



# final report

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## Protocols for the preparation and validation of GrassGro parameter files

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## **Abstract**

In order to broaden the applicability of the GrassGro decision support tool across Australia's livestock industries, there is a need to develop "parameter sets" that describe attributes of a wider range of pasture species. This report is intended to assist researchers to build these parameter sets. It describes the steps that are required to ensure that a pasture parameter set has the appropriate quality for incorporation into GrassGro (including evaluation by developers, by the custodians of GrassGro and by users of the new parameter set) and makes recommendations as to how parameter sets should be validated.

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## 1. Background

A review commissioned by MLA in 2012 (B.DSS.0002, *Inventory of modelling systems research and modelling for southern feedbase*) identified GrassGro as a significant modelling-based decision support tool used in Australia.

Opportunities for improvement and wider applicability of GrassGro include the need to develop parameter sets for a wider range of pasture species than currently exists. A number of projects funded by MLA (and other RDCs) have developed parameter sets for use in the GrassGro model. However, a number of tasks related to quality assurance, testing, and metadata need to be carried out before the parameter sets can be confidently incorporated into the GrassGro decision support tool for widespread public use.

## 2. Project objectives

The objective of this consultancy is to facilitate the incorporation of new parameter sets into GrassGro to increase the utility and applicability of the program, by developing and communicating protocols for these tasks to the network of GrassGro users and those who have the potential to contribute to the development of parameter sets for GrassGro.

These protocols include:

1. A description of the quality assurance process that is required to ensure that a pasture parameter set has the appropriate quality for incorporation into GrassGro;
2. Recommendations for developers of parameter sets as to how their results should be validated;
3. The necessary steps required to ensure that the parameter sets are plausible and have been verified; and
4. A description of how beta-version releases of parameter sets that have met the necessary requirements described in steps 1-3 can be incorporated into GrassGro for user testing.

## 3. Concepts and definitions

In the GrassGro decision support tool, the dynamics of grassland plants are modelled using a set of equations known as the “GRAZPLAN pasture growth model”. This model has been constructed to be able to represent the dynamics of a wide variety of herbaceous plants and small shrubs.

Some of the terms in the model equations therefore describe attributes that differ between different kinds of plants. Because the model has been designed to ensure that these quantities vary only from plant genotype to plant genotype, and not from environment to environment, these quantities are referred to as the “genotypic parameters”, or “parameters” of the pasture model. The GRAZPLAN pasture growth model has 252 such genotypic parameters; examples include the number of degree-days from the commencement of reproductive development to the commencement of flowering, the specific area of leaves under reference environmental conditions, the target root:shoot ratio during vegetative growth and the critical nitrogen concentration of newly-produced leaves.

Traditionally, each set of parameters in a biological simulation model is regarded – and stored – as a separate collection of values. As the number of distinct parameter sets increases this approach becomes unwieldy, especially when (as in the GRAZPLAN pasture growth model) some processes have alternative representations and so not all parameters have meaningful values for all species.

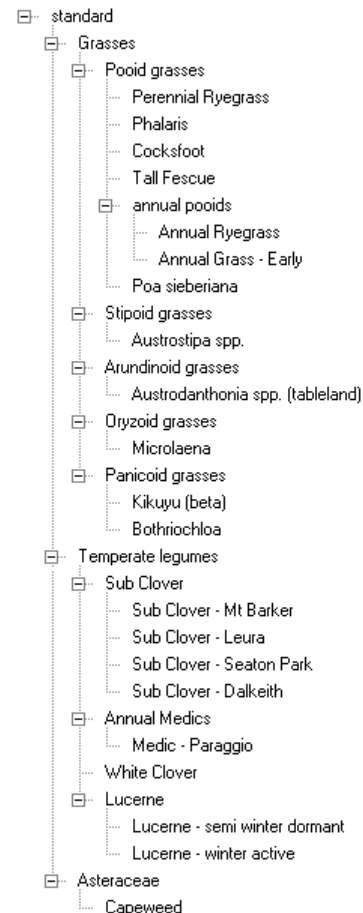
Further, different parameter values – or at least our knowledge of them – vary at different levels of the taxonomic hierarchy. For example, the attributes that control flowering time are likely to vary widely between cultivars of subterranean clover; other attributes such as leaf life spans will vary less within that species – or our knowledge of intraspecific variation is low – but will differ from one legume to another; still other attributes will, as far as we know, be common to all temperate legumes but will differ from grasses.

In the GRAZPLAN pasture model, therefore, the genotypes that are to be modelled are arranged in a hierarchy that is mainly defined by taxonomy (Figure 1), and the values of parameters are defined at different levels within that hierarchy. Genotypes at lower levels in the hierarchy then use parameter values from higher levels in the hierarchy by default.

When the GRAZPLAN pasture model is executed, the sets of parameters that describe the attributes of the relevant species are read from a file. This file is formatted using a technology known as Extensible Markup Language, or XML (Figure 2). A default version of this parameter file is compiled into the executable code of the GrassGro decision support tool (Moore *et al.* 1997) and of the “component” that implements the pasture model within the AusFarm and APSIM software (Moore *et al.* 2001; Keating *et al.* 2003). It is, however, possible to override this default parameter file when running GrassGro, AusFarm or APSIM and so to use an alternative set of genotypic parameters.

When developing a parameter set for a new species, a researcher must define a complete set of values for the genotypic parameters. Not all of the 252 parameters will be given a value in a complete parameter set, since some of the parameters appear in equations that are optional parts of the model. More importantly, however, many of the parameters will have default values that are defined at a higher level in the hierarchy shown in Figure 1; these parameter values can be left alone until evidence is found that the default value is inappropriate for the species under consideration.

As can be seen from Figure 2, pasture parameter files can be modified with any text editing program. A utility program for editing parameter files (param\_edit2.exe) is also available.



**Figure 1.** Genotypes (“species”) in the standard parameter set for the GRAZPLAN pasture growth model, arranged in their hierarchy.

```
<set name="Grasses">
  <par name="grass">true</par>
  <par name="legume">false</par>
  <par name="k-v-15">0.0</par>
  <par name="k-i-">,,,,,,0.7,1.0</par>
  <par name="k-wu-">0.35,1.0,,,</par>
  <par name="k-ru-">,99.9,0.6,,,</par>
  <par name="k-bt-">6.0,0.0</par>
  <par name="k-w1-">0.85,23.0</par>
  <par name="k-re-">0.4,1.75,,0.25</par>
  <par name="k-r-">,,,0.25,1.4,1.2,2.0,0.1,,</par>
  <par name="k-dr-">,0.002,,1.5</par>
  <par name="k-cp-">0.27,0.23,0.195,0.165,0.135,0.105,0.08,0.06,0.04,0.02,0.02,0.02</par>
  <par name="k-dg-">0.925,0.875,0.825,0.775,0.725,0.675,0.625,0.575,0.525,0.475,0.425,0.375</par>
  <par name="k-sf">0.0</par>

  <set name="Pooid grasses">
    <par name="longday">true</par>
    <par name="k-v-">,,,,,,0.25,,,,,-99.9,,,,,</par>
    <par name="k-i-6">0.18</par>
    <par name="k-wu-">,,,120.0,0.6</par>
    <par name="k-ru-">,,,16.0,35.0,55.0</par>
    <par name="k-w-1">0.7</par>
    <par name="k-re-3">0.05</par>
    <par name="k-d-">500.0,0.005,0.005,,,,,</par>
    <par name="k-f1-leaf">0.0025</par>
    <par name="k-q-leaf">0.85,0.75,0.65,300.0,0.006,4.0</par>
    <par name="k-q-stem">0.85,0.7,0.35,,0.004,4.0</par>

  <set name="Perennial Ryegrass" locales="au">
    <par name="annual">>false</par>
    <par name="k-v-">0.05,0.2,5.0,,400.0,400.0,,,600.0,,17.0,0.5,10.0,120.0,,,0.5,6.0,1600.0,,,</par>
    <par name="k-i-">0.0215,0.004,,,0.6,0.9,,</par>
    <par name="k-wu-">,,,100.0,0.9</par>
    <par name="k-ru-1">2.2</par>
    <par name="k-t-">6.0,12.5</par>
    <par name="k-mr-1">0.01</par>
    <par name="k-t1-">0.5,0.02,,</par>
    <par name="k-a-">0.4,0.15,,0.75,0.6</par>
    <par name="k-r-">850.0,2.0,0.0,,,140.0,0.0014</par>
    <par name="k-d-">,,,4.0,-10.0,1.0,,,</par>
    <par name="k-f1-stem">0.0012</par>
    <par name="k-y-1">0.02</par>
    <par name="k-hr">1.0</par>
  </set>
</set><!-- Pooid grasses -->
</set><!-- Grasses -->
```

**Figure 2.** A short section of the standard parameter file for the GRAZPLAN pasture model, showing the way that parameters are stored using Extensible Markup Language (XML).

