Appendix

A review of 11 applied dairy nutrition models used in Australia

– Technical details on how each model works

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Disclaimer

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Introduction

This appendix provides technical details for each of the tactical and strategic nutrition models reviewed:

- Key concepts used to model rumen function, predict energy and protein requirements, feed intake, milk response and liveweight changes, pasture subsititution
- Information required to perform a simulation
- Other aspects of the simulation process used

It also provides additional details on each model's development and objectives.

AminoCow

The AminoCow program makes some basic assumptions about the function of the rumen and the cow, which affect how the program performs. The model uses a factorial approach in setting amino acid requirements.
For milking cows, the factors involved are: maintenance, milk production, body growth and body condition repletion. Body growth is calculated if the animal is both less than 48 months of age and less than ideal body size. Body condition repletion is calculated from a desired body condition score of 3.5 at dry off (1-5 scale).

The model prediction for growing animals has two amino acid requirements: one for growth and the other for body condition repletion. All dry cows (including first lactation heifers within 60 days of calving) have a growth requirement (unless they are over 48 months old and over ideal body size), a body condition repletion requirement, again ideal body score at calving is assumed to be 3.5, and a gestation requirement. It has been assumed that all cows will have a minimum 60-day dry period. Therefore, milking cows that are more than 60 days from parturition will not have an added gestation requirement.

AminoCow assumptions on amino acid requirements of dairy cattle

- The true amino acid requirements of dairy cattle are unknown. However, their requirements are similar to other mammalian such as body repletion, maintenance and foetal growth
- Calculations of maintenance are based on the body weight specified by the user. Calculations of gain are based on ideal body weight at maturity. Body condition repletion assumes that all cows should dry off at a body condition score of 3.5.
- The CP requirement per Kg of bodyweight is based on NRC for dairy cattle (1989). For purposes of gain and body repletion, all of this protein is assumed to be true protein, and the protein is assumed to have a pattern of amino acids reflecting the composition of lean body tissue. Utilisation of amino acids for maintenance is assumed to be 80%, while 40% is assumed for gain. AminoCow reflects observations that amino acids are utilised 100% more efficiently for maintenance than for gain. Thus, AminoCow assumes there is less protein turnover for maintenance than for gain. This may not be true under all circumstances.
- Amino acid requirements for milk protein synthesis are assumed to reflect the relative composition of milk protein with a constant 70% utilisation for all amino acids. Amino acid use for gestation has an assumed 100% utilisation rate (this is a value regressed from swine literature). The model considers a linear growth rate for the foetus during the last 60 days of gestation.

In AminoCow amino acids are considered to be derived from two sources:

Microbial synthesised protein

The digestibility of microbial protein is 60% (which is true available protein), but these inputs are editable.

- AminoCow assumes 70% of the CP is from the rumen microbes, but 15% of this available CP is free ammonia and nucleic acids. Thus, the amount of true amino acid protein must be reduced by 15%.
- AminoCow calculates microbial protein synthesis in two ways: one limited by the amount of organic matter fermented and the other limited by the amount of RDP available for microbial synthesis. Total protein synthesis is based on NE for microbial synthesis, which is from NRC (1989). Total microbial protein synthesis is based on NRC (1989) recommendations.
- AminoCow reduces the energy value when RDP is deficient. Consideration has also been given to reducing the energy from RUP and from rumen undegradable starch, as these fractions would not contribute to microbial growth. Energy for microbial synthesis has been reduced when RUP is greater than 30%.
- Rumen microbial synthesis is 'net synthesis' per day.

Rumen undegradable protein (RUP

The digestibility of all RUP protein sources is assumed to be 80%, but these inputs are editable.

- RUP intake values are based on NRC, Spartan 2 and Feedstuffs (1994-2002) and journal publications. Increasing passage rates make only minor differences in the total flow of RUP to the intestinal tract.
- It is assumed that amino acids are not preferentially degraded in the rumen, and amino acids from RUP are not materially different from RDP.
- AminoCow doesn't model amino acid recycling in the rumen nor the peptide utilisation.
- Protein sub-fractions of the microbial protein, RDP or RUP, have not been considered in AminoCow.

Dry matter intake (DMI)

- AminoCow includes an adjustment factor for days in milk to calculate DMI. This factor adjusts for DMI depression in early lactation. Intake is predicted to reach maximum at 80 days in milk.
- For dry cows, the DMI requirement is predicted based on the needs maintenance only.
- For heifers, the DMI requirement predictions are generated as a function of the size of the breed and bodyweight.

Crude protein (CP)

- The information on CP of dairy cows provided by AminoCow is for informational purpose only. The users have been encouraged to use the metabolisable protein requirement as a better measure of the protein requirement.
- The crude protein requirement has components for maintenance, milk production and growth. The predictions are based on expected mature body size and body condition score at dry off.
- The CP requirements of dry cows vary during different days of transition period.
- The CP requirements for heifers also vary with the age of young cattle (e.g. less than or more than 12 months).

Metabolisable protein (MP)

- For lactating cows with > 14 days in milk, the MP requirements are the sum of 10 essential amino acids multiplied by 2.
- For lactating cows with < 14 days in milk, the MP requirements are the sum of 10 essential amino acids multiplied by two plus an extra 15% for gluconeogenesis.
- For dry cows the MP requirements are the sum of 10 essential amino acids divided by 0.45.
- For heifers the MP requirements are the sum of 10 essential amino acids divided by 0.33.

Metabolisable energy (ME)

- AminoCow discourages the use of energy in balancing rations, because energy intake is considered to be a prediction in the model. The users are encouraged to balance the components that provide energy (NDF, MP, Starch, Sugar, Fat, SolND).
- Energy requirements in AminoCow are calculated in megacalories (Mcal) as net energy (NE).
- NE for lactating cows is the sum of NE for maintenance, milk and growth.
- ME for dry cows is the sum of NE for maintenance, growth and pregnancy.
- ME for growing heifers is the sum of NE for maintenance and growth.

CamDairy

The starting point for development of CamDairy was a profit-maximising ration formulation model developed by Dean et al. (1969) and known as the California model. The program structure of the original California model has been retained, with modifications. However, the bio-mathematics of the CamDairy model differs in all aspects from the California model, with the exception of procedures for calculating mineral requirements. These were based on NRC (1978) in the California model and have been retained in the CamDairy model.

CamDairy, described by Hulme et al. (1986) is used by farmers, nutritionists and educational institutions throughout Australia. The core program of the CamDairy model is a bio-mathematical model that incorporates functions to predict nutrient requirements, feed intake, substitution effects when feeding concentrates, tissue metabolism and partition of nutrients between milk production and growth. Nutrition partitioning is described by a series of asymptotic curves relating energy intake to milk production, such that energy requirements per litre increase progressively with level of milk production (Hulme et al., 1986).

CamDairy allows for constraints to be applied relating to concentrations of energy, protein, crude fibre (CF), natural detergent fibre (NDF), fat, calcium (Ca), phosphorous (P), Ca:P ratio and ash in the ration. A minimum is set for roughage in the ration, to avoid problems of low milk fat, and this constraint can be edited.

This model incorporates an econometric model, 'Maximum Profit', which uses linear programming procedures to formulate rations for up to two groups of cows in a herd in a way which maximises income above feed costs, whilst meeting nutrient requirements and satisfying constraints on feed supply and milk production requirements. Other programs in the CamDairy package are 'Least Cost', a program which calculates a least-cost ration using fixed energy requirements for milk production, and 'Analysis', a program which predicts likely milk production given characteristics of the cows, feed intake and feed composition.

