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Modelling Livestock Component in FSSIM

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General information

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Related milestones:

Executive summary

This document summarises the development of a ruminant livestock component for the Farm System Simulator (FSSIM). This includes treatments of energy and protein transactions in ruminant livestock that have been used as a basis for the biophysical simulations that will generate the input production parameters for FSSIM. The treatments are derived principally from the “French” feed evaluation and rationing system for protein and energy. These are described in detail by Jarrige (1988) and for practical application along with a reasonable volume of data (that has been used for initial testing of the model) by Jarrige (1989). Currently, we have constructed routines that are capable of simulating input-output relationships for energy and protein in the following representative systems; dairy cattle; suckler cows (dams); growing and finishing cattle; sheep and goats. In addition to covering nutrient transactions in the animal, the document summarises the approach taken to modelling the delivery of forages from grass-based systems and the simulation of nitrogen and feed balances at the level of the livestock farm.

1 Introduction

Activity 3.2.4 in SEAMLESS comprises the development of livestock components. A static approach has been followed in which input-output relationships are described for current and alternative livestock production activities. In this respect, activity 3.2.4. is more equivalent to the "Generators of the Data" module of the Farm System Simulator (FSSIM), than the dynamic, mechanistic land-use models of the Agricultural Production and Externalities Simulator (APES) and has therefore been moved to Task 3.3. This document describes the general approach to quantifying the inputs and outputs for livestock activities, the data types required, and implementation in FSSIM.

1.1 Objectives

The broad objective of the livestock component in SEAMLESS is to quantify the relations amongst feed availability and quality, feed intake by the various selected animal species, animal production, and waste production.

1.2 General approach

We use the "French" feed evaluation and rationing system for protein and energy (Jarrige, 1988; 1989) to quantify the relationships between feed intake and animal production. The application of the French evaluation system within the livestock module of SEAMLESS is described in this document. Amongst the alternative feed evaluation systems available (e.g., the Dutch, Nordic and UK metabolizable energy and protein systems) the French system was identified as the most appropriate basis for this model because:

- It has been widely tested and shown to generate reasonably accurate predictions of livestock performance in both northern European- and Mediterranean-type ecological zones;
- A considerable volume of relevant feed composition data has been collated and published that would greatly facilitate the application of the French system with FSSIM.

Based on the EU production structure of livestock farms in the Farm Accountancy Data Network (FADN) system, the following ruminant animal types have been identified:

- dairy cattle;
- suckler cows;
- growing and finishing beef cattle;
- sheep;
- goats.

The calculations of energy and protein requirements for these classes of livestock are described in detail in this document.

Initial parameter values for the SEAMLESS livestock module have been collected through the so-called 'Simple Survey'. This survey has been carried out in 25 NUTS2 regions in the EU (Borkowski *et al.*, 2007). NUTS stands for 'Nomenclature of Territorial Units for Statistics' and is the EU standard for referencing administrative divisions of EU countries. Three NUTS levels exist; the NUTS2 level refers to provinces (Netherlands) and *regerungsbezirke* (Germany), for example. Within the simple survey (SS henceforth), basic information has been collected concerning the production systems for the different animal types. The parameter names used in the SS have also been used in this document to facilitate understanding of how the two SEAMLESS components are linked.

Part of the livestock component is a feed resources module consisting of a simple grassland module estimating grassland biomass and quality in different agro-environmental zones of the EU. Production of crop-based feeds such as silage maize is simulated using APES. Feed availability on-farm and the feed requirements of animals are matched endogenously in FSSIM.

In outline, the livestock component generates inputs (feed requirements in terms of availability and quality) and outputs (e.g., milk production, live weight gain) for different age cohorts that can be scaled up to the herd level. For this purpose, we have introduced the concept of a 'dressed animal'. This represents an adult animal with its associated young stock (e.g., a suckler cow and her followers) based on estimated replacement rates.

1.3 Feed parameters used by the French system

1.3.1 Energy

The French energy system is a net energy system (i.e., energy values represent ingested energy that is actually useable for maintenance and productive purposes). Feedstuffs are assigned two net energy values:

UFL: Net energy for maintenance and production in lactating animals.

UFV: Net energy for maintenance and body weight gain in meat producing animals.

Both net energy values are expressed in feed units that are defined relative to the net energy content of 1 kg of standard barley for milk (1700 k cal) and meat (1820 k cal) production. Feed units are additive.

1.3.2 Protein

The protein component of the French system represents, in common with most of the other more modern European systems, an attempt to treat protein transactions in a slightly more mechanistic way than the older systems based on DCP (digestible crude protein).

The principal aim is to characterise feeds according to their content of:

PDI: Protein that is truly digested in the small intestine, i.e., the fraction of the ingested protein that may be regarded as truly available for metabolism by the animal.

PDI is the sum of two biologically-distinct fractions:

PDIA: The dietary protein that remains undegraded after transit through the rumen but **is** digestible in the small intestine (sometimes referred to as "by-pass" protein in other systems).

PDIM: protein of microbial origin that is also truly digestible in the small intestine.

Microbial protein synthesis in the rumen can be limited by either the dietary nitrogen or the dietary energy that is useable by the microbial population. Thus the following terms are introduced:

PDIMN: The quantity of microbial protein that could be synthesised when energy and other nutrients are not limiting.

PDIME: The quantity of microbial protein that could be synthesised when ruminally degraded N and other nutrients are not limiting.

In effect, the PDI for a given feed used under a particular set of circumstances will be the lower of

PDIN: PDIN = PDIA + PDIMN, and

(truly digestible protein when nitrogen supply is limiting)

PDIE: PDIE = PDIA + PDIME

(truly digestible protein when energy supply is limiting)

1.3.3 Feed intake

Estimation of voluntary feed intake under the French system is based on the interaction of feed and animal characteristics that will determine the quantity of a particular forage that can be consumed. The "fill unit" is defined with respect to a reference forage (an average pasture grass cut at the grazing stage of the first growth) that contains one fill unit per kg of dry matter (DM). In fact, each feed is characterised according to each of three different fill units that relate to different classes of livestock:

LFU: Fill units for lactating cattle, sheep and goats;

CFU: Fill units for other cattle;

SFU: Fill units for sheep (and presumably goats).

1.4 Outline of deliverable

In the second section of this document, the approach used to design livestock activities is presented and discussed. The procedures for estimating feed requirements in term of energy, protein and intake capacity of the selected livestock activities are described in Sections 3, 4, 5 and 6, using the parameters of the French feed evaluation and rationing system (Section 1.3). The nutrient requirements of dairy cattle are described in Section 3. Beef cattle, sub-divided into suckler cows and growing and finishing cattle, are described in Section 4. The sheep and goat modules are described in Sections 5 and 6, respectively. In Section 7, a simple approach is described for estimating biomass production from grassland systems in the 25 NUTS2 regions in the EU. Section 8 describes the feeding restrictions developed in FSSIM-MP to match feed availability and feed requirements, and Section 9 describes how the nitrogen balance at farm level is calculated inside FSSIM-MP.

2 Definition of livestock activities

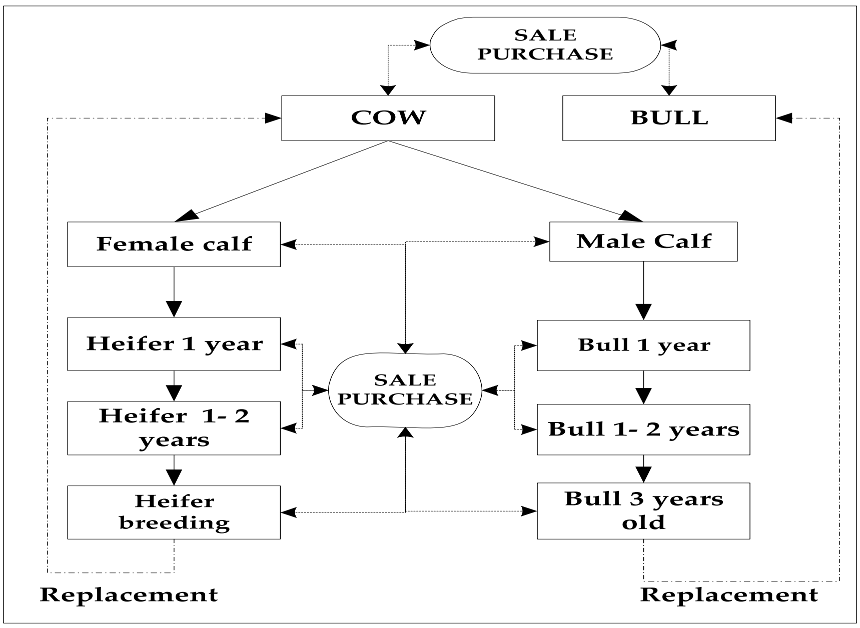
Livestock activities are defined in FSSIM as a combination of production enterprise, production technique (i.e., production intensity level), and production orientation (i.e., current and alternative). The set of production enterprises has been designed using the concept of 'dressed animal', which represents an adult animal and young stock taking into account the replacement rate. The idea behind this kind of activity specification is to adopt the same structure used to define crop activities, which are based on crop rotation instead of individual crop, and also to capture some temporal effects, even if the model is operated on a static, comparative basis. This section explains the main advantages of the approach adopted for representing livestock activities and how these activities are designed. The estimation of feed requirements for the generated livestock activities are specified in the next sections.

2.1 Methods for modelling herd demography

Herd demography represents the inter-generational dependences. It depends on fertility parameters but also on farmers' decisions concerning animal stocking and destocking. Two approaches may be used for modelling herd demography for ruminant animals: a dynamic and a static approach.

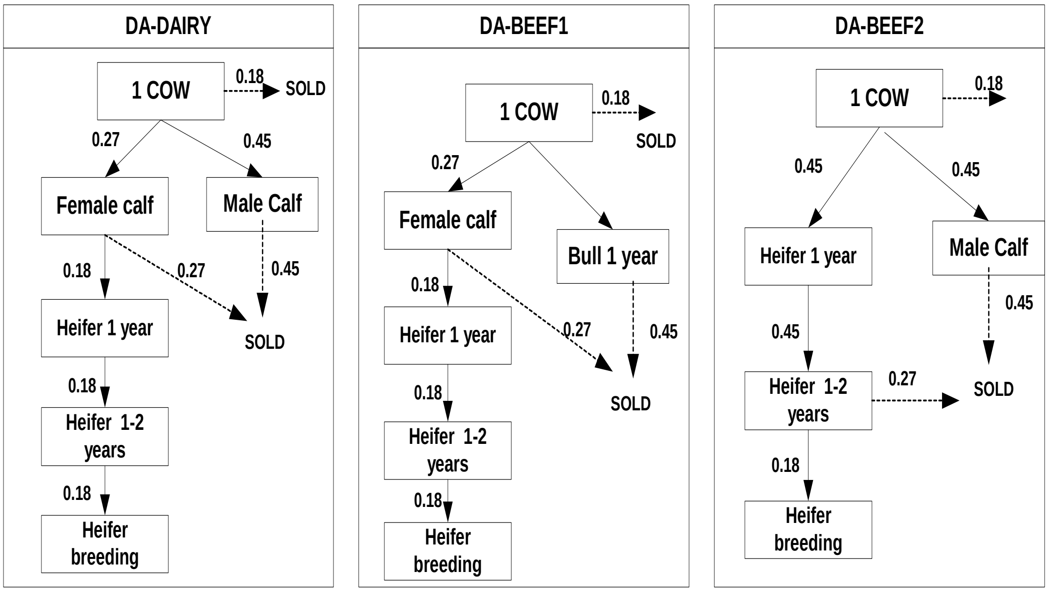
- The dynamic approach reflects the demographic growth and the production process in time. Each animal category is analysed separately but linked to other animal categories by explicit relations. Culling and fertility rates, which depend on farmers' strategies in terms of renewal and performance, are taken as exogenous parameter, whereas traded animals (sold and purchased animals) are determined endogenously (Louhichi *et al.*, 2004). An example of this approach is shown in Figure 2.1, which reflects, for a dairy herd, the demographic change at the herd level between years. It also reflects the diverse possibilities concerning purchases, sales and stocks of animals. The same structure can be applied to modelling demography for suckling cows, sheep and goats.

Figure 2.1: Modelling dairy herd demography using a dynamic approach.



- In contrast, the static approach is based on specifying animal activities in terms of a 'dressed animal' (DA), assuming a fixed herd size. That is, all the animal categories of the same "family" are grouped together as a dressed animal component. This is defined as a breeding female and its followers. In the case of the dairy herd, one dressed animal may comprise one dairy cow plus so many heifers and so many calves. Several dressed animals can be considered, depending on the livestock activities undertaken (e.g., dairy, beef) and production intensity (e.g. low, medium or high milk production per dressed animal or rate of weight gain per animal), and taking into account the link between intensity level and replacement and fertility rates (Figure 2.2). In other words, renewal and performance rates are chosen exogenously for each dressed animal, according to livestock activities and associated production goals. For example, a dairy dressed animal with a milk production of 9000 kg per year would be associated with a greater share of heifers and calves than a dressed animal with a milk production of 5000 kg per year (Aarts *et al*., 1999; Waltrick, 2003). According to this approach, the model will decide endogenously the number of dressed animals sold, purchased and stocked.

Figure 2.2: Modelling herd demography through the static approach (e.g., cattle herd)



Broadly, and as stated above, the static approach for modelling herd demography has been adopted for FSSIM because of its consistency with the approach taken for crops and crop rotations.

2.2 Specification of livestock activities

Based on the standardized EU production structures for livestock farms, four types of dressed animals are identified to represent the livestock systems in EU: dairy cattle, suckler cows, growing and finishing beef cattle, and small ruminants (sheep and goats). Each dressed animal type constitutes a production enterprise with one adult animal and a share of young animals, which are defined according to production intensity level and replacement and fertility rates. The following table shows the different animal age classes adopted in FSSIM to represent the structure of the dressed animal.