**Table 1.** A glossary of terms used in this document. Note that these terms have wider or narrower meanings in other contexts.

<b>Pasture Model</b>	The GRAZPLAN pasture growth model, which was originally described by Moore <i>et al.</i> (1997) but has since been modified.
<b>Parameter</b> (more fully, “genotypic parameter”)	A quantity that describes a specific physiological or physical attribute of a plant <i>species</i> . Parameter values are usually real numbers with specific units, but they can also be integer-valued numbers or logical (true/false) values. Two parameters (the name of the last person to modify a <i>parameter set</i> and the date of last modification) are text strings.
<b>Parameter Set</b>	A collection of parameters that together describe a <i>species</i>
<b>Species</b>	The term “species” is used loosely in this document to refer to any genotype of grassland plant that is sufficiently distinctive to require its own <i>parameter set</i> in the <i>pasture model</i> . A “species” can therefore be a cultivar or ecotype, a species in the strict sense, a genus, or a “functional group” of species with similar physiology.
<b>Custodian</b>	The individual, organization or group that takes responsibility for the quality of a model (in particular, the <i>pasture model</i> ) for scientific purposes. The custodian is often the creator of the model, and may hold or share intellectual property rights in it, but these three concepts are distinct.
<b>Parameter Set Developer</b> (or “Developer”)	An individual, organization or group that carries out the task of creating or modifying a <i>parameter set</i> .

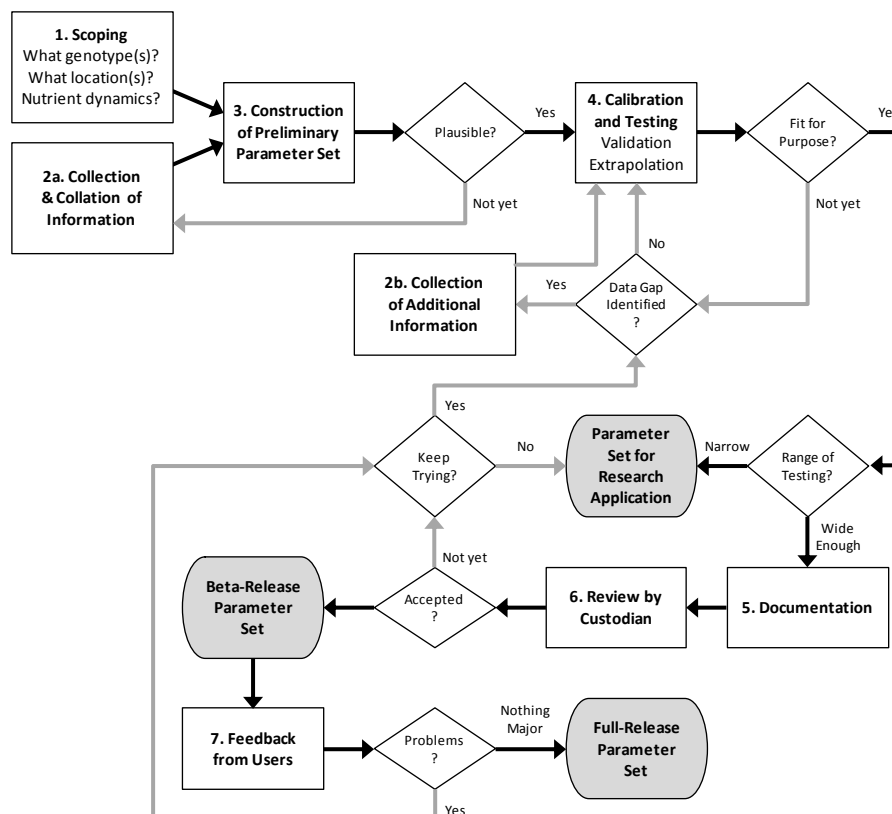
## 4. The quality assurance process for a GrassGro parameter set

Figure 3 shows, in schematic form, the processes that should be followed in developing a new parameter set for the pasture model (or for the GRAZPLAN animal model).

The work flow that is followed depends to some extent on the end point that is desired. For some applications, it is sufficient to develop a set of parameters for a species that works within a relatively narrow geographic area or set of management systems (the endpoint shown as a “parameter set for research application” in Figure 3). In this document, however, the focus will be on the development of parameters that are to be released to a wider set of model users, and which should therefore be evaluated over a range of possible environments and management contexts.

When a parameter set is intended for general use it should undergo three distinct kinds of evaluation, which are shown as steps 4, 6 and 7 in Figure 3:

- Evaluation by the *developer* of the parameter set. This takes place during the process of model calibration and testing, and is virtually always an iterative process.
- Review by the *custodian* of the pasture model (currently CSIRO), prior to release of the new parameter set as part of the modelling software for which the custodian is responsible.
- Evaluation by *users* of the pasture model and the parameter set. While this can,



**Figure 3.** The work flow by which a parameter set should ideally be developed. Black arrows show the case where all steps proceed according to plan.

and has been, done by providing a new parameter set to a selected set of model users, experience has shown the usefulness of releasing a new parameter set widely – explicitly noting its provisional status by declaring it to be a “beta” release – and allowing the community of GrassGro users to broaden the range of contexts in which it is applied.

While the discussion below will treat the development process step-by-step, it should be clear from Figure 3 that a certain amount of iteration is almost always needed.

## Setting the scope

The first step in the parameter development process is to decide what kind of plant is to be described by the new parameter set. This question has a number of parts:

- *What genotype will the parameter set represent?* Where the intent is to represent a specific cultivar of an improved pasture plant, this question is straightforward to answer. At higher taxonomic levels, however, a tradeoff emerges: should different ecotypes, cultivars or species be lumped together, so producing a parameter set that is broadly applicable but less accurate in any given setting, or should the focus be on accurately representing one specific genotype, so limiting the range of applications for the parameter set? The resolution of this tradeoff will depend on the relative importance of different cultivars or ecotypes; the availability of information about the differences between genotypes; and the time available to research and calibrate those differences.

It is advisable to choose a name for a new parameter set early in the development process. The name should clearly denote the genotype or set of genotypes that it represents.

- *What geographic scope will the parameter set have?* As noted above, for some purposes it is sufficient to ensure that the parameter set functions well in a single environment. In other cases, lack of data may restrict testing to a small part of a species' environmental range. The ideal, however, is to test a parameter set over a range of the environments in which the species might be expected to grow.
- *Will the parameter set be used in conjunction with soil nutrient cycling models?* The GrassGro decision support tool does not contain a soil nutrient cycling model, but for some R&D applications the representation of nutrient dynamics, especially of N, is important. If so, the parameters describing nutrient uptake and allocation (i.e. about 30% of the parameter set if all of N, P and S dynamics are described) must be specified.

## Collection and collation of data

Because the GRAZPLAN pasture model is designed to integrate the physiological responses of pasture plants into the agronomic and ecological responses of grasslands, data sets that are useful for specifying a parameter set come in two main forms:

- Physiological studies that directly measure the values of parameters in the model equations, or quantities that can be related directly to these parameters. Physiological measurements that are taken in the field are to be preferred to glasshouse or pot studies.
- Agronomic studies in which the outcomes of the equations (dates of commencement of growth, flowering or sward senescence; pasture growth rates, sward-level nutritive value; animal production) are measured. These data sets are used for testing and/or calibration purposes.



Development of parameter sets for new pasture species will inevitably be limited by lack of data. It is a matter for judgement whether the information that is available (including inference from the attributes of related species) is sufficient to justify an attempt to create a parameter set. If not, then experimental studies will need to be undertaken prior to further modelling work.

