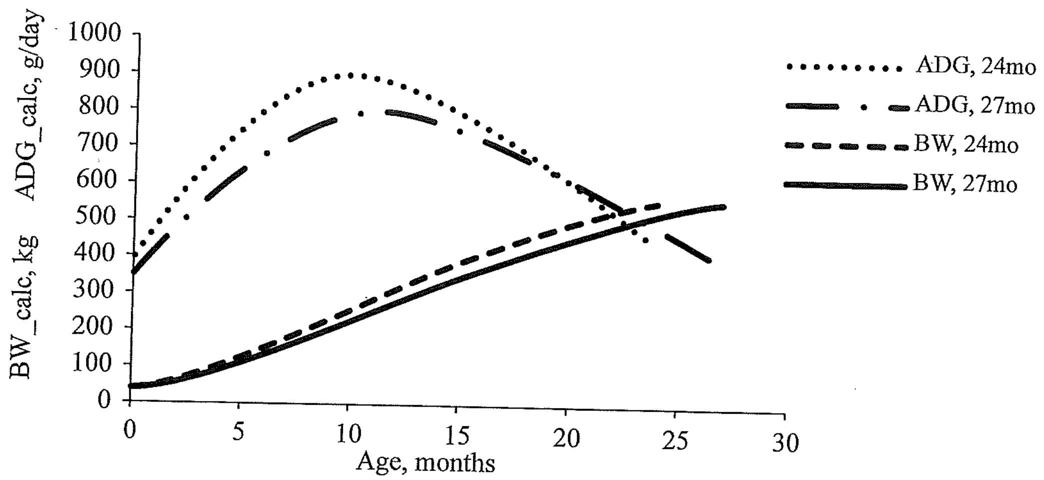

Figure 3.1. A logistic growth function predicting BW (BW_calc) and estimated weight gain (ADG_calc) during the rearing of a heifer which is scheduled to calve at a live weight of 560 kg at either 24 or 27 months of age. To achieve a final weight of 560 kg, the weight gain is faster for a heifer finished at 24 months of age (ADG, 24mo; BW, 24mo) than for a heifer finished at 27 months (ADG, 27mo; BW, 27mo).

Table 3.5. Default values for birth weight (BW_birth) and mature body weight (BW_mat) for heifers, bulls and steers of different breeds.

Breeds	BW_birth for heifer kg	BW_birth for bulls kg	BW_mat for heifer kg	BW_mat for bulls kg	BW_mat for steers kg
Early maturing dairy breeds					
Danish Holstein	40	41	640	950	750
Danish Red	40	41	660	950	750
Icelandic breed	33	33	470	800	700
Jersey	28	30	440	650	550
Norwegian Red	39	41	600	950	750
Swedish Holstein	39	41	640	950	750
Swedish Red	39	41	620	950	750
Early maturing beef breeds					
Aberdeen Angus	36	38	700	950	750
Dexter	21	24	340	450	400
Galloway	34	35	550	850	750
Hereford	40	42	700	950	750
Highland cattle	29	30	500	700	600
Tiroler Grauvieh	39	42	700	950	750
Late maturing beef breeds					
Belgian Blue	44	47	850	1,200	1,050
Blonde d'Aquitaine	44	47	850	1,200	1,050
Charolais	46	49	750	1,200	1,050
Chianina	50	55	850	1,200	1,050
Limosin	41	43	750	1,200	1,050
Piemontese	41	43	750	1,200	1,050
Saler	39	41	750	1,200	1,050
Simmenthal	44	46	750	1,200	1,050
Early-late maturing breed					
Crossbred[1]	42	44	750	1,050	950

[1] Crossbreeds of early and a late maturing breeds are assigned specific factors in some of the equations in Chapter 9.

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