Integrating diverse forage sources reduces feed gaps on mixed crop-livestock farms across Australia

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# Supplementary Material Part S1 - Livestock Forage Demand Calculations

This material describes the equations used to estimate requirements for forage by grazing livestock in the Farm Feedbase Risk Calculator (FFRC). The equations were originally derived for use in the *MLA Feed Demand Calculator* software and are derived from the GRAZPLAN ruminant biology model (Freer et al. 1997), as updated in an online technical paper by Freer et al (2012). Notation follows the technical paper as far as possible, and equations marked with “T” are taken from it.

The FFRC uses the total monthly requirements for metabolizable energy (ME) of a sheep flock or cattle herd composed of several classes of livestock. The internal calculations, however, operate at half-monthly time steps. Also, because of a requirement that joining periods of varying length be permitted, herbage requirements must be computed for cows and ewes at different stages of lactation and with different numbers of offspring and, after the specified weaning date, for weaned offspring of different ages. For each livestock class *c* and month *m*, the monthly ME requirement, *MMERcm* is computed as

 (1)

where  is the mean daily requirement for metabolizable energy (ME) per head, *Nci* is the number of animals present and *Ti* is the length of the *i*-th half-month in days. In order to compute the values of *MMER,* values for *MERci* and *Nci* must be obtained for each livestock class and for each of the 24 half-months, or “periods”.

## 1. Daily metabolizable energy requirements of livestock

To calculate *MER* for each livestock class or sub-group, the equations of the GRAZPLAN animal biology model are re-cast so that the ME requirement corresponding to a given age, weight, base weight change, reproductive status and external environment can be calculated[[1]](#footnote-1). The FFRC assumes that:

* All cattle are of beef genotypes, and all lactating animals have suckling calves or lambs.
* Protein supply does not limit intake or weight gain.
* No supplementary feed is provided.
* Calculations are performed at the mid-point of each time period.

In addition to the genotype (and hence a set of genotypic parameters), the following quantities are known or calculated for each livestock class at the mid-point of each time period, and are used in the *MER* calculations: average age (*A*, days); average weight, exclusive of conceptus and fleece (*W*, kg); average rate of weight change during the time period (Δ*W*, kg/d); number of foetuses and/or suckling young; time since conception (*Ac*, days); time since birth of young (*Ay*, days); average weight of young (*Wy*, kg); the ME content of forage intake (*M*/*Df*, MJ/kg) and the day length including civil twilight (*DL*, hours).

Under these specified conditions, the ME requirement of a group of animals in a given time period is the same as the ME intake from forage that results in the nominated weight change:

 (2)

The ME intake of milk (*MEImilk*) is zero for all weaned animals and is known from prior calculations of the mothers’ energy balance for unweaned animals. To obtain *MEItotal* and hence *MER*, we rearrange equation (T101):

 (T101)

 (3)

The ME requirements for maintenance and lactation (*MEm* and *MEl*) and the net energy requirements for weight gain and wool growth (*NEg* and *NEw*) all depend upon the value of *MEItotal*, so further manipulation of equation (3) is required.

To remove the dependency on *MEm*, equation (T41) is used:

 (T41)

Assuming relatively stable conditions, equations (T78), (T80) and (T81) can be used to obtain the following expression for *NEw*:

 (T81)

 (T78, T80)

 (4)

where

 (5)

 (6)

From equations (T104), (T115) and (T117), we obtain

 (7)

where the values of *ZF*1 and *ZF*2 are given by equations (T106) and (T107).

Equation (7) can be re-written as a linear function of the ratio *MEItotal*/*MEm*:

 (8)

where

 (9)

 (10)

Equation (T63) gives the total ME content of the conceptus, so the necessary values of *MEc* for pregnant livestock classes can be calculated using its derivative. For simplicity it is assumed that *BCfoet*= 1 in equation (T63).

Substituting equations (T41), (4) and (8) into equation (3), and neglecting the highly-unusual case where *MEItotal* < *MEc* + *MEl*, we obtain:

 (11)

The right-hand side of equation (11) still contains three terms that can depend upon *MEItotal*, namely *km*, *MEl* and *L*. Different methods are used to resolve these dependencies for different classes of animals:

* For animals that are neither lactating nor consuming their mothers’ milk, *MEImilk* = *MEl* = 0. Hence *MER* = *MEItotal* and *km* does not depend on *MEI* (see equation T33). For these animals, Equation 11 can be reduced to a quadratic equation in *MER* by substituting equation (T41) for *MEm* and re-arranging.
* For cows and ewes that are pregnant and/or lactating, *MEImilk* = 0, so *MER* = *MEItotal* and *km* does not depend on *MEI*. The ME requirement for lactation, *MEl*, is a non-linear function of *MEItotal* given by equations (T66-75). Equation (11) must therefore be solved numerically.
* Unweaned animals in the first period after birth are a special case. These animals cannot eat forage and so their *MER* is equal to zero.
* For other unweaned calves and lambs, *MEc* = *MEl* = 0 and *MEImilk* > 0 is known from prior calculations of the mothers’ energy balance. Because *NEmetab* and *km* depend on the proportion of dietary ME derived from milk (equations T42 and T33), equation (11) must also be solved numerically for these animals.