Prediction of feed intake

- Maximum voluntary intake of roughage (MVIR)
  - In CamDairy the initial estimate of intake is MVIR, which is defined as the maximum amount of good quality roughage that a cow can eat in a day.
  - MVIR is expressed as a percentage of liveweight. The user has the option of specifying the MVIR or may use the default value calculated by the program.
- Relative edibility
  - Relative edibility is defined as the edibility of roughage relative to the best-quality, temperate herbages, such as early growth of white clover and lucerne, voluntary intakes of which are normally higher than those of all other roughages.
- Stage of lactation
  - The changes in dry matter intake during different stages of lactation are not linear, since most of the change in intake occurs during early lactation. CamDairy distributes the increase in DMI in the first 14 weeks of lactation according to equation of Vadiveloo and Holmes (MVIR = MVIR (0.67 + (4.0401 log(n) – 0.095n + 0.095) x 0.0972), where n = week of lactation.
- Substitution effects
  - A curve composed of three linear segments is used to describe this change in substitution rate. The default values were calculated from Moran and Trigg (1985):
  - When concentrates comprise less than 25% of total ration dry matter, the roughage intake decreases by 0.64kg
  - When concentrates are between 25-50% of total ration dry matter, the roughage intake decreases by 0.84kg
  - When concentrates comprise more than 50% of total ration dry matter, the roughage intake decreases by 1.22kg
- Calculation of intake
  - The intake factors are combined to form the three equations (Hulme et al., 1986). If the substitution rates are altered from the default, then scalar factors with these equations must also change.

Milk response curves – partition of nutrients

- Effect of energy intake
  - Responses in milk production to incremental increases in energy intake above maintenance are not constant, and that a curve of diminishing returns applies due to increasing partition of nutrients from milk production to body tissue.
  - Studies of Jensen et al. (1942) have been used for the determination of response curves; using ability of milk production when nutrient intake is unlimited, ratio of milk produced from the nth MJ of net energy to milk produced from the (n-1)th MJ of net energy, feed intake and liveweight and lactation average.
- Milk production potential for the week (current potential)
  - To predict partition of nutrients for milk production the potential milk production for this week must be estimated.
  - The potential milk production for current week is calculated from potential peak milk yield (Wood, 1980) based on adjusted milk potential a week.
- Milk fat correction
  - Milk fat percentages are calculated based on the following equations:
    - » MJ NE(l)/litres of milk = 1.509 + 0.406 x fat% (ARC 1980); and
    - » (1.509 + 0.406 x fat)/(1.509 + 0.406 x 4).

Liveweight change during lactation

The non-linear relationships between milk production and energy intake above assume that the cow partitions an increasing part of energy intake to tissue deposition rather than milk production. Metabolisable energy associated with liveweight change is predicted by subtracting ME requirements for maintenance, pregnancy and milk secretion from the predicted ME intake. The following parameters were used in CamDairy to estimate liveweight changes during lactation:

- Predicting liveweight loss
- Predicting liveweight gain
- Protein content of liveweight change

Energy requirements

- Energy requirements for maintenance and growth – Maintenance energy requirements are calculated using the equation of Corbett et al. (1986), based on the net efficiency of ME use for maintenance, age, ME for production and liveweight. It is assumed that first-calf heifers are 2.5 years old and second-calf heifers are 3.5 years old.
- Energy requirement for pregnancy – Growth of the gravid uterus during pregnancy is predicted from data given by ARC (1980). The ME requirements for pregnancy are calculated as net energy of the gravid uterus/0.133 (0.133 is assumed to be the efficiency of the utilisation of ME for growth during pregnancy (ARC, 1980)).

Protein requirements

- Protein requirements used in the model are a modified version of the ARC (1980) system, which uses a factorial approach to determine protein requirements and specifies requirements in terms of rumen degradable protein (RDP) and undegradable dietary protein (UDP).

CPM-Dairy (CNCPS model)

The CPM-Dairy (CNCPS model) uses information and codes that can be universally obtained, understood, and applied to describe cattle, and can be easily used in formulae to calculate responses. Although not universally implemented, all of the critical carbohydrate and protein fractions can be routinely determined by feed testing laboratories. The user must have some nutritional knowledge to use the program because of the risks associated with not knowing how to choose inputs. However, with experience CPM-Dairy can be used to evaluate the interactions of animal type and production level, environment, feed composition, and management factors. Changes in the ration needed to meet animal and rumen fermentation requirements under widely varying conditions can also be identified.

CPM-Dairy V1 was evaluated and formulated according to a modified NRC and to an updated V3 of the CNCPS. CPM-Dairy V3 was evaluated and formulated according to V5 of the CNCPS that was in turn updated to include expanded carbohydrate fractions and a lipid sub-model. In CPM-Dairy V1 and CNCPS V5, fraction A of carbohydrate was defined as sugar, but also contained silage acids. However, in CPM-Dairy V3 silage acids and sugars have been separated. In CPM-Dairy V3 and CNCPS V5, fraction B1 of carbohydrate contained starch, pectins and β-glucan. Because these carbohydrates have different ruminal fermentation rates, these groupings did not appear to be appropriate. In CPM-Dairy V3, starch has been separated from β-glucan. CPM-Dairy V3 contains a lipid sub-model to describe ruminal metabolism and digestion of long-chain fatty acids (LCFA). Major aspects of the fat sub-model include:

- intake of fatty acids;
- ruminal lipolysis of dietary fats;
- biohydrogenation of fatty acids in the rumen;
- de novo production of fatty acids in the rumen;
- effects of fat on rumen digestion and fermentation; and
- intestinal digestion of fatty acids.

Energy and nutrient requirements

Energy available for productive functions depends on the proportion of energy consumed that must be used for meeting maintenance (NEm) requirements, and therefore it is considered first in evaluating a diet and animal performance.

Dry matter intake

The DMI predictions are intended as guidelines.

- If observed DMI is more than ±5% of predicted, the user should check that if observed DMI is correct.
- Rations should be formulated on the basis of actual DMI. Even when there are accurate records of feed delivered and unconsumed feed, actual DMI will be over-estimated because of the inability to completely account for feed wasted by cows selectively grazing, or throwing feed out of bunks, across feed alleys and into the animal area.
- Lactating cow and dry cow intakes are calculated according to CNCPS and Roseler et al. (1997)
- Growing dairy heifer intake is calculated according to NRC (1996).
- Intake of lactating cows is discounted during the early phase of the lactation cycle according to Roseler et al. (1997) and for environmental factors based on CNCPS.

Maintenance requirements

The requirements for maintenance in dairy cattle are determined by several factors.

- Maintenance energy requirements in CNCPS are determined by metabolic body size and metabolic rate accounting for breed, physiological state, activity, urea excretion cost, previous nutritional treatment, activity, heat or cold stress and environmental acclimatization effects (Fox et al., 2004).
- Proportion of energy available for productive functions depends on the proportion needed for maintenance.
- Basal maintenance requirement for dairy cows and replacement heifers is computed as 73 and 78 Kcal/kg metabolic body size, respectively.

Growth requirements

The requirements for growth are based on achieving target weights. Energy and protein requirements for growth include adjustments for:

- body weight;
- rate of body weight gain;
- body tissue composition of the gain expected;
- metabolisable protein (MP)- MP requirement for growth is based on composition of gain with efficiency that varies as a function of adjusted body weight;
- expected mature size for breeding herd replacements or expected weight at a particular final composition, considering body size, effect of dietary ingredients, and anabolic implants as adopted by the NRC (2000; 2001); and
- the mammogenesis requirements, for mammary gland growth, added to the growth requirements are 0.94Mcal ME and 277g MP per day.

Lactation requirements

The energy and protein requirements for lactation are calculated based on milk volume and milk components:

- energy and protein required for lactation are calculated from actual milk production and components;
- crude milk protein is adjusted to true milk protein (crude protein % 0.93) to compute requirements;
- metabolisable energy required for lactation is computed from milk energy with an efficiency of 64.4%;
- metabolisable protein requirements are computed from milk yield and milk protein content and MP is converted to milk protein with an efficiency of 65% (NRC, 1985); and
- day of lactation, duration of lactation, milk fat content, milk solids not fat, and protein as described by NRC (2000).

