Appendix 10. Improving and extending the parameter sets for the GRAZPLAN pasture model

<u>Performance of the GRAZPLAN models in central Victoria</u>

As part of their preparations for producer workshops, Kieran Ransom and Jane Court of DPI Victoria compared GrassGro modelling results with experimental data from two grazing trials in central Victoria. Their initial results suggested that the GRAZPLAN pasture model was under-predicting growth rates in spring; that in phalaris-based pastures, the modelled growing season was continuing too long; and that the timing of the start of the growing season was incorrect in some years. These concerns were strong enough to affect the confidence of DPI staff in being able to use GrassGro for climate change impacts analyses. The spring vs winter growth issue had previously been raised (with less urgency) by program participants working in southern NSW.

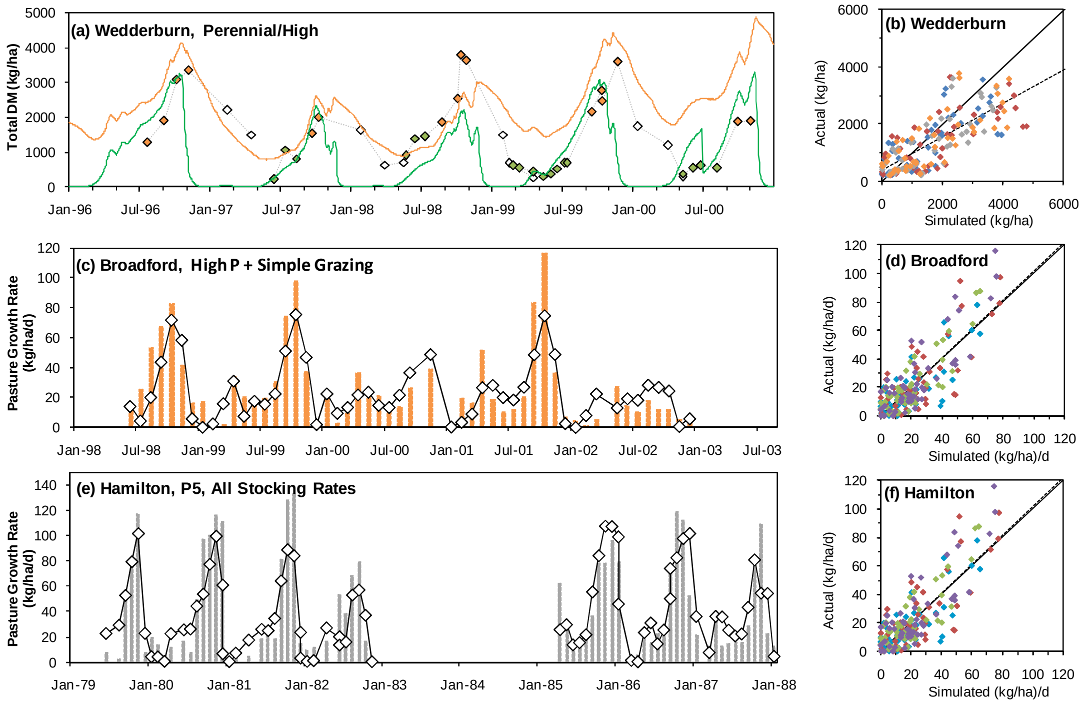
In response, we examined the performance of the GRAZPLAN pasture growth model across a number of locations in Victoria, in order to (i) assess the extent to which these perceived difficulties were borne out by a rigorous comparison with experimental data, and (ii) to correct the pasture growth model to the extent necessary to ensure that it was usable in central Victoria. Three experimental data sets were used for this purpose: the Broadford grazing trial near Seymour (Warn *et al.* 2002), an unpublished grazing trial at Wedderburn near Bendigo (K Ransom, *pers. comm.*), and a long-term phosphorus x stocking rate experiment at Hamilton (Cayley *et al.* 1998).

Weather data were taken from the nearest Patched Point dataset (Jeffrey *et al.* 2001); for Wedderburn, daily rainfall data from a nearby property were superimposed. Soil attributes were taken from measured data at Hamilton and inferred from the available soil descriptions and nearby soil pits at the other two sites. Management of the experimental treatments in each grazing experiment (e.g. fertilizer applications, grazing management, replacement of livestock and application of grass-specific herbicides) was carefully reproduced by implementing the test simulations in the AusFarm modelling software.