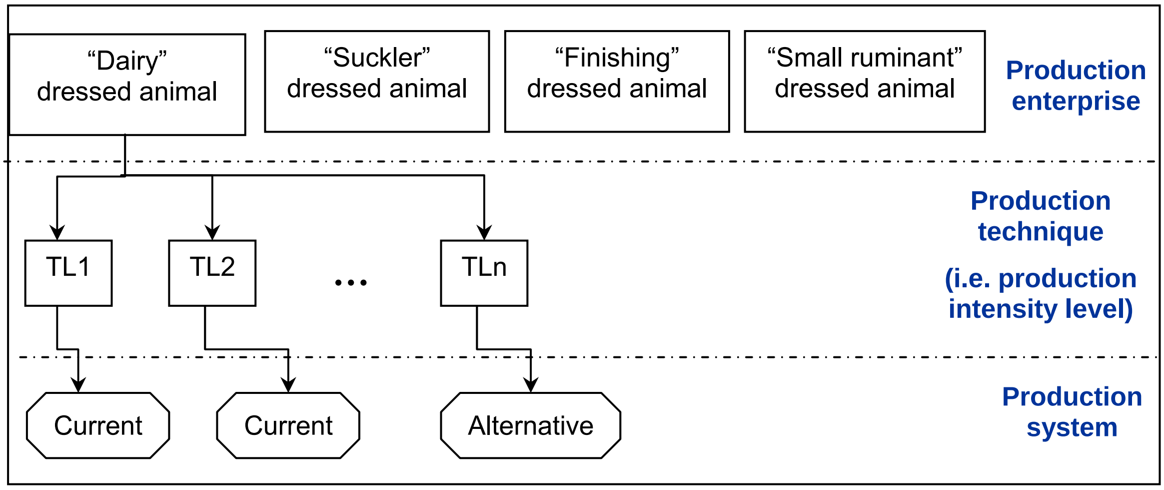
Table 2.1: Animal age classes retained in FSSIM to represent a cattle system

Animal age classes	**GAMS [1] code**
Dairy cows	DCOW
Dairy calves < 1 year	CAFR
Dairy heifers > 1 year	HEIR
Dairy adult male cattle (>1 yr)	DBUL
Suckler cows	SCOW
Beef calves < 1 year	CAFF
Beef heifers > 1 year	HEIF
Beef adult male cattle (>1 yr)	BBUL

[1] General Algebraic Modelling System.

Livestock activities have a similar structure as crop activities and are characterized by (i) animal type, (ii) production technique (production intensity level and associated replacement and fertility rates) determining the composition of dressed animals, and (iii) production orientation (current or alternative livestock activities), as shown in Figure 2.3.

Figure 2.3: Specification of livestock activities.



2.3 Estimation of shares of young animals per dressed animal

To estimate the shares of heifers, calves and adult males that should be associated with each dressed animal as well as the selling rates for each dressed animal, a number of different data sources were used. For current activities, the shares were derived from the herd composition data as defined in the FADN, augmented in some cases with information from the SS. For alternative activities, data were derived mainly from consultations with suitably qualified experts.

Table 2.2 summarises the list of FADN and SS variables that were used to estimate the shares of young animals associated with a current, dressed animal. It should be noted that the FADN database does not distinguish between the number of male and female animals less than one year of age: only the total number is given. Here we assume that the farmer will keep as many calves as are needed for replacement, and the rest will be sold. "Breeding heifers" correspond to female cattle older than two years of age (i.e., first-lactation cows). Rules were developed from this set of variables to derive the share of young animals associated with each dressed animal. Replacement rates were calculated from FADN using the rule given in Table 2.2, row (a), only if no data on replacement rate existed in the SS. Replacement rates calculated using both methods (i.e., (a) and (a') in Table 2.2) were compared in three regions, and were found to be comparable.

Table 2.2: FADN and survey data used to estimate the shares of young animals

Ref.	FADN variables	Ref.	SS variables
(1)	average value number other cattle < 1 yr	**(a')**	Replacement rate (in %)
(2)	average value number male cattle 1-2 yr	**(b)**	Fertility rate (in %)
(3)	average value number female cattle 1-2 yr	**(c)**	Loss rate (in %)
(4)	average value number male cattle >= 2 yr		
(5)	average value number breeding heifers		
(6)	average value number dairy cows		
(7)	average value number other cows		
(8)	sold cows		
(9)	average value number calves for fattening		
(a)	Replacement rate (dairy farm = ((5) + (4))/ (6); beef farm = ((5) +(4)) / (7))		

For the dairy system, dressed animal shares were calculated using the rules given in Table 2.3 assuming a fixed herd size.

Table 2.3: Shares of young animals for a dairy dressed animal

Animal age classes	GAMS code	Shares	Sold
Dairy cows	DCOW	= (6) / (6)	= (8) / (6)
Dairy calves < 1 year	CAFR	= (1) / (6)	= [b*(1- c) - a'] /100
Dairy heifers > 1 year	HEIR	= ((3) +(5)) /(6)	= 0
Dairy adult male cattle (>1 yr)	DBUL	= ((2) +(4)) /(6)	= ((2) – (4)) / (6) if (2) ≥ (4) = 0 if (2) <(4)

In order to calculate dressed animal shares in the beef system, it is first necessary to decide whether the simulated farm is based on a suckler or a finishing type system. Then the shares of young animals can be estimated (Tables 2.4 and 2.5). This decision is based on the simple demographic assumption that, if there are more than 0.4 cows for every heifer or young steer (i.e., ((7) / (3+2) > 0.4), then the system is most likely to be a suckler system. Otherwise, the system is assumed to be a fattening system, perhaps with some extra cows on the farms. Suckler systems can be highly variable, but in the absence of data for characterising the full range of systems, it is further assumed that for each cow about one calf is born each year. Most of these calves will be kept on the farm for fattening or as replacement breeding stock, while some will be sold to other farms. Fattened animals will be marketed for meat.

Table 2.4 Shares of young animals for a suckler dressed animal.

Animal age classes	GAMS code	Shares	Sold
Suckler cows	SCOW	= (7) / (7)	= (8) / (7)
Beef calves	CAFF	= (1) / (7)	= [(7)*(1-(c/100)) – ((2) + (3))] /(7)
Beef heifers	HEIF	= ((3) +(5)) /(7)	= 0
Beef adult male cattle (>1 yr)	BBUL	= ((2) +(4)) /(7)	= ((2) – (4)) / (7) if (2) ≥ (4) = 0 if (2) < (4)

For the finisher system, it is assumed that animals are sold at most after two years on the farm, when they are mature. They will not stay longer but be sold to a butcher.

Table 2.5: Shares of young animals for a finishing dressed animal

Animal age classes	GAMS code	Shares	Sold
Suckler cows	SCOW	= 0	= 0
Beef calves	CAFF	= (9) / (5+2+4)	= [9 - (5+2+4)] / (5+2+4)
Beef heifers	HEIF	= 5/(5+2+4)	= 5/(5+2+4)
Beef adult male cattle (>1 yr)	BBUL	= (2+4)/(5+2+4)	= (2+4)/(5+2+4)

Equivalent rules and assumptions have been adopted for defining the dressed animal shares in small ruminant (sheep and goats) systems for dairy and meat production.

3 Dairy Module

3.1 Energy requirements

3.1.1 Maintenance

[1] $E_{maint} = CF * (1.4 + 0.6 LW / 100) * 365$

where E_{maint} is the energy required for maintenance in UFL per year and LW is the live weight of the animal in kg (WeightAtMaturity in the SS). CF is a correction factor to account for the management system. Here, we use CF as a function of the length of grazing period, which can be derived from the SS. In the winter period it is assumed that housing is a mix of stalled and loosely housed cows (as we do not have information on housing):

[2] $CF = ((EndOfGrazingPeriod - BeginOfGrazingPeriod) / 52) * CF_{1.2} + ((52 - (EndOfGrazingPeriod - BeginOfGrazingPeriod)) / 52) * CF_{1.05}$

EndOfGrazingPeriod and BeginOfGrazingPeriod refer to variable names in the SS. The grazing period is defined in calendar weeks in the SS, thus we use 52 (parameter) to normalize to one year. Parameters in the equation are $CF_{1.2}$= 1.2 and $CF_{1.05}$ = 1.05.

3.1.2 Milk production

[3] $E_{lact} = MY * 0.44 * (0.4 + 0.15 * FC)$

where E_{lact} is the energy required for milk production in UFL per year, MY is the annual milk yield in litres (SoldMilk in the SS), and FC is the fat content of the milk in g per kg. At present, FC is set to 4 g per kg. In subsequent work, we may make FC dependent of mature live weight.

3.1.3 Gestation

In the French system, energy requirements for supporting the growth of the conceptus are assumed to be negligible during the first six months of a pregnancy. In the final three months of pregnancy a fixed allowance for UFL is made according to the following scale:

Month 7: $E_{gest} = 0.9$

Month 8: $E_{gest} = 1.6$

Month 9: $E_{gest} = 2.9$

where E_{gest} is the energy required for gestation in UFL per day.

Here, we use a fixed value for gestation requirements based on one calf per year. This means that E_{gest} equals (30*0.9+30*1.6+30*2.9) = 162 UFL per year.

3.1.4 Re-establishment of body reserves

[4] $E_{(reserves)} = WC * 4.5$

where $E_{(reserves)}$ is the energy required for the deposition of body reserves in UFL per day and WC is the anticipated weight gain of the animal in kg per day.

3.1.5 Energy release by catabolism of body reserves

In early lactation of high-yielding dairy cows, ingested energy is inadequate for supporting daily milk yield. The shortfall is made up by the catabolism of body reserves, resulting in loss of live weight.

[5] $e_{(cat)} = WC * 3.5$

where $e_{(cat)}$ is the energy released by the catabolism of body reserves in UFL per day and WC is the anticipated weight loss of the animal in kg per day.

3.1.6 Annual energy requirements

For dairy cattle beyond their first parity and managed under a reasonably efficient system, catabolism and the re-establishment of body reserves should cancel out over the 12-month production cycle (i.e., net body weight change over the period should be zero). A full statement of the annual energy requirement as defined by the French system is therefore:

[6] $E = E_{maint} + E_{lact} + E_{gest}$

3.1.7 Energy requirements of young stock (calves and replacement heifers)

To estimate the energy requirements for growth of young cattle, we first estimate the daily live weight gain on the basis of variables available in the SS:

[7] $LWG = (WHS - WCB) / (AFC * 30)$

where LWG is the daily live weight gain (in kg per day), WHS is the weight of heifer at selling (in kg), WCB is the weight of calves at birth (in kg), and AFC is the age of first calving (in months).

Subsequently, we take the integral over the period from birth till the age of first calving using equation [32] (see below) to calculate energy requirements of growing and finishing cattle in kg UFV per animal:

[8] $$E_{growth} = \int_{age=AFC*30}^{age=1} 0.042*DLW^{0.75} + 0.0435 * DLW^{0.75} * LWG^{1.4}$$

where DLW is the daily liveweight (in kg) of a young animal. For the energy requirements for maintenance of young cattle, we take the integral over the period from birth till first calving using equation [31] (see below) used for calculating energy requirements of growing and finishing cattle in UFV per animal:

[9] $$E_{main} = \int_{age=AFC*30}^{age=1} 0.0518 *DLW^{0.75}$$

Considering the level of detail of modelling in the SEAMLESS model chain, we assume UFV and UFL equal in the implementation of the livestock component.

3.2 Protein requirements

Compared to the energy requirements of dairy cows, fewer processes are of relevance. Based on Jarrige (1988; 1989), the annual protein requirements of an adult cow (Sub-section 3.2.3) are estimated, comprising maintenance requirements (Sub-section 3.2.1) and milk production (Sub-section 3.2.2). The protein requirements of young stock are negligible.

3.2.1 Maintenance

[10] $$P_{maint} = (95 + 0.5 * LW) * 365$$

where P_{maint} is protein required for maintenance in g PDI per year and LW is the live weight of the animal in kg.

3.2.2 Milk production

[11] $$P_{lact} = (48 * MY)$$

where P_{lact} is the protein required for milk production in g PDI per year and MY is the annual milk yield in litres.

3.2.3 Annual protein requirements

[12] $$P = P_{maint} + P_{lact}$$

We assume that young cattle receive sufficient protein for growth and maintenance in their feed rations required for fulfilling energy requirements (Boons-Prins and Van der Ven, 1993).

3.3 Feed intake

The French system aims to establish feasible levels of feed intake by balancing the intake capacity of the cow with the ingestibility of available forages. Both quantities are expressed in fill units (LFU). Intake capacities for both adult (Sub-section 3.3.1) and young (Subsection 3.3.2) animals are quantified.

3.3.1 Intake capacity (adult animal)

[13] $$IC = (22 - 8.25 * \exp(-0.02 * MY/315) + 0.01 * (LW - 600)) * 365$$

where IC is the intake capacity in fill units per year, MY is the current milk yield in kg per year, and LW is the live weight of the animal in kg. To arrive at the daily milk yield we divide by 315 (days), which is assumed to be the lactation period.

3.3.2 Intake capacity (young stock)

Based on equation [39] (intake capacity of growing and finishing cattle, see below), the annual fill requirement of young dairy cattle is:

[14] $$IC = \int_{age=AFC*30}^{age=1} 0.22 * DLW^{0.75}$$

where IC is the intake capacity in CFU fill units per year and DLW is the mean daily live weight in kg. Considering the level of detail of modelling in the SEAMLESS model chain, we assume LFU and CFU equal in the implementation of the livestock component.