## 2. Equations and quantities used in the daily metabolizable energy requirement calculations

### Equations

 (T1)

 (T2)

 (T31)

 (T33)

 (T34)

 (T35)

 (T36)

where  (T38)

  (T39)

  (T40)

 (T41)

 (T42)

 (T62)

 (T63)

 (T66)

 (T68)

where  (T69)

  (T70)

 (T71)

 (T75)

 (T78)

where  (T78a)

  (T78b)

 (T80)

 (T81)

 (T101)

 (T104)

where  (T106)

  (T107)

  (T108)

 (T115)

 (T117)

**Supplementary Material Table S1**. User-provided inputs to calculate livestock demand

| Quantity | Unit | Definition |
| --- | --- | --- |
| *SRW* | kg | Standard reference weight: live weight excluding fleece and conceptus) of an animal when skeletal development is complete and condition score is in the middle of the range |
| *SFW* | kg | Standard fleece weight: fleece weight grown by a dry ewe under optimal conditions. Calculated as by default |
| *λ* | degrees | Latitude |
| *M*/*Df* | MJ/kg | Metabolizable energy content of the forage intake during a period |
| *φlegume* | kg/kg | Legume content of the forage intake |

**Supplementary Material Table S2.** Quantities estimated using book-keeping calculations

| Quantity | Unit | Definition |
| --- | --- | --- |
| *DOY* |  | Day of year at the mid-point of a time period |
| *DL* | hour | Day length including civil twilight at the mid-point of a time period is approximated as a sinusoidal function of the day-of-year: (12)where the daylength amplitude, *ADL*, is computed from the latitude: (13) |
| *A* | days | Age of animals in the livestock class |
| *W* | kg | Live weight excluding fleece and conceptus |
| *Wprev* | kg | Highest previous value of *W*, with an upper bound of *SRW* |
| Δ*W* | kg/d | Average rate of change in *W* during the time period |
| *Nf* |  | Number of foetuses in pregnant animals |
| *Af* | days | Time since conception in pregnant animals |
| *Ny* |  | Number of suckling offspring |
| *Ay* | days | Age of suckling offspring |
| *Wy* | kg | Live weight excluding fleece of suckling offspring |
| *MEImilk* | MJ/d | MEI in milk intake of suckling offspring: of their mothers (14) |

**Supplementary Material Table S3.** Quantities in the ME requirement equations

| Quantity | Unit | Definition | Equation |
| --- | --- | --- | --- |
| *BCpart* | – | Relative body condition at parturition. Assumed to equal 1.0 for simplicity |  |
| *DMDf* | kg/kg | Dry matter digestibility of forage intake | (T31) |
| *EBG* | kg/d | Empty body weight gain | (T115) |
| *EVG* | MJ/kg | Energy content of empty body weight gain | (T104) |
| *kc* | – | Efficiency of use of ME for growth of the conceptus | (T35) |
| *kg* | – | Efficiency of use of ME for weight gain | (T36) |
| *kl* | – | Efficiency of use of ME for lactation | (T34) |
| *km* | – | Efficiency of use of ME for maintenance | (T33) |
| *LB* | – | Factor describing relative capacity of the udder. Assumed to equal 1.0 for simplicity |  |
| *MEc* | MJ/d | ME use for growth of the conceptus | (T63) |
| *MEl* | MJ/d | ME use for lactation | (T75) |
| *MEm* | MJ/d | ME use for maintenance | (T41) |
| *MEw* | MJ/d | ME use for wool growth (above maintenance) | (T80) |
| *MEIf* | MJ/d | ME intake in forage |  |
| *MEItotal* | MJ/d | Total daily ME intake |  |
| *M*/*Ds* | MJ/kg | Metabolizable energy content of solid intake = *M*/*Df* |  |
| *N* | kg | Normal weight for age | (T2) |
| *Nmax* | kg | Maximum normal weight for age | (T1) |
| *NEg* | MJ/d | Net energy use for weight gain | (T101) |
| *NEw* | MJ/d | Net energy use for wool growth | (T81) |
| *NEgraze* | MJ/d | Net energy (NE) requirement for moving and grazing. Equations (T43) and (T44) require the mass and DM intake of pasture, which are not available as inputs to the calculator. Instead, the following approximation is used: (14) |  |
| *NEmetab* | MJ/d | Metabolic component of NE required for maintenance | (T42) |
| *Pw* | kg/d | Protein requirement for wool growth. Assumed to equal  | (T78) |