Simulations using the default pasture parameter set in version 3.2 of GrassGro confirmed that pasture growth in spring was being significantly under-predicted in this environment, and that for phalaris-based pastures at Broadford the model predicted an end to the growing season that was too late. There were some discrepancies in the germination responses of the model at Broadford but they fell within the expected level of model accuracy for a specific set of conditions. The pasture parameters were therefore modified to resolve the problems with the pattern of pasture growth. Changes were made to alter the description of the phenology of phalaris so that it is predicted to commence reproductive growth much earlier under Victorian conditions, and to flower somewhat earlier as well; to set radiation use efficiency so that it no longer varies with radiation intensity for C_3 species; to shift the temperature responses of phalaris, perennial ryegrass, annual grasses and legumes and capeweed so that growth is more sensitive to low temperatures; and to slow the decay rate of the digestible portion of dead herbage. As part of the parameter modification process, validation simulations of several other grazing experiments in WA, Victoria, SA and NSW were also re-run to confirm that the GRAZPLAN models still gave credible results at those locations with the altered pasture parameter set.

A subset of the results of the validation simulations with the corrected pasture parameter set is shown in Figure A10.1. While there are still specific points where the GRAZPLAN models mis-predict the dynamics of these pastures, the overall level of

Figure A10.1. Selected results of validation simulations at three Victorian locations with the modified pasture parameter sets developed during the project (a, c, e) Time courses of pasture mass (Wedderburn) or pasture growth rate (Broadford and Hamilton) compared against measured data for one of the experimental treatments at each site. (b, d, f) Comparison of actual vs modelled pasture mass or growth rate across all modelled treatments in each experiment. Only the continuously-stocked and simple rotation treatments were modelled at Broadford.



accuracy is comparable to other validation tests, (for example in southern NSW where GrassGro is used with confidence by advisors and consultants). Long-term simulations with GrassGro (not shown here) have confirmed that the month-to-month pattern of pasture growth and composition predicted at Seymour is much more realistic with the modified parameters.

The new parameter set was distributed to Victorian participants in the Southern Livestock 2030 program immediately, and was “rolled out” to participants in other states at opportune times in their work programmes. It will be incorporated into the standard version of GrassGro at the time of the next software release.

Development of a parameter set for redgrass

There is a substantial area of central and northern New South Wales where native pastures containing C_4 perennial grasses are an important part of the feedbase. If the GrassGro decision support tool was to be used for climate change impacts and adaptation studies in these regions then this pasture type needed to be available in its underlying pasture growth model.

We therefore developed a parameter set for the GRAZPLAN pasture growth model that represented the C_4 native perennial grass species, redgrass (*Bothriochloa macra*). In the NPICC temperate pastures database (Pearson *et al.* 1997), redgrass is recorded as the most common C_4 species overall.

Methods

Pasture parameter development proceeded by a combination of literature review together with validation/calibration simulations against datasets from grazing experiments.

Experimental datasets. Relatively few experiments have been conducted on redgrass-dominant pastures. For this study two datasets were acquired: a stocking rate experiment at Armidale, NSW (Roe *et al.* 1959) and a stocking rate x grazing management experiment at Barraba, NSW (Lodge *et al*. 2003).

- *Roe 1948-52 trial* (Roe *et al.* 1959). This experiment was conducted over four years on low-fertility native pastures dominated by redgrass but with a small annual component. There were four treatments: three stocking rates under continuous grazing and a rotational grazing system at the intermediate stocking rate. The experiment also compared livestock performance with and without helminth parasite control, but only the animals with helminth control have been considered here.
- *Lodge 1998-2001 trial* (Lodge *et al.* 2003). This experiment formed part of the Sustainable Grazing Systems Key Program of Meat & Livestock Australia. It was conducted over three years on low-fertility native pastures dominated by redgrass and wallaby grass (*Austrodanthonia* spp.) Five combinations of pasture fertility, stocking rate and grazing management were compared in this experiment, but in this work only two treatments were considered:
  "C6" – continuous grazing at 6 ewes/ha, no fertilizer
  "R4/12" – rotational grazing of four subplots for 4 weeks, 4 ewes/ha, no fertilizer.