3.4 Dressed animal

The requirements of adult and young dairy cattle are combined to arrive at the energy, protein and fill requirements of a dressed animal:

$$[15] \quad E_{dress} = E_{adult\ dairy\ cow} + RR/100 * E_{young\ cattle} / NumYears$$

where RR is the replacement rate derived from the SS and NumYears is the number of years of the production cycle.

$$[16] \quad P_{dress} = P_{adult\ dairy\ cow}$$

$$[17] \quad IC_{dress} = IC_{adult\ dairy\ cow} + RR/100 * IC_{young\ cattle}$$

Overview of parameters and variables:

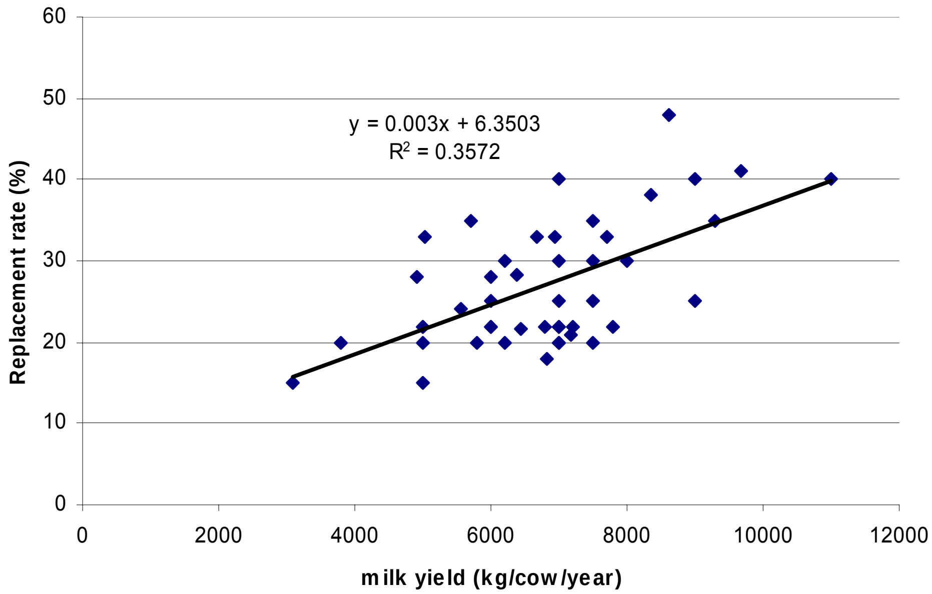
I/O/Int [1)]	Variable or parameter	Abbreviation	Name	Unit
O	Variable	E	Annual energy requirement	UFL
Int	Variable	E_{maint}	Annual energy requirement for maintenance	UFL
I	Variable	CF	Overall correction factor for housing/grazing	-
I	Parameter	$CF_{1,2}$	Correction factor for grazing	-
I	Parameter	$CF_{1.05}$	Correction factor for housing	-
I	Variable	LW	Weight at maturity (from SS)	kg per animal
I	Variable	MY	Annual milk yield (from SS)	kg per day
I	Parameter	FC	Fat content	g per kg
I	Parameter	AFC	Age of first calving (from SS)	Months
I	Parameter	WCB	Weight of calve at birth (from SS)	kg
I	Parameter	WHS	Weight heifer at selling (from SS)	kg
I	Parameter	RR	Replacement rate (from SS)	-
Int	Variable	LWG	Daily liveweight gain (calves +heifers)	kg per day
Int	Variable	DLW	Daily liveweight	kg per animal
Int	Variable	E_{lact}	Annual energy requirement for milk production	UFL
Int	Variable	P_{maint}	Protein requirement for maintenance	PDI per year
Int	Variable	P_{milk}	Protein requirement for milk production	PDI per year
O	Variable	P	Total protein requirements	PDI per year
O	Variable	IC	Fill requirement	LFU per year
Int	Variable	E_{growth}	Energy requirements growth young cattle	UFL
Int	Variable	E_{main}	Energy requirements maintenance young cattle	UFL
Int	Parameter	E_{gest}	Annual energy requirements for gestation	UFL

1) I = input; O= output; Int= Intermediate

3.5 Alternative dairy Systems

Alternative dairy systems are based on a target-oriented approach (Van de Ven *et al*., 2003; Aarts *et al*., 1999): users set a *predefined* milk yield for which the livestock component calculates the nutrient requirements. This differs from current dairy systems in that the livestock component determines the replacement rate based on the relationship between milk yield and replacement rate derived from the SS (Figure 3.1). The replacement rate determines the composition of the dressed animal and thus the nutrient requirements to achieve the targeted milk yield of a specific livestock activity.

Figure 3.1: Relationship between milk yield and replacement rates based on data collected with the Simple Survey in 25 NUTS2 regions.



3.6 Illustration of calculations

We illustrate the calculation rules for a current dairy activity using data from Flevoland in the SS:

BeginOfGrazingPeriod = 15 calendarWeek

EndOfGrazingPeriod = 42 calendarWeek

WeightAtMaturity (LW) = 650 kg

SoldMilk (MY) = 7500 kg per head per year

WeightOfHeiferAtSelling (WHS) = 550 kg per head

WeightOfCalveAtBirth (WCB) = 40 kg per head

AgeOfFirstCalving (AFC) = 24 months

ReplacementRate (RR) = 30 %

Maintenance energy requirements:

Equation [1] $E_{maint} = 1.13 * (1.4 + 0.6 * 650/100) * 365$

$E_{maint} = 2182$ UFL per year

Equation [2] $CF = ((42- 15)/52) * 1.2 + ((52 – (42 – 15))/52) * 1.05$

$CF = 1.13$

Energy requirements for milk production:

Equation [3] $E_{lact} = 7500 * 0.44 * (0.4 + 0.15 * 4)$

$E_{lact} = 3300$ UFL per year

Energy requirements for gestation:

This is a fixed value set to 162 UFL per year

Annual energy requirements:

Equation [6] $E = 2182 + 3300 + 162$

$E = 5644$ UFL per year

Energy requirements for growth of young stock:

Equation [7] $LWG = (550 – 40) / (24 *30)$

$LWG = 0.71$ kg per day

Equation [8] $$E_{growth} = \int_{age=AFC*30}^{age=1} 0.042 * DLW^{0.75} + 0.0435\ DLW^{0.75} * 0.71^{1.4}$$

$E_{growth} = 3516$ UFV over 2 years

Energy requirements for maintenance of young stock:

Equation [9] $$E_{main} = \int_{age=AFC*30}^{age=1} 0.0518 * DLW^{0.75}$$

$E_{main} = 2645$ UFV over 2 years

Total energy requirements for young stock:

$E = E_{growth} + E_{main}$

$E = 3516 + 2645$

$E = 6161$ UFV over 2 years

Protein requirements for maintenance:

Equation [10] $P_{maint} = (95 + 0.5 * 650) * 365/1000$

$P_{maint} = 153$ kg PDI per year

Protein requirements for milk production:

Equation [11] $P_{lact} = 48 * 7500/1000$

$P_{lact} = 360$ kg PDI per year

Annual protein requirements:

Equation [12] $P = P_{maint} + P_{lact}$

$P = 513$ kg PDI per year

Intake capacity:

Equation [13] $IC = ((22 – 8.25 * e^{(-0.02 * 7500/315)} + 0.01 * (650 – 600)) *365$

$IC = 6342$ LFU per year

Intake capacity of young stock:

Equation [14] $$IC = \int_{age=AFC*30}^{age=1} 0.22 * DLW^{0.75}$$

$IC = 11746$ CFU over 2 years

Energy requirements of dressed animal:

Equation [15] $E_{dress} = 5644$ kg UFL + 30/100 * 6161 kg UFV / 2 = 6568.15

Protein requirements of dressed animal equal protein requirements of adult dairy cow, i.e. equation [12]: 513 kg PDI per year.

Intake capacity of dressed animal:

Equation [17] $IC_{dress} = IC_{adult\ dairy\ cow} + 30/100 * IC_{young\ cattle}$

$IC_{dress} = 6342$ LFU per year + 3524 CFU over 2 years

4 Beef cattle module

In the beef module we distinguish between suckler cows and growing/finishing cattle, of which the feed requirements are described in Sections 4.1 and 4.2, respectively. The feed requiring processes are the same as in the dairy module, except for the protein requirements of suckler cows which also account for gestation. The functional forms of the equations are based on Jarrige (1988; 1989).

4.1 Suckler cows

4.1.1 Energy requirements

4.1.1.1 Maintenance

Maintenance energy for suckler cows is estimated using the same equation as for dairy cows, although with different correction factors:

[18] $E_{maint} = (1.4 + 0.6\ WEF/\ 100) *365$

where E_{maint} is the energy required for maintenance in UFL per year and WEF is the suckler live weight (in kg). In the absence of information on the weight of suckler cows in the SS we use the following rule: if the weight of a fattened animal is less than 550 kg in the SS, the suckler live weight is 450 g, otherwise it is assumed to be the same as the weight of the fattened animal (weight at end of fattening).

4.1.1.2 Milk production

[19] $E_{lact} = SMP * 0.45$

where E_{lact} is the energy required for milk production in UFL per year, and SMP is the estimated milk production[1] (suckled milk) in litres. Here, we assume a suckling period of 210 days and the milk daily removed by the calf of 12 l per day = 2520 l per year.

4.1.1.3 Gestation

As with the dairy cow, energy requirements for supporting the growth of the conceptus are assumed to be negligible during early pregnancy[2]. In the final four months of pregnancy a fixed allowance for UFL is made according to the following scale:

Month 6: $E_{(gest)} = 0.56$

Month 7: $E_{(gest)} = 1.08$

Month 8: $E_{(gest)} = 1.86$

Month 9: $E_{(gest)} = 2.93$

[20] $E_{gest} = (30*0.56) + (30*1.08) + (30*1.86) + (30 *2.93) = 193$ UFL per year

[1] This is different from the milk yield of a dairy cow, which represents the milk derived for commercial offtake. In a suckler beef system it is only possible to work with estimates of the quantity of milk removed by the calf.

[2] For some reason, presumably to do with larger conceptus weight, allowances are given from month 6 for the suckler cow.

4.1.1.4 Short-term body weight changes

Year-on-year, the live weight of a suckler cow should remain reasonably constant. However, seasonal weight losses might need to be accounted for in later prototypes as weight gains will generally occur at pasture whilst weight losses are likely to take place under the winter feeding regime. For weight gain, it assumed that the energy requirement is the same as that for dairy cattle:

[21] $E_{(reserves)} = WC * 4.5$

where $E_{(reserves)}$ is the energy required for the deposition of body reserves in UFL per day and WC is the anticipated weight gain of the animal in kg per day.

4.1.1.5 Energy released by live weight loss

[22] $e_{(cat)} = CF * WC * 5$

where $e_{(cat)}$ is the energy released by the catabolism of body reserves in UFL per day and WC is the anticipated weight loss of the animal in kg per day. CF is a correction factor for the physiological status of the animal (CF = 1 for lactating animals; 1.5 during late pregnancy)

4.1.1.6 Annual energy requirements

A full statement of the daily energy requirement for suckler cattle is therefore:

[23] $E = E_{maint} + E_{gest} + E_{lact}$

4.1.2 Protein requirements

4.1.2.1 Maintenance

[24] $P_{maint} = 3.25 * WEF^{0.75} *365$

where P_{maint} is protein required for maintenance in g PDI per year.

4.1.2.2 Milk production

[25] $P_{lact} = 53 * SMP$

where P_{lact} is the protein required for milk production in g PDI per year and SMP is the annual milk production in litres (2520 l per year). See Equation [19].

4.1.2.3 Gestation

As for energy, a fixed allowance for PDI (g per day) is made in the final four months of pregnancy according to the following scale:

Month 6: $P_{(gest)} = 47$

Month 7: $P_{(gest)} = 88$

Month 8: $P_{(gest)} = 148$

Month 9: $P_{(gest)} = 226$

[26] $P_{gest} = (30*47) + (30*88) + (30 *148) + (30*226) = 15270$ PDI per year

4.1.2.4 Annual protein requirements

[27] $P = P_{maint} + P_{lact} + P_{gest}$

4.1.3 Feed intake

4.1.3.1 Intake capacity

The empirical prediction equation used for feed intake depends on the physiological status of the animal.

For pregnant, dry cows:

[28] $IC_{ges} = (0.090 * WEF^{0.75} + 1.46)$

For lactating cows:

[29] $IC_{lac} = (0.083 * WEF^{0.75} + 0.244 * SMP/210 + 2.52)$

where IC is the intake capacity in fill units per day and SMP is the current milk production in kg per year. We assume a milk yield during 210 days per year (therefore divide SMP by 210).

We assume that 70% of the herd is lactating and 30% dry.

[30] $IC = (0.7 * IC_{lac} + 0.3 * IC_{ges}) * 365$

4.2 Growing and finishing cattle

4.2.1 Energy requirements

4.2.1.1 Maintenance

[31] $$E_{maint} = \int_{fatperiod}^{age=1} CF_{1.07} * 0.0518 * DLW^{0.75}$$

where E_{maint} is the energy required for maintenance in kg UFV over the fattening period and DLW is the current daily live weight of the animal in kg (start value is weight at beginning of fattening period derived from the SS). The end value of the integral is the length of the fattening period (*fatperiod*), also derived from the SS. $CF_{1.07}$ is a correction factor to account for the management system (CF = 1.15 for large steers and bulls and late maturing breeds; 1 for all other animals). We assume $CF_{1.07}$=1.07.

4.2.1.2 Growth

For our purposes, the following empirical equation is used:

[32] $$E_{growth} = \int_{fatperiod}^{age=1} 0.042 * DLW^{0.75} + 0.0435 * DLW^{0.75} * LWG^{1.4}$$

where E_{growth} is the energy required for growth in UFV per period, DLW is the current live weight of the animal in kg, and LWG is the daily live weight gain in kg.

4.2.1.3 Total energy requirements during fattening period

A full statement of the annual energy requirement for beef cattle is therefore:

[33] $E = E_{maint} + E_{growth}$

The energy requirements of growing and finishing cattle refer to the fattening period, which we assume to be less than one year.

4.2.2 Protein requirements

4.2.2.1 Maintenance

[34] $$P_{maint} = \int_{fatperiod}^{age=1} 3.25 * DLW^{0.75}$$

where P_{maint} is protein required for maintenance in g PDI per fattening period and DLW is the daily live weight of the animal in kg.

4.2.2.2 Growth

[35] $$NPR = \int_{fatperiod}^{age=1} LWG * (168.07 - (0.16869 * DLW) + (0.0001633 * DLW^2)) * (1.12 - (0.1223 * LWG))$$

[36] $$K_{PDI} = \int_{fatperiod}^{age=1} CF_{1.2} * (83.3 - (0.088 * DLW))$$

[37] $$P_{growth} = NPR / K_{PDI} * 100$$

Jarrige (1988, 1989) takes a rather complex approach to this. Here we have simplified by substituting the simple quadratic equation of ARC (1980) for net protein retention (NPR) in live weight gain (LWG in kg per day) and using the efficiency factors (K_{PDI}) for PDI utilisation of Jarrige (1989) to estimate daily requirements. LWG is live weight of the animal in kg and the correction factor (CF) accounts for breed differences (CF = 1 for Holstein and Friesian types; 1.4 for Charolais and other large late maturing breeds). Here, we assume CF =1.2.