**Supplementary Material Table S4.** Phenotypic parameters used to predict livestock demand

| Constant | Unit | Definition | Value |
| --- | --- | --- | --- |
| Sheep | Cattle |
| *CN*1 |  | Growth rate constant  | 0.0157 | 0.0115 |
| *CN*2 |  | Allometric scalar for growth rate  | 0.27 | 0.27 |
| *CN*3 |  | Weighting factor for slow growth  | 0.4 | 0.4 |
| *CM*1 | – | *MEm*: liveweight gain | 0.09 | 0.09 |
| *CM*2 | MJ kg-3/4 | Basal metabolism: weight scalar | 0.26 | 0.36[[2]](#footnote-2) |
| *CM*3 | d-1 | Basal metabolism: age | 0.00008 | 0.00008 |
| *CM*4 | – | Basal metabolism: age | 0.84 | 0.84 |
| *CM*5 | – | Basal metabolism: milk intake | 0.23 | 0.23 |
| *CK*1 | – | *km*: M/D in solid diet | 0.5 | 0.5 |
| *CK*2 | kg MJ-1 | *km*: M/D in solid diet | 0.02 | 0.02 |
| *CK*3 | – | *km*: milk intake | 0.85 | 0.85 |
| *CK*5 | – | *km*: M/D in solid diet | 0.40 | 0.40 |
| *CK*6 | kg MJ-1 | *km*: M/D in solid diet | 0.02 | 0.02 |
| *CK*8 | 0-1 | *kc* | 0.133 | 0.133 |
| *CK*9 | – | *k*g: lactating animals | 0.95 | 0.95 |
| *CK*10 | 0-1 | *k*g: lactating animals losing weight | 0.84 | 0.84 |
| *CK*11 | 0-1 | *k*g: weight loss  | 0.8 | 0.8 |
| *CK*12 | – | *k*g: milk intake | 0.7 | 0.7 |
| *CK*13 | – | *k*g: herbage, zero legume, mid-winter | 0.9 | 0.9 |
| *CK*14 | – | *k*g: legume effect | 0.3 | 0.3 |
| *CK*15 | kg MJ-1 | *k*g: time of year effect at 40° latitude  | 0.043 | 0.043 |
| *CP*1 | days | Gestation length  | 150 | 285 |
| *CP*5 | – | Final ratio of conceptus weight to foetus weight  | 1.43 | 1.80 |
| *CP*6 | – | Conceptus weight  | 3.38 | 2.42 |
| *CP*7 | – | Conceptus weight  | 0.91 | 1.16 |
| *CP8* | MJ/kg | Final conceptus energy content  | 4.33 | 4.11 |
| *CP*9 | – | Conceptus energy  | 4.37 | 343.5 |
| *CP*10 | – | Conceptus energy  | 0.965 | 0.0164 |
| *CP*15,*N* | kg/kg | Normal birth weight:SRW for animals bearing *N* young | 1: 0.102: 0.0853: 0.07 | 1: 0.072: 0.055 |
| *CL*0,*N* | MJ kg-3/4 | Peak yield scalar if suckling  | 1: 0.375[[3]](#footnote-3)2: 0.7783: 0.934 | 0.375 |
| *CL*1 | d | Lactation curve: offset | 2 | 4 |
| *CL*2 | d | Lactation curve: peak time | 22 | 30 |
| *CL*3 | – | Shape factor | 1.00 | 0.60 |
| *CL*5 | 0-1 | Metabolizability of milk | 0.94 | 0.94 |
| *CL*6 | MJ kg-1 | Energy content of milk | 4.7 | 3.1 |
| *CL*7 | – | Milk: energy deficit | 1.17 | 1.17 |
| *CL*12 | kg kg-3/4  | Milk consumption limit  | 0.30 | 0.42 |
| *CL*13 | kg kg-3/4 | Milk consumption limit  | 0.41 | 0.58 |
| *CL*14 | d-1 | Milk consumption limit  | 0.071 | 0.036 |
| *CL*19 | – | Milk: energy deficit factor  | 1.6 | 1.6 |
| *CL*20 | – | Milk: energy deficit factor  | 4.0 | 4.0 |
| *CL*21 | d-1 | Milk: energy deficit factor  | 0.008 | 0.004 |
| *CL*22 | d-1 | Milk: energy deficit factor  | 0.012 | 0.006 |
| *CL*23 | – | Milk: energy deficit factor  | 3.0 | 3.0 |
| *CL*24 | – | Milk: energy deficit factor  | 0.6 | 0.6 |
| *CPFW* | kg/kg | Ratio of reference fleece weight to standard reference weight | 0.09[[4]](#footnote-4) |  |
| *CW*1 | MJ kg-1 | Energy content of clean wool  | 24.0 |  |
| *CW*2 | kg/d | Basal clean wool growth  | 0.004 |  |
| *CW*3 | kg/kg | Clean:greasy wool ratio  | 0.70 |  |
| *CW*5 | d-1 | Wool growth: proportion at birth  | 0.25 |  |
| *CW*6 | h-1 | Wool growth: photoperiod  | 0.03 [[5]](#footnote-5) |  |
| *CW*8 | kg MJ-1 | Wool growth: MEI limitation  | 0.016 |  |
| *CW*12 | – | Wool growth: age factor exponent  | 0.025 |  |
| *CG*4 | – | EVG: effect of relative size on *ZF*1  | 6.0 | 6.0 |
| *CG*5 | – | EVG: relative size at which *ZF*1=0.5 | 0.4 | 0.4 |
| *CG*6 | – | EVG: relative size below which *ZF*2=0.0 | 0.90 | 0.90 |
| *CG*7 | – | EVG: relative size above which *ZF*2=1.0 | 0.97 | 0.97 |
| *CG*8 | – | EVG: reference value  | 27.0 | 27.0[[6]](#footnote-6) |
| *CG*9 | – | EVG: range with maturity at L=1 and BC=1  | 20.3 | 20.3 |
| *CG*10 | – | EVG: effect of feeding level  | 2.0 | 2.0 |
| *CG*11 | – | EVG: effect of body condition in near-mature animals  | 13.8 | 13.8 |
| *CG*18 | – | Base weight:empty body weight | 1.09 | 1.09 |