Depending on the research context, it may be possible to measure some of the relevant quantities as part of the parameter development process. Discussion of such experimental procedures is, however, beyond the scope of this document.

Experimental conditions are seldom the same as the reference conditions under which the parameters of the pasture model are defined. Care is therefore needed when interpreting measured values such as specific leaf areas or radiation use efficiencies, to ensure that they are translated correctly into the terms used in the pasture model.

Comparative studies are especially useful sources of information about pasture species. Relativities between species (for example knowing that species A flowers a certain number of degree-days after species B) can be used to infer parameters for a new species from those of species for which parameters have already been defined.

## **Construction of a preliminary parameter set**

Once information about a pasture species has been gathered, the next step is to construct an initial, complete parameter set that can be used as a basis for the process of model calibration and testing. At this stage of the development process, it is best to rely on physiological data where possible.

Construction of a preliminary parameter set will seldom start from scratch. Instead, it is usual to use an existing parameter set for another species and to modify it to represent the differences between the new and previously-described species.

During this process, it will usually become apparent which parameter values can be defined for the species under consideration from physiological evidence, which parameter values will need to be calibrated to agronomic data and which will have to be specified using defaults from higher levels in the parameter hierarchy owing to lack of information.

## **Calibration and testing**

This part of the work flow is discussed more fully in a following section.

## **Documentation**

Documentation of a new parameter set and its testing has 3 main purposes:

- To allow the custodian of the model to carry out an evaluation of its scientific quality;
- To allow future users of the parameter set to understand the origins of the parameter set and the extent to which it has been tested (with respect to both environments and management systems); and
- To document areas where future research would enhance the quality of the developer's work, i.e. to act as a starting point for future improvements.

Appendix 2 contains a pro-forma for documenting pasture parameter sets and their testing that is intended to meet these objectives.

In order to fulfil its second and third purposes, it is important that the documentation of a parameter set be made publically available.

## **Review by the custodian**

Since a pasture parameter set can only be used in conjunction with the pasture model, the reputation of the custodian of the model (i.e. CSIRO) depends to some extent on the predictive accuracy of pasture parameter sets. CSIRO also maintains and releases the GrassGro decision support tool, which is an important means of applying the scientific work embedded in a new parameter set.

Quality assurance by the custodian of the pasture model will typically take the form of a review of the developer's work, rather than a separate testing exercise. This review is a necessary step before a new parameter set can be regarded as part of GrassGro and/or AusFarm.

It is technologically possible to bypass this evaluation step, and to release a parameter set without a review by a model's custodian. However such a step has the potential to cause confusion and possibly also duplication of the research and development work by others.

## **Transition from beta- to full release**

On its first release to users, a parameter set should be regarded as provisional, that is to say a "beta" release, and the name of the parameter set should reflect this status. For example, a parameter set for *Bituminaria bituminosa* var. *albomarginata* might initially be named "Tedera (beta)".

Once a beta-release parameter set has been in use for a period of time, and assuming that its predictions are found to be credible by users, then it is converted to a full release parameter set; this is denoted by simply removing the "beta" designation from the name of the parameter set.

Because feedback from users (particularly of GrassGro) tends to be directed to CSIRO, CSIRO takes the responsibility for deciding on the transition from beta- to full release of a given parameter set. No firm rules as to the duration of a beta-release can be given, since it will depend on the number of model users who apply the parameter set in their research, development and extension work.

## **5. Steps required to ensure parameter sets have been verified**

The previous section described the quality assurance process for parameter sets. This section describes CSIRO's role in, and requirements for, this process as the custodian of the GRAZPLAN pasture model and the organization responsible for the ongoing maintenance of the GrassGro decision support tool.

CSIRO will provide parameter set developers with utility software for modifying parameter set files upon request and free of charge (see the following section). Developers will be required to agree to a software licence agreement for this utility. Developers are responsible for acquiring modelling software proper (i.e. GrassGro,

AusFarm and/or APSIM) on their own behalf. Full documentation of the GRAZPLAN pasture growth model will also be provided upon request.

Parameter set developers are, of course, responsible for steps 1-5 in the work flow shown in Figure 3.

When a parameter set developer wishes to progress a new parameter set toward release in GrassGro and believes that it is ready for review by CSIRO, they should send the parameter set file to CSIRO via email to [grazplan@csiro.au](mailto:grazplan@csiro.au) with a request that the new parameter set be reviewed for inclusion in the next GrassGro release. Documentation of the work and any auxiliary files – preferably using the pro-forma in Appendix 2 – should accompany the request.

The request should also state that the developer's organization grants CSIRO the right to publish the new parameters, to release them within the GrassGro software which is a commercial product, and to further modify them in light of new information. The request should also either state that the developer's organization grants CSIRO the right to publish the testing documentation or describe how the testing documentation will be made publically available.

If unpublished data have been used in the testing process and the developers wish to arrange for a non-disclosure agreement, this should be negotiated prior to the formal request for review.

Parameter set files contain a field (named "editor") that gives the name of the developer of each parameter set. Developers should provide the contents of this field at the time of review so that proper acknowledgement can be made.

CSIRO will conduct a review of the parameter set and its associated tests. This review will have one of 4 outcomes:

1. Acceptance by CSIRO for inclusion in the standard parameter set file for the GRAZPLAN pasture model as a "beta" version.
2. Acceptance by CSIRO for inclusion in the standard parameter set for the GRAZPLAN pasture model as a beta-release version, subject to the revision of specified parameter values and provision of a new set of documentation including test results.
3. A request for further information about the derivation and/or testing of the parameter set
4. A decision not to include the parameter set in the standard parameter set file. In this case the developer may still choose to use or publish the parameter set for research application.

On acceptance of a parameter set, the following steps will be taken by CSIRO:

- An updated version of the standard pasture parameter set file that contains the new parameters will be published on the Internet (initially at [www.grazplan.csiro.au](http://www.grazplan.csiro.au)) to allow existing GrassGro users immediate access to the new parameters. Due acknowledgement of the work of the developers will be made.
- The testing documentation will be published on the Internet unless otherwise agreed with the developer.
- At the next release of GrassGro and of AusFarm, the updated version of the standard pasture parameter set file that contains the new parameters will be incorporated into the executable code of the programs.

After release of the beta-release version of a new parameter set, feedback from users about the performance of the new parameter set will be provided by CSIRO to the developers. Modifications to the parameter set made by the developers in response to this feedback will be subject to the review process.

The decision to convert a parameter set from beta- to full-release status will be made by CSIRO as custodian of the model.

## **6. Recommended procedures for parameter development**

### **Development of a preliminary parameter set**

When developing a preliminary version of a parameter set, it is generally useful to consider the parameters in the following order:

- Life form (annual vs perennial, grass vs forb vs shrub, legume or not)
- Developmental cycle (phenology): whether there is an annual cycle of growth, and if so how it commences; the triggers for reproductive growth, flowering and seed set; cessation of growth
- Acquisition of light and water: specific leaf area, extinction coefficients, rooting depth and penetration of the rooting front
- Net primary productivity: radiation use and transpiration efficiencies and their dependence on temperature and waterlogging; respiration
- Allocation of net primary productivity between plant parts, and its changes over the developmental cycle
- Relocation of biomass from root to shoot and from stem to seeds
- Physiological senescence of herbage: changes in digestibility with tissue age and death of leaves and stems
- Seed and seedling dynamics
- Dynamics of nitrogen, phosphorus and sulphur under nutrient-limiting conditions: root attributes, maximum, critical and minimum nutrient concentrations and relocation of nutrients within the plant

Some iteration between different parts of the parameter set is usually required.

When estimating model parameters, and especially when using curve-fitting techniques to estimate them from experimental data, it is critically important to take account of the physiologically plausible range of values that a parameter can take. A parameter set developer should take a Bayesian approach to estimating parameters, i.e. to give weight to prior knowledge of what a parameter value ought to be, based on knowledge of biochemical or physiological constraints.

It is also important to be clear about the meaning of other terms in the model equations in which a parameter appears. In particular, radiation use efficiency in the GRAZPLAN model is given in units of whole-plant gross assimilation per unit of global solar radiation (many crop models use shoot net primary productivity per unit of photosynthetically active radiation); and the temperature response functions in the

pasture model are expressed in terms of average daytime temperature (not the commonly-used mean daily temperature).

