**IAT**

**INTEGRATED ANALYSIS TOOL**

**for**

**SMALLHOLDERS**

**Reference Guide**

**Version R1.38 – Nov 2015**

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**on behalf of**

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# 1 Overview of the model

This document is a ‘Reference manual’ describing the processes within the model rather than the input detail, and contains many of the relationships (algorithms) used in the model. A lot of detail description of crop and animal costs etc are in the User guide.

The Integrated Analysis Tool (IAT) was developed to explore the biophysical and economic impacts of adjustments to smallholder farming systems, primarily through changes to existing cropping practices, the adoption of forages and different livestock management. In Indonesia, the livestock component is dominated by husbandry of Bali cattle which have strong prospects for increasing the economic welfare of resource-poor smallholder households. In other south-east Asian countries, buffalo and other breeds of cattle play an important role. For west Africa, other breeds can be accommodated and small ruminants are also important.

The IAT: incorporates key economic and biophysical processes, and their interactions in the smallholder farming systems; accommodates a diversity of current and potential farming systems (i.e. management, soil and climate), as well as variation in commodity prices and seasonal climate; is easy to operate by research or extension professionals in an interactive way with farmers; enables rapid assessment of the potential production and economic impacts of changes in a farming system (i.e. management, crops, forages, prices, costs); and can be readily updated for application to new regions, changes in farming practices etc. While the model can be run for a specific, individual farm, it is more applicable to a ‘generic’ or ‘typical’ farm

The IAT was developed for Indonesian smallholders (Lisson *et al.* 2010), and has been used in project planning and development of intervention strategies in low and high rainfall areas. More recently it has been used in Vietnam, China (Komarek *et al*. 2012), Zimbabwe and Pakistan. The structure of the model is readily applicable to most smallholder farming systems in south-east Asia and elsewhere and, subject to some restrictions outlined below, additional crops, forages, animal types or other enterprises can be added with varying degrees of modification of the models.

## 1.1 Structure of the IAT

The IAT integrates data and output from 3 separate models (described below): a pre-existing farming system model (APSIM), and models for predicting cattle growth and mimicking the economic performance of a typical smallholder farm-household enterprise (Figure 1). The IAT specifically operates at the scale of the smallholder farm household and enables a whole-of-enterprise analysis of alternative crop, forage and livestock management options. A simple (user-friendly) interface forms the ‘hub’ of the IAT with links to other input forms. Different regions/climatic zones or soil types can be selected to align with the smallholder community being analysed. User forms allow entry of farm-specific details (i.e. model inputs) relating to farm area and design, household structure, labour allocations for household members, ruminant livestock herd structure and management, and keeping of other animal types (e.g. pigs, poultry), cropping sequence and management. Sub-forms allow for the addition of more detailed information on crop input costs, non-farm income, labour etc. This information parameterises the ruminant and economic models and directs the selection of input from a database of crop model (e.g. APSIM) output, or data from literature or research results. The ‘real-time’ cattle and economic models are then run over a given time period with the exchange of relevant output. Final model output is presented in graph or tabular form describing: (a) biophysical characteristics of the system (i.e. crop and forage yield/biomass and animal production); (b) labour details and; (c) economic performance (cash balance and gross margins).

By conscious design, the IAT does not employ an automated optimization strategy, but rather uses a creep budgeting approach (see explanation below) to explore the impacts of various options. Optimisation analyses typically require the problem setting to be heavily simplified and the process of actually finding a solution is rarely transparent to anyone other than highly specialised users. It was deemed desirable to be able to explore potential options and the complexity of the farm-household linkages in a transparent manner. The creep budgeting approach involves re-specifying various input and output variables in a systematic manner to explore the system response to these changes. That is, the decision-maker ‘creeps’ around the various response surfaces in a systematic fashion to examine whether there is a shift towards or away from a more satisfactory position than some present baseline or starting position. In this way, the use of ‘what-if’ questions is able to provide smallholders, researchers and extension specialists with many insights into how the welfare of the farm-household system will respond to different activities, input and output levels and their respective prices. By including all of the activities that are available to, or necessary for, the household to meet its needs and objectives, the model is able to provide an accurate guide as to whether exploiting different crop, forage and animal options will actually make it better or worse off. This insight is not restricted to financial gains and losses, as the output also includes information on labour requirements (including gender), food yield, and surplus resources which might be usefully employed within or outside the farming enterprise.

Output from each simulation can be saved for comparison with other simulations. The parameter settings used to generate the particular output are saved with the output and can be reloaded at a later date. The user can choose to operate the IAT in English, French or Indonesian languages, and the IAT is structured in such a way that additional languages can be easily added.



**Livestock**

**yield**

**Forage yield**

**Crop, forage yield**

Outputs

Cattle,

crop,

forage,

profit,

labour

Inputs

Climate

Soil

Management

Price

Costs

Labour

Machinery

Feasible / most profitable strategy

**Herd structure**

**& management**

**Livestock**

**model**

 **Economic**

**model**

**APSIM**

**(Crop/forage**

**model)**

**Figure 1**. Structure of the Integrated Analysis Tool (IAT)

## 1.2 APSIM Crop model

**NOTE**: It is not essential to use the APSIM crop model. Any crop/forage model, or series of models can be used, or the necessary information could be gathered from experimental records or from the literature (see Appendix A).

The *Agricultural Production Systems Simulator* model (APSIM) (Keating *et al*. 2003) simulates the growth of a wide range of field crops in response to site-specific soil, climate and management data. Simulation modules representing different elements of the farming system are integrated to represent the system of interest. For south-east Asia, crop modules for rice, peanut, mucuna, cowpea, maize, soybean and mungbean were combined with a soil water module, soil nitrogen and carbon modules and a residue module. These modules are parameterised using management, soil and climate data collected from surveys of smallholder households and biophysical monitoring activities of the farming activities.

APSIM simulations are configured for a range of species x soil type x climatic zone combinations, with the resulting model output relating to forage and crop yield and quality incorporated into a database for the particular region. The IAT user selects the crop/forage configuration that best matches the conditions of the smallholder enterprise under consideration. Additional regional databases can be added to the IAT database as application of the model is extended to new areas.

While APSIM captures the key processes influencing crop and forage production, it does not handle all yield-limiting constraints, such as insect damage, water logging and effects of severe weather on growth and yields. Therefore, simulated yields and resource demands can exceed field results, especially in low input smallholder production systems.In the absence of comprehensive field trials, ‘validation’ of the model is based on a comparison of model output (e.g. predicted yield) with village records and individual household records; which are considered adequate for the purposes of this application.

## 1.3 Ruminant growth model

A critical requirement for integrating a ruminant growth model into the larger IAT framework was that it be both simple and sufficiently precise to predict livestock production outcomes under local field conditions. While many models exist for predicting ruminant liveweight gain, most require information on forage passage rates through the rumen or were developed for European cattle breeds. The former data is not readily available for many of the feedstuffs commonly used by smallholders and the latter models could not be confidently applied to many tropical breeds which are small in comparison to European breeds. For example, Bali cattle are well adapted to heat, can work up to 5 hours per day without apparent physical distress and survive well on poor forages. Moreover, Bali cattle have higher fertility rates than many other cattle breeds and buffalo when raised under similar conditions, but have poorer milk production and suffer higher calf mortality rates. Nevertheless, the key determinant of animal growth, reproduction and mortality rates is animal nutrition. Forage quality, measured by digestibility and protein content, commonly limits production, but smallholders have an array of different feed sources of varying quality available at intermittent intervals; e.g. native and introduced grasses and legumes, field crop residues, plantation residues (leaf, stem, fruit), tree leaves etc.

The ruminant model combines published data and field data relating to animal liveweight, liveweight gain, milk production, age at first calf and calving interval, as well as the quality, composition and quantity of the various sources of feed. The model is largely based on published energy functions with coefficients adjusted for various breeds, with additional intake restrictions based on estimated crude protein (CP) requirements. Energy coefficients for different breeds are included, currently, calving and mortality rates are primarily based on published data for *Bos taurus* and *Bos indicus* breeds. The model is sufficiently robust to capture responses to both grazing and ‘cut and carry’ systems, cope with distinct wet and dry season conditions, and the feeding of crop residues.

Data input is restricted to the quantity and quality of available forage, with annual pasture, sown forage and crop residue biomass, nitrogen content and date of harvest sourced from the database created from APSIM output (or other crop model, published data, or research results).