Experimental datasets were acquired in electronic form from their custodians or (for the older experiments) by digitization of figures and tables in published papers. The kinds of data that were available and the level of detail varied from experiment to experiment, both for site characteristics and for the dynamics of the soils, pastures and animals. The management of the experimental plots was diverse, including activities such as sowing of pastures, fertilisation at varying rates, irrigation, cutting, herbicide application and rotational grazing.

Weather datasets for the experimental locations and dates were often incomplete (e.g. at some locations only monthly summaries were available). Where necessary therefore, the available weather data were disaggregated and interpolated to produce inferred daily weather time sequences, using a Patched Point dataset from the SILO website (Jeffrey *et al*. 2001; http://www.longpaddock.qld.gov.au/silo) as a reference. Site-specific soil and pasture characteristics (horizon depths, bulk densities, soil moisture characteristics, pasture species included in the models, maximum rooting depths etc.) were set as far as possible to those reported in publications or described in personal communication with the authors. Where necessary, soil characteristics were taken from McKenzie *et al.* (2001) and pasture attributes were drawn from experiments at nearby sites.

Modelling of experiments. In order to accurately reflect management activities, all experiments were modelled using the AusFarm software (Moore 2001). Apart from the management rules, the model configurations that were used were compatible with the GrassGro decision support tool, i.e. the water balance model in GrassGro was used and responses of growth to soil fertility were modelled by using a common "fertility scalar" for all pasture species in each plot.

For each species, a parameter set was developed by working step-by-step through a series of key physiological processes that together make up the dynamics of a pasture:

- the annual cycle of phenology (for example times of flowering and senescence);
- the capture of light and uptake of water by the plant, including consideration of the rooting depth;
- the conversion of these resources to net primary productivity (NPP), including the effect of temperature on growth rate;
- the allocation of NPP to different parts of the plant. In this case allocation to leaf, stem, and root was considered since in these perennial grasses seed and seedling dynamics could be neglected;
- changes in the nutritive value (in particular dry matter digestibility) of green and dry pasture;
- death, litter fall and the disappearance of dry pasture;
- the effect of pasture morphology and tissue structure on the grazing behaviour of livestock.

For each of these processes, the behaviour of each species was described by setting the value of a set of numbers (known as parameters) that govern the equations of the GRAZPLAN pasture model. The importance of these parameters differs – the behaviour of the model is very sensitive to some parameters, and these are the ones that have the most attention devoted to them. Parameterisation was conducted by manually altering coefficients used in the equations of the pasture growth model, running a simulation of each relevant experiment and assessing the goodness of fit between measured and modelled values.

Statistical assessment of model performance. Model performance was assessed using the root mean squared deviation (RMSD) between modelled predictions and measured values. MSD was also partitioned into components (squared bias, non-unity slope and lack-of-correlation; Gauch *et al.* 2003) in order to examine the degree of translation, rotation and scatter, respectively, when measured data were plotted against modelled values. This approach was followed as each component of the MSD is distinct and additive, has a straightforward geometric interpretation and relates transparently to regression parameters (Gauch *et al.* 2003), and so gives a better overall insight into model performance.

Results

In the interests of brevity, only selected results from the simulations of experimental results have been presented.

Roe 1948-52 experiment. This experiment was simulated as a four-species mixture of redgrass, *Austrodanthonia*, subterranean clover and capeweed (as a generic dicotyledonous annual). As shown in Figure A10.2(a), the dynamics of both green and total herbage mass were quite successfully modelled (green: RMSD = 204 kg/ha; total: RMSD = 398 kg/ha). The characteristic high ratio of dead to green mass throughout the year was successfully captured. Bias was small for green mass and the relationship between actual and modelled green mass did not depart significantly from the 1:1 line. For total mass, however, modelled values were higher than actual for high herbage masses and lower than actual at low herbage masses. The simulation of botanical composition (Figure A10.2(b)) was pleasing: the modelled pasture retained all four functional groups and the annuals appeared as only small components of the pasture. The pasture was described by Roe *et al.* (1959) as redgrass-dominant, so the ratio to redgrass to *Austrodanthonia* was probably somewhat too low. In order to both produce the pasture growth rates measured in the experiment and maintain a sensible pasture composition, a very low fertility scalar

Figure A10.2. Simulation of an unfertilized redgrass-dominant pasture at Armidale, NSW stocked at 2.5 dry sheep/ha between October 1948 and October 1952. (a) Actual (symbols) and modelled (lines) green and total herbage mass, (b) actual (LHS) and modelled (RHS) botanical composition by weight at 12 measurement dates Note that the data set does not distinguish between grass species, so that the grey bars the proportion of grass (i.e. redgrass+*Austrodanthonia*).