Pregnancy requirements

The requirements of energy and protein for pregnancy and weight gain from growth of the gravid uterus are based on;

- expected calf birth weight;
- day of gestation (Bell et al., 1995; NRC, 2000; 2001);
- metabolisable protein requirements for pregnancy is calculated from net protein using an efficiency of 33%;
- for pregnant heifers, weight of foetal and associated uterine tissue is deducted from equivalent empty body weight to compute energy and protein requirements for growth, but conceptus growth then is added to ME and MP allowable average daily gain (ADG) to target ADG for comparison with observed ADG;
- amino acids (56%) are the main source of foetal energy, and only 34% of amino acid nitrogen extracted by the uterus is used for tissue protein deposition and 56% is lost as urea; and
- uteroplacental tissues rather than foetal tissue consume a major portion (60-70%) of the organic nutrients taken up by the uterus.

Body reserves

Body reserves are used to meet requirements when nutrient intake is inadequate.

- the reserves model uses BCS rather than BW to compute energy reserves because most dairy producers monitor BCS to manage reserves;
- these must be taken into account when evaluating the ability of rations to meet requirements, especially under conditions of environmental stress, feed shortage or early lactation;
- the CNCPS uses the body reserve model developed for the NRC (2000) and adapted for dairy cattle (NRC, 2001) as described by Fox et al. (1999);
- the cycle of reserve depletion and replenishment during lactation and the dry period is reflected by predicted condition score change; and
- modifications and evaluations for dynamic application of the CNCPS model concepts have been published for lactating dual-purpose cows (Reynoso-Campos et al., 2004) and growth (Tedeschi et al., 2004).

Fat requirements

- The lipid sub-model in CPM-Dairy calculates ether extracted (EE) fat (crude fat) and long-chain fatty acids (LCFA).
- In total mixed ration diets (TMR), LCFA= EE -1
- Targets and lower limits for LCFA are based on 50% of milk fatty acids being derived by extraction of LCFA by the mammary gland from blood and, therefore, 50% are synthesised de novo.
- Fat type classifies feed ingredients on the basis of kind of crude fat (Ether Extract) to provide an accounting of rumen active and rumen inert fat.
  - EE 1 is fat in base feed ingredients like forages, grains and proteins. It normally accounts for 2% to 4% fat in ration dry matter.
  - EE 2 is fat in high fat feed ingredients like whole oil seeds, distillers grains and tallow.
  - EE 1 and EE 2 are considered rumen active fats and usually should be limited to 5.0% to 5.5% of ration dry matter to avoid adverse affects on ruminal fermentation.
  - EE 3 is inert in the rumen due to high amounts of saturated fatty acids such as stearic and palmitic or because fat is in the form of calcium salts. EE 3 can be used to raise concentration of fat to 7.0% of ration dry matter.
  - Because there apparently are limits to the amount of fat that can be absorbed from the small intestine, there is little benefit having more than 7.0% EE in rations.

Diet Check

Dairy farmers in the northern irrigation region of Victoria (NIRV) in Australia predominantly produce milk from flood irrigation. However, since the early 1980s, lactating dairy cows have been fed increasing amounts of concentrates and forages to supplement pasture intake. While lactating cows in the NIRV consume 75% of their diet from dry matter (DM) as pasture, on average, there is a wide range of feeding systems in operation, and pasture makes up to 30-100% of total metabolisable energy (ME) intake. The Victorian Department of Primary Industry developed a simple tactical decision support tool, 'Diet Check' to help dairy farmers in the NIRV to estimate whether their cows are consuming sufficient ME, crude protein (CP) and NDF for a specific level of milk production. This program intended to provide a medium for regionally-specific research results to be packaged into a decision support tool for farmers and service providers. The model also can predict pasture intake of grazing dairy cows, and substitution when supplements are fed, and provides estimates of marginal responses in milk yield to supplements.

The Diet Check program:

- is a series of Microsoft Excel™ spreadsheets navigable using visual basic commands. The program estimates requirement of grazing lactating cows for ME from Australian Feeding Standards- ruminants (SCA, 1990), and best estimates of both CP and NDF after herd and feed details have been entered by the user. These standards take into account the energy cost of grazing and of activity, as well as those for maintenance, lactation and pregnancy.
- estimates pasture mass, pasture intake, nutrient selection from pasture and substitution.
- calculates whether metabolisable energy, crude protein or NDF is likely to be deficient for a particular level of milk production.
- is designed for strip grazing or small paddock rotating systems where daily pasture allowance is between 15 to 70 kg DM/cow/day. It is not designed for use in other grazing system outside this range in pasture allowance.
- assumes that the costs of growing pasture have been incurred and the objectives of the user are to use supplements effectively while not unduly compromising the growth or utilisation of pastures.
- integrates nutritional principles included in the 'Nutrition Program' run by Target 10.
- estimates the energy requirements of cows based on equations in SCA (1990) with two modifications (Heard et al., 2004). Firstly, ECOLD, the additional ME required to alleviate cold stress, is not included in the program. This is because the lower critical temperature of lactating dairy cattle would be lower than the ambient temperature in Victoria in all but the most extreme scenarios. Secondly, the EGRAZE component of the maintenance requirement (SCA, 1990), which accounts for additional energy expended during grazing, is computed in a way that is more appropriate for lactating dairy cows (Heard et al., 2004). This increment has two parts; i) the cost of strip-grazing (intensive) and ii) cost of walking from the paddock to milking area.
- crude protein requirements are set at 185, 165, 150 and 120 g/kgDM intake for early, mid and late lactation and dry period, respectively. This may not accurately reflect current knowledge on the various pathways of protein metabolism, and doesn't adequately account for the energy cost associated with excess nitrogen excretion, common when cows graze spring pastures which often have high clover content (Cohen, 2001).
- predicts pasture intake from descriptions of pre-grazing pasture in strip-grazing systems. Functions within Diet Check estimate pasture mass from input of pasture height measured with a rising plate meter.
- uses a regression equation (Stockdale, 2000), based on pasture mass and allowance, pasture quality, and amount and type of supplements to estimate the substitution rate.
- contains a supplement database and users can select up to 5 different supplements, and modify the nutritive characteristics or include other supplements if required.
- can estimate the immediate marginal milk response to concentrate feeding, but the relationship does not account for type of supplement and would not account for decreasing marginal milk production responses at high supplement intakes.

Feed into Milk (FiM)

Platform

The Ultramix Professional Feed Formulation platform (UP) is used in 18 countries across a broad range of feed formulation applications. It was developed in the first instance as an on farm application for advisers and service providers to provide feed formulations that combine linear and non linear components. This is achieved through iterative or consequential linear programming. This provides opportunity costs for feedstuffs (used and unused) and marginal values for constraint parameters. The software is branded with the users logos or preferred images. Reporting options are flexible, in terms of number, type and design. The program is a modelling application and the user can review or modify existing programs or write new ones. There are a number of levels and types of controls to protect the user's intellectual property.

Feed into Milk (FiM) modelling

Feed into Milk (FiM) was designed to develop an improved nutritional model that can be applied in advisery practice. The project included review and evaluation of current information. A joint modelling of animal experiments and feed evaluation approaches was used to develop this feeding system and to construct an improved applied nutritional model to meet the needs of both the dairy farmers and the feed industry. There is a simple spreadsheet based version of FiM which can be used to assess current rations or construct a ration. However in conjunction with the UP platform FiM has become a formulation tool.

FiM uses ATP yield as the energetic basis for rumen function. This approach includes the effect of raw material on intake. Nutrient flows are divided into nitrogen and dry matter with s, a, b, and c descriptors. These inputs were chosen because they are biologically representative and meaningful. These concepts and relevant equations have been reviewed in the FIM text.

There are some Decision Support Systems (DSS) in the FiM model.