4.2.2.3 Annual protein requirement

[38] $$P = P_{maint} + P_{growth}$$

4.2.3 Feed intake

4.2.3.1 Intake capacity

[39] $$IC = \int_{fatperiod}^{age=1} a * DLW^b$$

where IC is the intake capacity in CFU fill units per year and DLW is the daily live weight of the animal in kg. Parameter values for a and b are determined as follows:

a = 0.197 (late maturing bulls);

a = 0.219 (early maturing bulls);

a = 0.220 (late maturing heifers);

a = 0.248 (early maturing heifers).

b = 0.6 (finishing cattle on high concentrate rations);

b = 0.9 (growing cattle on high roughage rations);

For the moment we use a=0.220 and b=0.75.

4.2.4 Dressed animal

We define a dressed animal for suckler systems based on information from the FADN in relation to the share of suckler cows ('opening value number other cows' in FADN) and young cattle (including the following FADN categories):

'opening value number calves for fattening'

'opening value number other cattle < 1 yr'

'opening value number male cattle 1-2 yr'

'opening value number female cattle 1-2 yr'

'opening value number heifers for fattening'

We distinguish two dressed beef systems, one based on sucklers and one on finishing cattle only:

[40] For suckler system: $E_{dress} = E_{suckler} + (\text{young cattle}/\text{total cattle}) * E_{young\ cattle} * 365/\text{fatperiod}$

[41] For finishing system: $E_{dress} = E_{young\ cattle} * 365/\text{fatperiod}$

[42] For suckler system: $P_{dress} = P_{suckler} + (\text{young cattle}/\text{total cattle}) * P_{young\ cattle} * 365/\text{fatperiod}$

[43] For finishing system: $P_{dress} = P_{young\ cattle} * 365/\text{fatperiod}$

[44] For suckler system: $IC_{dress} = IC_{suckler} + (\text{young cattle}/\text{total cattle}) * IC_{young\ cattle} * 365/\text{fatperiod}$

[45] For finishing system: $IC_{dress} = IC_{young\ cattle} * 365/\text{fatperiod}$

We multiply the feed requirements of finishing cattle with a factor to normalize the requirements to one year. This is needed to account for the differences in the length of the fattening period, which varies between 130 to over 600 days in the SS.

4.3 Overview of parameters and variables

I/O [1)]	Variable or parameter	Abbreviation	Name	Unit
O	variable	E	Annual energy requirement	UFL
Int	variable	E_{maint}	Annual energy maintenance requirement	UFL
I	Variable	WEF	=WeightAtEndOfFatteningy (in SS)	kg per animal
I	Parameter	SMP	Annual removed milk by the calf	kg per year
I	parameter	FC	Fat content (4 g/kg)	g per kg
Int	Variable	E_{lact}	Annual energy requirement for milk	UFL
Int	Variable	P_{maint}	Protein requirement for maintenance	PDI per year
Int	Variable	P_{lact}	Protein requirement for milk production	PDI per year
O	Variable	P	Total protein requirements	PDI per year
O	Variable	IC	Fill requirement	LFU per year
Int	Parameter	E_{gest}	Annual energy requirements gestation	UFL
Int	Variable	IC_{lac}	Fill requirement during lactation	CFU per day
Int	Variable	IC_{ges}	Fill requirement during gestation	CFU per day
I	Parameter	LWG	Daily live weight gain (calves +heifers) from SS	kg per day
Int	Variable	DLW	Daily live weight	kg per animal
I	Parameter	SLW	WeightAtBeginningOfFattening (from SS)	kg
Int	Variable	NPR	Net protein retention	
Int	Variable	Kpdr	Efficiency factor	
I	Parameter	$CF_{1.07}$	Correction factor	
I	Parameter	$CF_{1.2}$	Correction factor	
I	Parameter	A	Parameter (0.220)	
I	Parameter	b	Parameter (0.75)	

[1)] I = input; O= output; Int= Intermediate

4.4 Alternative beef production systems

Alternative beef production systems have not yet been implemented in the livestock component of FSSIM. The following offers a proposal to allow simulation of alternative beef systems. The characterisation of alternative beef production systems can be based on the level of intensification, which is generally strongly related to the breed used. In this context we can consider:

- Breed and production system characteristics as they affect parameter values in the basic beef model, such as length of fattening periods and weight at slaughter
- Impacts on product pricing; again these are likely to be breed related.

4.4.1 Breed / Production system characteristics

Late-maturing breeds have longer fattening periods but on average will grow faster. They are also generally leaner (on a whole carcass basis), so the energy value of live weight gain will be lower. To characterise the alternative systems, we can use the correction factors of AFRC (1993) and apply them to equation [32] so that this becomes:

Equation [32] $$E_{growth} = \int_{fatperiod}^{age=1} (0.042 * DLW^{0.75} + 0.0435 * DLW^{0.75} + LWG^{1.4}) * CF$$

where CF is derived from the following table:

Maturity type	Bulls	Castrates	Heifers
Early	1.00	1.15	1.30
Medium	0.85	1.00	1.15
Late	0.70	0.85	1.00

AFRC (1993) gives the following examples of each maturity type (this list is expandable based on local expert opinion):

Early	Medium	Late
Aberdeen Angus	Hereford	Charolais
North Devon	Lincoln Red	Friesian
Friesian	Sussex	Limousin
		Simmental
		South Devon

Protein utilisation will not be affected in alternative systems, and so the same equations can be used as presented in Sections 4.1.2 and 4.2.2. Meat production systems are generally open-ended. This means that farmers have a window that may extend over several months during which they can decide whether to slaughter or not. For example, they may delay slaughter if they think that the price will increase or they may bring slaughter forward if they are running out of conserved forages (or if concentrate prices are increasing). However, this is difficult to account for, given the data constraints of the SS. This has led us to use indicative fattening periods for early, medium, and late types (430, 480, 520 days, respectively).

4.4.2 Impacts on product pricing

Selection of breeds can make a considerable difference to the price received at the end of the production cycle. This is likely to be related to the country (i.e., the market) as well as being influenced by breed. For example, in the UK Angus beef can command a considerable premium over that from dairy crossbreds. This kind of information may be derived from EU price statistics.

4.5 Illustration of calculations

We illustrate the calculation rules for beef using data from Northumberland and Tyne and Wear in the SS:

WeightAtEndOfFattening (WEF) = 562 kg per head

LengthOfFatteningPeriod (fatperiod)= 350 days

WeightAtBeginningOfFattening = 212 kg per head

Daily liveweight gain = 1 kg per day

Proportion of young cattle in total cattle = 0.3 (from FADN)

4.5.1 Suckler cows

Maintenance energy requirements:

Equation [18] $E_{maint} = (1.4 + 0.6 * 562/ 100) *365$

$E_{maint} = 1742$ UFL per year

Energy requirements for milk production:

Equation [19] $E_{lact} = 2520 * 0.45$

$E_{lact} = 1134$ UFL per fattening period

Energy requirements for gestation is a fixed value based on Equation [20]:

$E_{gest} = 193$ UFL per year

Annual energy requirement:

Equation [23] $E = 1742 + 1134+ 193$

$E = 3069$ UFL per year

Protein requirements for maintenance:

Equation [24] $P_{maint} = 3.25 * 562^{0.25} * 365/1000$

$P_{maint} = 5.8$ kg PDI per year

Protein requirements for milk production:

Equation [25] $P_{lact} = 53 * 2520/1000$

$P_{lact} = 133.5$ kg PDI per year

Protein requirements for gestation is a fixed value based on Equation [26]:

P_{gest} = 15.3 kg PDI per year

Annual protein requirements:

Equation [27] $P = 5.8 + 133.5 + 15.3$

$P = 154.6$ kg PDI per year

Intake capacity for pregnant cows:

Equation [28] $IC_{ges} = (0.090 * 562^{0.75} + 1.46)$

$IC_{ges} = 11.8$ LFU per day

Intake capacity for lactating cows:

Equation [29] $IC_{lac} = (0.083 * 562^{0.75} + 0.244 * 12 + 2.52)$

$IC_{lac} = 15$ CFU per day

Average intake capacity:

Equation [30] $IC = (0.7 * IC_{lac} + 0.3 * IC_{ges}) * 365$

IC = 3832 CFU per year + 1292 LFU per year

4.5.2 Growing and finishing cattle

Maintenance energy requirements:

Equation [31] $$E_{maint} = \int_{fatperiod}^{age=1} 1.07 * 0.0518 * DLW^{0.75}$$

$E_{maint} = 1683$ UFV per period

Energy requirements for growth:

Equation [32] $$E_{growth} = \int_{fatperiod}^{age=1} 0.042 * DLW^{0.75} + 0.0435 * DLW^{0.75} + LWG^{1.4}$$

$E_{growth} = 2606$ UFV per period

Total energy requirements:

Equation [33] $E = 1683 + 2606$

$E = 4289$ UFV per period

Protein requirements for maintenance:

Equation [34] $$P_{maint} = \int_{fatperiod}^{age=1} 3.25 * DLW^{0.75}$$

P_{maint} = 99 kg PDI per fattening period

Protein requirements for growth:

Equation [35] $$NPR = \int_{fatperiod}^{age=1} 1 * (168.07 - 0.16869 * DLW + 0.0001633 * DLW^2) * (1.12 - 0.1223 * 1)$$

NPR = 45132

Equation [36] $$K_{PDI} = \int_{fatperiod}^{age=1} 1.2 * 83.3 - 0.088 * DLW$$

K_{PDI} = 23101

Equation [37] P_{growth} =NPR/K_{PDI} * 100

P_{growth} = 195 kg PDI per fattening period

Total protein requirements for finishing cattle:

Equation [38] P = 99 + 195

P = 294 kg PDI per period

Intake capacity:

Equation [39] $$IC = \int_{fatperiod}^{age=1} 0.22 * DLW^{0.75}$$

IC = 6681 CFU per period

Energy requirements for dressed beef systems:

For suckler system:

Equation [40] E_{dress} = 3069 UFL per year + 0.3 * 4289 * 365/350 UFV per year

E_{dress} = 3069 UFL per year + 1342 UFV per year = 5167 UFV per year

For finishing system:

Equation [41] $E_{dress} = 4289 * 365/350$ UFV per year

$E_{dress} = 4473$ UFV per year

Protein requirements for dressed beef systems:

For suckler system:

Equation [42] $P_{dress} = 5.8 + 222.6 + 15.3 + 0.3 * (195 +99) * 365/350$

$P_{dress} = 336$ kg PDI per year

For finishing system:

Equation [43] $P_{dress} = (195 +99) * 365/350$

$P_{dress} = 298$ kg PDI per year

Intake capacity for dressed beef systems:

For suckler system:

Equation [44] $IC_{dress} = 3832$ CFU per year + 1292 LFU per year + 0.3 * 6681 * 365/350 CFU per year

$IC_{dress} = 3832$ CFU per year + 1292 LFU per year + 2090 CFU per year

$IC_{dress} = 5922$ CFU per year + 1292 LFU per year

For finishing system:

Equation [45] $IC_{dress} = 6681 * 365/350$ CFU per year

$IC_{dress} = 6967$ CFU per year

5 Sheep Module

5.1 Energy requirements

5.1.1 Maintenance

[46] $E_{maint} = 0.033 * LW^{0.75} * 365$

where E_{maint} is the energy required for maintenance in UFL per year and LW is the live weight of the animal in kg (derived from the SS).

5.1.2 Milk production

[47] $E_{lact} = (0.00588 * MF + 0.265) * MP$

where E_{lact} is the energy required for productive purposes in UFL per year, MF is the milk fat concentration in g per litre, and MP is the milk production in litres per year. Where MF is not known, it can be assumed to be 60. MP is derived from the SS.

5.1.3 Annual energy requirements

A full statement of the daily energy requirement for sheep is therefore:

[48] $E = E_{maint} + E_{lact}$

5.1.4 Energy requirements for growing and maintenance of lambs

We use tabulated values for estimating the energy requirements of lambs for two different intensity levels, intensive and extensive (Jarrige, 1988):

In UFV per month	**Extensive**	**Intensive**
Month three	18.9	19.5
Month four	22.8	26.4
Month five	28.8	31.5
Month six	33.3	39.9
Month seven	38.1	48
Total energy requirement (E_{lamb})	141.9	165.3

5.2 Protein requirements

5.2.1 Maintenance

[49] $P_{maint} = 2.5 * LW^{0.75} * 365$

where P_{maint} is protein required for maintenance in g PDI per year and LW is the live weight of the animal in kg.

5.2.2 Milk production

[50] $P_{lact} = 1.72 * Pr * MP$

where P_{lact} is the protein required for productive purposes in g PDI per year, Pr is the milk protein concentration in g per litre, and MP is the milk production in litres per year. Where Pr is not known, it can be assumed to be 50 g per l. MP is derived from the SS.

5.2.3 Annual protein requirements

A full statement of the annual protein requirement for sheep is therefore:

[51] $P = P_{maint} + P_{lact}$

5.2.4 Protein requirements for the growth and maintenance of lambs

We use tabulated values for estimating the protein requirements (PDI in kg per month) of lambs for two different intensity levels, intensive and extensive (Jarrige, 1988):

In PDI per month	**Extensive**	**Intensive**
Month three	1.92	2.76
Month four	2.01	3.21
Month five	2.46	3.69
Month six	2.49	4.08
Month seven	2.61	4.02
Total protein requirements (P_{lamb})	11.49	17.76

5.3 Feed intake

5.3.1 Intake capacity

There are no predictive equations for the intake capacity of sheep. Therefore, we base it on a lookup table (Table 10.7 from Jarrige, 1989):

Litter gain (g per day) between days 10 and 30	150	250	350	450	550
Initial body condition	(2.0) 3.0	(2.0) 3.0	(2.0) 3.0	(2.0) 3.0	(2.0) 3.0
Weeks 1 to 3	1.48	1.72	1.96	2.20	2.44
Weeks 4 to 6	(2.00) 1.85	(2.30) 2.15	(2.65) 2.45	(2.95) 2.75	(3.20) 3.05
Weeks 7 to 10	(1.85) 1.70	(2.10) 1.90	(2.20) 2.05	(2.40) 2.25	(2.60) 2.35
Weeks 11 to 14	(1.85) 1.60	(2.00) 1.65	(2.00) 1.75	(2.05) 1.85	(2.10) 1.95

Feed intake capacity of ewes of different post-lambing live weight varies by 0.1 SFU per 5 kg live weight difference from 60 kg.