Intake is determined from the age and current or previous highest weight of the animal. This growth rate is adjusted for the effects of available forage (for grazing), forage quality, and whether the animal is lactating. Protein requirements are calculated on the basis of the adjusted intake, which, if insufficient, is reduced linearly in relation to CP required and CP supply. The digestibility and calculated intake determines the digestible and metabolisable energy intake which is partitioned into energy for maintenance and for growth. Calving interval, age at first calf and calf mortality rates are related to the condition of cows, based on published survey data and field observations for the particular breeds.

Labour requirements for ‘cut and carry’ forages can be varied according to forage availability, or lack thereof, if none is available on farm. Normally, the greater the shortage of forage, the greater the labour requirement as smallholders need to collect forage from greater distances or spend time herding animals on common land. The model runs on a monthly basis with information on calving, animal liveweight, sales, and labour requirements passed to the economic model.

 1.4 Smallholder enterprise economic model

The complexity of a typical smallholder farm-household production system is presented schematically in Figure 2. While the overall performance of this system might be judged in terms of monetary outcomes (e.g. annual net profit), production and consumption pathways are typically indirect and not always well defined. A key aim of biophysical and economic modelling components of smallholder systems is to better understand how these pathways might operate in order to provide new options that may generate an improved level of farming system performance and positive welfare outcomes for the smallholder communities.

The central features of the household enterprise model are the interlinking of a wide array of activities that may be undertaken by the household. These include plantation trees, crops, forages, livestock and non-farm activities that are linked systemically through 4 resource ‘pools’ on which they can either draw or contribute. Non-farm activities (e.g. operating a kiosk, seasonal construction labour) also potentially contribute to, or draw on, the resources that are available to the family for production, consumption (e.g. education, consumer goods) or wealth accumulation (including increased animal herd or flock sizes).

The core of the household model is the constraining and enabling potentials of the 4 resource pools. These include:

(a) labour, including both household members and access to additional casual labour - by functional category and season,

(b) land by type and quality,

(c) forage by type and seasonal availability, including crop and plantation residues, and

(d) cash reserves and credit - i.e. working capital to support production and consumption activities.

The starting size of the different pools is set according to assumptions on the resource endowment associated with the particular smallholder enterprises that are under review. Crop and livestock activities provide input for home consumption also. As different activities are specified, their net demands and contributions to the 4 resource pools are evaluated. The model specifically identifies which pools are acting as constraints on the particular activity mix that is being explored, and the extent to which other resources might be free to provide opportunities for other activities within or outside the farming system.

**Figure 2**. Schematic representation of the complexity of smallholder systems.

Inputs to the household model are drawn from several sources. Yield data for crop, forage and livestock activities are sourced directly from the database and the ruminant model. Price and cost data, production input levels (e.g. fertiliser, seed, materials), and home consumption needs of different products and family expenses are usually derived from a baseline survey of households located in the target communities, although secondary data such as survey reports or informed person interviews might also be usefully employed.

 The economic measures that are produced by the household model include:

(a) total gross margin - including value of home consumed produce,

(b) disposable income after household consumption,

(c) net cash balances, and

(d) the level of accumulated household capital and any outstanding debt balances.

The advantage of the gross margin budgeting approach lies in its simplicity and transparency for potential users of the model. It also has the capacity to run simple sensitivity and risk analyses by varying the main parameter values in the underlying gross margin budgets.

## 1.5 Data structure

The IAT selects and processes data based on 3 broad categories – climate zone, soil type, and years. There are different amounts data required depending on what is being grown. For grain/food crops and forages, details of yield etc over a number of years is required, while for plantation and fruit trees, vegetables and spice crops, only a single value is needed for each attribute and the crop will have the same value each year. When entering grain crop and forage data it is important to specify to which climate zone and soil type the data belongs (see Appendix A).

Climate zone – to specify a new country or a new region within a country that has a different climate, each can be given a zone number. For example, the dry areas of a country might be climate zone 1, the wet areas zone 3, and intermediate areas zone 2. Alternatively, the zones could represent different villages which have different crop and forage growth characteristics.

Soil type –ten different soil types are presently allowed: currently 5 of these are named sand, silt, loam, clay, and heavy clay, but these are merely names, the model uses the soil number.

Time period – the IAT is can run over any number of years. The limit for the user will be the availability of reliable climate data for their region.

## 1.6 Processing sequence of the model

Initially the model reads in all the parameter information regarding the land area and soil types on the farm, the structure of the family, who can do what labour, what crops and forages are grown, what animals are kept etc. The model then proceeds to process the crop, forage and animal data (Figure 3).

## 1.7 Climate information

The IAT does not use any direct climate information e.g. temperature, rainfall, etc. so there is no need to input any climate information into it. The impact of climate variability is captured in crop and forage yields, and subsequent animal growth and farm income, although crops with fixed yields (such as tree crops) will not change. However, if the user is modelling crops or forage yields in a crop/forage model, such as APSIM, then they will need a climate file in order to run those models.

# 2 Land and household information

The area of different land parcels and their soil types is required to match with crop yields in the crop database (see section 3.1), and information on the family structure and their availability for labour in each month determines the potential labour supply.

**Figure 3.** Processing sequence of IAT model

Read initial parameter settings, calculate animal ages, check crops grown and determine monthly costs and labour, and monthly off-farm labour income, get initial crop, forage and natural pasture yield from database

Add forage yields from all crops to forage pools if the correct month

See Figure 4

Determine growth and sales of ruminants

Update ruminant costs and revenue

Determine labour requirements for ‘cut and carry’

Monthly time step

Add up cost, revenue and home consumption for ‘Other’ animals

Update forage pools for consumption by ‘Other’ animals

Add on monthly crop costs and revenue

Accumulate manure composts for all ruminants

Check and add up monthly labour requirements

Add in off-farm income and costs for hired labour, bought forage, overheads, interest, and update cash balance

Store monthly Output

Yes

If 12th month

Check crop, forage and natural pasture yield for next 12 months

No

Yes

Calculate summaries, write output, END

If last month

No

## 2.1 Land areas and soil types

Up to 10 different land parcels can be specified for any one farm. Each land parcel can have a different soil type, or they can all have the same soil type. The soil type is important as this used to select the yield data from the database of crop and forage yields. When a crop is selected by the user, it is necessary to specify which land parcel it is grown on. When the model runs, it looks the soil type for that land parcel, and searches for the selected crop ON THAT SOIL TYPE. The name of the soil type is not important, the model searches of the number i.e. if soil type number 3 is loam and the user specifies loam, then it searches for soil type number 3. The User Guide explains how to change the names of the soil types to suit your region.

The area of each land parcel is specified, and any area that is not available for growing crops or forages (buildings, dams, roadways, etc), and any area that is bunded. Bunds are mounds on which crops might or might not be grown. They might be banks between rice paddies, or contour banks. The user specifies if the crop or forage is to be grown between the bunds (I), or on the bund (B). If there are no bunds then specify I (Interbund).

Common land. In many countries farmers have access to common land. This can be dedicated ‘common land’, unused range or forest land, or, as in the case of west Africa, transhumance herding. This presents a problem when determining available resources. As yet, no real solution has been found for this because the individual farmer has no control over the available resource, and the area available is not known, nor the number of animals using it. To accommodate this problem, a yield for common land is included as a ratio of the on-farm native pasture yield, and given a quality of half that of the native pasture. It is assumed this is an inexhaustible supply. This allows the farmers to keep their animals alive after they have exhausted their on-farm feed resources, which is basically what happens in reality. The model determines the animal intake based on the yield calculated for the common land (see equations in Ruminant section).

## 2.2 Family structure, labour supply and labour priority

Family structure and priority. There are 8 categories within the family structure. These are male and female elderly, adults, teenagers and children. In general terms these represent the following:

* Elderly – people over 60 who now do little work, or only limited activities
* Adults – people between 20 and 60 who are still fully active
* Teenagers – people aged 13-19 who may do some work or may be away at secondary school for lengthy periods
* Children – people less than 13 years old, who may be at school, or may do limited activities such as herding or weeding.

However, in terms of labour, these characterisations are all treated equally by the model. They are merely a means of separating people who contribute different amounts of time and/or can do limited activities. The only difference with children is in the amount of food allocated for home consumption. People in this category (male and female) will be allocated half the adult ration.

