National Research FLAGSHIPS
Sustainable Agriculture

CSIRO

Modelling native pastures in the Monaro region of New South Wales with GrassGro

Andrew D. Moore
7 January 2010

Report to the Southern Rivers Catchment Management Authority

www.csiro.au

Enquiries should be addressed to:
Dr Andrew Moore
CSIRO Plant Industry
Black Mountain Laboratories
GPO Box 1600
Canberra 2601

Ph. 02 6246 5298

Distribution list

Brett Miners Southern Rivers Catchment Management Authority	1 copy
Nancy Spoljaric Monaro Farming Systems	1 copy

Contents

List of Figures

List of Tables

1. INTRODUCTION

Controlling land degradation is a key objective of the Southern Rivers CMA. Land degradation risks in the Monaro region are largely determined by the interaction between climatic variability and graziers' livestock management, through their effects on the persistence of perennial plant species and on the level of ground cover. Managing this interaction well is also vital for graziers' economic sustainability (and for generating income needed to carry out other natural resource management activities).

CSIRO has developed a decision support tool called GrassGro (Moore *et al.* 1997) that has been used extensively in other parts of southern Australia. The core of GrassGro is a dynamic model of pasture and livestock production based on soil type, weather and pasture species at any given site. GrassGro can assess the effect of management options on gross margins, pasture and animal production, supplementary feeding, and a series of environmental indicators such as persistence of species, ground cover and deep drainage. GrassGro's strength is that it enables producers and other land managers to see the "big picture" of possible outcomes from making a particular decision – including the risks imposed by uncertainty in the weather. Through discussion of the issues raised by working with GrassGro, producers and other land managers can gain a greater understanding of the impact of their strategic and tactical decisions on profit and sustainability and can make more informed decisions.

The Monaro Farming Systems producer group has expressed interest in using GrassGro to better understand the effects of different management practices on grazing properties in the Monaro region that are predominantly based on native grasslands. To use GrassGro in a region, however, the physiological and agronomic characteristics of the main pasture types have to be described as a set of "genotypic parameters". These parameters were not available for important species of the Monaro region such as *Poa sieberiana* and *Austrostipa spp.*, and as a result GrassGro could only be applied to improved pastures that make up a relatively small proportion of the grazed area in the Monaro.

In this project, published and unpublished data have been used to derive genotypic parameters for key native grasses of the Monaro region, so as to enable the use of GrassGro by local graziers and their advisors. The parameter sets have been tested against experimental data from the region and also evaluated by a panel of graziers from the local farming systems group.

2. DEVELOPMENT OF GENOTYPIC PARAMETERS

When developing a set of genotypic parameters, the first question that must be answered is: "Which species (or groups of similar species) should be described?" In this study, the great majority of the pasture mass at the experimental sites was made up of *Poa sieberiana* (henceforth *Poa*), *Austrostipa* spp. and *Austrodanthonia* spp., and much of the remainder by legumes and by a variety of broadleaf annuals and perennials. The *Austrostipa* and *Austrodanthonia* plants were not classified to species. It was therefore decided that the focus of this work should be on describing *Poa* and two "functional groups" representing the relevant species of *Austrostipa* and *Austrodanthonia*. The remaining perennial grasses (mainly

Enneapogon spp. with some *Themeda australis*, *Bothriochloa macra* and *Elymus* spp.) were present in small quantities. These species were arbitrarily lumped with *Austrodanthonia* as the least dissimilar species. The remainder of the pasture – about 10% of pasture mass at Bungarby and 16% at Berridale – was divided into legumes and all other plants (labelled as "broadleaf" species). These components were modelled using existing parameter sets for subterranean clover (*Trifolium subterraneum*) and capeweed (*Arctotheca calendula*), respectively.

For each species or functional group, 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 (dry matter digestibility and protein content) 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. The genotypic parameters for a new species are often derived by taking an existing set of parameters for a more-or-less related species and then adapting it to account for the differences between the two.

Given that our understanding of the physiology of these pasture plants is highly incomplete, parameter values had to be derived through a mix of different approaches. Published and unpublished data sets were consulted and parameter values taken or inferred from them. Physiological data sets that compare different plants were particularly useful, since often the relativities between species are as important as the absolute values of the parameters. The values of other parameters (for example those describing the phenology) must be inferred by running simulations with candidate values and checking model outputs against field data or the experience of knowledgeable colleagues. Finally, some parameters can be given default values that are known to hold for a wider set of species. For example, the relationship between digestibility and crude protein content is reasonably consistent for all grasses with the C_3 photosynthetic pathway.