Values for litter gain and initial body condition score are set on the basis of expert opinion relating to the level of intensification in the system.

We assume that the IC of sheep before littering is similar to the IC for weeks 1 to 3 given in the previous table. The minimum litter gain corresponds with the extensive system, and the maximum litter gain with the intensive system. The initial body condition of sheep in the extensive systems corresponds to 3.0 and 2.0 in the intensive system. We base the intensification level on the indicated intensity level of the simulated farm type from FADN.

The IC for the intensive system is:

[52] $IC = 275 * 1.48 + 30 * 1.48 + 30 * 2.00 + 30 * 1.85$

The IC for the extensive system is:

[53] $IC = 275 * 2.44 + 30 * 3.05 + 30 * 3.05 + 30 * 2.35$

5.4 Alternative sheep meat systems

The definition of alternative systems for fattening sheep should follow similar principles to those for beef cattle. However, due to a lack of hard data and the relatively limited influence that can be exerted over the shorter fattening period, it proved to be both impractical and unnecessary to derive similar correction factors. In the case of fattening sheep, the main issues are likely to be related to differences in slaughter weights and daily gain (fattening period length). For the sheep systems, we also categorise by breed, but two maturity classes are deemed to be adequate. As with alternative beef production systems, the alternative sheep meat systems have not yet been implemented in the livestock component. The following provides guidance on future implementation of such a module in the livestock component.

Early	Late
Charmois	Ile de France
Limousine	Berrichons du Cher
Most mountain / moorland breeds	Texel
	Border Leicester

Sheep producers are more likely to aim for a specific target weight than beef producers, so slaughter weight can be used as the key variable rather than the length of fattening period. Final live weights for early breeds (after 4-5 months) are estimated to be in the region of 40 – 65 kg, with late breeds (after 7-8 months) finishing up at 90 - 100 kg.

Again, there is the opportunity to produce for a premium market although the potential benefits are likely to be less than for some beef producers. Expert opinion should be able to provide local examples of where this may not be the case, however.

The energy, protein and fill requirements of a dressed animal, an overview of parameters and variables, and an illustration of the calculations for sheep, are given in Sections 6.4, 6.5 and 6.6 below.

6 Goat module

6.1 Energy requirements

6.1.1 Maintenance

[54] $E_{maint} = CF * 0.039 * LW^{0.75} * 365$

where E_{maint} is the energy required for maintenance in UFL per year and LW is the live weight of the animal in kg (derived from the SS). CF is a correction factor for environment and/or production system, with the following values possible:

1.4, southern European rangeland (e.g., Midi-Pyrénée);

1.8, arid Mediterranean environment (e.g., Andalucia);

1.25, lowland temperate pasture (e.g., Flevoland);

1.5, extensive hilly or mountainous pastures (e.g., Sweden).

6.1.2 Milk production

[55] $E_{lact} = 0.385 * MP$

where E_{lact} is the energy required for productive purposes in UFL per year and MP is the milk production in litres per year.

6.1.3 Daily energy requirements

A full statement of the daily energy requirements for goats is therefore:

[56] $E = E_{maint} + E_{lact}$

6.1.4 Energy requirements for the growth and maintenance of goat kids

Here we have again used tabulated values for estimating the energy requirements of goat kids, but only for one system (Jarrige, 1989).

In UFV per month	**Extensive**
Month three	16.5
Month four	18.6
Month five	19.8
Month six	20.4
Month seven	20.7
Total energy requirements (E_{lamb})	96

6.2 Protein requirements

6.2.1 Maintenance

[57] $P_{maint} = 2.5 * LW^{0.75} * 365$

where P_{maint} is protein required for maintenance in g PDI per year and LW is the live weight of the animal in kg (derived from the SS).

6.2.2 Production

[58] $P_{lact} = 45 * MP$

where P_{lact} is the protein required for productive purposes in g PDI per year and MP is the milk production in litres per year.

6.2.3 Annual protein requirements

A full statement of the daily protein requirement for goats is therefore:

[59] $P = P_{maint} + P_{lact}$

6.2.4 Protein requirements for the growth and maintenance of goat kids

We use tabulated values for estimating the protein requirements of goat kids (Jarrige, 1989):

In PDI per month	**Extensive**
Month three	1.92
Month four	1.86
Month five	1.77
Month six	1.65
Month seven	1.50
Total protein requirement (P_{lamb})	8.7

6.3 Feed intake

6.3.1 Intake capacity

A lookup table is used, based on Table 11.1 from Jarrige (1989):

Live weight (kg)	Physiological state	Feed intake capacity	
		DM (kg)	LFU
40	Maintenance and early gestation	1.07	1.52
	4th month of gestation	1.07	1.52
	5th month of gestation	0.97	1.43
50	Maintenance and early gestation	1,20	1,62
	4th month of gestation	1.20	1.62
	5th month of gestation	1.09	1.53
60	Maintenance and early gestation	1.33	1.72
	4th month of gestation	1.33	1.72
	5th month of gestation	1.21	1.61
70	Maintenance and early gestation	1.47	1.82
	4th month of gestation	1.47	1.82
	5th month of gestation	1.34	1.71
80	Maintenance and early gestation	1.60	1.92
	4th month of gestation	1.60	1.92
	5th month of gestation	1.46	1.79

This is not ideal, but for goats (and probably for sheep too), the significance of variation in other factors will most likely be relatively low in the model as a whole.

Currently, we use a goat of 60 kg for estimating intake capacity:

[60] $IC = 300 * 1.72 + 30 * 1.72 + 30 * 1.61$

6.4 Dressed animal goats / sheep

The requirements of adult dairy sheep/goats and lambs/kids are combined to arrive at the energy, protein and fill requirements of a dressed animal:

[61] $E_{dress} = E_{adult} + RR/100 * E_{lamb}$

in which RR is the replacement rate, derived from the SS.

[62] $P_{dress} = P_{adult} + RR/100 * P_{lamb}$

[63] $IC_{dress} = IC_{adult}$

The intake capacity of a dressed sheep/goat animal equals the intake capacity of an adult ewe.

6.5 Overview of parameters and variables

I/O [1)]	Variable or parameter	Abbreviation	Name	Unit
O	Variable	E	Annual energy requirements	UFL
Int	Variable	E_{maint}	Annual energy maintenance requirements	UFL
I	Parameter	LW	Adult liveweight (weightAtMaturity in SS)	kg
I	Parameter	CF	Correction factor (function of Nuts 2 region)	-
I	Parameter	MP	Annual milk yield	kg per year
I	Parameter	MF	Milk fat content (60 g/l)	g per l
I	Parameter	Pr	Milk protein content (50 g/l)	g per l
Int	Variable	E_{lact}	Annual energy requirements for milk	UFL
Int	Variable	P_{maint}	Protein requirements for maintenance	PDI per year
Int	Variable	P_{lact}	Protein requirements for milk production	PDI per year
O	Variable	P	Annual protein requirements	PDI per year
O	Variable	IC	Fill requirement	SFU per year
I	Parameter	RR	Replacement Rate	-

[1)] I = input; O= output; Int= Intermediate

6.6 Illustration of calculations

We illustrate the calculation rules for sheep using data from Castilla y Leon in the SS:

WeightAtMaturity (LW) = 75 kg

SoldMilk (MP) = 350 kg per head per year

Ageofsheeporgoatatselling = 120 days

Numberofbirthsperadultfemale = 1.5

Milk fat content (MF) =60 g per l

Replacement rate (RR) = 35%

Milk protein content (Pr) = 50 g per l

Maintenance energy requirements for the ewe:

Equation [46] $E_{maint} = 0.033 * LW^{0.75} * 365$

$E_{maint} = 307$ UFL per year

Energy requirements for milk production:

Equation [47] $E_{lact} = (0.00588 * MF + 0.265) * MP$

$E_{lact} = 216$ UFL per year

Annual energy requirements for the ewe:

Equation [48] $E = 307 + 216$

$E = 523$ UFL per year

Energy requirements for growth and maintenance of young stock (from the table in Section 5.1.4, using the data of the third and fourth month, extensive system, because ageofsheeporgoatatselling = 120 days):

$E_{[lamb]}$ = Number of lambs per female per year * 41.7

$E_{[lamb]} = 1.5 * 41.7$

$E_{[lamb]} = 63$ UFV per year

Protein requirements for maintenance:

Equation [49] $P_{maint} = 2.5 * LW^{0.75} * 365$

$P_{maint} = 23$ kg PDI per year

Protein requirements for milk production:

Equation [50] $P_{lact} = 1.72 * Pr * MP$

$P_{lact} = 30$ kg PDI per year

Annual protein requirements for the ewe:

Equation [51] $P = P_{maint} + P_{lact}$

$P = 53$ kg PDI per year

Protein requirements for growth and maintenance of young stock (from the table in Section 5.2.4, using the data of the third and fourth month, extensive system, because ageofsheeporgoatatselling = 120 days):

$P_{[lamb]}$ = Number of lambs per female per year * 3.9

$P_{[lamb]} = 1.5 * 3.9$

$P_{[lamb]} = 6$ kg PDI per year

Intake capacity of the ewe:

Equation [52] $IC = 275 * 1.48 + 30 * 1.48 + 30 * 2.00 + 30 * 1.85$

$IC = 567$ LFU per year

Energy requirements of dressed animal:

Equation [61] $E_{dress} = E + RR/100\ E_{[lamb]}$

$E_{dress} = 523$ kg UFL per year + 0.35 * 63 kg UFV per year

$E_{dress} = 523$ kg UFL per year + 22 kg UFV per year

Protein requirements of dressed animal:

Equation [62] $P_{dress} = P + RR/100 * P_{[lamb]}$

$P_{dress} = 53 + 0.35 * 6$ kg PDI per year

$P_{dress} = 55$ kg PDI per year.

Intake capacity of dressed animal is equivalent to the intake capacity of the ewe (i.e. Equation [52]): 567 LFU per year.

7 Feed resources

The FSSIM-livestock feed resources module consists of a grassland module, FSSIM-AM generating crop rotation activities comprising feed crops, and a database describing the supplementary feed resources that can be purchased. In this section the grassland module and the feeds database is described. FSSIM-AM is described in Janssen *et al*. (2006). The grassland module consists of a simple approach to establishing a relationship between grassland production and quality characteristics.

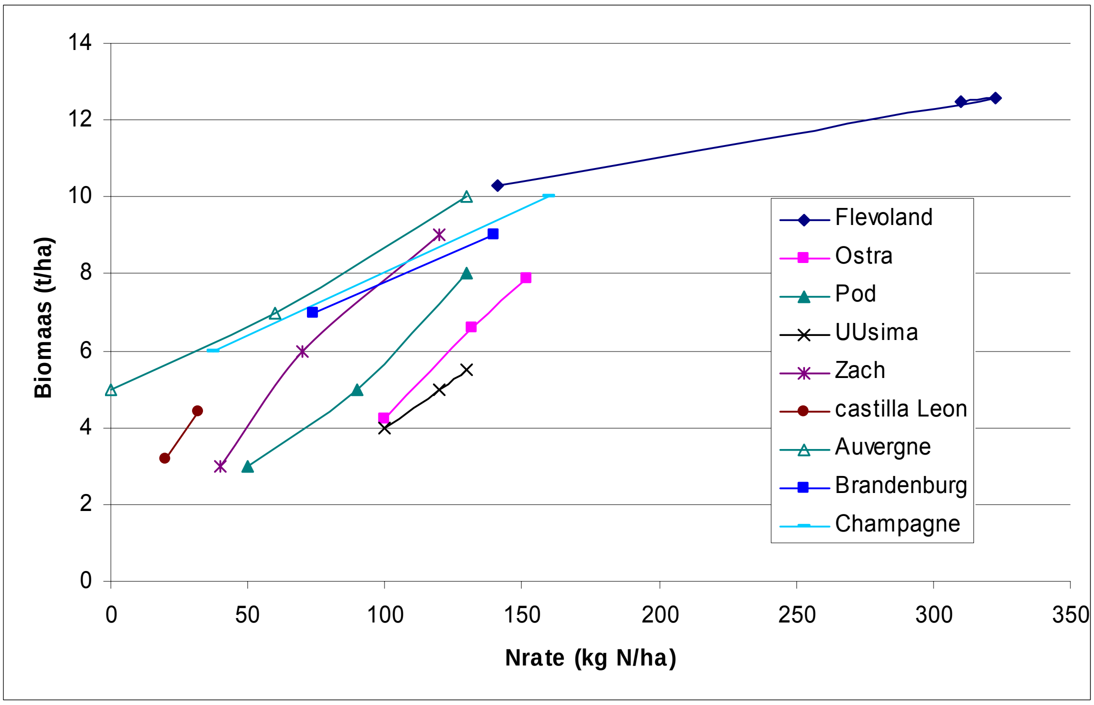
7.1 Grassland module

Prediction of the level and quality of production from grass-based systems is not available from APES. This section describes the approach that we have taken to providing these data, which are required to drive the livestock simulations for grass-based systems in FSSIM.

7.1.1 Introduction

The SS contains regional estimates of grassland yields for a maximum of three intensity levels, corresponding to different N fertilizer input levels. The relations between available regional grassland yields and N input levels are shown in Figure 7.1.

Figure 7.1:. Relations between grassland harvested biomass production and N rates in various EU regions derived from the SS.



In addition, data describing the partitioning of total biomass amongst hay, silage and fresh fodder, and the number of cuts, are available in the SS. In order to use these regional grassland data in FSSIM-MP, they need be linked to quality characteristics, i.e. energy (UFL), protein (PDIN), and fill units (UEM, UEL and UEB that have been defined above for small ruminants, dairy and beef cattle, respectively). This section describes a simple approach that links biomass and N content, which can then be used to derive other feed quality characteristics.