Hence the user can interpret the 4 broad categories (elderly, adult, teenager, child) in any they want.

PLEASE NOTE: the model does NOT increase the age of people over time. The model assumes that the family structure remains constant through time and that the number or people in each category remains the same (even though in reality individuals get older, and eventually die).

Labour supply. The amount of labour specified for each person is the total amount of labour they can do in each month. This includes non-farm as well as on-farm labour. This should be expressed in man-days for each person category, where a man-day is considered to be an 8-hour worked by an adult male. If a particular category is considered to be less effective, then their time can be reduced accordingly. All people within a category are considered to work the same number of days per month, and this will remain unchanged each year. We assume that work done helping other farmers will be compensated for when the other farmer helps them.

Non-farm labour. If non-farm labour is specified, then this labour will be allocated to the particular category first i.e. if a category can do 25 days labour per month, but they are working 10 days doing non-farm work, then they will have only 15 days left for on-farm work.

The way the model allocates labour is to determine how many people can do the activity, and then allocate it to the person with the highest priority, if they have time available. Usually the people who can do the least number of activities are allocated the first priority (1). For example, if a child can do only weeding and herding, and the adult male can do everything, then if there is a need for weeding and ploughing, then the model will allocate the weeding to the child and the ploughing to the adult male. This is how most farmers would allocate the work. It would be silly for the adult male to do the weeding and leave the ploughing undone because the child cannot do it. Generally the order of priority is set to children first, then elderly, teenagers, and adults respectively, but the user can change this order if they wish.

## 2.3 Labour activities and permissions

On smallholder farms there are many activities to be completed. Often, particular activities are done by a particular family member. Hence, in considering changes to a farming system it is vital to consider the impacts on family labour and whether or not particular family members have the capacity to do any extra work.

The 22 labour activities include ploughing, planting, weeding, harvesting, herding, milking, etc. It is necessary to indicate which members of the family can do each of the activities.

PLEASE NOTE: At least one box has to be ticked for each activity i.e. there must be at least one person who can do the activity, even if it is not usually done at the location.

When allocating family members to activities, the model checks those activities that the least number of people can do, first, allocates the labour required to the people who can do that activity, in order of priority (as described in 2.2 above), then allocates other activities progressively. If there is no one with time available to do an activity, there will be a labour deficit for this activity, unless labour is hired as required (see section 2.4).

Unfortunately the labour activities cannot be changed at present. This is because particular activities have particular meaning as to when they occur. These are as follows:

Land preparation, ploughing, planting and fertilising are all allocated to the sowing month of the particular crop or forage to which they refer.

Harvesting tree crops, grain crops and other crops, post-harvest activities, storage, transporting and other crop activities all occur in the harvest month of the particular crop or forage.

Weeding, manuring, spraying (chemicals), irrigation/watering and tree management are deemed to occur evenly over the months between sowing and harvest. For example, if 15 days are indicated for these activities, and there is 3 months between sowing and harvest, then 5 days will be allocated to each of the intervening months. If there is only 1 month between sowing and harvest then the 15 will all be allocated to that month. If sowing and harvest are in consecutive months, then it will be divided evenly between those two months.

Animal activities (‘cut and carry’, herding , feeding, milking, and other livestock activities) are deemed to occur every month, while transporting occurs in the month in which animals are sold.

## 2.4 Hired labour

Labour can be hired either on a permanent basis, or as required. There are the same people categories for hired labour as there are for the family household, and the allocation of labour activities are the same. The rate of pay can vary across months, as often the cost of labour increases when there is increased demand e.g. at harvest times.

If labour is hired on a permanent basis, then the specified monthly labour is hired in those months, irrespective of whether there is a need for it or not, and the cost will be added to the whole farm costs. If labour is hired on an ‘as required’ basis, then labour is hired when and only when there is no family labour available for the particular activity in the particular month, with costs attributed to the whole farm.

## 2.5 Overheads, interest and living costs

Overheads are those farm costs that cannot be directly attributed to any particular crop or livestock activity. These include such things as costs for electricity, mobile phone, government fees, etc. but not living costs.

Living costs are the costs for items not associated with farming activities. These would include such things as food, school fees, health costs, etc.

There is no specific facility in the model for farmers to borrow money. However, if the farmers cash balance becomes negative, then it is assumed they have borrowed money from somewhere and will be paying interest on that money, at the rate specified on the form.

# 3 Crop and forage data

There are 4 different types of crops that can be grown, and different information is required for each. The main crops are grain crops (e.g. rice, maize) and forage crops (e.g. Panicum, lucerne, lablab, elephant grass). The annual or monthly yields of the crops/forages are stored in the database (see later), and yields can vary from year to year (or month to month for forages). The other 2 categories are tree crops (e.g. bananas, cashews, coconuts) and vegetable crops (e.g. tomato, cucumber, chilli, tobacco). For tree and other crops, there is no database of yields. The user specifies the annual yield of each crop, and the crop will have the same yield for each year of the model run.

No detail is given regarding the formula and assumptions within any crop model. This is because any crop model could be used to generate the crop and forage data, or indeed, no crop model might be used and data will come from experiments, local knowledge and expert opinion. If a model is used, then the relevant formula and assumptions will be provided in the documentation for the particular model used. See the IAT users guide for how to set up crop and forage data in a parameter file. If no model or literature data is available, then crop and forage yields and nitrogen contents can be estimated by experienced people, allocated to year types, and loaded into a parameter file for use with the IAT (see Appendix A).

## 3.1 Grain Crop data

Information input. The user selects the particular crops they want to grow, and on which piece of land. The soil type for this land will have been specified. When the model runs, it looks up the selected crop number from the crop database in the parameter file, and matches up the climate zone (or village) number, the year and the soil type number. When it finds it, it reads in the month of harvest, the grain yield, stover (residue after grain harvest) yield, the N % of the stover, the feeding priority (or forage pool number) and the yield of any by-products. There is only ONE harvest per year for grain crops. When the harvest month is reached, the grain yield will be used for home consumption (if specified), or sold. A percentage (specified by the user) of the stover will be kept for feeding to animals and will be added to the forage pool indicated by the priority number.

The contents of the forage pool are available for both grazing and ‘cut and carry’, and this information is used by the ruminant model to determine on-farm fodder availability and quality. The N value will determine the quality of the fodder for ruminant feed (protein and digestibility) and the average N content of the indicated forage pool will be adjusted accordingly.

*Protein % = N% \* 6.25*

*Dry Matter Digestibility (DMD) = 36.7 + 9.36\*N%*

Crop costs and labour. Costs and labour will be allocated according to the planting month and harvest month. Seeds and fertiliser costs are allocated to the planting month (specified by the user), and the other ‘per ha’ costs are spread evenly across the intervening months from sowing to harvest month (read from the database). If there is no intervening month then these costs are allocated to the sowing and harvest months. Whole crop costs are allocated to the harvest month. Costs for perennial crops are spread across the whole year, excluding the harvest month.

Similarly, labour for land preparation, ploughing, planting, and fertilising are allocated to the sowing month, while labour for harvesting, post-harvest activities, storing residue, transport and other are allocated to the harvest month. Labour for manuring, weeding, spraying, irrigation and tree management are spread across the intervening months. If there is no intervening month then the labour for these activities are allocated to the sowing and harvest months. Labour is based on a ‘man day’, which is the average amount of work one man can do in an 8 hour day. If other family members work less than 8 hours or their time is not as productive then their available time (work days per month) should be reduced accordingly.

The monthly crop costs and labour requirements are calculated at the start of the model run, and then applied as each month is processed. This is possible because the same crops are grown each year. There can be a small discrepancy if the indicated harvest month (in the crop specifications) does not coincide with the harvest month in the database. Due to rainfall variability, the predicted harvest month output from crop models sometimes varies by a month or two.

Home consumption and revenue. Some grain may be kept for home consumption (kg/year per adult). The amount specified will be kept for adult, elderly and teen in the family, and half the specified amount for each child. If farmers normally keep more than 1 year in storage, this can be specified, along with the amount already in storage. The model will calculate the total amount required for the current year and any storage, deduct the amount already in storage, and retain the balance. The amount for home consumption is deducted from the amount for sale. If there is insufficient to meet the requirements for home consumption, then all grain from the harvest will be kept and any shortfall will be purchased, when supplies run out. If the household simply keeps all the yield, whatever it is, and does not buy any more if there is no yield, then entering a value of ‘-1’ for home consumption will indicate this to the model.