## Calibration and testing against field data

Testing of agricultural and ecological simulation models against measurements is partly a science and partly an art. There is a diversity of views in the literature both on the concepts that should be used and on the techniques that should be applied (e.g. Oreskes 1994; Sinclair and Seligman 2000; van Ittersum *et al.* 2003; Bellocchi *et al.* 2010). The views expressed here are necessarily those of the author.

In a world with ample physiological measurements, all the parameters of the pasture model would be estimated directly from the quantities they represent and agronomic data sets would be used for testing the adequacy of the model equations, i.e. for validating the model itself rather than its parameter sets. Even for well-studied species such as perennial ryegrass, however, some of the physiological attributes required by the GRAZPLAN pasture model are not known. For newly-domesticated or indigenous pasture plants, it will almost always be necessary to infer the values of some of the key parameters from field observations, i.e. to *calibrate* the parameter set to field data.

In a world with ample field data, a common view of good modelling practice would dictate that some data sets should be used for these calibration tasks while others should be reserved for an independent test of the complex scientific hypothesis embodied in the model+parameters. Once again, however, the quantity of agronomic data will in practice usually be insufficient to take this “purist” approach and to completely separate the calibration and testing steps.

In the usual case where both physiological and agronomic information about a pasture species are in limited supply, the best compromise will generally be to calibrate and test a parameter set simultaneously. Some workers, e.g. Sinclair and Seligman (2000), argue that this is a preferable approach on philosophical rather than practical grounds. Because testing and calibrating simultaneously involves a reduction in the power of the test of the model (i.e. a reduction in the effective degrees of freedom), it is important to document which parameters have been calibrated to the field data sets when presenting comparisons of model predictions with observed data.

When testing model performance against measured data, it is important to estimate the magnitude of the errors in the measured data (using statistical inference where possible). Departures of the model's predictions from the measurements should be assessed relative to these measurement errors. When comparing results from multi-treatment experiments against a model, the standard errors of the treatment means need to be estimated, not the standard errors of the differences between means. The former are generally greater than the latter in field experimental datasets, because common designs for experiments (e.g. randomized complete blocks) are intended to detect differences between treatments.

Where the intent is to develop a parameter set that can be used by a wide range of users, it is important to test the parameter set against data from multiple locations if at all possible. The optimal number of locations to examine depends on the quality of the available data, the climatic and management differences between the field studies and the time available to the developer. As a rule of thumb, though, 2 locations are almost always much better than 1 location; studies at 3-4 separate locations seem to provide a working minimum.

Modelling studies at multiple locations will usually be more informative than modelling multiple experimental treatments at a single location. However the effort required to configure simulations of multiple treatments in a single experiment is often little more than the effort required to simulate a single treatment.

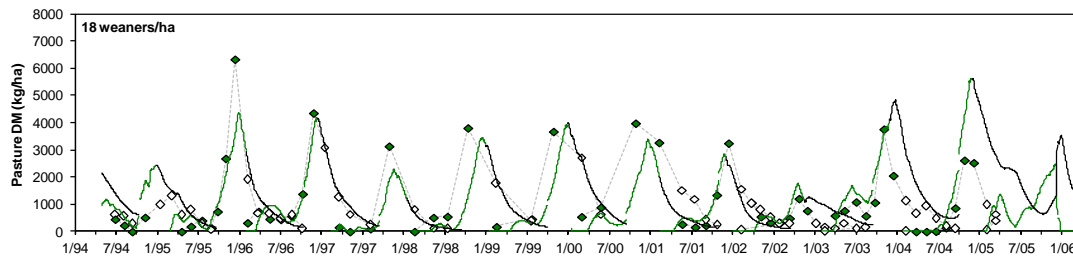
Real-world grasslands are almost always mixtures of pasture species. It becomes difficult to test a parameter set against field data sets where the target species is only a small proportion of the biomass (less than 50% or so).

Within each field study, a wide variety of measured attributes of grassland plants, the soils that support them and the animals that graze them can be informative for calibrating parameters of the pasture model and/or testing a parameter set. These measurements can be divided into several kinds:

- The times of events such as flowering; to be of value, these measurements should be obtained across a range of sites and/or years (e.g. Archer *et al.* 1987).
- Measurements of the time course of important system-level variables such as soil water content, pasture mass or digestibility, or the live weight of livestock.
- Measurements of process rates, such as the growth rate of a pasture measured with exclusion cages
- Measurements (often once per year) of quantities that arise from the cumulative effect of processes over time, such as rooting depth, shorn fleece weight or the birth weight or sale weight of young livestock.

When testing the pasture model against time course data, it is important to take account of the likely autocorrelations in the data set. One way of dealing with these autocorrelations is to compare the rate of change in a quantity from measurement to measurement with model predictions of the rate of change, even though taking a difference between two measurements will increase the relative size of measurement errors. Time courses of animal weights are an example of a variable for which this approach works well.

**Figure 4.** Visualizing the time course of pasture mass in an field experiment with well-defined growing seasons by dividing mass into “new” (current-year, green+dry) and “old” (previous-year, dry) components. Measured values of “new” pasture are shown with green symbols and “old” pasture with white symbols.



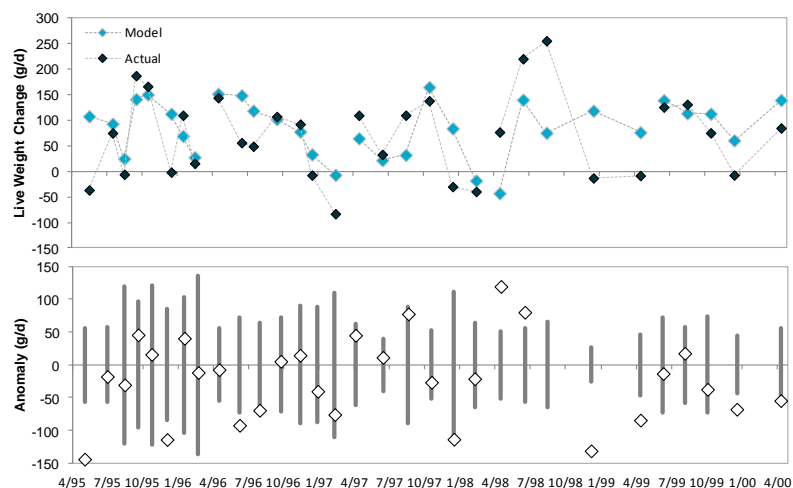
Where a pasture species has a well-defined growing season, and where time courses of live and dead herbage have both been measured, it can be useful to test model predictions against the time course of each year’s production of pasture, separating “new” and “old” cohorts (as in Figure 4).

Animal production data, in particular rates of weight gain, can be used as a check on otherwise poorly-measured quantities such as the digestibility of dead pasture residues. Weight gain of livestock can also serve as a check on measured pasture mass data at times when the mass of green herbage is low and measurement errors are relatively high.

A useful way to visualize model performance against time course data (either quantities or rates) is shown in Figure 5. The time courses of the measured and modelled values are compared in the upper pane, while in the lower pane the anomalies (observed – predicted) are compared with the confidence intervals of the measured values, following Mitchell (1997). If the modelled values fall within the confidence intervals for 95% of the values, then the model can be said to fit the data set. The times at which the model is mis-predicting the data can also be more readily seen with this visualization.

For rate data and for cumulative summary values such as fleece weights, a good

**Figure 5.** Time courses of a hypothetical sheep live weight change model-data comparison, with the extent of lack of fit between model and data shown using confidence intervals.



method for comparing observed and modelled data is to regress the observed data against the model predictions (Mayer *et al.* 1994). In a perfect model, the slope of this regression would be 1.0 and the intercept would be 0.0. For a sceptical view of this technique, however, see Mitchell (1997).

Interpretation of the statistics in a regression analysis requires some care. Mayer *et al.* (1994) point out that the F-statistic should be used in testing for departure from the null hypothesis of zero slope. Correlation coefficients should be interpreted carefully, if at all: it is possible for  $r^2$  to be very high where the model is failing badly (e.g. by over- or under-predicting the data), and where the range of data values is similar to the size of the measurement errors it is possible for a model to fit the data well while having a low value of  $r^2$ .