7.1.2 Approach

The approach consists of deriving stylised, regional fertiliser response functions and consists of three steps:

1. Based on the topsoil carbon content of each agro-environmental zone (AEZ) and a net mineralization rate, indigenous soil N supply is calculated.
2. Step 1 provides the N-uptake of non-fertilized grassland. If the biomass production is known, the associated N content can be calculated. If biomass production of non-fertilized grassland is not known in the SS, we derive it from the lowest yield (and associated N application).
3. We assume that biomass production increases proportionally with N application rates up to a certain threshold. A yield plateau is reached at N rates exceeding this threshold.

These steps are described in more detail below.

Step 1:

Topsoil Organic Carbon content (OCTOP) in the 0-30 cm layer is available for each AEZ (Hazeau *et al.*, 2006). In total, six OCTOP classes are identified.

Further, we assume:

- C/N ratio of soil organic matter = 15 (Paustian *et al.,* 1990; Janssen, 2002)
- Rooting depth = 0.2 m
- Soil bulk density = 1.3 g cm^{-2}
- Net N mineralization = 2% per year

These values can be further specified or adjusted, based on available regional information.

Example:

If OCTOP = 3%, then 1 ha contains 78,000 kg C (100 * 100 * 0.2 * 1300 * 0.03), and 5200 kg N (78,000/15). Annually, 2% mineralizes, which is 104 kg N/ha (5200 * 0.02). This 104 kg N per ha is the so-called indigenous soil N supply.

We introduce upper thresholds to avoid unrealistic indigenous N supply. Based on Dutch conditions, the maximum indigenous N supply on sandy soils is assumed to be 200 kg N per ha, and on clay soils, it is 230 kg N per ha (Vellinga and André, 1999; Vellinga and Hilhorst, 2001).

Step 2:

We assume that the indigenous soil N supply (step 1) is the total N uptake of non-fertilized grassland. Dividing N uptake by biomass gives the N content, which can be linked to other quality characteristics of the biomass (Section 7.3).

We introduce lower and upper thresholds for the N-content to avoid unrealistic outcomes. The lower and upper thresholds for unfertilized grassland are 1.2 and 2.5%, respectively. (Van der Meer and Van Uum-Van Lohuyzen, 1986; Vellinga and André, 1999). If calculated N contents are lower than 1.2% they will automatically be set to 1.2%, and if they exceed 2.5%, they will be set to 2.5%.

Example:

If the biomass yield of unfertilized grassland is 5 t per ha and N uptake is 104 kg N per ha (step 1), then its N content is 2.08% (104/5000).

In cases where the SS does not provide biomass of unfertilized grassland (see Figure 7.1), we calculate maximum N uptake from indigenous supply (step 1) and N application rate at the lowest yield level. Because we assume a linear increase in yield with N application rates up to a certain threshold, unfertilized yields can thus be derived.

Example:

For a given SS region, the lowest biomass is given for an N rate of 100 kg N per ha. Not all N fertilizer will be recovered in the biomass. We assume a recovery of 60%, which implies that 60 kg N per ha is taken up by the grass. (Van der Meer and Van Uum-Van Lohuyzen, 1986; Van der Meer, 1996; Vellinga and André, 1999; Rotz *et al.*, 2005). Total uptake is 60 kg N + 104 kg N (from step 1) or 164 kg N per ha. To derive the corresponding N content, we divide the lowest SS yield by 164 kg N per ha. We apply the same lower and upper N contents as specified in Step 1.

To calculate the unknown yield of unfertilized grassland, we divide the indigenous N supply (104 kg N per ha from step 1) by the N content calculated above.

Step 3:

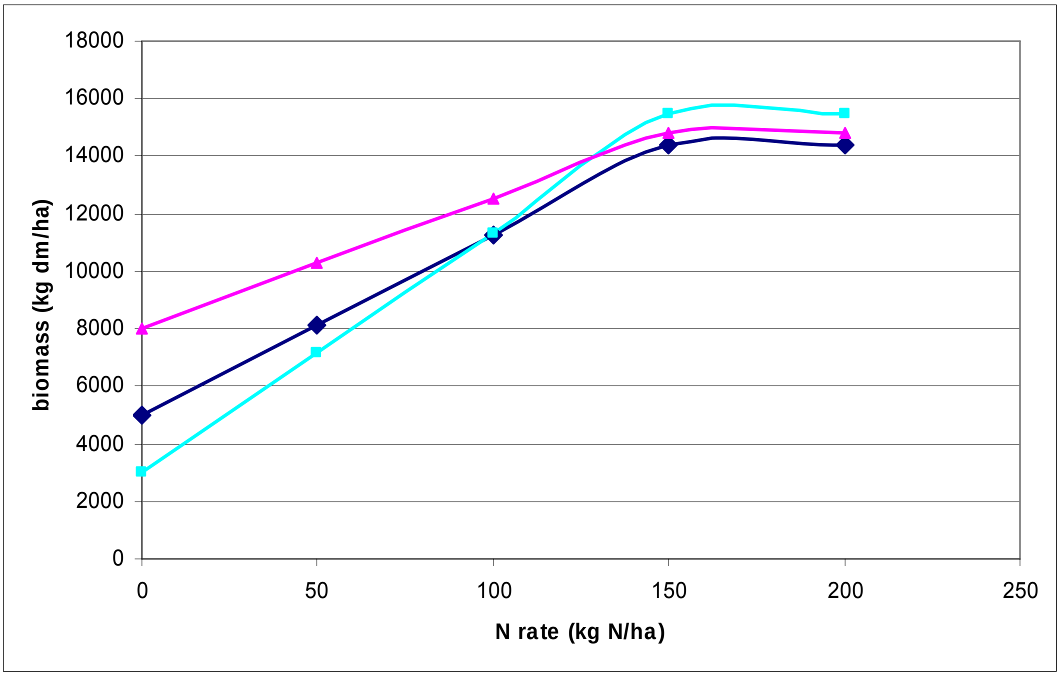
N content from yields obtained with 150 kg N per ha or more are based on the indigenous N supply (step 1) plus the recovered fraction of the applied N divided by the yield level. The N content has an upper limit, which we set at 4%. We set N recoveries for clay soils at 60%, for sand at 50%, and for other soils at 55% (Van der Meer and Van Uum-Van Lohuyzen, 1986; Vellinga and André, 1999; Anonymous, 2002).

Example:

For an N rate of 150 kg N per ha the yield level is estimated:
((150 * 0.60) / 0.0208) / 1000 (step 2) + 5 t per ha unfertilized yield = 9.4 t per ha, with an average N content of 2.08%

For an N rate of 200 kg N per ha the yield level is the same (9.4 t per ha) but the biomass has a higher N content: (104 kg N per ha (step 1) + (200 kg N per ha * 0.6)) / 9.4 t per ha = 2.38 %. The overall fertilizer response curve for this example is shown in Figure 7.2.

Figure 7.2: Typical fertiliser response curves based on the approach described.

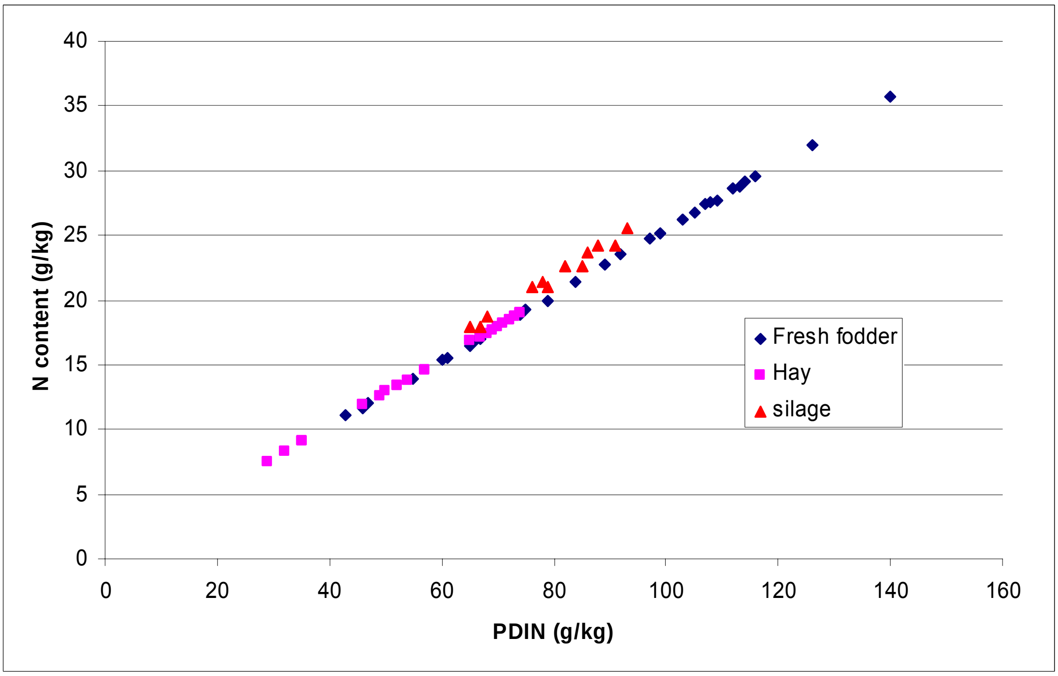


7.1.3 Quality relationships

The French feed evaluation system provides quality information not according to N input level but to species, development stage, and utilization type (fresh, silage and hay). Therefore, we have used various data in Jarrige (1988) to derive quality relationships.

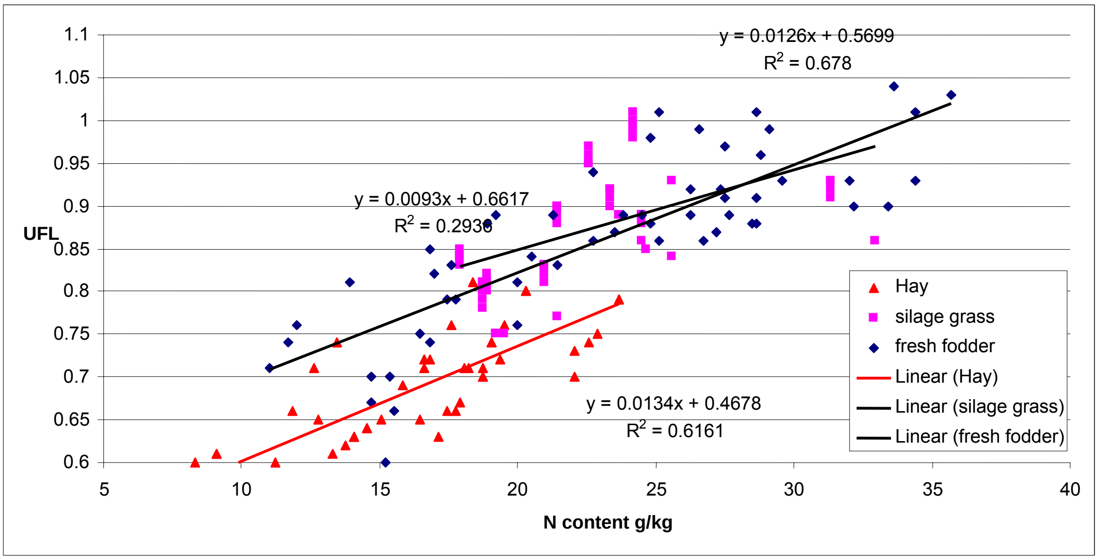
Using English ryegrass data for fresh fodder (n = 33) and silage fodder (n = 20) and English ryegrass and Italian ryegrass data for hay (n = 24), we find a clear linear relationship between N content and PDIN (Figure 7.3). Roughly, 1 g N per kg DM corresponds to 4 g PDIN per kg DM for fresh fodder, silage, and hay.

Figure 7.3 Relationship between PDIN and N content in fresh fodder, hay, and silage fodder based on English ryegrass (Fresh fodder and silage) and English and Italian ryegrass from Jarrige (1988).



We used additional data to establish a relationship between N content and energy content (UFL) of different grassland utilization types (Figure 7.4). For each utilization type, data have been used from different grassland species and development stages. In addition to the English ryegrass data, we included data from 'praire permanente de plain' and 'praire permanente de demi montagne' for the three utilization types. Compared with using ryegrass data alone, the R^2 of the regressions increased for hay, decreased for silage, and changed little for fresh fodder.

Figure 7.4: Relationship between N content and energy (UFL) for three grassland utilization types: fresh fodder (n = 55), silage grass (n = 49), and hay (n = 50).

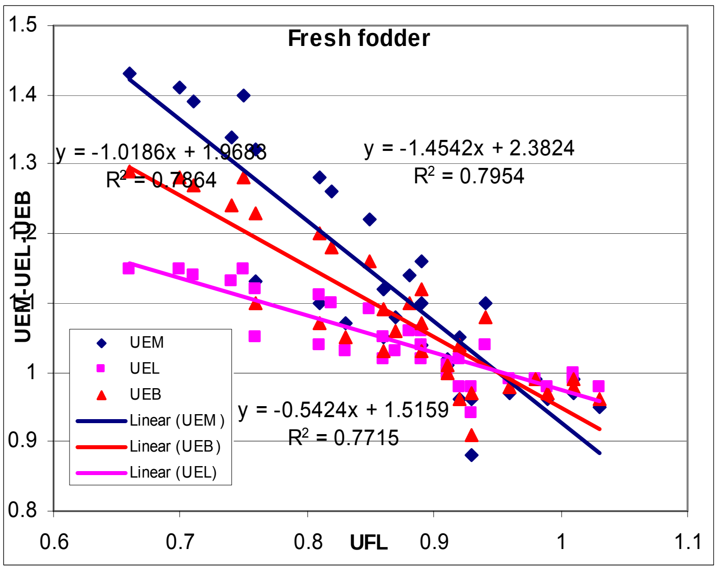


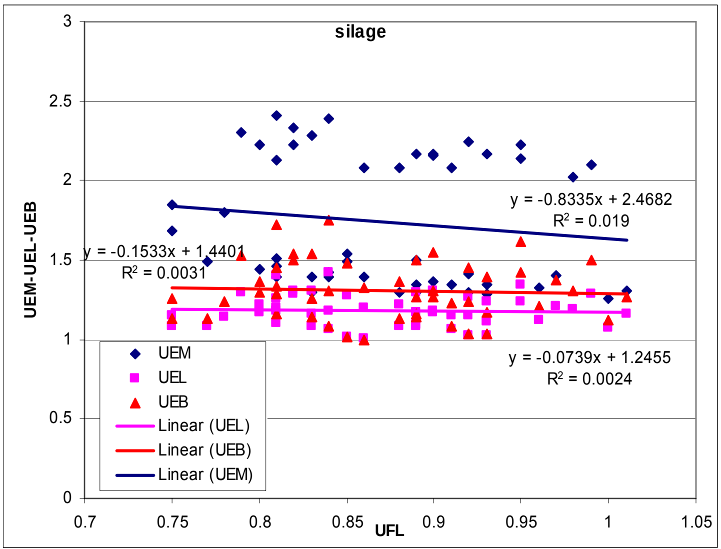
From Figure 7.4 it appears that hay has a lower N content than silage and fresh grass. This is partly due to the effect of hay production from older grassland, where hay is made after grasses have flowered, while silage and fresh grass is clipped in an earlier development stage. (Vellinga and André, 1999).