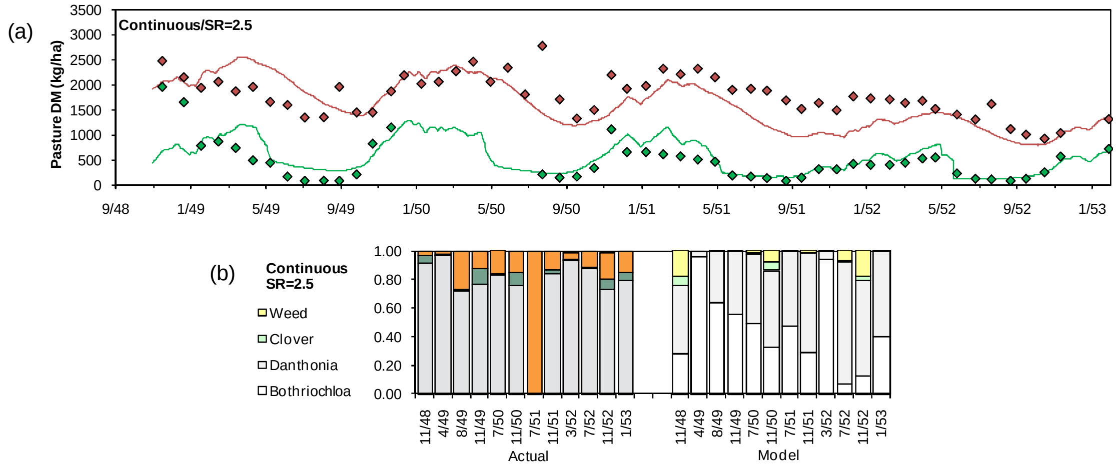
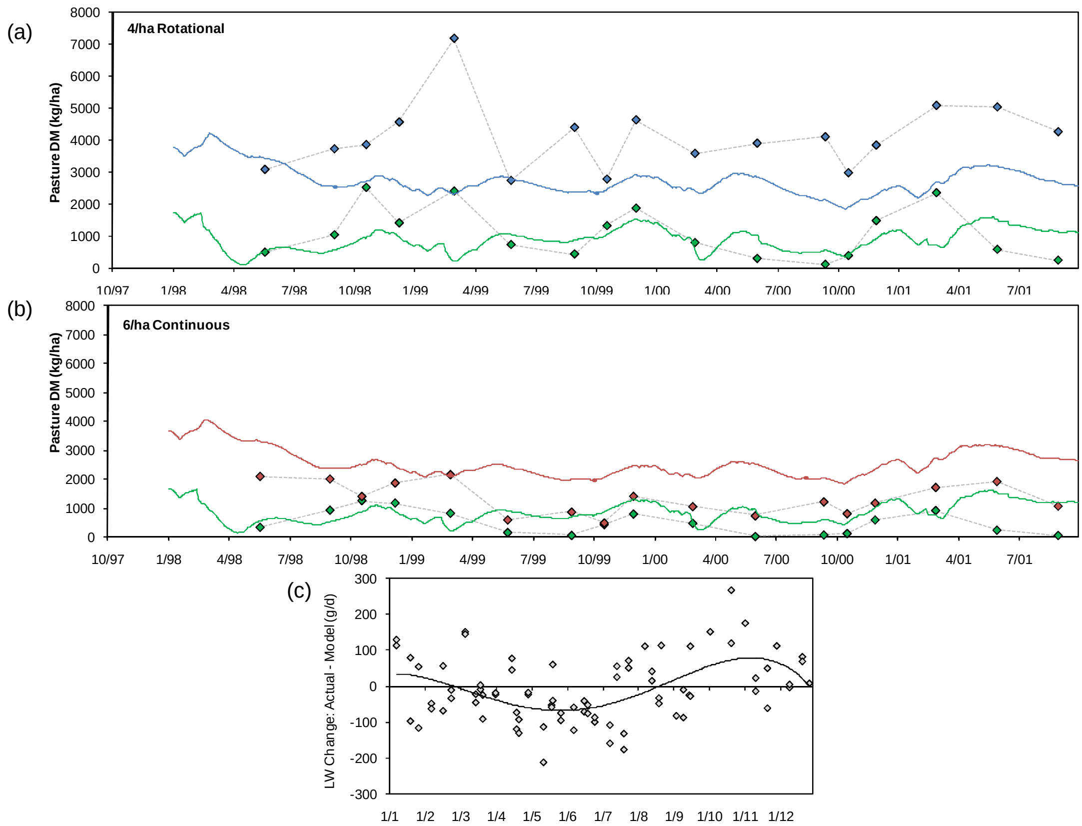