Instead, the primary statistic in these comparisons should be the mean squared deviation (MSD), or equivalently its square root, the root-mean-square deviation (RMSD) which has the advantage of having the same units as the measurements:

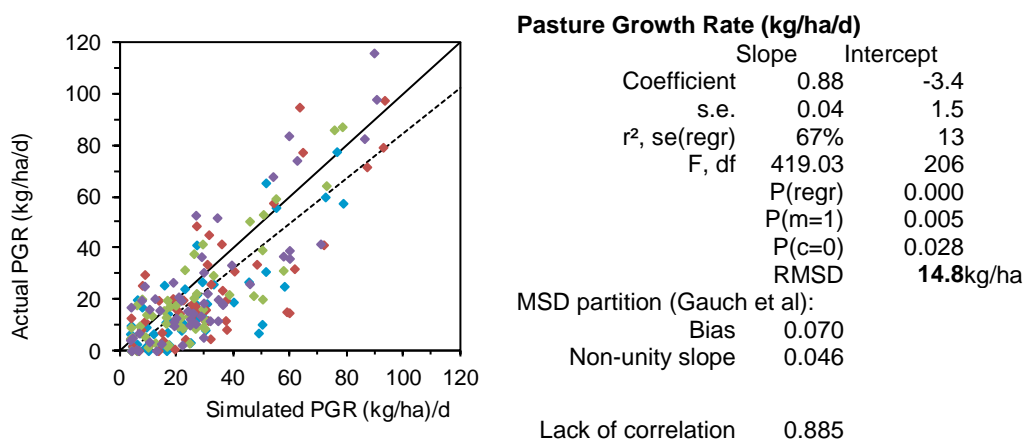
$$RMSD = \sqrt{\frac{1}{N} \sum_{i=1}^N (Y_i - \hat{Y}_i)^2}$$

where  $Y_i$  is one of  $N$  measured values and  $\hat{Y}_i$  is the corresponding model prediction. Wallach and Goffinet (1989) provide a more sophisticated account of the use of MSD and related statistics when a model is being calibrated.

After the RMSD, the statistics of most interest are the slope and intercept of the observed-vs-predicted regression. When the slope is not significantly different to 1.0, the intercept is not significantly different to 0.0 and the RMSD is of the same magnitude as the measurement errors, then the model can be said to fit the data well.

Further insight into the sources of model error can be obtained by partitioning the MSD into three terms (Gauch *et al.* 2003, Figure 6): a term due to bias, a second term due to non-unity slope and a term due to lack of correlation. If the bias term is large, then there is a difference in the measured and modelled means, i.e. the model

**Figure 6.** A hypothetical comparison of observed vs modelled pasture growth rates using regression analysis. Different colours in the scattergram denote different experiments or treatments; the 1:1 line is shown in solid black and the regression line with dashes. Note that the quantity that is predicted (the data) has been placed on the Y-axis, while the predictor (the modelled values) has been placed on the X-axis; this format is logically sound and matches the regression analysis, but many workers plot these graphs the other way around.





is over- or under-predicting the data overall. In the absence of bias, a departure from unity slope indicates that the model is not properly capturing the variability in the experimental data set.

Automatic algorithms for estimating parameters of models through data fitting exist, but they are difficult to apply to agricultural systems models – especially pasture growth models – because (i) the models have many parameters relative to the number of data points that are usually available, (ii) correlations exist between parameter values due to links between the physiological processes they describe, and (iii) for pasture models in particular there are multiple outputs of interest, and the means by which to weight them in a goodness-of-fit statistic are unclear. Examples of approaches that have been used with crop models can be found in He *et al.* (2009) and Wallach *et al.* (2011). Automated calibration of phenology models to event data is much more straightforward as long as sufficient observations are available and the observations are carefully matched to the stages of the phenology sub-model; see Soltani *et al.* (2006) for an example in a cropping context.

## Extrapolative evaluations

Extrapolative evaluations (also known as “plausibility tests” or “sensitivity tests”) are sets of simulations that are used to explore the behaviour of a model and parameter set across a range of years and/or sites. Their purpose is to provide some confidence that the parameter set remains coherent when used in contexts beyond those found in the experimental data used for calibration and testing.

Extrapolative evaluations can be used to examine the performance of a parameter set when modelled in mixtures with other pasture species. Persistence of a modelled species mixture at locations where such mixtures actually exist is an important criterion for evaluating a parameter set that is difficult to assess except through long-run simulations.

Assessment of the results of extrapolative evaluations will perforce be qualitative in nature. Because of this it can be useful to engage with individuals who have local expertise, and it can also be useful to compare extrapolative evaluation results with corresponding simulations of a well-known pasture type and to assess the differences between them as well as the absolute values of the results.

Field experimental data relating to a pasture species will seldom span the full range of climatic variability. At a minimum, therefore, a new parameter set should be extrapolated in time using 30-50 year simulations at one or more of the test locations (e.g. Moore *et al.* 2010 for *Poa sieberiana*). If time permits, the parameter set should also be extrapolated in space, to 3-5 locations in different parts of the species’ potential range.

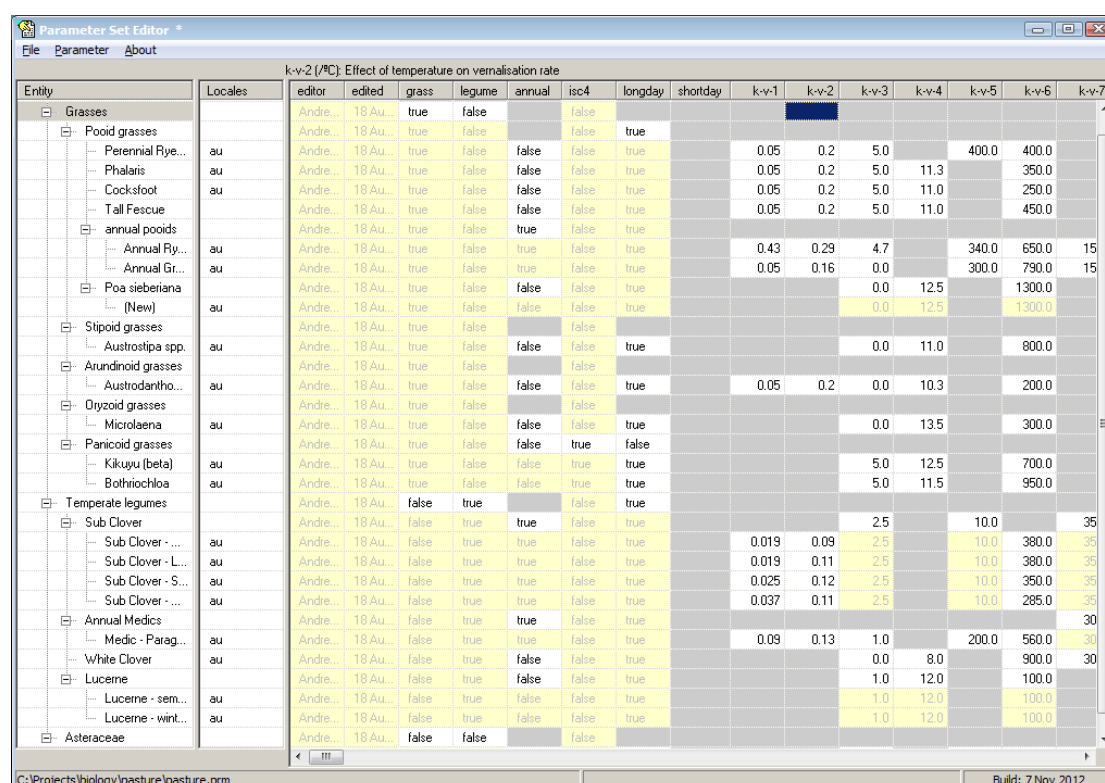
The GrassGro software is a useful tool for carrying out this kind of simulation, as it contains facilities for running simulation “experiments” where locations and management systems can be varied systematically. The standard farm systems and “acceptability reports” used in GrassGro are useful resources for designing sensible inputs to, and outputs from, an extrapolative evaluation.