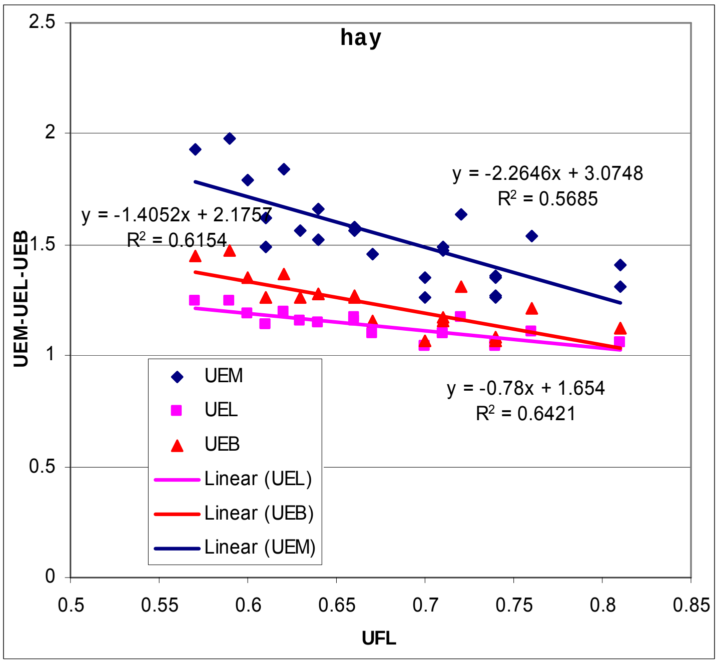
For fresh fodder and hay, the relationship between N content and energy content (expressed in UFL) is satisfactory. (R^2 = 0.68 and R^2=0.61, respectively). For silage grass the relationship is less satisfactory (R^2 = 0.29), perhaps because the quality of the silage process is playing a key role.

We also determined the relationship between energy content and different fill units (UMB, UEL and UEB) for fresh fodder, silage grass, and hay (Figure 7.5). For fresh fodder and hay we used only English ryegrass data; for silage fodder we used the same data set used to derive the relationship between N and energy content.

Figure 7.5: Relationship between N content and different fill units UEM, UEB, UEL for fresh fodder (n = 33), silage fodder (n = 49), and hay (n = 24).







As before, the relationships for silage are less convincing, based on the R^2, than those for fresh fodder and hay. It seems that fill unit values are almost constant over the entire range of energy content.

7.1.4 Application to SS data

We established an N response curve for each SS region, as described in Section 7.1.2. This response curve can be used in two ways: (i) to calculate the biomass for a given N rate (derived from the SS), which may be different from the SS yield; and (ii) to calculate for a given biomass yield (from the SS) the corresponding N rate, which may be different from the N rate in the SS.

The corresponding N content for a given point on the curve can be used to determine PDIN, UFL and UEM, UEL and UEB. The partitioning of biomass amongst hay, fresh fodder, and silage, can be carried out according to the SS.

7.2 Manure N

In FSSIM-MP, the N balance for livestock farms is calculated on the basis of the N intake of animals, the N exported in products, and the N retained by animals (Section 9). The surplus N is manure N, which can be applied to (forage) crops and grassland. Only for livestock farms can N management for forage crops and grassland be (at least partly) based on manure N (Section 9). This means that rotations and grassland will be simulated in which N is applied in the form of fertilizer N (mineral) and the same activities in which N is applied in the form of manure N (mineral and organic). The mineral form of N in manure is predominantly ammonium.

We assume that the N rates as specified in the SS refer to mineral N. If this amount has to be supplied by manure N then we base it on the mineral N fraction in manure. The share of mineral and organic N in manure differs greatly depending on the type of manure: for example, whether it is slurry, thin manure, or farm-yard manure. (Ketelaars and Van der Meer, 1998; Van der Meer, 2008). The more diluted the manure, the higher the share of mineral N in the total. Because we do not have information about the type of manure we assume the following percentages of organic N (Norg) and mineral N (Nmin) in total manure N:

Large ruminants (thin manure): 50% Norg and 50% Nmin

Sheep: 77% Norg and 23% Nmin

Goats: 69% Norg and 31% Nmin

Example:

If the N rate from the SS is 150 kg N per ha, then the amount of manure N from large ruminants that needs to be provided is 300 kg N per ha. Based on sheep manure, this amount will be 150 / 0.23 = 652 kg N per ha.

7.3 Other feed resources

In addition to the grassland products from permanent grassland activities described in the previous sections, FSSIM livestock farms can choose from two other feed resources.

First, there are crop and grassland products available from crop rotation activities, such as potatoes, barley and wheat grains and straw, and maize silage and grains. Availability of these products depends on the region-specific rotations. Quality characteristics of these crop products are based on Jarrige (1988). Temporary grassland activities can be part of rotations providing grazed grass, fresh grass (through cut-and-carry), silage, and hay. To account for differences in product quality, three fertilizer N levels have been assumed, i.e., 0-100, 100-200, and > 200 kg N per ha, for which different qualities have been defined. Quality characteristics of these grassland products are based on Jarrige (1988) and are associated with different grassland types and grassland development stages. Further, we assume that the protein and energy content of fresh grass is 5% lower and the amount of fill units 5% higher than in grazed grass. Table 7.1 is an overview of the data used to characterize products from temporary grassland.

Table 7.1: Overview of used data from Jarrige (1988) to characterize the quality of grassland-based feeds in FSSIM-MP

FSSIM description	Description in Jarrige (1988) and line number
Grass temporary grazing N level 3	Ray-grass anglais (average of line no. 128, 137, 145, 153)
Grass temporary grazing N level 2	Ray-grass anglais (average of line no. 131, 140, 147, 150, 155)
Grass temporary grazing N level 1	Ray-grass anglais (average of line no. 135, 144, 149, 152, 157)
Grass temporary hay N level 3	Praire permanente de demi-montagne (line no. 478)
Grass temporary hay N level 2	Praire permanente de demi-montagne (line no. 482)
Grass temporary hay N level 1	Praire permanente de demi-montagne (line no. 486)
Grass temporary silage N level 3	Ray-grass anglais (average of line no. 385)
Grass temporary silage N level 2	Ray-grass anglais (average of line no. 390)
Grass temporary silage N level 1	Ray-grass anglais (average of line no. 395)
Permanent grass hay	Praire permanente de demi-montagne (average of line no. 478, 482, 486, 490)
Permanent grass silage	Ray-grass anglais (average of line no. 385, 390, 395, 400)

Second, FSSIM livestock farms have the option to purchase feed that is not produced on-farm. Because the CAPRI model contains a database with regional prices of such supplements, it was decided to use the classification of feed resources that is associated with it (Britz *et al.*, 2005). However, the quality characteristics of these feeds are not specified in the CAPRI database. Therefore, we have identified indicator/substitute feeds to characterize the quality of these feed resources using the French feed evaluation system (Table 7.2). In addition to the CAPRI feeds, two grassland products have been defined, i.e. hay and silage grass, which can be purchased using the prices of these products specified in the SS. Table 7.1 summarises the data used from Jarrige (1988) to specify the quality of both grassland products. Because we do not have any information about the N input levels under which hay and silage grass have been produced, no N levels are identified, in the same way as for the temporary grassland activities (see above).

Table 7.2: Indicator feeds used to characterize the quality of feed supplement categories available in CAPRI.

CAPRI supplement name:	CAPRI variable	Indicator feed
Feed cereals	FCER	Average spring and winter wheat grain
Feed rich protein	FPRO	Maize gluten
Feed rich energy	FENE	Sugarbeet molasses
Feed based on milk products	FMIL	Whey
Grass hay	FHAY	Average permanent grassland hay
Grass silage	FSILE	Average permanent grassland silage
Fodder maize	FMAI	Silage maize
Other feed from arable land	FOFA	Barley grain
Fodder root crops	FROO	Potato
Feed other	FOTH	Soya
Straw	FSTRA	Wheat straw

8 Feeding requirement and restrictions

Restrictions to livestock feeding levels are critical, particularly in a mixed farming system where part of the crop production is used as animal feed. The livestock components of FSSIM allow the simulation of the relations amongst available feed quantity and quality, feed intake by the relevant animal species (cattle, small ruminants, pigs, poultry), animal production (meat, milk, eggs), and nutrient excretion (manure, slurry). As described above, quality characteristics of the available feed as well as animal feed requirements are quantified in FSSIM using the French feed evaluation and rationing system for protein and energy (Jarrige, 1988; 1989). Feed availability and feed requirements are matched endogenously in FSSIM-MP via a set of constraints developed below.

8.1 Matching feed requirement and feed availability

The main constraint for feeding is that the feed produced for on-farm use (Use) plus the supplement feed purchased (Quantf) must cover herd requirements. The feed ration is based on silage, fresh grass (grazed or cut), hay, pulses, straw and grain cereals that are produced on the farm and those bought from the market as well as on purchased concentrates. Feed production depends on many factors, such as available amounts of water and nutrients, growing conditions, length of the growing season, harvesting frequency, etc.

Two methods can be applied for modelling the feeding constraint:

- The first involves identifying for each animal several feeding systems described in terms of level, duration, and type of feed. The selection of these feed systems is based on current systems applied in practice on some farms or regions as well as alternatives systems. A potential problem with this method is its rigidity. In order to avoid this difficulty, it is necessary to define a large number of feeding systems from the outset.
- The second approach, adopted in our model (Figure 8.1), consists of specifying animal requirements and feed availability in a nutrient term (nut), particularly in terms of energy (UF), protein (PDI) and intake capacity (LFU, CFU and SFU, see Section 1.3.3), and then ensuring that the available quantity of nutrients covers animal requirements. In this case, the distributed quantity of each feed category (silage, fresh grass, hay, pulses, straw, grain, concentrates) as well as the grazed activity level are endogenously determined. The advantage of this method is that the model is more flexible, as we have significant substitution amongst the various categories of feed. This approach does, however, require the definition of additional constraints to limit potential excess of consumption of certain feed components:

$$\sum_{c,prd} VUse_{c,prd,\mathrm{nut}} + \sum_{sfeed} VQuantf_{sfeed,\mathrm{nut}} \geq \sum_{\mathrm{DA,int,sys}} Feed\,\mathrm{Re}q_{\mathrm{DA,int,sys,nut}}.Dalvl_{\mathrm{DA,int,sys}}$$

- **VUse** is the nutritive value of the feed produced (grazed or cut grass, fodder and crop products) for on-farm use ($USE_{c,prd}$), expressed in terms of energy and protein. The nutritive value of the grass produced depends on fertilizer level and harvesting system (grazing or cutting). This is calculated as follows:

$$VUse_{c,prd,,nut} = Use_{c,prd}.FeedCont_{c,prd,nut}$$

Nut = indices of the nutrient term, such as energy (UF), protein (PDI) and fill units (FU).
Use = on-farm production used, specified per crop and product (t DM).
Feedcont = nutrient value of the feed produced for on-farm use (grass, fodder and crop products) expressed in term of protein and energy per t DM.

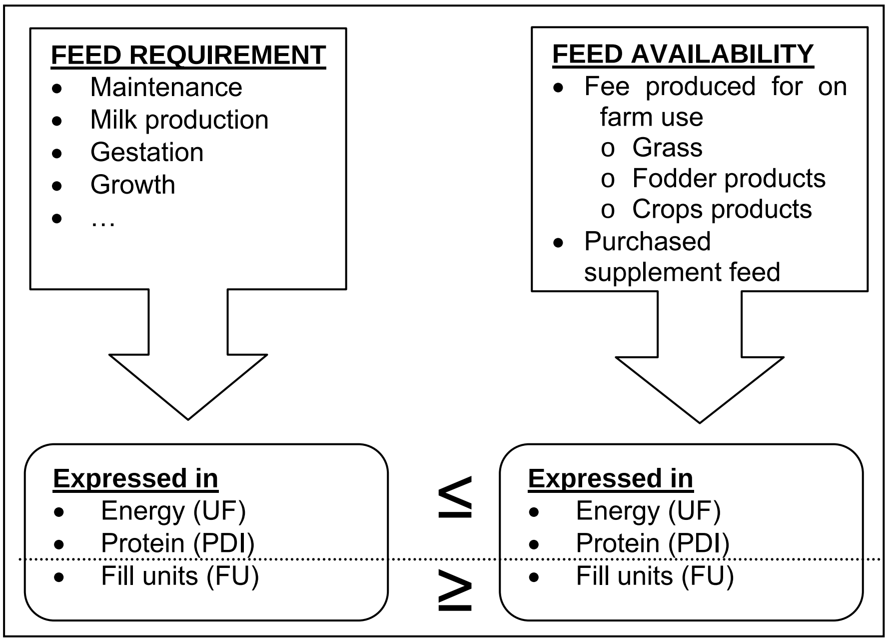
- **VQuantf** is the nutritive value of purchased supplementary feed (including concentrates):

$$VQuantf_{sfeed,nut} = Quantf_{sfeed}.VALF_{sfeed,nut}$$

Sfeed = indices of different purchased feed types.
Quantf = quantity of purchased supplement feed (t DM).
VALF = nutrient value of the purchased feed expressed in term of protein and energy per t DM.