Figure A10.3. Simulation of unfertilized redgrass-dominant pastures at Barraba, NSW. (a, b) Actual (symbols) and modelled (lines) green and total herbage mass for two stocking rate and grazing management treatments; (c) differences between actual and predicted rates of sheep live weight change.



(0.40) had to be set. At higher fertilities, the *Austrodanthonia*, clover and weed components – for which existing parameter sets were used – dominated the pasture.

There was a systematic pattern of under-prediction of sheep weight change in spring each year (Figure A10.2(c)). This mis-prediction was particularly marked in the spring of 1951, when spring growth was correctly predicted as being lower than in other years, but it occurred in all four years of the experiment.

Lodge 1998-2001 experiment. This experiment was modelled as a redgrass monoculture, as redgrass was almost always at least 80% of pasture mass. Results of the validation simulations were not as good as for the Roe 1948-52 experiment (Figure A10.3). While the general patterns of herbage availability were reproduced, the RMSD for pasture mass (green and dead combined) was 1066 kg/ha. There was, however, negligible bias and the relationship between measured and modelled pasture masses did not depart significantly from the 1:1 line. Discrepancies in live weight change predictions showed similar month-to-month variation to the Armidale experiment.

Conclusions

The redgrass parameter sets remains a work-in-progress. However it received a good level of acceptance from NSW Department of Primary Industries staff at a GrassGro training workshop in June 2011, and so a decision was taken to release it for use in *Southern Livestock Adaptation 2030*. It has since been used in NSW regional workshops and in the work presented in Appendices 6 and 7.

Spring is the critical period where further improvement of model predictions is required. This outcome is not especially surprising; the commencement of the pasture growing season is often the most difficult part of describing a new pasture species, mainly because the perennating organs (below-ground reserves in the case of redgrass) are not often measured directly, and because small errors in relative growth rates at the start of growth can result in large changes in predicted pasture mass over 60-90 days.

<u>Development of a parameter set for kikuyu</u>

Kikuyu (*Pennisetum clandestinum*) has long been used as a forage grass in northern and coastal eastern Australia (Mears 1970). Like redgrass, kikuyu uses the C_4 photosynthesis pathway and so can be regarded as "summer-active" species. In the NPICC temperate pastures database (Pearson *et al.* 1997), kikuyu is the second most common.C_4 grass.

Recently, research and producer attention has shifted toward the inclusion of kikuyu in the feedbase in southern Australia (McDowall *et al*. 2003). The primary benefits sought by adding kikuyu to southern Australian pastures include high potential growth rates during late spring, summer and early autumn when growth rates of C_3 species are comparatively low (Neal *et al.* 2010); relatively deep roots that can inhibit rainfall accession to ground water and thus secondary salinisation (Sanford *et al*. 2003, White *et al*. 2003); and the fact that C_4 grasses often display greater water-use efficiency than C_3 species, even in temperate environments (Neal *et al*. 2011). These attributes may also mean that grasses such as kikuyu may be better suited to warmer future climates in southern Australia, especially if rainfall patterns shift toward a greater proportion of summer rainfall.

We therefore sought to develop a kikuyu parameter sets for the GRAZPLAN pasture growth model (Moore *et al.* 1997) that enabled adequate representation of dry matter production, botanical composition and pasture nutritive value.

Methods

As with redgrass, pasture parameter development proceeded by a combination of literature review and validation/calibration simulations against experimental datasets from cutting and grazing experiments.

Experimental data. After considering numerous experiments involving kikuyu, three experiments were chosen for validation work in order to span a range of environments and also on the basis of the completeness of the dataset. The selected experiments were two cutting trials conducted at Taree, NSW (Kemp 1975, 1976) and a grazing experiment at Albany, WA (Sanford *et al.* 2003). Together, these experiments included both a summer-dominant and a Mediterranean rainfall environment and had measurements of dry matter production, botanical composition, soil water content and (where applicable) livestock weights.