6 For *B. indicus* and Charolais type cattle, *CG*8 = 23.2, *CG*9 = 16.5, *CG*12 = 0.092 and *CG*13 = 0.120

## 3. Flock & herd dynamics: basics

* Wethers and steers are each treated as single group of animals with a common average age and weight. For these livestock classes the calculation of *Nci* is a straightforward book-keeping exercise involving the initial number of animals and the time and number of purchases and sales.
* For ewes and cows, the initial computation of *Nci* is the same as for wethers and steers. Animals in these classes must be further sub-divided according to the number of foetuses they are carrying and/or offspring they are suckling.
* For weaned lambs and calves, the number of animals present at a given time equals the number present at the start point, plus any preceding purchases, less any preceding sales, plus the number of animals weaned. Those present at the start point are considered to be a single group of animals (as for wethers and steers), while animals weaned during the year are distinguished according to their age (i.e. the time period in which they were born). *MER* values for each sub-group are calculated separately and then a number-weighted average value is computed. In practice, weaners that are present at the start of the simulated year and those that are weaned during the year are treated separately in the calculations and only combined for output purposes.
* For unweaned lambs and calves, the number of animals present at a given time equals the number present at the start point, plus offspring of any purchased cows or ewes, less any preceding sales or weanings. Animals born during each time period (including periods prior to the start point) are distinguished in the *MER* calculations.

The numbers of animals born or weaned during the simulated year are calculated from the number of their mothers multiplied by the number of calves per cow or lambs per ewe, i.e. unweaned offspring are purchased and sold along with their mothers. The weighted average values of *MER* over the age classes are also computed using these proportions rather than the absolute numbers of animals.

*M*/*Df*,*i* is calculated from *DMDf,i*, the expected dry matter digestibility of forage intake, using equation (T31) of the Technical Paper. Values for *DMDf,i* are stored as a table of location- and period-specific values. These values have been derived from a set of simple grazing system simulations carried out with the GrassGro decision support tool.

## 4. Deriving conception and weaning rates from input information

In order to calculate the number of unweaned and weaned young present during each time period, and the distribution of cows and ewes across different reproductive statuses, it is necessary to compute the fertility rates and fecundity of cows and ewes in each time period.

The input information provided to estimate these rates is, for each of one or two distinct mating periods,

* the start and end dates of joining (i.e. the set of periods when animals are mated); and
* an overall value for the number of calves per cow or lambs per ewe that survive to weaning, *OPM*.

The pattern of fertility is computed separately for each of the two “joining periods” and the values, scaled for the proportion of mothers mated in each joining period, are then added together.

In order to estimate the time course of fertility within each of the two joining periods, it is necessary to take the following factors into account:

* twin conceptions in sheep;
* variation in fertility and fecundity with time of year, again in sheep;
* neo-natal mortalities; and
* the possibility that animals that conceive at a time late in the joining period will still be pregnant in the early time periods of the next annual joining period. For example, if cattle are joined from 1 January to 31 October, then animals conceiving on 15 October will still be pregnant until the following July, and so will not be available to conceive at time periods from January to July.

The best way to deal with the last of these issues is to assume that the nominated times of joining and the conception rates implied by the number of offspring per mother have operated in the past, such that an equilibrium pattern of conceptions has arisen.

For simplicity, it is assumed that all mortality of offspring happens near the time of birth and that the neo-natal mortality rates, *NNMn*, are constant at 0.0 for calves, 0.10 for single lambs and 0.25 for twin lambs.

Define the following quantities:

*MATEi* equal to 1 if the joining period includes time period *i* and 0 otherwise. This is an input;

*FRi* the “fertility rate”, i.e. the proportion of animals in a livestock class that conceive at least one foetus during time period *i*.

*TWi* the “twinning rate”, i.e. the average proportion of twin conceptions *per mother* *conceiving* in time period *i.*

*PCni* the proportion of animals in a livestock class that conceive *n* foetuses during time period *i*.

*PBni* the proportion of animals in a livestock class that conceive *n* foetuses during time period *i* that then survive past birth.

By definition, and given that multiple births are restricted to twins in sheep,

 (15)

 (16)

 (17)

and the average number of foetuses conceived per mother during time period *i* equals *FRi*∙(1+*TWi*).

To obtain the fertility schedule, a set of *FRi* and *TWi* must be found that together give the user-supplied value of the number of offspring per mother,

 (18)

Once the *FRi* and *TWi* are known, values for *PPnj* and *PLnk*, and the numbers of weaned offspring per cow or ewe, can be obtained as a book-keeping calculation from the corresponding *PCnj* and *PBnj* and the times of weaning and sales.