Revenue comes from the sale of grain and forage (percentage specified by the user), as well as from any by-products. The yields of these come from the database, and the sale prices are specified by the user. For grain, this can be sold over a full 12 months period, with different proportions sold each month, and with different prices each month, each specified by the user. By-products are sold in the harvest month, unless kept for home consumption.

## 3.2 Forage crop data

Information input. Forage data is read and used in almost the same way as crop data. The difference is that there can be multiple harvests per year. There can be any number of harvests per year, however, because the model runs on a monthly time step there is no advantage to having more than 12 harvests per year. If there are more, then there will be multiple harvests in some months and the yields will be added together and allocated to the specified forage pool. Costs and labour are allocated as for grain crops, with the harvest month taken as the month of the final harvest. Similarly to grain crops, revenue can come from the sale of forage and by-products. Because grain is input as a by-product (within the forage crop section only), there is a fixed price for grain, and it is all sold in the harvest month. The protein and DMD are calculated using the same formula as for crop residue. See Appendix A for how to create a database of forage crop yields.

## 3.3 Dual purpose crops

Dual purpose crops are those crops which are harvested for forage and then let regrow to produce grain and residue. These crops should be included in the forage crop database with the forage harvests included as for forage crop data, and the grain yield included as a by-product in the month in which it is harvested.

## 3.4 Other crops and tree crops

Yields of other crops and tree crops are not pre-modelled and hence there is no database for them. For each crop, the yield is specified by the user, and hence it has the same yield every year of the model run. Crops costs and labour are allocated as for grain and forage crops. There are 3 differences on the tree selection form: instead of the area of crop, the number of trees are entered; instead of % residue retained, the area per tree is entered; and, because there is no residue retention, there is none sold, so this is disabled. Similarly, costs of tree crops are expressed as costs ‘per tree’ rather than ‘per ha’ and it is adjusted to a ‘per ha’ basis based on the number of square metres per tree. Labour requirements should still be entered on a ‘man-days per ha’ basis.

Revenue comes from the sale of fruit or vegetable, and possibly from by-products (the yield and price are specified by the user). Any forage from trees or vegetables (leaf, stem or fruit) is specified by the user and is assumed to be used on the farm. The approximate N content is entered so that the quality of the forage can be determined for ruminant consumption, and the forage can be allocated to a forage pool of the user’s choice. If kept specifically for pig feed (or some other animal) then it can be allocated to a separate forage pool.

Home consumption is indicated as for grain crops and often households simply consume whatever grain or fruit they grow (indicated by entering a value of -1 for home consumption).

## 3.5 Crop specifications

For details of the information required regarding crop costs, home consumption, sale prices, labour requirements, by-products and forage components, see the IAT Users Guide.

## 3.6 Purchased (bought) fodder

Fodder can be purchased to make up any shortfall in supply from the farm. The quality of each type of purchased fodder is specified by the user, and the forage pool into which it is to be added.

Specific amounts of fodder can be purchased in a given month, or the user can indicate that they want fodder purchased only when there is a shortfall in supply. If purchased in a specific month, then the specified amount is bought, amount (kg) is added to the specified forage pool and the protein content of that pool adjusted accordingly. If purchased as required, then, when all forage pools are empty and more forage is required, the number of units of the forage will be purchased and added to the specified forage pool as above. If there is still a shortfall in required forage to feed animals, then another lot will be purchased, and so on until the demand is satisfied.

The cost of the purchased fodder is accounted for and listed as an overhead in the output. The reason for this is that it is not possible for the model to determine which ruminant type or non-ruminant animal the fodder was actually purchased for. Any labour for collection of the fodder is added to the ‘cut and carry’ labour demand.

# 4 Ruminant model

The ruminant model processes each ruminant type separately, and processes 17 different animal categories within each ruminant type (see descriptions below). The model does not process individual animals, hence there is no direct link between individual suckling animals and their mothers.

* ruminant TYPE is referring to a breed of cattle, buffalo, sheep, goat, etc.;
* ruminant CATEGORY refers to the age and sex of the animal, (such as sucklings, weaners, breeding females, sires, etc).

Animals are grouped into 17 categories:

* sucklings (animals less than the specified weaning age,
* weaners (animals aged between the weaning age and 12 months),
* breeding females aged from >1 to <15 years old,
* male animals from >1 to <15 years old, and
* breeding sires.

Male and females are in individual year categories from 1 to 5 year old, then grouped in ages 6-10 and 11-15 years. For sucklings and weaners, each category is divided into male and female.

**Note**: Because of the low animal numbers on most smallholder farms, the IAT works in fractions of animals. For example, if there are only 2 cows and the calving rate is 80%, then 1.6 calves are born. While this is not possible physically, it allows better comparisons to be made and is an accurate way of modelling average performance. This is another reason why the absolute values indicated by the IAT should be taken only as a guide for comparison.

The user specifies which TYPE of ruminants the farmer keeps and, within each ruminant type, how many animals of each CATEGORY there are at the start of the model run, and the approximate liveweight of each category. When the model starts, it looks at the age of the suckling or weaner animals, and the minimum age for mating, and calculates the age of the youngest female with a suckling or weaner. It then determines the actual age (in months) of all the older females based on this. For example: if sucklings are 4 months old, and the minimum mating age is 27 months, then the breeding animal must be 31 months old, or some multiple of 12 months plus 31 i.e. 43, 55, etc. This is why it is important to start with either sucklings or weaners, but not both.

As the model runs, in each month, it loops through each animal category (except suckling animals) within each animal type, calculates the liveweight gain based on the age and weight of the animal, the intake, and the quality of the feed (protein and digestibility) (Figure 4). The suckling animals are modelled separately due to their intake of milk. During this process, any male animals that have reached sale weight or age (whichever comes first) will be sold.

To simplify the aging process of animals, for each ruminant type, all females are deemed to give birth in the same month, provided they have reached the minimum age or weight to breed. The average inter-parturition interval is calculated prior to the model looping through each animal category. Similarly the average mortality rate for juveniles is determined prior to the loop.

After 12 months the animal mortality is determined, the model checks for any females that have reached maximum age and sells them, sells any excess young females, transfers each animal category to the next age category, and buys young females if there are less females of breeding age than indicated as the desired number by the user.

After looping through each ruminant type and category the model processes any ruminant trades.

## 4.1 Fodder/ forage pools and limits of use

Forage pools. A forage pool is a way of keeping account of the available forage on the farm via simple budgeting. For example, if there is 1 ha of grass with a yield of 2000 kg/ha, and 1ha of crop residue with a yield of 3000 kg/ha, then from the 2ha there is a total of 5000 kg of fodder available for animals to eat, or the farmer to sell. It is nearly always desirable to separate forages of different quality and to use and account for them separately, hence the model has 10 forage pools.

**Figure 4.** Processing sequence of Ruminant model within IAT

Call from IAT

Loop for each ruminant type categories 3 to 17

Get ruminant coefficients, specifications, forage pool limits, current numbers, ages and weights, determine average juvenile mortality, average inter-birthing interval and check if birth month

Loop for animal categories 3 to 17

Determine normal weight for age, and calculate potential intake, and adjust for availability of feed

Update forage pools and determine protein content of feed, adjust intake

Determine Energy intake and growth of animal

Check for births and update breeder status

Accumulate total intake, methane production, wool and cashmere production, and manure output, check for home consumption

Check for any male animals sold

Update animal numbers, weight, age

No

If last animal category

Yes

Calculate growth of suckling animals, check for weaning, and update parity status of females

Yes

Determine annual mortality, update animal ages, check for sales of females

If 12th month

Calculate ruminant costs & revenue

No

Return to IAT

Yes

No

If last ruminant type

Process ruminant Trades

Crop residue and forage crop harvests are allocated to the various fodder pools (priority), as determined by the user, in the databases for crop and forage yields, and selected by the user on the input form for tree and other crop forage components. While different crops can be allocated to any of the fodder pools, if the best quality fodder is to be rationed in any way, then the best quality forage should be allocated to fodder pool 1 (priority 1), with lower quality forage to pool 2, and so on. Rice or maize straw might be allocated to pool 5 or 6, depending what other forage is available.