- *Kemp 1968-72 experiment* (Kemp 1975). This cutting trial on essentially pure kikuyu swards was conducted as part of a larger forage species evaluation over three seasons. Treatments were irrigation (irrigated vs dryland) x N fertilization (nil, 170 or 680 kg N ha^{-1} yr^{-1}). Shoot dry matter growth rates were measured in six replicates by cutting kikuyu to a height of 7-8 cm with an autoscythe.
- *Kemp 1970-74 experiment* (Kemp 1976). This cutting trial was also conducted over three seasons. Again, pastures were strongly kikuyu-dominant. There were two irrigation treatments (irrigated vs dryland); swards were given a maintenance nitrogen supply.
- *Sanford 1998-2001 experiment* (Sanford *et al.* 2003). The third dataset was from an experiment that formed part of the Sustainable Grazing Systems Key Program of Meat & Livestock Australia.. It was designed to test the impact of tree belts and kikuyu-based pastures on sheep production and groundwater recharge. Pastures included clover and annual grasses as well as kikuyu and were grazed with sheep in an irregular sequence (see Fig. 4a in Sanford *et al*. 2003). Because this experiment provided data on sheep live weight changes it gave an insight into the nutritive value of kikuyu-based pastures as well as competitive interactions with annual C_3-based pastures.

The processes of identifying parameter values, carrying out simulations of the experimental datasets and evaluating simulation results were conducted in a similar way as for redgrass.

Results

Kemp 1968-72 experiment. Shoot dry matter growth rates of the high N, irrigated treatment at Taree are shown in Figure A10.4. Model representation of measured growth rates was reasonable (RMSD = 21 kg/ha/d), though there was some tendency of the model to overestimate lower growth rates (normalised bias = 0.30).

Kemp 1970-74 experiment. Simulation of total dry matter growth of kikuyu for the Kemp 1970-74 data was very good (Figure A10.5). The RMSD was 1044 kg/ha (or about 25 kg/ha/d on a growth rate basis). There were no systematic under- or over-estimation of measured data (normalised squared-bias < 0.01) and the normalised non-unity slope was small (0.02).

Figure A10.4. Shoot dry matter growth rates from July 1969 to December 1972 at Taree, NSW. Open and closed points represent measured and modelled values, respectively.

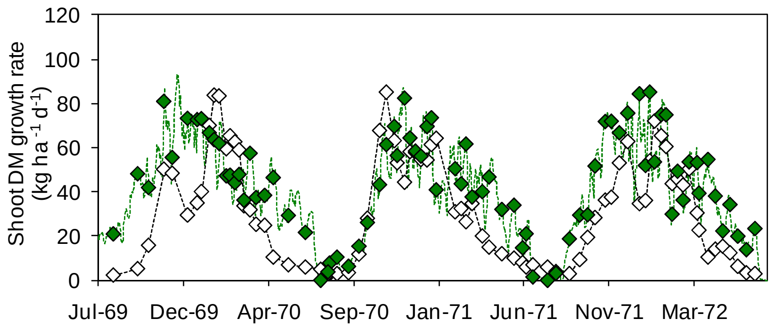


Figure A10.5. Shoot dry matter harvested from July 1971 to August 1974 at Taree, NSW. Open and closed points represent measured and modelled values, respectively.