Analysis of the conception equations in the Technical Paper indicates that the twinning rate, *TWi*, can be satisfactorily approximated by a piecewise linear function of *CRi*:

 (19)

where *CTW,A* and *CTW,B* are 0.0 and 0.0 for cattle, -0.15 and 0.96 for Merino-type sheep and -0.12 and 1.28 for meat-type sheep.

To complete the fertility calculations, two assumptions are made:

* a minimum period between matings of 9 months (18 time periods) is assumed for both sheep and cattle.
* the reproductive history of the herd or flock has been the same as that specified by the user for some years, so that the distribution of conceptions through the year is at equilibrium.

Given these assumptions, the fertility rates, *FRi* (for those periods where *MATEi*=1) are the solutions to the set of simultaneous equations

 (20)

where *CR­i*, the conception rate per available animal per time period, is computed taking time-of-year effects into account via the first term of equation (T122):

 (21)

and the “reference” conception rate, *CRref*, is the conception rate at the optimal time of year for fertility.

Equations (18)-(21) together give *OPM* as a function of *CRref*. An iterative process is used to find the *CRref* that gives the user-specified *OPM* for each animal type and mating period.

## 5. Deriving animal ages, numbers and weights from input information

### Ages

For unweaned young, or animals weaned during the simulated year, the time period of birth is known and hence computing animal age is straightforward. For all other animals, the fertility schedule is used to compute a weighted average day-of-year of birth, *DOYB*. The age of animals in the stock class at the start time (day-of-year *DOY*0) is then computed as

 (22)

and values of *AYc* are

|  |  |  |  |
| --- | --- | --- | --- |
| Cows (3 years or older) | 6 | Ewes (2 years or older) | 4 |
| Cows (2-3 years old) | 2 | Ewes (1-2 years old) | 1 |
| Heifers (1-2 years old) | 1 | Wethers (1 year or older) | 3 |
| Steers (2 years or older) | 2 | Weaned young sheep | 0 |
| Steers (1-2 years) | 1 |
| Weaned young cattle | 0 |

Once the starting age is known, the age at each period is computed from the time from *DOY*0 to the midpoint of the period.

### Numbers

The numbers of animals in each livestock class are simulated through the year, taking purchases, sales and weaning into account. To carry out this simulation, however, the following quantities must be known:

* the proportions of cows and ewes that are pregnant with foetuses of each possible age;
* the proportion of cows and ewes giving birth to surviving offspring at each time period; and
* the initial proportions of cows and ewes with suckling offspring of each possible age.

Note that no age distribution for weaned offspring is required.

These values are calculated from the fertility, twinning and neo-natal mortality rates, assuming that the nominated joining schedule applied in the past. Care must be taken when establishing the previous year’s values for *MATEi* for each age class; for example, 2-3 year old cows in the current year were 1-2 year old heifers in the previous year, and so whether of not they were mated in the period leading up to the start time depends upon a user-supplied input.

### Weights – animals present at start or purchased

For simplicity, fleece weights are neglected; the “weight” values in the following are interpreted as fleece-free live weights.

Live weights are simulated through the year, using a weight change pattern that depends upon location, time of year and animal maturity. The weight schedule is further adjusted to match user-supplied sale weights and to allow for the change in average weight that takes place when animals are purchased.

Without loss of generality, let the initial time period be period 1, the time from the start date to the midpoint of period *i* be *Ti* days, the time from the start date to the sale date be *S* days and the time from the start date to the purchase date be *P* days. Then

 (23)

 (24)

where

 (25)

 (26)

*N­i* is the normal weight for age, *dWdef*,*i* (kg/kg/d) is a default pattern of live weight change that is stored as a location- and period-specific value, *LWCP* is the step change in average live weight due to purchase of stock and *LWCS* is the difference between the user-supplied sale weight and the sale weight that would be obtained by assuming the default pattern of live weight change.

Location- and period-specific values for *dWdef*,*i* have been derived from the same set of GrassGro used to provide values for *DMDf*.

The initial live weight, *LW*0, is set at the user-supplied value if it is given, otherwise to the normal weight for age.

In the following equations,

*Pbought* is the ratio of (number of animals purchased):(number present at start + number purchased),

*LWP* is the user-supplied purchase weight,

*LWS* is the user-supplied sale weight,  is the default weight at the purchase date, and
 is the default weight at the sale date.

Five different cases can be distinguished, depending on which weights the user provides:

1. Neither purchase nor sale weight supplied

In this case *LWCS* = *LWCP* = 0, i.e. the animal weights follow the default pattern determined by the change in the animals’ normal weight for age and the location-specific weight change schedule.

2. Purchase weight supplied, no sale weight supplied

 (27a)

 (28a)

3. No purchase weight supplied, sale weight supplied

 (27b)

 (28b)

4. Purchase weight and sale weight supplied, purchase precedes sale

 (27c)

 (28c)

5. Purchase weight and sale weight supplied, sale precedes purchase

 (27d)

 (28d)

Finally, the live weights are corrected to conceptus-free, fleece-free weights. For steers, wethers, and young animals, the base weight equals the fleece-free weight. For cows and ewes, the average base weight is computed as the difference between the fleece-free weight and an average conceptus weight for each time since mating. Conceptus weight values are computed with equation (T62), assuming that *Wfoet* = *Nfoet*.