For this study, comparative data on relevant attributes of the native perennial grasses were drawn from the literature (Archer & Robinson 1988, Lodge & Whalley 1983, Robinson & Archer 1988) and from unpublished specific leaf area data of Damien Tanner (a summer student at CSIRO Plant Industry in 2006-7). Many of the parameters were calibrated to simulations of the Monaro Grasslands R&D Project experimental data sets described in section 3.1.

A preliminary genotypic parameter set had already been developed for “tablelands” species of *Austrodanthonia* spp. (i.e. species other than *A. caespitosa*); these preliminary parameters were refined in this study. Parameters describing radiation use efficiency and its response to temperature, the allocation between root and shoot and the re-translocation of dry matter from the root back into the shoot, the rate at which shoot nutritive value declined and the rate of fall of standing dead shoots were calibrated to the experimental data.

The genotypic parameter set for *Austrostipa* was based on a parameter set for *Stipa grandis*. *S. grandis* grows in the grasslands of Northern China and had been described for the GRAZPLAN pasture model in an earlier collaboration with the Chinese Academy of Agricultural Sciences. The parameters controlling flowering date were changed so that flowering depends on day length. Since the *Austrostipa* species will grow throughout the year, the winter dormancy modelled in *S. grandis* was removed and the rate of senescence at the end of the reproductive cycle was reduced. Parameters describing radiation use efficiency and its response to temperature, the allocation between root and shoot, the re-translocation of dry matter from the root back into the shoot and the rate of fall of standing dead shoots were calibrated to the experimental data.

Poa has a very different morphology from other C_3 perennial grasses for which genotypic parameters already existed. *S. grandis* was the closest approximation and was used as a starting point for the *Poa* parameter set. The parameters controlling flowering date were changed so that flowering depends on day length, with reproductive growth in *P. sieberiana* later than that in *Austrostipa*. The parameters that were calibrated for *Austrostipa* were also calibrated for *P. sieberiana*. In particular, the rate at which standing dead shoots fall was greatly reduced, allowing the model to represent the typical tussock form of *P. sieberiana* in which live shoots are intermingled with previous years’ dead shoots.

Since both *P. sieberiana* and *Austrostipa* take a tussock form, their availability to grazing livestock was set to a relatively high level by assigning them low values for sward bulk density. Sward bulk density for *Austrodanthonia* was set to a value intermediate between that of the tussock grasses and of improved grasses such as *Phalaris aquatica*.

The complete genotypic parameter sets are provided as an Appendix.

3. VALIDATION OF GENOTYPIC PARAMETERS

Two separate sets of model runs were used to test the performance of the GRAZPLAN models and the new pasture parameter sets. First, a set of “validation” simulations was carried out that tried to replicate the experimental results over 2004-08 at the two sites of the Monaro Grasslands Research & Demonstration Project (MGRDP). While not a pure validation of the model (since the MGRDP data set was also used to calibrate model parameters), these simulations are a strong test of the model because of the relatively long period of experimental records available (~ 4 years) and the detailed nature of the experimental data set.

A complementary set of long-term simulations was also carried out. The purpose of these simulations was to examine the behaviour of the model against a wider range of climatic variability than that encountered during the MGRDP experiments, and in particular to assess the long-term average pattern of growth rates across the months of the year, whether the model successfully predicted the persistence of the main pasture species, and whether long-run animal production figures were sensible. Evaluation of these results necessarily relied on the judgment of local producers and advisory staff.

3.1 Data sets from the Monaro Grasslands R&D Project

The main experiments in the MGRDP were located at Bungarby (36° 38′ S, 149° 2′E, 825 m ASL) and Berridale (36° 25′ S, 148° 52′E, 895 m ASL). As can be seen in Figure 1, the Bungarby site is wetter and has slightly lower minimum temperatures than the Berridale site. The soils at the two locations have very different parent materials; the soil at Berridale in particular is highly deficient in both phosphorus and sulphur. The Bungarby site is dominated by *P. sieberiana*; the Berridale site is more diverse, with *Austrostipa* and *Austrodanthonia* the most common genera.