For example:

|  |  |
| --- | --- |
| Forage pool 1 | legume crop residue |
| Forage pool 2 | sown grass yields |
| Forage pool 3 | natural grass yields |
| Forage pool 4 | fine grain crop residue (e.g. rice) |
| Forage pool 5 | coarse grain crop residue (e.g. maize) |
| and so on to |  |
| Forage pool 10 |  |

Then each time there is a harvest of a crop with ‘priority’ of say 5, the yield will be added to forage pool 5, and the protein content of the forage pool recalculated based on the previous protein content and the protein content of the new forage to be added.

 If the residue from a particular crop is to be fed to a particular animal type (ruminant or non-ruminant) then that residue can be allocated to a separate pool (say pool 6) and the particular animal fed from that pool.

Limits of use. In order to ration out the better quality feed and make better use of it, the user can limit the proportion of animal intake that can come from each of the forage pools. For each forage pool (1-10) the user indicates the maximum percentage that can be fed to a particular ruminant type, or non-ruminant animal.

For example:

if 20kg/day is fed to the particular animal type, and the limit of use of pool 1 is 20%, and pool 2 is 50%, then 4kg will be taken from pool 1, 10kg from pool 2, and the remaining 6kg from other pools, assuming there is sufficient feed in the pools.

Set the limit to 100% if there is no limit on the pool.

If some pools are limited, then these limits can be fixed or flexible. If fixed, then, if there is no other fodder available, no more feed will be taken from the forage pool than the amount specified, and any shortfall will be purchased (if applicable), come from common land, or the farm will show a fodder deficit. If the limits are flexible, then, if there is no other feed available (the other forage pools are empty), the model will exceed the specified limit in order to feed the animals (see Table 1).

**Table 1.** Example of amounts of fodder removed from each fodder pool with different limits, under different combinations of availability. In each case it is assumed that 100kg of feed is required.

|  |  |  |  |
| --- | --- | --- | --- |
| Fodder availability | Enough in all pools | No biomass in unlimited pools | No biomass in some limited pools |
|  |  |  |  | Flexible | Fixed |  | Flexible | Fixed |
| Fodder pool | Limit of use % | kg in pool | kg taken from pool | kg in pool | kg taken from pool | kg taken from pool | kg in pool | kg taken from pool | kg taken from pool |
| Pool 1 | 20 | 1000 | 20 | 1000 | 29 | 20 | 0 | 0 | 0 |
| Pool 2 | 100 | 1000 | 30 | 0 | 0 | 0 | 1000 | 50 | 50 |
| Pool 3 | 100 | 1000 | 0 | 0 | 0 | 0 | 1000 | 0 | 0 |
| Pool 4 | 50 | 1000 | 50 | 100 | 71 | 50 | 1000 | 50 | 50 |
| Pool 5 | 100 | 1000 | 0 | 0 | 0 | 0 | 1000 | 0 | 0 |
| etc | 100 | 1000 | 0 | 0 | 0 | 0 | 1000 | 0 | 0 |
|  |  |  |  |  |  |  |  |  |  |
| Elsewhere |  | 0 |  | 0 | 30 |  | 0 | 0 |

## 4.2 Standard Reference Weight (SRW) and Normal Weight

Animals are assumed to have a normal skeletal growth pattern (Figure 5). This determines the weight an animal should be at a given age, if conditions are reasonable. A growth curve of the form presented in the Feeding Standards book (NRDR 2007) was used:

**Figure 5**. Normal growth pattern for animals with mature weights (SRW) of 450 and 600 kg.

*Normal Weight = SRW- (1-Bwt\_prop)\*SRW\*Exp(-(a\*age)/(SRW^b))*

where *Bwt\_prop* is the birth weight as a proportion of Standard Reference Weight ( *SRW)*, and *a* and *b* are growth coefficients. This function is used throughout the model to determine the expected or ‘normal’ weight of an animal at any particular age. The usual coefficients given in NRDR (2007) are, *Bwt =* .07, *a =* .0115 and *b =* 0.32*.* These values were adjusted for Bali cattle to 0.0472, 0.0126 and 0.32 respectively.

The Standard Reference Weight (SRW) for a particular breed is the weight of a mature female in good condition. Example values are: *Bos taurus* 600kg, large *B.indicus* 550, small *B.indicus* 270-350, Bali cattle 340, goats and sheep 50-60.

The values for ‘a’, ‘b’ and SRW are set in the parameters in the section ‘Ruminant coefficients’, named ‘grwth\_coeff1’, ‘grwth\_coeff2’, and ‘SRW’ respectively. These values can be changed by directly editing the parameter worksheet only, and this should be done with caution.

## 4.3 Intake

An animal has a potential intake based on its current or previous size. The potential intake can then be adjusted for the effects of available forage (for grazing), the amount of ‘cut and carry’, forage quality, or whether the animal is currently lactating. Changes in forage intake associated with supplements are affected by the digestibility and protein concentration of the forage and the supplement, the type of forage, the type of supplement and the intake of supplement.

 *Potential Intake = a \* SRW \* (LWTintake ^ 0.75 / SRW ^ 0.75) \**

*(b - (LWTintake ^ 0.75 / SRW ^ 0.75))*

Where *LWTintake* is the highest weight this animal has been, and *a* and *b* are coefficients. Example values for ‘a’ are 1.7 for cattle and 1.9 for sheep and goats, and for ‘b’ 0.024 for cattle and 0.033 for sheep and goats. The values for ‘a’, and ‘b’ are set in the parameters in the section ‘Ruminant coefficients’, named ‘intake\_coeff’, and ‘intake\_incpt’, respectively. These values can be changed by direct editing only, and this should be done with caution.

If breeding females are lactating, then the potential intake will be increased by a lactation factor, which varies according to the day of lactation(dol) (Figure 6).

*Lactation factor = 1 + 0.57 \* (dol / 81) ^ 0.7 \* Exp(0.7 \* (1 - (dol / 81)))*

*Potential intake = potential intake \* lactation factor*

The potential intake is reduced if the amount of ‘cut and carry’ fed to the animals is less than the potential intake. The total amount of ‘cut and carry’ is allocated to animals on the basis of their metabolic liveweight (MLwt; MLwt = actual liveweight^0.75).

For grazing animals, the intake will be adjusted according to the amount of feed available (yield in kg/ha) for grazing, and the time spent grazing (Figure 7).

*Intake = Potential Intake \* (1 - Exp(-0.002 \* yield))*

*(* with a minimum value of 0.2 of potential intake.)

The intake while grazing is assumed to occur over an 8 hour grazing period. If the grazing time is less than this, the intake from grazing is reduced proportionately.

**Figure 6**. Increase in intake due to lactation (Intake=Intake \* Intake factor)

**Figure 7**. Relationship between forage available and likely intake by an animal using 3 different coefficients, assuming a potential intake of 10 kg/day.

## 4.4 Protein

Protein also affects the animal intake. The crude protein (CP) requirements of a ruminant are determined as

*CP\_required = protein\_coefficient \* Diet\_DMD / 100*

*CP\_supply = protein\_concentration \* 0.9*

*Adjustment factor = CP\_supply / CP\_required,* with a minimum value of 0.3

*Intake = Intake \* adjustment factor*, with a maximum of 1.2 times the potential intake.

The ‘protein coefficient’ is generally set at 130 g/kg of digestible dry matter, although there are indication that Bali cattle require only 110 or less (D.Poppi, *pers.comm*.). The work of Schlecht *et al.* (1999a, b) suggests that west African zebu breeds may be similar to Bali cattle. The values are adjusted assuming the protein is 90% degradable. The protein concentration is the protein content of the available feed supply, taking into account any supplements fed, and the proportion of the ruminant diet taken from each of the 10 forage pools. The protein coefficient (*protein\_coeff*) is set in the ‘Ruminant\_coefficients’ section of the parameters. This value can be changed by direct editing only, and should be done with caution.

## 4.5 Supplements

Up to 5 different supplements can be fed to any one ruminant type. After calculation of the intake, the amount of supplement is added to that intake. There is no allowance for substitution.

By selecting different supplements, different animal categories within the same ruminant type can be fed different supplements. This option can be used to apply preferential feeding of supplements to particular animal categories e.g. weaners, lactating females, etc. The supplement does not have to be a supplement *per se*, it could be lucerne hay, but it would need to be specified in the supplements list. This can be used to preferntially feed certain forages to particular animals. If the forage is grown on the farm, then there will be no cost involved so the user needs to specify that all that particular forage is sold (for zero price), then set the cost of the supplement/forage at zero as well. This does not account for varying amounts of the forage that might be available, si the user needs to ensure they are not specifying more than is available, on average.