- The first DSS allows the users to predict the likely effect of a given ration on milk yield and components. This DSS takes into account the stage of lactation, energy intake, CP, NDF, starch, sugar, and the fatty acid profile of the ration, as well as the expected yield and components for the cow or herd.
- The second DSS predicts the supply and adequacy of amino acids. Rulquin's equations are used for the basis of this model applying requirement versus supply logic.
- The third DSS is focused on rumen stability. These equations do not attempt to predict rumen pH, however, these determine what level of Rumen Stability Value (RSV) is required for a given animal and balance that against the RSV supplied from the feed. The inclusion of a meal factor in this DSS is significant to address the impact of 'slug' feeding; the other factors are milk yield and milk fat, and the number of lactations completed.

Within the UP platform, the user can chose to set these DSS values as formulation constraints, hence meet the determined requirements for the DSS in question, or the user can allow the ration to be solved without reference to the DSS and review the suitability of the formulated ration with reference to the requirement.

Feed into Milk (FiM) has the capacity to take into account feed impacts on intake, and assess the effects of a ration and the feeding system. Feed into Milk (FiM) has been based on development of a framework that can drive an improved nutritional model which can form the basis of a decision support system (DSS) to predict wider consequences of future developments in dairy systems. The program comprises reviews and evaluations of current relevant information on feeding systems, a joint modelling (animal experiment and feed evaluation approach) to derive an improved diet formulation system and the construction of an improved applied nutrition model which can meet the future needs of dairy farmers and feed industry. The model has been based on series of parameters:

- **Feed intake**: Prediction of feed intake of grass silage-based diets were developed based on step-wise multiple linear regression approach. The parameters included concentrate feed level, milk energy output, live weight, silage intake potential (SIP), week of lactation, body condition score and crude protein intake. Inclusion of forage intake potential (FIP) and forage starch (FS) contents and an early lactation adjustment, along with original parameters, can allow the development of a single FiM intake model across the range of grass silage, whole crop wheat, forage maize and concentrate diets.
- **Metabolisable energy (ME)**: Metabolisable energy (ME) developed by AFRC and calorimetric data from ARINI and CEDAR indicated differing maintenance and efficiency values between sites. Feed into Milk uses new approaches to define the ME. One linear and four non-linear regression programs were used to analyse the data for MEm and its efficiency for dairy cows. The residual of sum of squares and variation were similar across all five models. The non-linear functions showed the effects of level of feeding clearly and allow calculation of an overall ME efficiency, and its efficiency within a specific range of ME intakes. This resulted to series of recommendations on ME which can be obtained from FiM manual.
- **Metabolisable protein (MP)**: The MP system, as published by AFRC (1992), has been reviewed and compared with a number of other systems introduced at about the same time. Although it shares a common framework, the MP system in FiM differs from others in a number of details. The MP system underestimates requirements for or over-predicts production from MP. Comparisons with other protein rationing systems suggested that this likely to be due to an underestimation in maintenance requirements, attributable to the fact that the MP system did not include an allowance for metabolic faecal nitrogen (N) losses above a maintenance level of feeding. Feed into Milk has incorporated an allowance for metabolic faecal N losses based on dry matter intake. The efficiency of utilisation of MP for milk protein synthesis in FiM is within the range of values used in other systems as recommended by AFRC (1992). Similarly, the requirements for MP for pregnancy, dermal losses and liveweight change recommended by AFRC (1992) have been incorporated into FiM program.
- **Nutrient supply to the rumen**: The rumen model predicts the amount of rumen microbial protein and digestible undegradable protein that a diet will supply to the dairy cow. The model also has two sub-components:
  - The first of these predicts whether a diet is likely to result in problem with rumen acidosis
  - The second estimates the supply of digestible amino acids to the cow and predicts whether either lysine or methionine is likely to be limiting.

A decision support system (DSS) has also been developed to provide a warning if a diet that has been formulated is likely to give rise to problems with rumen acidosis. The supply of fibre from the diet is calculated from the NDF content of the feeds, but it also allows for the acid generating potential of the feed and its potential acid load (PAL). This ensures that diets containing highly fermentable feed will be balanced by a higher inclusion of fibre.

The amount of energy available to the rumen microorganisms is estimated in terms of ATP supply. The estimated ATP production replaces the concept of fermentable metabolisable energy that was used in the MP system. Feed into Milk doesn't assume that all degraded DM (or organic matter) yields the same amount of energy for the rumen microorganisms. It distinguishes between protein and carbohydrate, and between different sources of carbohydrate (i.e. fibre and starch).

- **Decision support system (DSS)**: Empirical multivariate models were developed to predict effects of diet composition on composition of milk. Apart from diet description, a simple description of dietary fat as saturated, mono-saturated, poly-unsaturated, and long-chain poly unsaturated classes is included in the model.
- **Diagnostic systems based on milk analysis**: Continuous monitoring of individual cow milk composition has the potential to provide detailed useful information on the nutritional status of the cow allowing timely adjustments to the cow's diet.

GrazFeed

The GrazFeed decision support tool (DST) is a component of the GRAZPLAN decision support project, developed by CSIRO Plant Industry, for Australian grazing enterprises, to help graziers improve the profitability of livestock production, through more efficient use of pastures and supplementary feeds. GrazFeed has been designed for any breed of cattle or sheep and for any pasture except the shrub vegetation of semi-arid rangelands. GrazFeed is also designed to help the user assess the nutritive value of a specified pasture for specified animals grazing it and to show the extent to which a desired weight gain or milk yield might be achieved through supplementation. GrazFeed does this by predicting the intake of energy and protein and their use for maintenance and production according to the recommendations in SCA (1990), with some more recent modifications reflected in Nutrient Requirements of Domesticated Ruminants (2007).

GrazFeed provides predictions of intake and productivity at one point in time, using similar procedures to predicting animal reproduction and mortality and pasture growth, from the dynamic biological model underlying the GrassGro DST (Donnelly et al., 1997; Moore et al.,1997) and the FarmWi$e DST (Moore, 2001). The animal biological model was developed from part of the grazing management model described by Christian et al. (1978) and a forerunner of the GrazFeed DST was described by Freer and Christian (1983). It is suggested by the developers of GrazFeed that the animal biological model is suitable for any kind of sheep or cattle, a generality that is achieved very largely by scaling many of the functions to the mature size of the animal. A brief description of version 1 was reported by Freer and Moore (1990) on the initial release of GrazFeed and a full specification of version 3 was published by Freer et al. (1997).

The developers suggest that GrazFeed can help to:

- decide what level of annual production a particular pasture will support;
- minimise the cost of supplementary feeding;
- select the most suitable feeds;
- use only the amount required to maintain stock or achieve a production target; and
- to calculate the energy and protein requirements of sheep and cattle grazing a particular pasture or even lot-fed.

GrazFeed takes into account the type of animal, the availability and quality of pasture, selective grazing and interaction with supplementary feeds (eg. the substitution of supplement of pasture). GrazFeed can also predict the liveweight change of dairy cows after estimating, where appropriate, foetal growth and milk production. Spreadsheet programs (CattleExplorer) that allow the user to test the effect of different variable values and different parameters may be downloaded from the Plant Industry website (www.pi.csiro.au/grazplan). GrazFeed can also be used to test the effect of up to six feeding levels of the specified supplement.

Parameters that are used in GrazFeed model are:

Normal weight, relative size and relative condition

Many of the functions in the model depend on either the stage of development of the animal relative to its mature size or on its body condition, rather than its current weight. The starting point is the standard reference weight (SRW), which is defined in SCA (1990) as the base weight of an animal when skeletal development is complete and condition score is in the middle of the range.

Feed intake

Potential intake

- Potential intake is defined as the amount eaten when unrestricted access is allowed to a feed with DM digestibility of at least 80% (but without pasture legumes in the diet).
- It depends linearly on standard reference weight (SRW) and is a quadratic function of the relative size of the animal.
- For non-lactating animals with body condition >1.0 (1- 8 scale) the condition factor reduces potential intake with increasing relative condition. The potential intakes of mature animals are considerably greater than those predicted by ARC.
- As potential intake depends on relative size, whereas the maintenance requirement for MP depends on body weight, the model allows growing animals recovering from a period of under-nutrition to exhibit compensatory weight gain.