- **FeedReq** is the feed requirement per dressed animal, intensity level, and production system, expressed in term of energy, protein and intake capacity. This requirement is calculated as described above, taking into account requirements for maintenance, milk production, growth, gestation period, and grazing/moving.
- **Dalvl** is the number of dressed animals per intensity level (int) and production system (sys) generated by the model (i.e., an endogenous variable).

Figure 8.1: Feed requirements versus feed availability



8.2 Feeding restrictions

Three feed restrictions are retained in the FSSIM model:

Fill units supplied should be less than or equal to intake capacity

$$\sum_{c,prd} VUse_{c,prd,"FU"} + \sum_{sfeed} VQuantf_{sfeed,"FU"} \leq \sum_{DA,int,sys} Feed\,Req_{DA,int,sys,"FU"} \cdot Dalvl_{DA,int,sys}$$

FU indexes fill units.
VUse is the fill units contained in the feed produced (grazed or cut grass, fodder and crop products) for on-farm use.
VQuantf is the fill units contained in the purchased supplementary feed.
FeedReq is the fill units for each dressed animal, intensity level, and production system.

Dalvl is the number of dressed animals per intensity level (int) and production system (sys) generated by the model (i.e., an endogenous variable).

❖ **Share of concentrates in animal diets expressed in energy term is bounded to a maximum**

$$\sum_{con} VQuantf_{con,"UF"} \leq Maxcon. \sum_{da,\text{int},sys} Feed\,\text{Re}\,q_{da,\text{int},sys,"UF"}.Dalvl_{da,\text{int},sys}$$

Maxcon = maximum share of concentrates in the ration (in %). This share depends on farm type/region (i.e., it is independent of production level inside the same farm type).
VQuantf = energy value (UF) of purchased concentrates.
FeedReq = energy requirement per dressed animal, intensity level, and production system.
Dalvl = number of dressed animals (*da*) per intensity level (*int*) and production system (*sys*) generated by the model.

❖ **Maximum feed availability from grazing**

The feed available from grazing varies according to season and is highly weather-dependent. This variability is represented in the model by the length of grazing period. For example, a grazing season of 120 days means that about 120 / 365 of the energy and protein requirements can be met by grazing systems, and the remainder should be met by others feeds (silage, hay, etc.).

$$VUse_{c,Graz,nut} \leq Grzday. \sum_{da,\text{int},sys} Feed\,\text{Re}\,q_{da,\text{int},sys,nut}.Dalvl_{da,\text{int},sys}$$

Grzday = length of grazing period, which depends on farm type and region.
FeedReq = feed requirement per dressed animal, intensity level, and production system expressed in term of energy and protein.
Dalvl = number of dressed animals per intensity level (*int*) and production system (*sys*) generated by the model.

9 Farm-level nitrogen balance

For livestock farms a nitrogen (N) balance at farm level is calculated in FSSM-MP based on the difference between the total N imported and the total N exported in products. The following variables are accounted for in the balance calculations (Schröder *et al.*, 2003):

Imported:	**Exported:**
• Purchased feed	• Sold feed
• Fertilizer	• Sold milk
• Purchased animals	• Sold meat
• Imported manure N	• Sold animals
• N deposition	• Exported manure N
• Biological N fixation	

Based on the N balance at the farm level, the following environmental indicators have been defined:

$(N_{import} - N_{export})$ / farm area = average farm N surplus (kg N/ha)

$(N_{import} - N_{export})$ = farm gate N surplus (kg N)

N_{export} / N_{import} = farm gate N efficiency

In the following sections the different import and export components are described in detail.

9.1 Nitrogen imported to the farm (Nimport)

9.1.1 Purchased feed

The N in purchased feed refers to the amount of N imported through the purchase of additional concentrates and roughages that form part of the ration in the optimal FSSIM solution:

$$[64]\ N_{pfeed} = \sum_{sfeed} Quantf_{sfeed} Valf_{sfeed,NC}$$

where:

Npfeed = total N in purchased feeds at farm level (kg N per farm).

sfeed = indices of different purchased feed types.

Quantf = quantity of purchased feed supplements (t DM).

Valf = N content (NC) of purchased feeds (kg N per t DM).

9.1.2 Fertilizer

The N in fertilizer refers to the amount of fertilizer N that is required to satisfy the N requirements of crops and grassland grown on the farm:

$$[65]\quad Nrequirement = \sum_{r,s,t,sys,p} Nuse_{r,s,t,sys,p} \frac{X_{r,s,t,sys}}{N_r}$$

$$[66]\quad Nfertilizer = Nrequirement - man\_used * Nman\_coef$$

where:

r = indices of crop rotations,

s = indices of agri-environmental zones,

t = indices of production techniques,

sys = indices of production orientations,

p = indices of the number of years in a rotation,

$\mathbf{X}_{r,s,t,sys}$ = agricultural activities (ha),

$\mathbf{N}_{\mathbf{r}}$ = length of a rotation (number of year),

Nuse = N requirement of each crop within each agricultural activity (kg N per ha),

Nrequirement = N requirement of all crops and grassland produced on the farm (kg N per farm),

Nman_used = amount of manure N that is used to satisfy the N requirements (kg N per farm),

Nfertiliser = amount of mineral N fertilizer that is used to satisfy the N requirements (kg N per farm),

Nmanure_coef = N manure coefficient (to equate manure N to fertilizer N; assumed to be 75%).

9.1.3 Imported manure N

The N in imported manure refers to the amount of manure N that is used to satisfy the N requirements of crops and grassland grown on the farm (see also Sections 9.2.4 and 9.3.1.1):

$$[67] \qquad Nman\_import = Nman\_used + Nman\_export - Nman\_prod$$

where:

Nman_used = amount of manure N that is used to satisfy N requirements (kg N per farm),

Nman_prod = amount of manure N that is produced on the farm (kg N per farm),

Nman_export = amount of exported manure N (kg N per farm),

Nman_import = amount of imported manure N (kg N per farm).

9.1.4 N deposition

N deposition refers to region-specific atmospheric deposition of N, which is available in the CAPRI database at NUTS 2 level (Britz *et al*., 2006):

$$[68] \qquad Ndeposition = \sum_{r,s,t,sys} X_{r,s,t,sys} Ndepo$$

where:

Ndeposition = total N supplied at farm level through atmospheric deposition (kg N per farm),

N_depo = atmospheric N deposition (kg N per ha per year).

9.1.5 Biological N fixation

Biological N fixation refers to legume crops that are able to fix N from the atmosphere. Here we assume that 75% of the N uptake of the legumes grown on farm is fixed by biological processes (Schils *et al*., 2000).

[69] $$Nfixation = \sum_{r,s,t,sys,p} Nuse_{r,s,t,sys,p} \frac{X_{r,s,t,sys}}{N_r}(1 - Nfix_{r,p})$$

where:

Nfixation = total amount of N supplied at farm level through biological N fixation (kg N per farm),

Nfix = biological N fixation of crops (75% for pulses; Grashoff, 2000).

9.1.6 Purchased animals

The N in purchased animals refers to the N contained in body tissue of purchased animals:

[70] $$Npanimal = \sum_{da,\text{int},An} Dapurs_{da,\text{int}} Share_{da,\text{int},An} Weight_{da,\text{int},An} Nap\_content_{An,\text{"meat"}}$$

where:

Npanimal = total amount of N in purchased animals at farm level (kg N per farm),

da = indices of dressed animal types (dairy, beef, sheep, goat),

int = indices of intensification levels (different milk and meat yields),

An = indices of age cohorts (cows, calves, heifers),

Dapurs = purchased dressed animals per intensity level (head),

Share = share of age cohorts in dressed animal and intensity level,

Weight = live weight per age cohort at purchase (t)**,**

Nap_content = N content of body tissue (%N).

9.2 Nitrogen exported from the farm (N_{export})

9.2.1 Sold feed

The N in sold feed refers to the amount of N in feed crops and roughages that is produced on farm and sold (exported from the farm):

[71] $$Nsfeed = \sum_{c,prd} Sales_{c,prd} Valf_{prd,\text{"NC"}}$$

where:

Nsfeed = total N in sold feeds produced on farm (kg N per farm),

c = indices of crops (wheat, barley, grass, etc),

prd = indices of product types (silage, hay, straw, etc),

Sales = total sold crop products (t per farm),

Valf = N content (NC) of feeds (kg N per t DM).

9.2.2 Sales of animal products (milk and meat)

The N in sold animal products refers to the amount of N in milk and meat that is sold:

[72] $$Nsaproduct = \sum_{An} Sales_{An,prd} * 1000 * Nap\_content_{prd}$$

where:

Nsaproduct = total N in sold animal products (kg N per farm),

Sales = sold animal products (t per farm).

9.2.3 Sold animals

The N in sold animals refers to the N contained in body tissue of sold animals:

[73] $$Nsanimal = \sum_{da,\text{int},An} Dasell_{da,\text{int}} Share_{da,\text{int},An} Weight_{da,\text{int},An} Nap\_content_{"meat"}$$

where:

Nsanimal = total N in body tissue of animals sold (kg N per farm),

Dasell = sold dressed animals per intensity level (head per farm).

9.2.4 Exported manure N

The N in exported manure N refers to the total amount of N in manure that is exported from the farm. In some regions with a manure surplus, such as the Netherlands, the export of manure is associated with costs, but in most other regions farmers will receive money for exported manure. The method to calculate the amount of manure N produced by animals on the farm is explained in more detail in the next section:

[74] $$Nman\_export = Nman\_prod + Nman\_import - Nman\_used$$

9.2.4.1 Production of manure N

Based on the approach of EC (1999) and Schröder *et al.* (2003), the production of manure N (Nman_prod) is the difference between feed N intake (Nration) by animals and the N retained (Nretention) in body tissue and in animal products (e.g. milk):

[75] $$Nman\_prod = Nration - Nretention$$

- **Nration** is the product of feed consumption and N content of the ration. The amount of each feed in the animal ration is the outcome of the FSSIM-MP optimization. The N contents of the individual feeds are available in the SEAMLESS database.
- **Nretention** is the product of live weight gain and N content of body tissue plus the product of milk production and N content of the milk. The various N contents are available in the SEAMLESS database, while milk production and live weight gain are a function of the production level and herd structure on the farm.

9.3 Example of calculations

The following example illustrates the manure N calculations in FSSIM-MP:

N intake	Value	Dimension	Comments
Feed intake herd (a)	100000	kg DM per herd per year	FSSIM-MP solution
Average N content of diet (b)	2	%	In database
N intake herd (c)	2000	kg N per herd per year	(c) = (a) * (b)

N retention			
Live weight gain cow (d)	20	kg per cow per year	FSSIM-MP solution
Live weight gain heifer (e)	230	kg per heifer per year	FSSIM-MP solution
Live weight gain calve (f)	250	kg per calf per year	FSSIM-MP solution
Calf liveweight at birth (g)	40	kg	In database
Milk production (h)	8000	kg per cow per year	FSSIM-MP solution
Number of cows in herd (i)	25		FSSIM-MP solution
Number of heifers in herd (j)	10		FSSIM-MP solution
Number of calves in herd (k)	10		FSSIM-MP solution
N content cow, heifer, calf (l)	2.5	%	In DB
N content calf production (m)	2.9	%	In DB
N content milk production (n)	0.5	%	In DB
N retention in herd (o)	1154	kg N per herd per year	(o) = (i)*(d)*(l) + (j)*(e)*(l) + (k)*(f)*(l) + (h)*(n) + (m)*(k)*(g)

N excretion			
N excretion herd (p)	846	kg N per herd per year	(p) = (c) – (o)

Available manure N at farm			
Unavoidable losses (q)	10	%	In database
Available N in manure on farm (r)	761	kg N per farm	(r) = (p) * (100 - (q))

Note that the unavoidable manure N loss fraction (q) is not part of the N balance calculations at farm level (Section 9.1), which calculates a farm gate N surplus. Unavoidable manure N losses are associated with animal management, stable design, and location-specific climate conditions, and thus may differ widely accross the EU. Because information is lacking to estimate this loss accurately, it is set here at 10% of the total excreted N (EC, 1999).

9.3.1 The use of manure N in crop and grassland activities

In FSSIM-MP, the available N in manure produced on farm (Section 7.2) is preferentially used to satisfy N requirements of crops and grassland in FSSIM-MP. If not all N requirements can be met with manure N, the rest is met with fertilizer (mineral) N (Section 9.1.2). Nitrogen requirements are quantified in FSSIM-AM and make up part of the technical coefficients describing the inputs and outputs of crop and grassland activities. It is assumed that the "effectiveness" coefficient of manure N is 75%, i.e., 100 kg of manure N is equivalent to 75 kg of fertilizer N. (Van Dijk *et al*., 2004; Van der Meer, 2008). Depending on the region under study (Section 9.2.4), any manure N on the farm that is surplus to the N requirements of crops and grassland is sold (adding to the farm income) or exported against certain costs.

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Glossary

Catabolism	The release of energy stored in tissue in order to contribute to the immediate needs of the animal for maintenance or productive purposes.
Dairy cow	A cow kept for the commercial production of milk.
Dressed animal	The combination of an adult and young animal taking into account the replacement rate, enabling the estimation of animal feed requirements of a productive animal and its replacement.
Lactation	The period during which a reproductively active female animal is producing milk for her offspring or for sale.
Maintenance	Nutrients or energy that are utilised for supporting tissue turnover, heat generation or other non-productive functions.
Microbial protein	Protein that is synthesised by the microbial population of the rumen and is subsequently available for digestion in the small intestine.
Net energy	An energy evaluation system in which the energy values represent ingested energy that is actually useable for maintenance and productive purposes.
Production cycle	The period over which a animal fulfils the entire range of its productive functions. For example, the production cycle of a dairy cow covers the period from the birth of a calf through lactation, re-breeding, and drying off, to the birth of the next calf.
Replacement rate	The percentage of the productive population that must be replaced on an annual basis. For example, a replacement rate of 25% in a dairy herd means that animals will, on average, remain in the herd for four years.
Suckled milk production	An estimate of the quantity of milk removed by a calf that is partially or completely dependent on its mother for milk.
Suckler cow	A cow kept for rearing beef animals for slaughter.