## 4.6 Energy

Functions for determining energy intake, energy use efficiency for maintenance, growth and lactation, energy requirements for maintenance etc, have been taken from NRDR (2007).

Gross energy (*EG*) content of feed is set at 18.4 MJ/kg DM, and the proportion of digestible energy that is metabolisable (*EM*) is set at 0.81. The digestible energy is determined by multiplying the gross energy by the dry matter digestibility (DMD) of the diet (*Diet\_DMD*).

Efficiency of use of energy for maintenance (*km*), growth (*kg*) and lactation (*kl*) are:

*km = 0.37 \* EM/EG + 0.538*

*kg = 1.16 \* EM/EG – 0.308*

*kl = 0.35\* EM/EG + 0.42*

Energy required for maintenance (*Emain*) is given by:

*Emain = Kme \* Sme \* (0.34 \* LWT^ 0.75 / km) \* Exp(-0.000082 \* age) + (0.09 \* EMintake)*

where *LWT* is the liveweight (kg), *age* is the age of the animal in days, *Kme* is a breed factor, *Sme* is a gender factor, and *EMintake* is the total intake of metabolisable energy (MJ).

The values for the coefficients and intercepts for *Kme, km, kg* and *kl* are set in the parameters in the section ‘Ruminant coefficients’. These values can be changed only by direct editing, and changes should be done with caution. The value for ‘*Sme*’ is set to 1 for females and 1.15 for males.

Energy required for milk production (*Emilk*) is given by:

*Emilk = milk\_production \* 3.2 / kl*

The feeding value of the balance of energy (*Ebal*), which is the metabolisable energy intake minus the energy required for maintenance and milk production, is adjusted for the rate of loss or gain.

If *Ebal* > 0 then

*Feed\_value = 2 \* (Kg \* Ebal) / (km \* Emain) - 1*

Otherwise

*Feed\_value = 2 \* (Ebal) / (0.8 \* Emain) - 1*

## 4.7 Growth

 The megajoules (MJ) of energy required per kg empty body gain (*Eebg*) is given by:

*Eebg = 6.7 + Feed\_value + (20.3 - Feed\_value) / (1 + Exp(-6 \* (LWT / SRW - 0.4)))*

Liveweight change is determined by calculating empty body change from *Eebg* and *Ebal*, and for *Bos indicus* breeds, increasing by 9%.

If *Ebal* > 0 then

*Liveweight change = 1.09 \* kg \* Ebal / Eebg*

o\Otherwise

*Liveweight change = 1.09 \* km \* Ebal / (0.8 \* Eebg)*

There are studies which suggest that, for some tropical breeds, the efficiency of use of energy during weight loss may be better than that indicated by the equation above, and hence the actual weight loss less.

##  4.8 Milk production

The current relationship for milk production is based on NRDR (2007) (Figure 8).

*Milk\_production = Milk\_max \* LWT / norm\_Anim\_Wt \* (((dol + Milk\_offset\_day) / Milk\_Peak\_day) ^ a) \* Exp(a \* (1 - (dol + Milk\_offset\_day) / Milk\_Peak\_day))*

where *Milk\_max* is the maximum milk production (litres/day), *Milk\_peak\_day* is the day of lactation for maximum production (usually around day 30), *Milk\_offset\_day* is an offset value (usually 4), *dol* is the day of lactation, and ‘a’ is an adjustment coefficient for suckling (0.6) or non-suckling (0.11).

**Figure 8**. Predicted milk production in relation to day of lactation, assuming a maximum of 15 litres per day at day 30.

The values for the coefficients *Milk\_peak\_day* , *Milk\_offset\_day* , *Milk\_curve\_suck* and *Milk\_curve\_nonsuck* are set in the parameters in the section ‘Ruminant coefficients’. These values can be changed by direct editing only, and changes should be done with caution. The value for *Milk\_max* is set via a user input form.

## 4.9 Juvenile growth (calves, lambs, kids, etc.)

The initial birth weight of the juvenile is set as a proportion of the LWT of the mother animal. Hence, the condition of the mother will affect the birth weight of the offspring. The proportion coefficient (*birth\_SRW*) is set in the parameters in the section ‘Ruminant coefficients’. This value can be changed only by direct editing, and should be done with caution.

Juvenile growth rate will depend on both forage intake and milk intake. This is highly complex in that we have to predict both forage intake and milk intake. Incorporating milk quality would improve these estimates, but the model does not predict milk quality. With more data, it may be easier to use an alternative predictor such as the condition score of the mother animal which could act as a surrogate indicator of all these factors. There is no distinction between male, female or castrate juveniles.

*Potential milk intake = 3.8146 + 0.1206 \* LWT*

If the potential milk intake is greater than the predicted milk production for the breeding female, then it is set to that predicted milk production. Further, if the milk intake is less than 3% of the bodyweight of the juvenile, then the difference is made up from forage.

If any supplements are fed then this is added to the intake, then the energy for maintenance and growth are determined as in the formulas in section 4.5 and 4.6, except that the values for kg for milk is set to 0.85, otherwise kg and km are set to 0.7 and 0.85 respectively.

## 4.10 Parturition (birthing) interval and age at first parturition

These linear relationships defining age at first parturition (AFP) and inter-parturition interval (IPI) have been derived from a very limited literature data and confirmed with limited field data and anecdotal evidence. Currently these are determined by the liveweight of the breeding animal in relation to its SRW.

The formula for inter-parturition-interval (IPI in days) and age at first parturition (AFP in days) are:

*IPI = Int((IPI\_incpt \* (LWT / SRW) ^ IPI\_coeff) \* 30)*

*AFP = Int((AFP\_incpt \* (LWT / SRW) ^ AFP\_coeff) \* 30)*

The IPI value for each age group of breeding female is determined at the beginning of each month, and the average value determined. If the value is less than the seasonal mating interval, or if seasonal mating is used, then IPI is set to the seasonal mating interval. If the time elapsed since the last parturition equals the inter-parturition interval then the current month is determined as the month of birth for ALL age groups for this ruminant type. Then, as the model cycles through each age group, if it is a birth month it checks if the female animal has reached the age for parturition, and is not below the minimum LWT for parturition (*Critical\_cow\_wt*). Note: the *Critical\_cow\_wt* is expressed as a percentage of SRW.

The values for the coefficients *IPI\_incpt, IPI\_coeff, AFP\_incpt, AFP\_coeff*, and *Critical­\_cow\_wt* are set in the parameters in the section ‘Ruminant coefficients’. These values can be changed by direct editing only, and changes should be done with caution. The value for seasonal mating interval (*Seas\_mating\_int)*  is set via a user input form.

## 4.11 Conception rates and birth rates

If seasonal mating is used, then the conception rates are derived from the condition of the breeding female (Figure 9). The conception rate is then adjusted for twinning rate to give the birth rate. If this value is greater than the *birth\_rate\_max*, then it is set to *birth\_rate\_max.*

*concep\_rate = birth\_rate\_assym / (1 + Exp(birth\_rate\_coeff \* LWT /SRW + birth\_rate\_incpt))*

*Birth\_rate = concep\_rate + concep\_rate \* Twin\_rate / 100*

If mating is not seasonal, then the conception rate is set to 100%, and the reproduction rate is determined by the inter-parturition interval. For example, if all breeding females give birth every 16 months, on average, then the equivalent annual birthing rate is 75%.

The values for the coefficients *birth\_rate\_assym,birth\_rate\_coeff* and *birth\_rate\_incpt*

are set in the parameters in the section ‘Ruminant coefficients’. These values can be changed by direct editing only, and changes should be done with caution. The value for twinning rate (*Twin\_rate*) is set via a user input form.

**Figure 9**. Predicted conception rate (%) in relation to liveweight of the breeding female, for females with an SRW of 350kg (top line) and 500kg (bottom line).

## 4.12 Mortality/survival rates

 For older ruminants (those >= 1year old), mortality rates are based on the animal condition in relation to its expected ‘Normal weight’ at its particular age (Figure 10), after deduction of the base mortality rate. The base mortality rate is the percent mortality even if animals are well fed and cared for. The mortality is calculated at the end of each 12 month period when animals ages are updated.