### Weights – animals weaned or born during the year

For animals that are weaned or born during the simulated year, a live weight schedule is computed as a function of age. The process used is as follows:

1. Values of normal weight for age are computed for the all ages from birth to 48 months. If no user-supplied weight at sale for these animals is given, then these weights (and the corresponding weight changes) are used in the *MER* calculations. Otherwise,
2. From the schedule of livestock numbers, the proportions of animals in each age class present on the sale date are determined.
3. A weighted average normal weight for age at the sale date is computed.
4. The live weight and rate of weight change for each age class are multiplied by the ratio of the nominated sale weight to the weighted-average normal weight.

The seasonally-varying term in the weight equations for other animals is therefore not used for animals that are weaned or born during the simulated year.

## 6. Location-specific information

Four location-specific inputs are required for the *MER* calculations: the latitude **, the proportion of legume in the diet (*legume*), the average dry matter digestibility of pasture herbage intake *DMDf* and the default seasonal pattern of weight change *dWdef* (see equation 26). For the FFRC, calculations were carried out at fixed levels of *DMDf*, as described in the main paper. The remaining input parameters are given in the table below:

**Supplementary Material Table S5.** Location-specific details of seasonal pattern of weight changes (g/kg), proportion of legume in the diet (*legume*) and latitude (**) required to calculate livestock energy demand for livestock enterprises.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Parameters | Period | Roma, Queensland | Temora, NSW | Charlton, Victoria | Hamilton, Victoria | Waikerie, SA | Katanning, WA |
| ** | -26.5 | -35.1 | -37 | -37.8 | -35.3 | -33.7 |
| *legume* | 0.05 | 0.3 | 0.20 | 0.20 | 0.30 | 0.3 |
| *dWdef*  | 1-15 Jan | 0.42 | -1.07 | -0.08 | 0.55 | -0.51 | -0.62 |
|  | 16-31 Jan | 0.36 | -1.37 | -0.22 | -0.34 | -0.68 | -0.85 |
|  | 1-15 Feb | 0.43 | -1.62 | -0.56 | -0.76 | -0.94 | -1.13 |
|  | 16-28 Feb | 0.51 | -1.75 | -0.77 | -0.91 | -1.14 | -1.31 |
|  | 1-15 Mar | 0.58 | -1.72 | -0.59 | -1.26 | -1.52 | -1.61 |
|  | 16-31 Mar | 0.67 | -1.50 | -0.63 | -1.51 | -1.84 | -1.75 |
|  | 1-15 Apr | 0.70 | -1.09 | -0.32 | -1.81 | -1.96 | -1.9 |
|  | 16-30 Apr | 0.75 | -0.31 | 0.23 | -1.94 | -1.75 | -2.03 |
|  | 1-15 May | 0.76 | 0.37 | 0.53 | -1.61 | -1.32 | -2.02 |
|  | 16-31 May | 0.79 | 1.01 | 1.12 | -1.34 | -0.63 | -1.67 |
|  | 1-15 Jun | 0.61 | 1.44 | 1.38 | -1.03 | 0.10 | -1.01 |
|  | 16-30 Jun | 0.24 | 1.58 | 1.33 | -0.54 | 0.64 | -0.04 |
|  | 1-15 Jul | -0.30 | 1.55 | 1.12 | 0.12 | 1.01 | 1.00 |
|  | 16-31 Jul | -0.88 | 1.48 | 0.86 | 0.77 | 1.40 | 1.63 |
|  | 1-15 Aug | -1.15 | 1.49 | 0.71 | 1.23 | 1.72 | 2.41 |
|  | 16-31 Aug | -1.28 | 1.57 | 0.69 | 1.68 | 1.99 | 2.86 |
|  | 1-15 Sep | -1.44 | 1.64 | 0.83 | 1.96 | 2.30 | 3.06 |
|  | 16-30 Sep | -1.24 | 1.63 | 0.97 | 2.12 | 2.28 | 2.85 |
|  | 1-15 Oct | -0.96 | 1.49 | 0.93 | 2.15 | 2.22 | 2.24 |
|  | 16-31 Oct | -0.47 | 1.14 | 0.79 | 2.13 | 1.91 | 0.92 |
|  | 1-15 Nov | -0.01 | 0.28 | 0.54 | 1.96 | 1.09 | 0.27 |
|  | 16-30 Nov | 0.25 | -0.32 | 0.20 | 1.72 | 0.23 | 0.14 |
|  | 1-15 Dec | 0.36 | -0.64 | -0.32 | 1.35 | -0.20 | -0.10 |
|  | 16-31 Dec | 0.33 | -1.38 | -1.22 | 0.49 | -1.01 | -0.62 |

# Supplementary Material Part S2 - Details for simulated forage growth and quality

This material describes additional details used to predict the forage energy supply from various forage sources at each of the 6 study locations simulated in the Farm Feedbase Risk Calculator. Firstly, Table S1 provides the details on the soil types, the plant available water holding capacity for annual and perennial plants assumed at each location. These were derived from common soils in each region and further details can be found at [www.apsim.info/Products/APSoil.aspx](http://www.apsim.info/Products/APSoil.aspx). Secondly, after monthly forage growth was predicted for each forage at each location, this needed to be converted into the units of Metabolizable Energy (ME) provided by each on a monthly basis. The predicted average cycles in forage ME content for each of the forages contributing to the feedbase at each study location are provided in Table S2.