- In lactating dairy cows, potential intake depends primarily on the time from parturition, adjusted for number of young cows and modified to relative potential intake in circumstances that may have affected potential milk yield in the current lactation.

Relative intake

- The proportion of its potential intake that a cow can satisfy reflects the attributes of the feed supply: its 'relative availability' and 'relative ingestibility'.
- For the pasture component of the diet, the first is predicted mainly from pasture mass, and the second mainly from the digestibility of the selected herbage.
- To simulate selective grazing, the herbage mass is divided between 6 pools, each of fixed digestibility (means 0.8 to 0.3), with an additional pool for seeds. The algorithm for calculating relative availability is applied to each pool or class, starting with the most digestible. The exponent in these two equations increases with the proportion of the herbage DM.
- This model incorporates the grazing of seed as well as herbage. Ripe and unripe seeds of each annual species are assigned in the selection hierarchy and are combined with herbage to form the array of available fodder.
- In this model the seed pools may not have the same digestibility, protein content, etc. as herbage at the same level in the selection of hierarchy.

Energy and protein use

The fate of dietary energy and protein use in GrazFeed is based a series of equations (Freer et al., 1997), and is shown diagrammatically in Figure 1. Numbers indicate the corresponding equations in Freer et al. (1997).

Substitution

The procedure used by GrazFeed to predict substitution rate involves integrating the supplement into the hierarchy of herbage pools for estimating relative intake, based on assumption that the grazing animal will select the supplement before it selects herbage of the same or lower quality. The parameters of this function have been selected to fit the data on substitution rate from Allden and Jennings (1962), Langlands (1969), Allden (1981), Milne et al. (1981) and Stockdale (2000). In grazing situations where the effect of the supplement is to rectify a deficiency of protein, herbage intake may be increased by supplementation and substitution rate will be negative, an effect that is simulated through the balance of rumen degradable protein.

There are two options for supplementation; i) roughage alone, which may be offered ad libitum, or ii) concentrate: a mixture of feeds, which may include a roughage offered in limited quantities. This avoids the problem of predicting the 2-way substitution that may occur between pasture, roughage and concentrate feeds if both a concentrate feed and unlimited roughage were available. If roughage option is selected, its composition will be entered in a simple table. If the concentrate option is selection, a mixture from the feed menu will be composed, which may be changed to suit requirements.

- Efficiency of energy use
  - Efficiencies of energy use for maintenance, lactation and growth of conceptus, are in general based on SCA (1990).
- Energy and protein use for maintenance
  - Equations developed by Corbett et al. (1987) were used for predicting ME requirements for maintenance to include the effect of feeding level within the maintenance requirement.
  - The maintenance protein requirement was based on the endogenous urinary protein, endogenous faecal protein and dermal protein. Endogenous faecal protein for solid diets is estimated as a function of dry matter intake (SCA 1990)
- Rumen degradable protein and digestible protein leaving the stomach
  - The total intake of rumen degradable protein is calculated after adjusting the intake from pasture and supplement for the level of feeding to account for changes in the residence time of protein in the rumen.

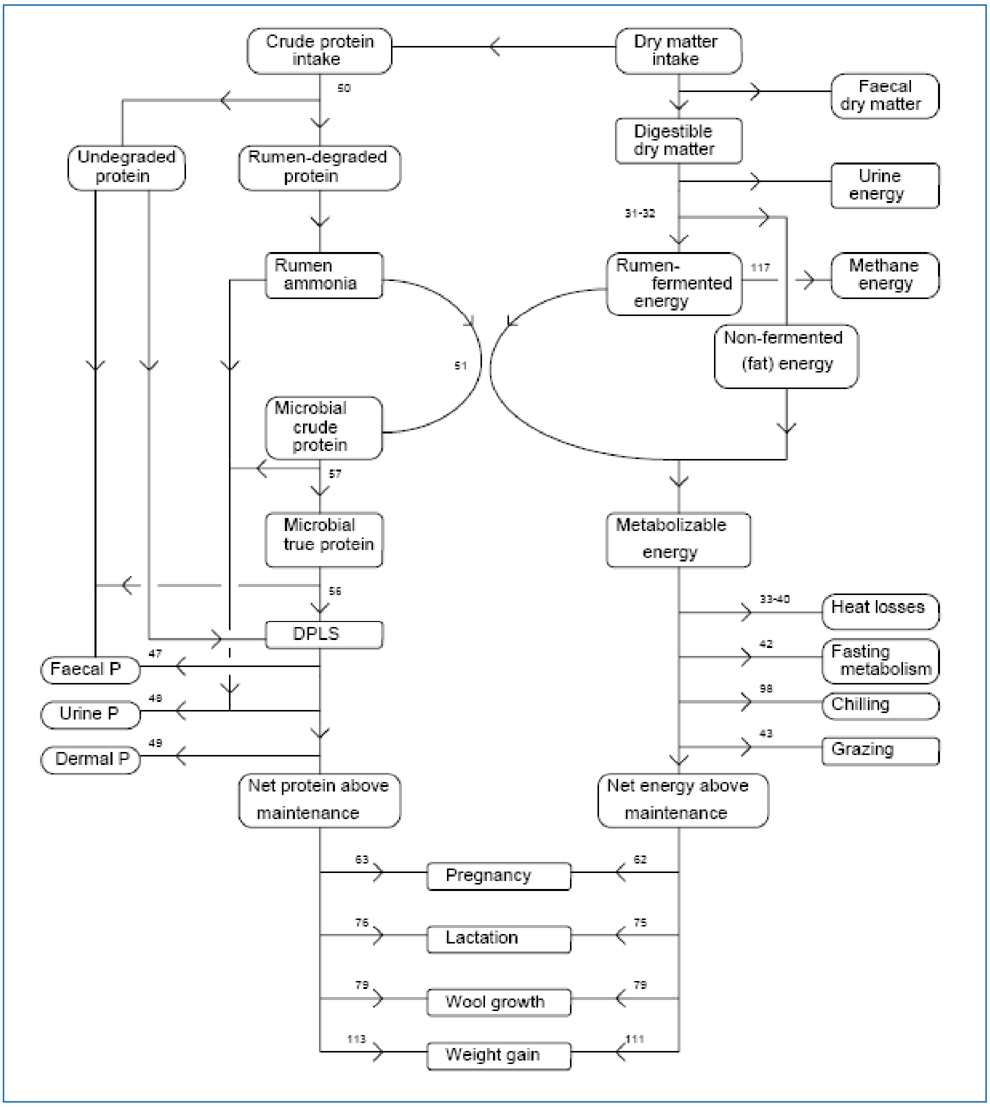

Figure 1: Flows of dietary protein and energy through the ruminant, as represented in the animal biology model (Source: Freer et al., 2006)

- The slope of the adjustment for herbage depends on the digestibility of the pasture component of the diet. The intake of degradable protein from the solid diet is calculated by difference and added to any protein consumed in milk.
- The requirement for rumen degradable protein depends on feeding level (AFRC, 1992) and on time of the year for consistency with the evidence presented in SCA (1990) for seasonal variation in microbial crude protein.
- For supplements, requirement for rumen degradable protein is predicted from fermentable ME intake.
- The assumption is made that recycling of urea to the rumen will offset the remaining deficiency of rumen degradable protein.

- Pregnancy requirements
  - The requirements for the weight of foetus and its growth rate in cows in average condition are calculated according to ARC recommendation (ARC, 1980), with some modifications based on foetus number and base weight of a mature cow.
- Lactation requirements
  - The potential production of milk is expressed as the ME value of the milk for the young cattle based on Wood's (1969) equation to relate the peak milk production to stage of lactation expressed as a proportion of the time to peak lactation and body condition score at parturition.