 *Survival (%) = (100 - mortality\_base) \* (1 - Exp(-(2.5 \* (LWT / Norm\_Anim\_Wt - 0.1)) ^ 3))*

For juvenile animals (sucklings and weaners) the proportional mortality is based on the condition of the breeding females using a similar equation to that above, but with different coefficients. The potential mortality rate for each age category of breeding female is determined and an average value calculated. The mortality rate is taken into account at the time of weaning.

 *juv\_mortality = Exp(-(juvenile\_mort\_coeff \* (LWT /Nnorm\_Anim\_Wt)) ^ juvenile\_mort\_exp)*

The *base\_mortality* is added to this average juvenile mortality, but the total mortality is limited to a maximum specified by the parameter *juvenile\_mort\_max* and is expressed as a percentage.

The values for the coefficients *juvenile\_mort\_coeff, juvenile\_mort\_exp* and *juvenile\_mort\_max* are set in the parameters in the section ‘Ruminant coefficients’. These values can be changed by direct editing only, and changes should be done with caution. The value for maximum juvenile mortality rate ( *juvenile\_mort\_max*) is set via a user input form.

**Figure 10**. Predicted survival rates based on actual liveweight in relation to the animals ‘normal’ liveweight, for animals with normal weights of 200, 300, 400 and 500kg liveweight.

## 4.13 Weaning

Each month the age of suckling juveniles (categories 1 and 2) is checked to see if the animals have reached the specified weaning age, or the age for natural weaning if natural weaning is being used. The natural weaning age is set at one month greater than the gestation period for the particular type of ruminant (cattle, sheep, goat, etc.). This is set by the parameter *Rum\_gest\_int* in the ‘Ruminant coefficents’ section of the parameter sheet.

The status (dry or wet) of breeding females are updated at weaning time, where ‘wet’ means the female is lactating.

## 4.14 Manure and methane

Manure output is calcualted from the estimated animal intake and the dry matter digestibility (DMD) of the forage eaten. For example, if the estimated intake for an animal is 10kg/day of dry matter, and the DMD is 50% then 5 kg of dry manure is produced. This value will be adjusted for the proportion of manure collected. If the proportion collected is indicated as 60%, then 3kg would be saved for composting, then this value is multiplied by 3 to give the kg of composted manure produced i.e. the composted manure is assumed to be 33% dry matter.

While there are numerous formulae for estimating ruminant methane production, many of these require information that is not readily available e.g. the proportion of legume in the diet. For this reason, earlier versions of the IAT uses the simple formula of Kunihara *et al*. (1999) adjusted by Hunter (2007):

*Methane (grams/animal/day) = 35.16 \* Intake(kg) - 34.8*

However, this formula is specific to large ruminants and is unsuitable for use with sheep or goats. The model now used the formula suggested by Mike Freer:

*Methane (MJ/animal/day) = 0.02 \* Intake \* ((13 + 7.52 \* Emetab) + Emetab\_intake / Emain \* (23.7 - 3.36 \* Emetab))*

where Emetab = the metabolisaable energy content of the diet (MJ/kg), Emetab\_Intake is the total energy intake of the animal (MJ), and Emain is the energy required for animal maintenance (MJ), then

 *Methane (grams/animal/day)* = *Methane (MJ/animal/day)*  / 55.28 \* 1000

There is no calculation of methane production from non-ruminants.

## 4.15 Sales

Each month all male animals are checked to see if they have reached the age or weight for selling males, specified by the user. If so, animals are sold at the price specified for the ruminant type and category, and the income added to the revenue for that type of ruminant. Currently, females are not sold until they have reached the maximum age for breeding females, or there is an excess of females above the maximum number of breeders to be kept. This is checked during the annual update (see section 3.14).

## 4.16 Annual age update

At the end of each 12 month period, all animals have their age increased by 12 month, the number of animals in each category is decreased by the mortality rate (see section 3.10 above), and animals are transferred up to the next age category. If the age of any females exceeds the maximum age for breeding females then they are sold at the price specified by the user and the income added to the revenue for the particular ruminant type. The number of breeding females remaining is calculated, and if less then the number of breeding females desired (as specified by the user) then 1-year-old females are kept for replacement, otherewise all 1-year-old females are sold at the specified price. If there are insufficient 1-year-old females, then 1-year-old females are purchased at the same specified price.

Weaner animals are transferred to the 1-year-old category at this time.

## 4.17 Labour for ‘cut and carry’

Labour for ‘cut and carry’ is based on the time taken to find, cut and collect 25 kg dry matter. This represents an armload (approximately). The time taken could vary considerably during the year if feed is not available on the farm or close by. The model will determine the actual time taken based on the time to collect 25 kg and the amount of cut & carry specified.

The time for ‘cut and carry’ needs to be adjusted if more forage is grown on the farm.

## 4.18 Traded ruminants

Note: for ruminant animals traded, the same number of animals of the specified ruminant type and category will be bought and sold each and every year of the model run, using the same selling criteria each year.

Animals bought and sold are grown using the same intake and growth parameters as those used for the equivalent ruminant type (cattle, sheep, goat) in the breeding section (see above). Any limits of usage from forage pools, specified for the breeding animals, will apply to traded animals also.

# 5 Non-ruminant animals

The growth and reproduction of non-ruminant animals are not predicted by the model. Non-ruminant animals are included purely for the purpose of accounting for the cost of keeping them and the amount of food they consume, any labour required, and any revenue that might be derived from the enterprise.

The user specifies which animals types (pigs, chickens, etc) the farmer is breeding, and specifies the reproduction rate of the breeding animals. The model simply multiplies the number of breeding animals by the reproduction rate to determine the number of off-spring available for home consumption or sale.The bred animals are sold in a particular month for a specfiied price. The same number of breeding females, the same reproduction rate and the same price will be used for each year of the model run. If forage from the farm is used, then limits on particular forage pools can be specified as for ruminant animals (see section 4.1 above).

Non-ruminant animals can be traded as well. Again, their growth is not predicted by the model. The user specifies which animal types (pigs, chickens, etc.) are traded, how many, the purchase and sale prices, and in what month they are sold.

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# Appendix A - Creating a database of crop and forage yields for the IAT

The IAT requires a database of crop, forage and native pasture yields in order to run. This data can come from the output of a crop/forage model such as APSIM, (or any other similar model), from experimental results, from literature, or can be generated using the best estimates of experienced researchers/technicians.

For crops, the IAT requires the grain yield, the residue (stover) yield, the N content of the residue, and the yield of any by-products, and the month of harvest. All yields are in kg/ha, and the N content is a percentage. For forages, the requirements are almost the same except there is no grain yield, and there can be several harvests per year (see sections 5.14.1 and 5.14.2 of the User Guide for more detail of the data required).

## A.1 Estimating yields when no actual data are available

If no actual crop or forage data are available, and there is no suitable model or expertise to model crop and forage yields, then the yields can be estimated by people who have experience with the relevant crops or forages. These estimates should be done for a range of year categories. For example, you might use 3 categories (good, average, poor), or 5 categories (very good, good, average, poor, bad).

This is a 3 stage process:

1. Estimate the yield of the particular crop or forage in each year category e.g. for maize in a 3 category system, its yield in a poor year might be 500kg/ha of grain and 400kg/ha of residue, with an N% of 0.6. In an average year it might be 900, 800 and 0.5, and in a good year 1500, 1950 and 0.4, respectively. If you use a 5 category system then you will need estimates for each of the 5 categories.
2. Select a number of calendar years (e.g. 2003 to 2012) and categorise them as good, average or poor years (or into 5 categories if you used that). For example, year 2003 might be ‘average’, 2004 might be ‘good’, 2005 and 2006 might be ‘average’, 2007 ‘bad’, and so on.
3. Allocate the respective yields to each year based on its category and your estimated yield for that category, and enter into the database as indicated above. For example, if 2003 was an average year, our estimated maize yield for an average year was 900kg/ha of grain, 800kg/ha of residue, with an N content of 0.5%, so enter these values for maize for 2003 (Table 1).