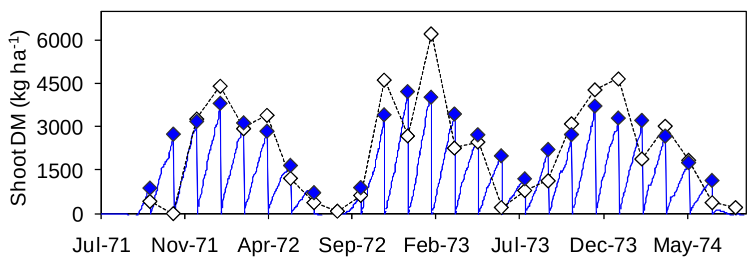
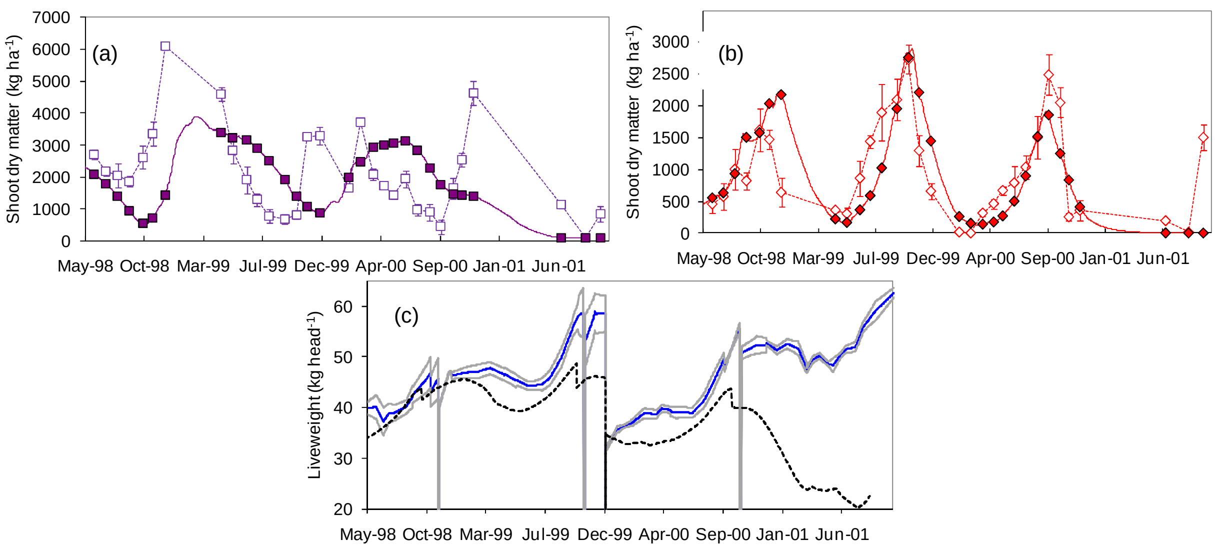


Figure A10.6. Simulation of a kikuyu-subterranean clover pasture grazed by Merino hoggets at Albany, WA from May 1998 to September 2001 . (a) Kikuyu shoot dry matter, (b) subterranean clover shoot dry matter and (c) Merino hogget live weights. Open and closed points in (a) and (b) represent measured and modelled values, respectively, and bars represent standard deviations. Solid blue and grey lines in (c) denote measured sheep live weight means and standard deviations, respectively, and dotted black lines represent simulated live weights. Note that ordinate axes in (a) and (b) differ, and that the ordinate axis in (c) does not begin at the origin.



Sanford 1998-2001 experiment. Simulated shoot dry matter of kikuyu for the Sanford dataset was less accurate than for the Taree trials (Figure A10.6(a), RMSD = 1238 kg ha^{-1}). The current parameter set under-predicts kikuyu growth during the spring of 1998, resulting in peak shoot dry matter values of around 4 t ha^{-1} (vs the 6 t ha^{-1} measured). Subsequent simulated decomposition rates of above-ground litter during winter of 1999 were lower than observed, and regrowth in autumn of 2000 also later than expected. Regrowth during the summer periods of 2001 was not reproduced by the model. The representation of the subterranean clover growing with the kikuyu is very good, on the other hand (Figure A10.6(b)), so that the GRAZPLAN model is simulating the co-existence of the different species reasonably well.

Simulated sheep live weight changes were often below measured values (Fig. A10.6(c)), consistent with the under-prediction of green herbage mass in late spring.

Discussion and conclusions

The kikuyu parameter set is not ready for release, either to GrassGro users in general or to participants in the *Southern Livestock Adaptation 2030* program in particular.

As for redgrass, spring is the critical period where further improvement of model predictions is required. Lack of data on pasture phenology at the experimental sites has also hampered parameter development. The onset of reproductive growth typically produces a shift in allocation of assimilate toward the shoots. Because kikuyu flowers are minute, sub-sessile and enclosed within leaf sheaths (Mears 1970) it is not surprising that the phenology of this species is rarely documented (e.g. see Hacker and Evans 1992). Consequently, assessment of simulated phenology can only be performed in qualitative terms (e.g. by comparison with Carr and Ng Kok 1956 and Mears 1970).

Further work on the kikuyu parameter set is required. An additional data set that may be employed for this purpose is from a cutting experiment at Camden, NSW (Neal *et al.* 2010, 2011), a site that has summer-dominant rainfall but cooler winters than Taree.

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