## 7. Tools for parameter development

### Parameter editor utility

As described earlier, parameter sets for the GRAZPLAN models are stored in XML data files. Because XML is a text-based technology, it is possible to edit the parameter files directly using a text editing program. This approach can be useful for tasks such as changing single parameter values or making a copy of an existing parameter set as the first step in modifying it to describe a related species.

CSIRO has developed a utility program for creating and editing the XML parameter set files. This parameter set editor program can be obtained by sending an email request to [grazplan@csiro.au](mailto:grazplan@csiro.au).



**Figure 7.** The user interface of CSIRO's parameter set editor program.

As can be seen in Figure 7, the parameter set editor presents the set of genotypic parameters in a matrix, with each species occupying a row and each parameter a column. The hierarchical structure of the parameter set file is, however, preserved: the tree of genotypes is shown to the left of the editing matrix.

Parameters that are defined at each level of the hierarchy are shown with a white background; parameters that are taken from values defined at a higher level in the hierarchy are shown with a yellow background; and parameters that are not defined are shown as grey cells. A description of the currently-selected parameter appears at the top of the editing screen.

Menu options allow the user to open and save parameter set files, to add new parameter sets at any level of the hierarchy, to delete existing parameter sets, and to

copy the full matrix of parameters to the clipboard in a format that can be pasted into a spreadsheet.

To replace the default pasture parameter set in GrassGro with a different parameter set file, choose the “File|Register...” menu option in the parameter set editor, complete the dialog that appears and click OK. This procedure sets values in the Windows registry key

HKEY\_CURRENT\_USER/Software/CSIRO/Common/Parameters/PASTURE\_PARAM\_GLB. When a custom parameter set file has been registered in this way, its name will appear in the background of the GrassGro main window.

## AusFarm

The AusFarm software (Moore *et al.* 2001) is the recommended tool for simulating experimental data sets in the validation and calibration stage of developing a new pasture parameter set. Experimental management can be more accurately represented using AusFarm, and when using AusFarm it is possible to run simulations with alternative parameter sets simultaneously and to compare the results.

At the time of writing, the AusFarm software can be obtained from Horizon Agriculture ([www.hzn.com.au](http://www.hzn.com.au)).

## GrassGro

The GrassGro decision support tool (Donnelly *et al.* 2002) can be used for validation and calibration exercises, but it has not been designed to capture a number of common practices in experimental settings, for example irregular movements of livestock or the sowing of pastures. It will, however, often prove to be the tool of choice in carrying out extrapolative evaluations of a new parameter set. It is a straightforward matter to construct a GrassGro Analysis that models a set of grazing systems that utilize a particular pasture species across a range of different environments and/or soil types, and the reporting facilities in GrassGro allow the modelled patterns of production to be presented side-by-side.

At the time of writing, the GrassGro software can be obtained from Horizon Agriculture ([www.hzn.com.au](http://www.hzn.com.au)).

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## Appendix 1: Parameters of the GRAZPLAN pasture model

Parameter <sup>1</sup>	Name in Parameter Editor	Units	Meaning
	grass		TRUE for grasses
	legume		TRUE for legumes
	annual		TRUE for annuals, FALSE for perennials
	isc4		TRUE if the species has the C <sub>4</sub> photosynthetic pathway
	longday		TRUE if long days required to induce reproductive growth
$K_{V1j}$	k-v-1	/d	Vernalisation rate at 0°C
$K_{V2j}$	k-v-2	/°C	Effect of temperature on vernalisation rate
$K_{V3j}$	k-v-3	°C	Base temperature for degree-day computations
$K_{V4j}$	k-v-4	hr	Day length for commencement of reproductive growth
$K_{V5j}$	k-v-5	°d	Degree-day sum for commencement of reproductive growth
$K_{V6j}$	k-v-6	°d	Degree-day sum for commencement of flowering
$K_{V7j}$	k-v-7	d	Maximum length of flowering period
$K_{V8j}$	k-v-8	d	Effect of soil moisture stress on flowering duration
$K_{V9j}$	k-v-9	°d	Degree-day sum beyond which the reproductive phenostage can end
$K_{V10j}$	k-v-10	0-1	Value of the soil moisture growth-limiting factor that defines "drought" for the senescence calculations
$K_{V11j}$	k-v-11	°C	Temperature threshold for the end of summer dormancy
$K_{V12j}$	k-v-12	0-1	Soil moisture threshold for the end of summer dormancy
$K_{V13j}$	k-v-13	d	Initial duration of cool, moist conditions to break summer dormancy
$K_{V14j}$	k-v-14	d	Time required for summer dormancy requirement to reduce to zero
$K_{V15j}^*$	k-v-15	0-1	Reduction in the rate of development due to water stress in pre-flowering, reproductive plants
$K_{V16j}^*$	k-v-16	°C	Temperature threshold for the onset of winter dormancy
$K_{V17j}^*$	k-v-17	hr	Threshold day length to end of winter dormancy at Tlag=0.0
$K_{V18j}^*$	k-v-18	hr/°C	Reduction in threshold day length to end winter dormancy
$K_{V19j}^*$	k-v-19	0-1	Decrease in the moisture threshold for summer dormancy after KV14j days
$K_{V20j}^*$	k-v-20	d	Length of the drought period required to induce senescence (i.e. end reproductive growth) when DD(j)=KV9j
$K_{V21j}^*$	k-v-21	°d	Value of DD(j) at which senescence occurs in the absence of drought
$K_{V22j}^*$	k-v-22	0-1	Upper margin of phenology-sensitive horizon during vegetative growth
$K_{V23j}^*$	k-v-23	0-1	Thermal time (as fraction of K(V,6)) for upper margin of phenology-sensitive horizon to reach top of sward
$K_{V24j}^*$	k-v-24	0-1	Final lower boundary of phenology-sensitive horizon
$K_{V25j}^*$	k-v-25	0-1	Height of removal for reset of phenology (as fraction of lower boundary of phenology-sensitive horizon)
$K_{I1j}$	k-i-1	m <sup>2</sup> /g	Reference specific leaf area (ratio of leaf area index to leaf weight)
$K_{I2j}^*$	k-i-2	m <sup>2</sup> /g	Reference specific stem area
$K_{I3j}^*$	k-i-3	MJ/m <sup>2</sup> /d	Curvature factor for effect of light on specific area
$K_{I4j}^*$	k-i-4	°C	Temperature threshold for maximal specific area
$K_{I5j}^*$	k-i-5	0-1	Relative specific area at 0°C
$K_{I6j}^*$	k-i-6	-	Relative decrease in specific leaf area at twice reference [CO <sub>2</sub> ]
$K_{I7j}^†$	k-i-7	0-1	Apparent light extinction coefficient under ungrazed conditions
$K_{I8j}^†$	k-i-8	0-1	Apparent extinction coefficient under heavily grazed conditions
$K_{WU1j}^†$	k-wu-1	0-1	Available soil water threshold for growth limitation
$K_{WU2j}^*$	k-wu-2	0-1	Proportion of any transpiration deficit that can be recovered from moist layers

<sup>1</sup> Parameters marked with \* have been added since the GRAZPLAN pasture model was originally published (Moore *et al.* 1997); parameters marked with <sup>†</sup> have changed their name or meaning.