**Table 1**. Example crop database based on estimated values.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Climate zone | Soil type | Crop No. | Crop name | Year No. | Year | Month | Grain yield | Stover yield | N% | Forage pool | By-prod1 | By-prod2 |
| 1 | 3 | 1 | maize | 1 | 2003 | 10 | 900 | 800 | 0.5 | 3 | 0 | 0 |
| 1 | 3 | 1 | maize | 2 | 2004 | 10 | 1500 | 1950 | 0.4 | 3 | 0 | 0 |
| 1 | 3 | 1 | maize | 3 | 2005 | 9 | 900 | 800 | 0.5 | 3 | 0 | 0 |
| 1 | 3 | 1 | maize | 4 | 2006 | 9 | 900 | 800 | 0.5 | 3 | 0 | 0 |
| 1 | 3 | 1 | maize | 5 | 2007 | 10 | 500 | 400 | 0.6 | 3 | 0 | 0 |
| and so on for each year for each crop |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |

The process is similar for forage crops and natural pasture. The only difference is that you need to estimate the harvest (or growth) for a number of periods each year. For example, the average annual yield for Panicum might be 5000kg/ha, but maybe 10% of this grows in May, 30% in June, 30% in July, 20% in August and 10% in September, then you will need to enter values for 5 harvests which would be 500, 1500, 1500, 1000, and 500 respectively, for May to September (Table 2).

**Table 2**. Example forage crop database based on estimated values.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Climate zone | Soil type | Crop No. | Forage name | Year No. | Year | Cut No. | Month | Stover yield | N% | Forage pool | By-prod1 | By-prod2 |
| 1 | 3 | 2 | panicum | 1 | 2003 | 1 | 5 | 500 | 1.6 | 2 | 0 | 0 |
| 1 | 3 | 2 | panicum | 1 | 2003 | 2 | 6 | 1500 | 1.2 | 2 | 0 | 0 |
| 1 | 3 | 2 | panicum | 1 | 2003 | 3 | 7 | 1500 | 1.2 | 2 | 0 | 0 |
| 1 | 3 | 2 | panicum | 1 | 2003 | 4 | 8 | 1000 | 1.0 | 2 | 0 | 0 |
| 1 | 3 | 2 | panicum | 1 | 2003 | 5 | 9 | 500 | 1.0 | 2 | 0 | 0 |
| And so on for each forage for each year |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |

The process of linking your estimated yields to your year categories can be done easily in Excel using the ‘Vlookup’ function (see below). Set up a table of the estimated yields with the categories in the first column, numbered 1 to 3, or 1 to 5. Then set up a table with your years in one column (e.g. 1981 to 2000) and the category in the next column.

Lets say your yield data for maize is in rows A2 to G4 (category in B, followed by grain yield, residue yield, residue N%, and by-products. B3, B4 and B5 will have the numbers 1, 2 and 3 in them (see Figure next page). Lets say your year and year category data is in A7 to B26, with the year in column A and the category in column B.

Then, in column C7 enter the formula VLOOKUP ($B7, $A$2:$G$4,2)

 and drag this down to row 40. This will put the grain yields next to each year according to its category. B7 specifies the year category to look up; $A$2:$G$4 specifies the array to lookup, and the ‘2’ tells it which column to retrieve.

Then do the same for the residue yields and N% and by-products in columns D to G. Just drag the formula across row 7, then change the column number from 2 to 3 to 4, etc, and then drag them all down to row 26.

VLOOKUP($B7,$A$2:$G$4,2) to VLOOKUP($B7,$A$2:$G$4,6)



##

## A.2 Incorporating crop and forage yields into a database

For crops, the IAT requires the grain yield, the residue (stover) yield, the N content of the residue, and the yield of any by-products. All yields are in kg/ha, and the N content is a percentage. For each year of results, record the yields for the particular crop, on the soil type, for the particular climate zone or village. For example, Koumbia village might be village number 1, local maize might be crop number 1 (see Params sheet after the heading ‘Crop specifications’), and the soil type is a loam, which might be soil type 3. If your data begins in 2003, then this is year number 1, and the year is 2003. Indicate the month of harvest, the grain yield, stover yield, N%, and any by-products. The ‘forage pool’ indicates which forage pool you want to add the residue to. Then enter similar data for 2004, and so on, for however many years you have yield data (as per Table 1). Then, if you have other crops, these follow on after crop number 1, starting at 2003 again.

For forage crops, the process is similar. The difference for forage crops is that there can be multiple harvests per year (see Table 2). For example, mucuna might be harvested once in August (185kg/ha in 2003), then let grow to seed for the final harvest in October, when both grain and forage are harvested (165kg/ha of forage and 100kg/ha of grain). Note: the grain yield is recorded as a by-product. Continue this process for each year of data. If there are other forage crops, then they can be added to the database as well. NOTE: for any one forage crop, there must be the same number of harvests every year, even if some of them have zero yields. Different forages can have different numbers of harvests e.g. *Panicum* might have 4 harvests per year and mucuna might have 2.

**Table 1**. Example Crop database

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Climate zone | Soil type | Crop No. | Crop name | Year No. | Year | Month | Grain yield | Stover yield | N% | Forage pool | By-prod1 | By-prod2 |
| 1 | 3 | 1 | maize | 1 | 2003 | 10 | 1000 | 1500 | 0.8 | 3 | 0 | 0 |
| 1 | 3 | 1 | maize | 2 | 2004 | 10 | 1250 | 1800 | 0.7 | 3 | 0 | 0 |
| 1 | 3 | 1 | maize | 3 | 2005 | 9 | 700 | 1000 | 1.0 | 3 | 0 | 0 |
| ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 1 | 3 | 1 | maize | 10 | 2012 | 10 | 1300 | 2000 | 0.7 | 3 | 0 | 0 |
| 1 | 3 | 2 | cotton | 1 | 2003 | 12 | 900 | 1130 | 0.5 | 5 | 0 | 0 |
| 1 | 3 | 2 | cotton | 2 | 2004 | 12 | 300 | 370 | 0.5 | 5 | 0 | 0 |
| ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 1 | 3 | 2 | cotton | 10 | 2012 | 12 | 1500 | 1950 | 0.5 | 5 | 0 | 0 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |

In the forage database, there is an extra forage crop, and that is native pasture. This is the yield of the natural grasses that grow on land that has no crop or forage grown on it. Native pasture is forage crop number 0, and should ALWAYS be specified as growing on soil type 1 (because it covers the whole farm, which may have several soil types). Enter data for natural pasture in the same manner as for other forage crops. In this example it has 3 harvests per year.

**Table 2**. Example Forage database

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Climate zone | Soil type | Crop No. | Foragename | Year No. | Year | Cut No. | Month | Stover yield | N% | Forage pool | By-prod1 | By-prod2 |
| 1 | 3 | 1 | mucuna | 1 | 2003 | 1 | 8 | 185 | 3 | 1 | 0 | 0 |
| 1 | 3 | 1 | mucuna | 1 | 2003 | 2 | 10 | 165 | 3 | 1 | 100 | 0 |
| 1 | 3 | 1 | mucuna | 2 | 2004 | 1 | 8 | 485 | 3 | 1 | 0 | 0 |
| 1 | 3 | 1 | mucuna | 2 | 2004 | 2 | 10 | 385 | 3 | 1 | 300 | 0 |
| ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |
| 1 | 3 | 1 | mucuna | 10 | 2012 | 1 | 10 | 500 | 3 | 1 | 0 | 0 |
| 1 | 3 | 1 | mucuna | 10 | 2012 | 2 | 12 | 550 | 3 | 1 | 600 | 0 |
| 1 | 1 | 0 | native | 1 | 2003 | 1 | 7 | 350 | 1.2 | 3 | 0 | 0 |
| 1 | 1 | 0 | native | 1 | 2003 | 2 | 9 | 300 | 1.0 | 3 | 0 | 0 |
| 1 | 1 | 0 | native | 1 | 2003 | 3 | 11 | 150 | 0.7 | 3 | 0 | 0 |
| ~ | ~ | ~ | ~ | ~ | ~ |  | ~ | ~ | ~ | ~ | ~ | ~ |
| 1 | 1 | 0 | native | 10 | 2012 | 1 | 7 | 350 | 1.2 | 3 | 0 | 0 |
| 1 | 1 | 0 | native | 10 | 2012 | 2 | 9 | 300 | 1.0 | 3 | 0 | 0 |
| 1 | 1 | 0 | native | 10 | 2012 | 3 | 11 | 150 | 0.7 | 3 | 0 | 0 |

##

## Additional help

For additional help on using the model, more detailed explanation of the functioning of the model, or to report any errors detected in the model, please contact :

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