Supplementary Table S6. Details of the soil types in each location used in simulations of forage production.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Location | APSoil No. | Soil type | Latitude and longitude of soil | PAWC1 – annuals (mm) | PAWC - perennials (mm) |
| *Roma, Qld* | 81 | Grey Vertosol | 27.779 S, 150.224 E | 148 | 242 |
| *Temora, NSW* | 913  | Red Chromosol | 34.409 S, 147.531 E | 147 | 221 |
| *Charlton, Vic* | 736  | Red Sodosol | 36.261 S, 143.349 E | 130 | 304 |
| *Hamilton, Vic* | 555 | Brown Sodosol | 37.328 S, 143.463 E | 208 | 208 |
| *Waikerie, SA* | 341 | Supracalcic Calcarosol | 34.496 S, 140.573 E | 118 | 150 |
| *Katanning, WA* | 464 | Yellow Sodosol | 33.796 S, 119.20 E | 83 | 124 |

1 Plant available water-holding capacity (PAWC) used for annuals was the same as for wheat and for perennial pastures was DUL minus LL15 (15 bar) throughout the whole documented soil profile (to 1.5-1.8 m depth)

**Supplementary Table S7.** Details and assumptions used for simulating water and nutrient limited forage growth for common forage sources across 6 locations in the crop-livestock zone of Australia.

| Forage type | Model used | Location | Cultivar  | Grazing/ defoliation management | Fertility scalar/ N inputs | Initial plant density  | Sowing window | Sowing rule | Annual resets |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Annual pastures (Base) | GrassGro | Temora |  | Self-replacing sheep flock grazed year round at stocking rate that kept ground cover > 0.70 for more than 20% of the time.  | 0.80 | n/a | - | - | - |
| Katanning |  | 0.80 | n/a | - | - | - |
| Charlton |  | 0.80 | n/a | - | - | - |
| Waikerie |  | 0.70 | n/a | - | - | - |
| Perennial ryegrass (Base) | GrassGro | Hamilton |  | 0.85 | n/a | - | - | - |
| High input annual pasture (P) | GrassGro | Waikerie |  | 0.85 | n/a | - | - | - |
| Charlton |  | 0.95 | n/a | - | - | - |
| Phalaris grass (P) | GrassGro | TemoraKatanning |  | 0.80 | n/a | - | - | - |
| Tall Fescue (P) | GrassGro | Hamilton |  | 0.85 | n/a | - | - | - |
| Buffel grass (Base) | APSIM-GRASP | *Roma* | *Gayndah* | 1.5 x 200 kg steers/ha grazed when DM> 1.5 t/ha until DM < 0.8 t/ha | 50 kg N/ha/yr | 2.1% cover | *-* | *-* | *-* |
| Bambatsi panic (P) | APSIM-bambatsi | Roma | *Bambatsi* | Remove 60% leaf and 40% stem when DM > 3.5 t/ha | - | 10/m2 | - | - | 1 Aug – soil organic matter to 2 t DM/ha |
| Medic (M) | GrassGro  | Roma | *Parraggio* | 50% removed when DM > 1.5 t/ha | n/a | 10 g seed/m2 | 10 Apr | - | 1 Apr – soil water and N to 0.  |
| Lucerne (U) | APSIM-Lucerne | All except Roma | *Trifecta* | Remove 85% when DM > 2.5 t/ha or mid flowering | - | 120/m2 | - | - | - |
| Dual-purpose wheat (Dw)/ Wheat crop residues (Sw) | APSIM- wheat | All except Roma | *Wedgetail* | Graze 15 DSE/ha when crop DM > 1 t/ha until stem elongation or DM < 0.3 t/ha | 100 kg N @ sowing | 200/m2 | 15 Mar-15 May | Rain ∑ 25 mm over 5 days | Soil N set to 50 kg on 1 Feb |
| Hamilton | *Chara* | 15 May- 1 July | Rain ∑25 mm over 5 days |
| Charlton, Waikerie, Temora, Katanning | *Yipti* | 150/m2 |
| Oats (O) | APSIM-oats | Roma | *Coolibah* | Remove 50% biomass when DM > 3 t/ha | 80 kg N @ sowing | 120/m2 | 1 Apr - 1 Jul | Rain ∑20 mm over 3 days & > 60 mm PAW | Terminate crop when max. temp > 35oC |
| Lablab (Lb) | APSIM-lablab | Roma | *Highworth* | Remove 50% biomass when DM > 4 t/ha | n/a | 20/m2 | 20 Oct- 15 Dec | Rain ∑20 mm over 3 days & > 60 mm PAW | Terminate crop when min. temp < 5oC  |