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Parameter <sup>†</sup>	Name in Parameter Editor	Units	Meaning
$K_{RU1j}$ <sup>†</sup>	k-ru-1	g/MJ	Radiation use efficiency under reference conditions (formerly $K_{R3j}$ , now gross assimilation)
$K_{RU2j}$ <sup>†</sup>	k-ru-2	MJ/m <sup>2</sup> /hr	Effect of radiation intensity on radiation use efficiency (formerly $K_{R4j}$ )
$K_{RU3j}$ <sup>*</sup>	k-ru-3	0-1	Relative photosynthetic efficiency of stems
$K_{RU4j}$ <sup>*</sup>	k-ru-4	ppm	CO <sub>2</sub> compensation point at 0°C
$K_{RU5j}$ <sup>*</sup>	k-ru-5	Ppm	CO <sub>2</sub> compensation point at 20°C
$K_{RU6j}$ <sup>*</sup>	k-ru-6	°C	Maximum temperature for CO <sub>2</sub> compensation function
$K_{BT1j}$ <sup>*</sup>	k-bt-1	kPa g kg <sup>-1</sup>	Biomass-transpiration coefficient
$K_{T1j}$ <sup>†</sup>	k-t-1	°C	Temperature for 5% of maximum gross assimilation rate
$K_{T2j}$ <sup>†</sup>	k-t-2	°C	Temperature for 95% of maximum gross assimilation rate
$K_{W1j}$ <sup>†</sup>	k-w-1	0-1	Transpiration ratio below which assimilation rate decreases
$K_{WL1j}$ <sup>†</sup>	k-wl-1	0-1	WFPS threshold for waterlogging
$K_{WL2j}$ <sup>†</sup>	k-wl-2	-	Curvature of growth limitation by waterlogging
$K_{MR1j}$ <sup>†</sup>	k-mr-1	/d	Maximum relative growth rate of shoots during dormancy (formerly $K_{A5j}$ )
$K_{U1j}$	k-tl-1	-	Threshold growth-limiting factor for translocation from belowground reserves
$K_{U2j}$	k-tl-2	/d	Relative rate of translocation from belowground reserves
$K_{U3j}$ <sup>*</sup>	k-tl-3	0-1	Maximum proportion of stem (or shoot) mass at flowering to be relocated to seed
$K_{U4j}$ <sup>*</sup>	k-tl-4	°d	Degree-days required for completion of relocation from stem to seed
$K_{RE1j}$ <sup>*</sup>	k-re-1	g/g/d	Maintenance respiration rate at 10°C (g DM/g N/d)
$K_{RE2j}$ <sup>*</sup>	k-re-2	-	Q10 factor for maintenance respiration
$K_{RE3j}$ <sup>*</sup>	k-re-3	0-1	Reduction in maintenance respiration in summer- or winter-dormant plants
$K_{RE4j}$ <sup>*</sup>	k-re-4	g/g	Growth respiration rate
$K_{A1j}$	k-a-1	-	Target root:shoot ratio during vegetative growth
$K_{A2j}$	k-a-2	-	Target root:shoot ratio during reproductive growth
$K_{A3j}$	k-a-3	-	Maximum allocation to reproductive structures
$K_{A4j}$	k-a-4	0-1	Maximum value of the ratio (leaf allocation):(shoot allocation)
$K_{A5j}$ <sup>*</sup>	k-a-5	0-1	Minimum value of the ratio (leaf allocation):(shoot allocation)
$K_{MO1j}$ <sup>*</sup>	k-mo-1	-	Parameter governing height distribution of leaves
$K_{R1j}$ <sup>*</sup>	k-r-1	mm	Maximum rooting depth under optimal soil conditions
$K_{R2j}$ <sup>*</sup>	k-r-2	mm/°d	Maximum rate of root front extension
$K_{R3j}$ <sup>*</sup>	k-r-3	°C	Base temperature for root front extension
$K_{R4j}$ <sup>*</sup>	k-r-4	0-1	ASW below which root extension is reduced
$K_{R5j}$ <sup>*</sup>	k-r-5	Mg/m <sup>3</sup>	Threshold bulk density for reduced root extension in 100% sand
$K_{R6j}$ <sup>*</sup>	k-r-6	Mg/m <sup>3</sup>	Threshold bulk density for reduced root extension in 0% sand
$K_{R7j}$ <sup>*</sup>	k-r-7	m <sup>3</sup> /Mg	Rate of decrease in root extension with increasing bulk density
$K_{R8j}$ <sup>*</sup>	k-r-8	0-1	Minimum value of the bulk density effect on root extension
$K_{R9j}$ <sup>*</sup>	k-r-9	m/g	Specific root length
$K_{R10j}$ <sup>*</sup>	k-r-10	m	Average radius of effective roots
$K_{D1j}$ <sup>*</sup>	k-d-1	°d	Thermal age at which death of shoots commences
$K_{D2j}$ <sup>*</sup>	k-d-2	/°d	Background death rate of old shoots in seedlings & established plants
$K_{D3j}$ <sup>*</sup>	k-d-3	/°d	Additional death rate of all shoots in senescing plants
$K_{D4j}$ <sup>†</sup>	k-d-4	°C	Temperature for 5% mortality at the first frost (formerly $K_{D2j}$ )
$K_{D5j}$ <sup>†</sup>	k-d-5	°C	Temperature for 95% mortality at the first frost (formerly $K_{D3j}$ )
$K_{D6j}$ <sup>†</sup>	k-d-6	°C	Frost-hardening factor (formerly $K_{D4j}$ )
$K_{D7j}$ <sup>†</sup>	k-d-7	0-1	Value of the seedling stress index at which seedling mortality commences (formerly $K_{Z1j}$ )
$K_{D8j}$ <sup>†</sup>	k-d-8	0-1	Value of the seedling stress index for 100% seedling mortality (formerly $K_{Z2j}$ )
$K_{D9j}$ <sup>*</sup>	k-d-9	/d	Lag coefficient for computation of the seedling stress index
$K_{DR1j}$ <sup>*</sup>	k-dr-1	/d	Specific root "aging" rate at 10°C
$K_{DR2j}$ <sup>*</sup>	k-dr-2	/d	Specific root loss rate at 10°C
$K_{DR3j}$ <sup>*</sup>	k-dr-3	g/g	Recovery rate of mass from dying roots
$K_{DR4j}$ <sup>*</sup>	k-dr-4	-	Q10 for root aging and loss

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Parameter <sup>†</sup>	Name in Parameter Editor	Units	Meaning
$K_{F1,leaf,j}^{\dagger}$	k-f1-leaf	/d	Fall of standing dead: reference rate for leaf
$K_{F1,stem,j}^{\dagger}$	k-f1-stem	/d	Fall of standing dead: reference rate for stem
$K_{F2j}^{\dagger}$	k-f2-2	-	Fall of standing dead: maximum relative effect of precipitation
$K_{F3j}^{\dagger}$	k-f2-3	/mm	Fall of standing dead: curvature of precipitation effect
$K_{F4j}^{\dagger}$	k-f2-4	/kg animal/d	Fall of standing dead: trampling effect
$K_{Q1pj}^*$	k-q-p-1	g/g	Average digestibility of newly-produced herbage ( $p$ =leaf, stem)
$K_{Q2pj}^*$	k-q-p-2	g/g	Minimum digestibility of green herbage during vegetative growth ( $p$ =leaf, stem)
$K_{Q3pj}^*$	k-q-p-3	g/g	Minimum digestibility of green herbage during reproductive growth ( $p$ =leaf, stem)
$K_{Q4j}^*$	k-q-leaf-4	°d	Thermal time during which green leaf maintains its digestibility
$K_{Q5pj}^*$	k-q-p-5	/°d	Rate parameter for decline of DMD of green herbage ( $p$ =leaf, stem)
$K_{Q6j}^*$	k-q-leaf-6	°C	Base temperature for maturation & senescence of green tissue
$K_{Y1j}^*$	k-y-1	/d	Reference rate of microbial decomposition of digestible DM
$K_{Y2j}^*$	k-y-2	-	Factor for temperature response of decomposition
$K_{Y3j}^*$	k-y-3	°C	Factor for temperature response of decomposition
$K_{Y4j}^*$	k-y-4	-	Minimum value of the moisture factor for standing dead
$K_{Y5j}^*$	k-y-5	g/g	Maximum moisture content of standing dead
$K_{Y6j}^*$	k-y-6	-	ASW for 5% of maximum decomposition
$K_{Y7j}^*$	k-y-7	-	ASW for 95% of maximum decomposition
$K_{Y8j}^*$	k-y-8	0-1	Relative rate of decomposition of indigestible DM
$K_{Y9j}^*$	k-y-9	g/m <sup>2</sup>	Critical mass for "thatch" effect on litter decay
$K_{BR1pj}^*$	k-br1-p	/d	Background rate of breakdown of litter ( $p$ =leaf, stem)
$K_{BR2j}^*$	k-br2-2	/kg animal/d	Litter breakdown: trampling effect
$K_{BR3j}^*$	k-br2-3	/d	Rate of litter incorporation under dry soil conditions
$K_{BR4j}^*$	k-br2-4	/d	Rate of litter incorporation under wet soil conditions
$K_{BR5j}^*$	k-br2-5	g/m <sup>2</sup>	Critical mass for "thatch" effect on comminution
$K_{S1j}$	k-s-1	/d	Rate of "hardening" of immature seeds
$K_{S2j}$	k-s-2	d	Length of period of innate dormancy
$K_{S3j}$	k-s-3	/(°C.d)	Effect of maximum temperature on seed "softening"
$K_{S4j}$	k-s-4	°C	Threshold temperature for seed "softening"
$K_{S5sj}$	k-s-5-s	/d	Specific death rate for seeds ( $s$ =soft, hard)
$K_{G1j}$	k-g-1	-	Surface ASW above which germination takes place
$K_{G2j}$	k-g-2	°C	Minimum temperature for germination
$K_{G3j}$	k-g-3	°C	Lower bound of optimal temperature range for germination
$K_{G4j}$	k-g-4	°C	Upper bound of optimal temperature range for germination
$K_{G5j}$	k-g-5	°C	Maximum temperature for germination
$K_{G6j}$	k-g-6	d	Time to first seedling emergence under optimal conditions
$K_{G7j}$	k-g-7	d	Time to complete seedling emergence under optimal conditions
$K_{G8j}$	k-g-8	-	Proportion of reproductive structures which is actually seed
$K_{Z1j}^{\dagger}$	k-z-1	-	Threshold of the establishment index at which seedlings are regarded as established plants
$K_{NU1epj}^*$	k-conc-e-p-1	g/g	Maximum content of mineral element $e$ in green herbage ( $e$ =N, P, S; $p$ =leaf, stem)
$K_{NU1e,root,j}^*$	k-conc-e-root-1	g/g	Maximum content of mineral element $e$ in live root
$K_{NU1e,seed,j}^*$	k-conc-e-seed-1	g/g	Maximum content of mineral element $e$ in seed
$K_{NU2epj}^*$	k-conc-e-p-2	g/g	Minimum content of mineral element $e$ in green herbage at maximum DMD ( $e$ =N, P, S; $p$ =leaf, stem)
$K_{NU2e,root,j}^*$	k-conc-e-root-2	g/g	Minimum content of mineral element $e$ in live root ( $e$ =N, P, S)
$K_{NU2e,seed,j}^*$	k-conc-e-seed-2	g/g	Minimum content of mineral element $e$ in seed ( $e$ =N, P, S)
$K_{NU3epj}^*$	k-conc-e-p-3	g/g	Minimum content of mineral element $e$ in green herbage at midpoint DMD ( $e$ =N, P, S; $p$ =leaf, stem)
$K_{NU4epj}^*$	k-conc-e-p-4	g/g	Minimum content of mineral element $e$ in green herbage at minimum DMD ( $e$ =N, P, S; $p$ =leaf, stem)
$K_{NU5,leaf,j}^*$	k-conc-n-leaf-5	-	Relative decrease in leaf N content (per unit leaf area) at twice reference [CO <sub>2</sub> ]; note less-than-ideal notation
$K_{NU5pj}^*$	k-conc-n-p-5	-	Relative decrease in N content (per unit mass) at twice reference [CO <sub>2</sub> ] ( $p$ =stem, root, seed; note less-than-ideal