  - Adjusted lactation for weight loss is estimated from the loss of weight since parturition, and this adjustment is recalculated daily as a function of the maximum value of the lagged mean of the ratio of actual to potential milk production.
- Energy cost of chilling
  - The effects of chilling are calculated for each two-hour period of day, using seasonally-varying temperature and wind speed functions and the contributions of each period to additional requirement of ME for maintenance in chilling conditions are summed.
  - The total insulation of the animal is provided by tissue insulation which is depended on body condition and by external insulation that is associated with the coat and the boundary layer of air.
- Weight change and protein balance
  - Efficiency of use of truly digestible protein leaving the stomach depends upon whether is derived from milk or solid sources.
  - The functions for the prediction of the energy (MJ/kg) and protein (kg/kg) in empty body weight change in growing cattle, as used in SCA (1990), were developed with the aim of relating compositional changes to relative size rather than weight.
  - In mature cattle, the composition of weight change depends on body condition (SCA 1990).
  - Any deficiency in protein that is relieved by reducing milk production, thereby allowing a reallocation of net energy and protein for weight gain.
  - The total faecal and urinary proteins are calculated to compute the nitrogen mass balance.

RationCheck

The NSW Department of Primary Industry developed a simple tactical program, RationCheck. This software was developed to help dairy farmers to check if the formulated ration meets the requirements of lactating dairy cows for ME, CP and NDF for a specific level of milk production. The function of RationCheck is to analyse the current ration for lactating cows, dry cows or replacement heifers. The program can then identify, which, if any, major feed components are not balanced to the herd's requirements given its current level of production, stage of pregnancy or stage of growth. The model has not been designed for milk production prediction, and cannot predict pasture and supplement intake of grazing dairy cows nor the substitution rate.

The RationCheck program:

- calculates the requirements (with lower and upper limits) for each nutrient and concentrate from the inputs data supplied in the herd details;
- calculates the intake for each nutrient and concentrate from the feed supplied in the ration;
- checks if the ration on offer does not meet intake requirements, or the concentration in the diet exceeds the recommended safety limit;
- checks if the ration on offer meets intake requirements, or the concentration in the diet does not exceed the recommended safety limit;
- checks if the ration on offer well exceeds the intake requirement, but not the recommended concentration safety limit;
- calculates the margin over feed from the input supplied on number of cows, and average milk production/day/cow. The average cents per litre or dollar per kg of solid milk, and feed cost for each ingredient in the ration (as fed or DM basis) are used to estimate the margin over feed cost;
- calculates and compares between the price of various feeds either on a c/MJME or $/kg protein basis;
- uses a monthly change in body condition score as an index of average body liveweight change per day. This is then used to calculate how much metabolisable energy is being used or stored as body condition. Changes in BCS are calculated based on NRC (1989) recommendation and, Grifiths and Granzin unpublished data;
- estimates the daily requirement of ME, MP, CP and fat for lactating and dry cows, and replacements based on NRC (1989, 2001) and AFRC (1992) recommendations; and
- estimates on the NSC requirement were based on CPM-Dairy (1998) recommendations.

Rumen8

Rumen8 was developed by Department of Agriculture and Food WA in 2003, and the first version of this program was completed and released in 2006. The beta-version of Rumen8 (2003) has been tested by commercial dairy consultants over a three-year period. The program is a dairy cow nutrition model based on AFRC (1993) equations, except for dry matter intake which is estimated using NRC (2001) equations. The main objective of Rumen8 model was to create a program that could accurately predict milk production when pasture is the major part of the diet and to allow for an estimation of the amount of pasture in the ration. Rumen8 has been designed as a tool for farmers and nutritionists to explore diets and make adjustments according to production and estimates of pasture utilization and consumption.

Rumen8 has the ability to provide a least cost diet from selected feed components, which permits the user to:

- select up to 10 different diet components;
- specify constraints under which the optimisation occurs; and
- store and compare two or three different optimised diets

Rumen8 utilises the non-linear optimising function of Solver that is included in Microsoft Excel™ to provide least cost diets. Information on optimiser function is provided with the program as a separate file.

Energy and nutrient requirements

The Rumen8 model estimates requirements for feed intake, ME and MP. For these requirements the model uses warning lights that change colour. The sensitivity of the warning lights can be adjusted. Default value is 2% (within, above or below range).

- Dry Matter Intake

Rumen8 assumes that the NRC (2001) equations for DMI are valid. Parameters used to describe maximum DMI in the model are:

  - Max NDF DMI% – the theoretical maximum DMI calculated accordingly to the diet and animal described. This assumption works entirely on liveweight and standard value is DMI=1.2% of LW. This value can be adjusted in Rumen8 preferences.
  - Max NRC DMI% – the theoretical maximum DMI calculated accordingly to the diet and animal described. This is calculated according to NRC (2001) as a function of fat-corrected milk, bodyweight and week of lactation.

- Metabolisable energy
  - Total – amount of ME supplied by the diet entered.
  - Requirement – amount of ME required for the animal described (AFRC, 1993).
  - Balance – difference between total and required.
  - Density (MJ/kg DM) – the average ME/kg DM consumed.
- Metabolisable Protein and Crude Protein
  - Total – amount of MP supplied by the diet entered.
  - Requirement – amount of MP required for the animal described (AFRC, 1993).
  - Balance – difference between total and required.
  - CP (%) – the average CP% of the diet.

Diet information

Information provided for the diets modelled in Rumen8:

- NDF in the DMI (as % and in kg/cow/day)
- Effective NDF (% of DMI)
- NDF from all forages (% of DMI)
- NFC %
- Sugar %
- Starch %
- Effective rumen degradable protein (% of CP)
- Total DMI from concentrate and by-products
- P, Ca and Mg (g/kg DM)
- Lysine and methionine (g/cow/day and ratio)
- Cost of the diet ($/t DM), c/MJ ME and $/cow)
- Margin (milk income – feed cost in $/cow)
- Cost of excreting excess ERDP (in litres of milk equivalents)

Feed library

The feed library in Rumen8 contains a total of 42 feeds and the details of each feed can be edited. If none of the feeds match one or more of the components required, new feeds can be created and saved in the feed library.

Margins

Rumen8 calculates a margin over feed cost for selected diets and is expressed as $/cow. Margin ($/cow) is of most use when pasture is in limited supply and supplementary feeding decisions do not impact on pasture intake.

Dairy Predict

Dairy Predict is a dairy feedbase and enterprise planning model developed by the Department of Primary Industries and Fisheries (DPI&F), Queensland, as a DSS tool for the subtropical dairy industry. Dairy Predict resulted from the Dairy Australia and Subtropical Dairy Program project "Sustainable Dairy Farm Systems for Profit". The FeedPlan forage database was adapted from data supplied by NSW Department of Primary Industries.

Dairy Predict has been developed with two potentially important roles:

- to develop suitable farming systems for a particular environment; and
- to explore the effects of different forages, herd sizes, calving patterns and supplementary feeding strategies on individual dairy farm gross margins.

The model has been designed to allow different herds and supplement plans to be compared. The program allows a forage plan for a dairy enterprise to be described by areas and forage type. The model uses monthly dry matter production and ME available from the forage feedbase of a dairy enterprise in combination with different herd structures and supplementary feed plans to provide estimates of the adequacy of dry matter and ME intake. From the latter milk production of the herd can be predicted. The model is based on a combination of NRC and ARC ruminant nutrition equations.

Forage data has been included derived from pasture analyses in the subtropical dairy areas of Queensland and NSW. The forage feedbases, QFEED and NSW FeedPlan, provide average DM production of pastures for each month of the year. A second type of forage feedbases have been developed using the pasture and forage growth rate simulation program 'DairyMod', this makes Dairy Predict possibly unique in that it can account for seasonal variation in pasture and forage production. DairyMod simulations use daily climate files from a locality to predict forage growth. Simulations for a range of locations and forages have been made to produce a database which contains monthly DM production data over 50 years. The advantage of the DairyMod derived forage database is that they allow a particular year to be analysed and also the average of the best, average and worst years to be compared. Users can also enter their own forage feedbase data.