**Supplementary Table S8.** Monthly metabolizable energy content (MJ ME/kg) of different forage sources and locations. Pastures at different locations have different growth patterns and hence different patterns of forage quality over the year.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Location | Forage type | J | F | M | A | M | J | J | A | S | O | N | D |
| Roma | Tropical grasses (Base + P) | 8.3 | 8.3 | 8.3 | 7.9 | 7.9 | 7.4 | 7.1 | 7.1 | 9.5 | 9.1 | 8.8 | 8.6 |
| Oats (O) | 8.8 | 8.8 | 9.3 | 9.6 | 9.8 | 10.3 | 10.3 | 10.3 | 10.3 | 9.8 | 9.6 | 9.3 |
| Medic (M) | 8.8 | 8.8 | 9.3 | 9.6 | 9.8 | 10.3 | 10.3 | 10.3 | 10.3 | 9.8 | 9.6 | 9.3 |
| Lablab (Lb) | 9.5 | 9.5 | 9.5 | 9.0 | 8.6 | 7.8 | 7.4 | 7.4 | 10.3 | 10.0 | 10.0 | 9.6 |
| Temora | Annual pasture (Base) | 9.4 | 9.0 | 8.8 | 8.9 | 9.6 | 10.2 | 10.5 | 10.8 | 10.9 | 10.5 | 10.1 | 9.7 |
| Phalaris grass pasture (P) | 9.2 | 8.7 | 8.4 | 8.7 | 9.6 | 10.5 | 11.0 | 11.1 | 11.0 | 10.6 | 10.1 | 9.7 |
| Lucerne (U) | 9.7 | 9.7 | 9.7 | 9.9 | 10.2 | 10.3 | 10.4 | 10.5 | 10.6 | 10.4 | 10.1 | 9.8 |
| Charlton | Annual pasture (Base) | 9.6 | 9.1 | 8.9 | 9.1 | 9.8 | 10.3 | 10.6 | 10.9 | 10.9 | 10.5 | 10.3 | 10.0 |
| High input annual pasture (P) | 9.5 | 9.1 | 9.0 | 9.3 | 10.1 | 10.6 | 10.9 | 11.0 | 10.9 | 10.5 | 10.2 | 9.9 |
| Lucerne (U) | 9.7 | 9.5 | 9.4 | 9.6 | 9.9 | 10.2 | 10.3 | 10.5 | 10.6 | 10.4 | 10.1 | 9.8 |
| Hamilton | Annual pasture/perennial ryegrass (Base) | 9.7 | 8.8 | 8.3 | 8.9 | 10.0 | 11.0 | 11.2 | 11.3 | 11.5 | 11.4 | 11.1 | 10.5 |
| Tall Fescue (P) | 9.6 | 9.2 | 8.9 | 9.5 | 10.3 | 10.9 | 11.0 | 11.2 | 11.3 | 11.3 | 11.0 | 10.3 |
| Lucerne (U) | 10.0 | 9.8 | 9.6 | 10.0 | 10.3 | 10.4 | 10.2 | 10.2 | 10.6 | 10.8 | 10.7 | 10.4 |
| Waikerie | Annual pasture (Base) | 9.6 | 9.4 | 9.1 | 9.0 | 9.4 | 10.0 | 10.5 | 10.7 | 10.6 | 10.4 | 10.1 | 9.8 |
| Phalaris grass pasture (P) | 9.6 | 9.5 | 9.2 | 9.1 | 9.6 | 10.2 | 10.6 | 10.7 | 10.6 | 10.4 | 10.1 | 9.9 |
| Lucerne (U) | 9.6 | 9.4 | 9.4 | 9.5 | 9.8 | 10.1 | 10.3 | 10.5 | 10.4 | 10.3 | 10.0 | 9.8 |
| Katanning | Annual pasture (Base) | 9.5 | 9.1 | 8.7 | 8.4 | 8.5 | 9.3 | 10.8 | 11.2 | 11.1 | 10.5 | 10.1 | 9.9 |
| Phalaris grass pasture (P) | 9.5 | 9.0 | 8.6 | 8.3 | 8.6 | 9.7 | 11.0 | 11.3 | 11.1 | 10.5 | 10.0 | 9.7 |
| Lucerne (U) | 9.5 | 9.3 | 9.3 | 9.3 | 9.5 | 10.2 | 10.7 | 10.9 | 10.8 | 10.4 | 10.0 | 9.8 |
| All | Dual-purpose wheat (Dw) | - | - | - | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | - | - | - | - |
| Wheat crop residue (Sw) | 5.5 | 5.5 | 5.5 | 5.5 | - | - | - | - | - | 6.5 | 6.5 | 6.0 |

1. In this and the following section, indices for each livestock class and time period will be left implicit. [↑](#footnote-ref-1)
2. In *Bos indicus* breeds, *CM*2 = 0.31 [↑](#footnote-ref-2)
3. In wool sheep breeds, *CL*0,1= 0.389 and C*L*0,2= 0.746 [↑](#footnote-ref-3)
4. 0.09 for wool sheep breeds; 0.063 for meat sheep breeds [↑](#footnote-ref-4)
5. Values for *CW*6 are: Merinos 0.03; Southdown, Ryeland 0.09; Corriedale, Romney 0.06; Dorset, Suffolk, Border Leicester 0.11; Border Leicester x Merino 0.07 [↑](#footnote-ref-5)
6. [↑](#footnote-ref-6)