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Parameter <sup>1</sup>	Name in Parameter Editor	Units	Meaning
			notation)
$K_{FX1j}^*$	k-fix-1	0-1	N-fixation: relative depth of nodulation
$K_{FX2j}^*$	k-fix-2	0-1	N-fixation: nodulation at depth:nodulation at surface
$K_{FX3j}^*$	k-fix-3	0-1	N-fixation: ASW for maximum fixation rate
$K_{FX4j}^*$	k-fix-4	mg/l	N-fixation: solution NO3 conc. for maximum fixation rate
$K_{FX5j}^*$	k-fix-5	mg/l	N-fixation: solution NO3 conc. for suppression of fixation
$K_{UE1,NO3,j}^*$	k-eff-no3	-	Uptake effectiveness parameter for nitrate
$K_{UE1,NH4,j}^*$	k-eff-nh4	-	Uptake effectiveness parameter for ammonium
$K_{UE1,PO4,j}^*$	k-eff-pox	-	Uptake effectiveness parameter for phosphate
$K_{UE1,SO4,j}^*$	k-eff-so4	-	Uptake effectiveness parameter for sulphate
$K_{RL1ej}^*$	k-reloc-e	/d	Relocation rate parameter for element e (e=N, P, S)
$K_{AA1j}^*$	k-aa-1	mol/kg	Ash alkalinity of newly-grown leaves
$K_{AA2j}^*$	k-aa-2	mol/kg	Ash alkalinity of newly-grown stems
$K_{AA3j}^*$	k-aa-3	mol/kg	Ash alkalinity of newly-grown roots
$K_{AA4j}^*$	k-aa-4	mol/kg	Ash alkalinity of newly-grown seeds
$K_{AA5j}^*$	k-aa-5	-	pH below which no cation uptake takes place
$K_{AA6j}^*$	k-aa-6	-	pH above which maximal cation uptake takes place
$K_{CPcj}$	k-cp-c	g/g	Crude protein content of herbage in digestibility class c (1=80-85% DMD, 2=75-80% DMD...)
$K_{DGcj}$	k-dg-c	g/g	Degradability of protein in of herbage in digestibility class c (1=80-85% DMD, 2=75-80% DMD...)
$K_{SCRj}$	k-seed-r	1-6	Equivalent digestibility class of seeds (1=75-85%, 2=65-75%...; r=unripe, ripe)
$K_{SDrj}$	k-dmdseed-r	g/g	Digestibility of seed+diaspore (r=ripe, unripe)
$K_{SPj}$	k-cpseed	g/g	Crude protein content of seed+diaspore
$K_{HRj}$	k-hr	-	"Height ratio": also governs the size of the ungrazeable portion of the pasture
$K_{SFj}$	k-sf	-	Parameter controlling the relationship between DMD and relative quality



## Appendix 2: Documenting new parameters for the GRAZPLAN models

*Title*

*Date*

*Developers*

*Description*

Provide a summary of the parameter set(s) that have been created or modified, and justify the approach taken. A full description of the processes used and the assumptions made should be provided in following sections.

*Problem addressed*

What is the reason and rationale for the changes?

*Implications*

Are there any implications for other users of the GRAZPLAN models?

*Derivation*

The parent parameter set in the hierarchy must be identified.

The derivation of each parameter not taken directly from this parent parameter set should then be described in tabular form:

Parameter	Units	Estimated Value	Details of Derivation

- If a parameter value has been taken directly from the literature, then give the citation along with a with figure, table or page number.
- If a parameter value has been calibrated from a “validation” test simulation, note this.
- If a parameter value has been assumed to be the same as that for another (non-parent) parameter set, enter “Value for [genotype] used”
- Where (e.g.) an analysis of experimental data was used to derive a number of parameters simultaneously, or the process of derivation requires detailed description, note “See section [section title]” and provide details in subsequent text.
- Use the notation for parameter names that is used in the parameter set editor (Appendix 1).

For proposed modifications to existing parameter sets, only the subset of the table describing the changes should be provided.

Any limitations of the new parameter set should be described. Are there suggestions for further work?

*Validation tests*

For each validation test, provide:

- a description of the data sources (experiments/treatments/literature), including identification of data set custodians

- a description of the experimental system (site, soils, grassland type, animals, management), or a reference to a publication containing this information
- a short summary of how the measured data were collected; methods for taking sampling for pasture mass or quality are particularly important
- labelled graphs showing how well predicted results match the observed data.

If the AusFarm or APSIM software has been used to run the test simulations, then the .afs or .apsim file containing the validation tests should be provided. In this case, the notes section (AusFarm) or a memo component (APSIM) should be used to provide the descriptive material.

Subject to intellectual property constraints, summary experimental data and weather data sufficient to re-construct the validation graphs should be provided. Any IP constraints on data sets should be identified by the developer and noted in this document.

#### *Extrapolative evaluations*

Provide:

- a description of the tests and of the expected outcomes
- labelled graphs showing the model responses

One or more of the AusFarm, APSIM or GrassGro software will have to be used to run test simulations. The relevant .afs, .apsim or farm system library file containing the evaluation inputs should be provided, along with the relevant weather data files (or instructions for obtaining them).

#### *References*

Provide citations to all literature used in parameter derivation, validation tests or preparation of extrapolative evaluations. Include digital object identifiers where possible.