Dairy Predict develops a feed plan, indicating the months of year in which particular forages are available in the identified farm areas. The program also allows for double cropping and for scaling monthly dry matter production up or down for any area in the feed plan.

In Dairy Predict, herds are described in terms of number of cows and calving pattern, potential milk production and composition, liveweight, plus other animal parameters used to calculate the dry matter and energy requirements of each of the herd structures described.

Dairy Predict allows for different supplement strategies, using a variety of concentrates and conserved forages. Several different plans can be defined, for example low or high concentrates, and plans with or without conserved forage supplements. The program then balances the forage base against the selected supplementary feed and herd information, indicating matches, gaps and surpluses.

There is a financial analyse module that allows dairy gross margins for the herds and supplement plans to be compared using the average, worst and best years of the feedbase.

FeedSmart

FeedSmart is designed to assist dairy farmers in efficiently allocating pasture and supplements on a daily basis. This program was developed by NSW Department of Primary Industries, and Dairy Australia as part of the Future Dairy Project. The program has been developed in association with dairy farmers. FeedSmart is based on obtaining measurements of pasture on offer from weekly 'farm walks'. These data are then used in the central part of the program 'feed allocation', where the pasture available, herd requirements and feed deficit for each milking are calculated.

There are a number of supplementary feed options for filling the feed deficits. Options include concentrates, silage, hay or other, or a combination of these. The impact of these options on ration quality and costs of producing milk are estimated. The program provides several options on feed allocation, which describe where to graze the herd each milking and supplements to be fed, and paddock details. Pasture growth, pasture available and the pasture wedge, that is a graph of available pasture by paddock, can also be estimated with the situation on the farm. These outputs can be compared with previous seasons or to other farms.

The allocation of feed is driven by ME requirements, as this invariably limits production under Australian pasture-based system of farming, but protein and fibre contents in the ration are also considered. Both the ration formulation and the calculation of the cost of pasture are only guides and the user is referred to more sophisticated decision support packages if more precise estimates are required.

Model structure. The links between various worksheets that comprise FeedSmart are illustrated in the diagram below.

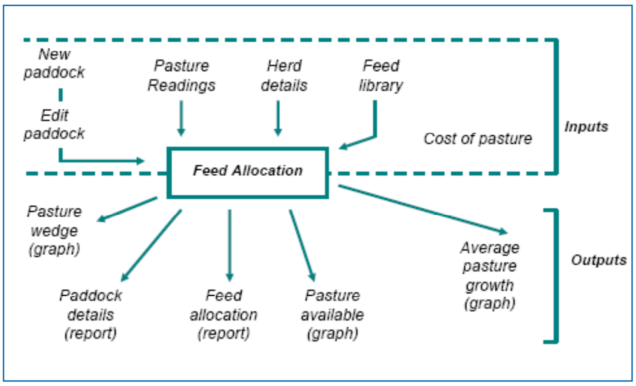

Figure 2: Links between various worksheets in FeedSmart (Source: FeedSmart manual)

FeedSmart contains three main compartments;

- Feed allocation
- Input worksheet
- Output worksheet

The program estimates the feed allocation, pasture availability and growth based on a series of assumptions and estimates:

- Paddock details
  - Land area
  - Post-grazing residues desirable
  - Pasture species
- Herd details
  - Number of cows
  - Body weight of cows
  - Milk yield and composition
- Feeds
  - Available feeds and nutritive values

Following this initial assessment, the routine weekly operation can be conducted for the feed allocation for the lactating cows. If the farm is a steady state (e.g. number of cows, milk yield, pasture types), then the following steps should be taken to estimate the routine feed allocation:

- Measuring pasture DM (kg/ha) using the 'farm walk' method
- For the feed allocation calculation, data from last 'farm walk' are used, and the number of milking cows estimated for selected paddocks
- Supplement options are identified for filling feed deficits

Feed requirements

Herd details are used to calculate feed requirements based on SCA (1990) guidelines. The number of cows, milk yield, milk fat % and milk protein % determine the energy required for production. Liveweight is used to estimate maintenance energy requirements. The calving pattern is used to allow for body reserve changes during different stages of lactation. If an all-year-round calving pattern is selected, then it is assumed that the uniform calving results in equal numbers of cows losing and gaining weight, so no energy allowance is required. When seasonal calving is selected, it is assumed that an amount of body reserves are mobilised to meet milk energy needs in early lactation (first 100 days) that cannot be met by intake, there is no change in body reserves for cows in mid lactation and there is a gain in body reserves in late lactation (last 100 days). The degree of mobilisation or gain of body reserves depends on the level of milk production.

Number of milkings/paddock

The number of milkings/paddock will affect pasture available/cow/milking and the grazing interval. The correct grazing interval should be calculated before allocating feed with this program and should be based on leaf number which in turn depends largely on ambient temperature.

One of the following options may be used to estimate the grazing intervals:

- 3 x (22 -0.55 x mean temperature); and
- the 'rotation right' program developed by the Department of Primary Industries, Victoria

Pasture available and growth

The available pasture depends on the area of the paddock, and the desired post-grazing pasture reside. The pasture on offer in the last 'farm walk' for the last one or two paddocks of each pasture type grazed, can provide the most appropriate post-grazing pasture residue. FeedSmart calculates pasture growth/day since the last farm walk' and uses this to adjust the feed pasture available for each paddock when allocating pasture for the days ahead. If the paddock has been grazed since the last 'farm walk', and so no growth can be obtained for that paddock, then an average growth rate for the whole farm is used. This is a critical part of the program, and if this is not done then the available pasture will be underestimated, particularly in spring.

Feed allocation for weight gain

If it is desirable to feed cows to gain weight then an extra amount of feed should be allocated. FeedSmart provides guidelines to provide specific surpluses for typical Friesian or Jersey cows.

Pasture wedge

The pasture wedge chart in FeedSmart is useful tool to estimate grazing intervals. The following diagnostic chart has been provided to assist farmers identify appropriate management changes.

- If the wedge is concave (Figure 3a), then the grazing interval is too short and the farm will run out pasture, that is cows are eating the pasture at a faster rate that it is growing.
- If the wedge is a straight line (Figure 3b), then the cows are eating the pasture at the same rate as it is growing.
- If the wedge is convex (Figure 3c), then the grazing interval is too long and paddocks would probably need to be dropped out of the grazing rotation and either cut for conserved feed or fed to other stock.

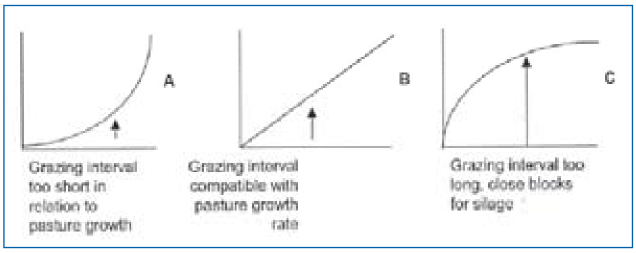

Figure 3: Grazing intervals using pasture wedge chart (Source: FeedSmart manual).

UDDER

This program is a decision support model that predicts the expected milk production of dairy herds grazing pasture under different management systems and pasture growth. UDDER helps farmers make management decisions, and has optimising routines that select management systems that are likely to increase farm profitability. It is a simulation model of a dairy farm where the major food supply is pasture. UDDER can also be used to calculate the feed requirements of a herd provided milk production and body condition of the cows are known.

UDDER can predict the milk production of herds with different calving patterns. Because many factors interact to determine milk production, UDDER accounts for the effect of variables such as pasture growth, stocking rate, supplementary feeding, grazing management and fodder conservation. Milk production is predicted using a simulation of the utilisation of energy within the dairy cow, estimated DMI of cows at pasture, and predicted accumulation and quality of pasture on farms over a year.

UDDER consists of two modules;

1. Standard module

The Standard module is required by all users. It is the simulation model which predicts herd milk production under different systems of management and pasture growth. Sets of data representing farms in different regions are distributed with the program and can be used to investigate management options appropriate to the selected dairying area. With sufficient expertise, UDDER can be calibrated to simulate an individual farm.

2. Professional module

The Professional module is an optional module providing facilities relevant to the analysis of management options on multiple farms. Different types of simulations can be conducted including multiple simulations for multiple farms. The Professional module also enables the user to modify most of the equations used by UDDER to make predictions. It can be used to improve the accuracy of the program for a particular environment or to experiment with the likely effects of implementing new technologies (e.g. better growth or quality pastures).

UDDER is capable of testing large numbers of management options. The Professional module enables UDDER to calculate the values of a variety of variables resulting in an optimum gross margin. It also provides the ability to conduct sensitivity factorial experiments using optimisations.

Farm information

In order for UDDER to simulate the milk production of a dairy farm, this interface of the model allows the users to describe the management of the farm.

The following information is required to carry out a simulation:

- The date to start simulation
- Description of the farm:
  - Size of the farm grazed by the milking herd
  - Standard milking area
  - Average herbage mass (kg DM/ha) on the farm at the start of simulation
  - Whether dry stock graze the milking area
  - Milking cow management
  - Supplementary feeding strategies
  - Maintenance factors (varies in hilly or long narrow farms)
  - Average herbage accumulation rate (kg DM/ha/day) expected for each month of the year for pasture growing from 1500-2500kg DM/ha
  - Stocking rate
  - Supplementary feeding strategies
  - Hay making and fodder strategies
  - Milk price factor (increase or decrease in milk price by a fixed proportion throughout the year)
  - Feed price
- Pasture management
  - Nitrogen fertiliser used (date, amount and expected response in pasture production)
  - Fodder conservation strategies
  - Topping area and post-topping herbage mass
  - Pasture growth factor (growth for each day of year)

  - Pasture quality factor (digestibility for each day of year)
  - Monthly or 10-day period of pasture growth
- Grazing management- UDDER simulates a farm using rotational grazing and so the duration of each grazing rotation is required.
- Animals on the farm
  - Number of lactating, dry cows, replacement heifers, calves
  - Initial average body weight and BCS of adult cows
  - Genetic merit (as measured by the average butterfat production)
- Cow management
  - Calving pattern
  - Drying off strategies
  - Proportion of cull cows due to death, sale, etc.
  - Dry stock (dry cows, replacement heifers and calves)
  - Fat and protein test predictors
- Concentrate supplement (amount, dry matter digestibility and dry matter of supplements)
- Prices of butterfat and variable costs to estimate gross margin analysis

Simulation process

UDDER carries out simulations covering one year, but multiple simulations can be conducted to make predictions for successive years. Each month is treated as three intervals beginning on the 1st, 11th and 21st day, and predictions are made for each of the 36 periods during the year. The farm is divided into 50 paddocks or strips so that rotational grazing can be simulated and the amount of herbage in each strip is stored in an array. The livestock are classified on the basis of whether or not they are lactating, the stage of lactation and age.

Three procedures are executed at the start of a simulation:

- Herbage accumulation rate expected for each day- UDDER takes account of three factors to calculate this:
  - The day of the year
  - The herbage mass present
  - Applications of fertiliser which may provide a period of increased accumulation rate.
- Pasture digestibility- UDDER takes account of two factors to calculate this:
  - The day of year
  - The herbage mass present.
- Initialise variables- UDDER uses the following classifications to simulate this process:
  - Lactating cows are classified based on their stage of lactation
  - Dry cows are classified based on their stage of pregnancy
  - Replacement heifers and calves are classified on the basis of age.

Following this, each of the 36 periods covering a 12-month period is simulated. At the beginning of each time period, arrays storing the number of cows in different classes are updated. This represents the increase in stage of lactation, stage of pregnancy and age. The number of cows which calve is calculated from the calving pattern, and these move into the first class of the herd array.

The average quantity and quality of pasture offered during the period is then calculated, and the herbage intake of each class of livestock predicted. The milk production of lactating cows is simulated, and the dry cows either gain or lose weight depending on their predicted intake. The results of each period are carried forward to simulate the next period. A range of simulation options is available, and these can generate up to three sets of results and can load:

- The actual data and calculate energy intake
- The results predicted for an initial simulation from the start date specific to the strategy
- The results predicted for a subsequent year of simulation

There are several options available for simulations:

1. Unspecified
2. Enter actual – will work when an incomplete data set is used, no prediction made.
3. Calculate growth – requires all strategic and actual information and can predict pasture cover.
4. Fit and actuals – results generated from actual and predictions for the 1st and 2nd years of a simulation based on the growth rates.
5. Single – used to compare results from different management systems, predicts milk production for a single year.

6. Double – used to compare results from different management systems, predicts milk production for a two-year period

The simulation process used by UDDER during each 10-day period can be described as follows:

1. Take the current number of animals in each class and the current amount of pasture in each strip on the farm (the farm is divided into 50 strips). These could be initial values or the values generated from the previous 10-day simulation period.
2. Use the calving, drying off, selling, and agistment patterns entered in the strategy to determine the number of stock actually on the farm during the 10-day period.
3. Use the grazing management details in the strategy to determine the area of pasture to be grazed on a daily basis during the 10-day period.
4. Predict the amount of pasture that will accumulate in each grazing area using the pasture growth rates and nitrogen applications entered in the strategy and determine the average pre-grazing mass on offer during the 10-day period.
5. Predict the pre-grazing pasture digestibility based on the time of year, the pre-grazing mass, and the simulation digestibilities specified through the control menu.
6. Determine the height of pasture available based on the calibration equations provided in the farm data file.
7. Predict the pasture intake of adult cows with the intake of milking cows being calculated separately for each stage of lactation group. The pasture intake of adult cows is based on their potential rate of intake (depends on cow size, body condition, stage of lactation, and pasture digestibility), the height, density, and quality of pasture offered, and the amount of supplement being fed.
8. Calculate the pasture intake of replacements (calves and yearlings) based on the target liveweights specified.
9. Predict the digestibility of pasture consumed by each class of stock and calculate the total energy intake of each class of stock including supplements.
10. Predict the partitioning of energy to milk production and condition score change in adult animals. Replacement heifers are assumed to achieve a standard growth curve.
11. Calculate the residual pasture, final condition score, and liveweight of replacements at the end of the 10-day period.
12. Load all results of the simulation into the results section of the strategy where they will remain unchanged until a subsequent simulation.

The predicted energy requirements of the different processes within cows are based on the recommendations of ARC (1980). The remaining relationships which are distributed with the program have been derived from experimental data from Victoria and from published results. These equations can be modified to suit your environment using the Professional module. The 'Watch and Learn' option located on the Results menu allows the users to observe how UDDER makes the calculations during a simulation to make a prediction.

Predictions

The process of getting UDDER to predict what actually happens on a farm is quite challenging, and calibrating UDDER for a farm requires thorough understanding of the change in pasture which occurs during the year. The user needs 12 months of farm data for at least the following variables:

- Milk production and composition
- Body condition score
- Average pasture cover on the farm during the year
- Fodder conserved on the farm
- Pasture digestibility

The following is a list of predictions that can be made when the required information is provided:

- Pasture cover on the farm (shortest, longest and density)
- Pasture regrowth
- Pasture digestibility (DMD%)
- Potential pasture intake
- Base pasture intake
- Substitution rates when supplements are fed
- Actual pasture intake
- Digestibility of pasture consumed
- Energy use in the cow
- Milk production