The main experiments at the two sites are of similar design. A single "management intensity" treatment (i.e. fertiliser + stocking rate) with three levels is replicated three times in a randomised complete blocks design. At each site one of the management levels is a control (unfertilized pasture managed at typical district stocking rates), and there are two higher levels of inputs and stocking rate. Fertiliser applications have been varied year by year to build soil tests for P and S to target levels, and stocking rates are set each year in response to climatic conditions and the availability of forage.

The main measurements on this part of the MGRDP are hourly weather data; pasture mass and composition (assessed with the BOTANAL procedures of Tothill *et al.* 1992); pasture DMD and crude protein measurements; animal live weights and annual data for fleece weights and fibre diameters.

Figure 1 Mean monthly maximum and minimum temperatures and rainfalls at the two MGRDP sites over the period June 2004 to July 2008.

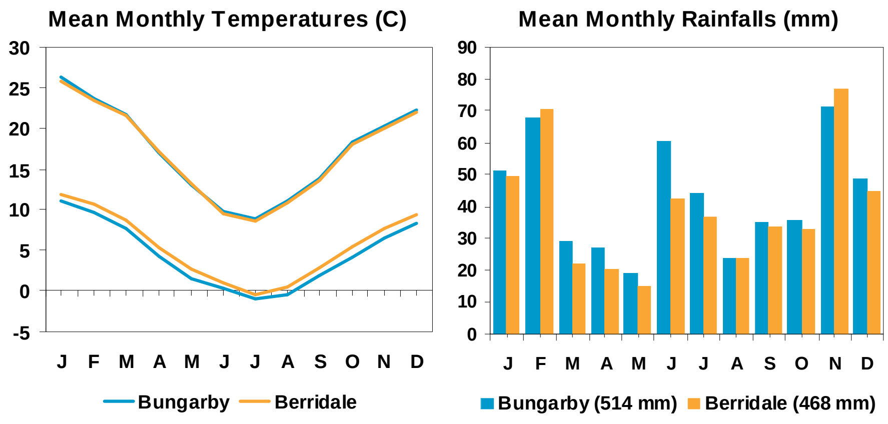


Table 1 Summary of site attributes and experimental treatments at the two MGRDP sites.

	Bungarby	Berridale
Soil type	Basalt	Granite
Main perennial grass	*Poa sieberiana*	*Austrostipa* spp, *Austrodanthonia* spp
Initial Colwell P (mg/kg)	48	17
Target Colwell P (mg/kg)	40	25
Initial KCL40 S (mg/kg)	5	2
"Low" treatment	125 kg/ha gypsum	125 kg/ha super
"High" treatment	125 kg/ha gypsum + 125 kg/ha super	250 kg/ha super + 125 kg/ha gypsum
2008 stocking rates (sheep/ha)	3.4, 4.8, 6.0	2.0, 3.2, 3.6

Table 2 Soil properties used in the validation and long-term simulations.

	Bungarby		Berridale	
	Topsoil	Subsoil	Topsoil	Subsoil
Depth to base of horizon (mm)	300	1000	300	1000
Bulk density (Mg/m^3)	1.16	1.20	1.45	1.66
Wilting point (m^3/m^3)	0.22	0.37	0.07	0.11
Field capacity (m^3/m^3)	0.35	0.45	0.18	0.20
Saturated hydraulic conductivity (mm/d)	100	10	100	10

As part of the current project, undisturbed soil cores were sampled from the A1 and A2 horizons of soil pits at each site. The bulk density and soil water contents at water potentials of 0.1 bar and 15 bar of these cores were analysed by CSIRO Land and Water and the soil properties in Table 2 (which are required to run the GRAZPLAN models) were derived from them.

3.2 Validation simulations

The validation simulations were carried out using the AusFarm modelling software (Moore 2001), which allowed the fertilizer and livestock management of the experimental treatments to be closely mimicked. The hourly weather data were converted to daily summaries and short gaps in the weather records were filled using files downloaded from the Data Drill (Jeffrey *et al.* 2001). Pastures at Bungarby were modelled as a mixture of *P. sieberiana*, *Austrostipa* spp.

and legume; pastures at Berridale were modelled as a five-component mixture (*P. sieberiana*, *Austrostipa* spp., *Austrodanthonia* spp., legume and other broadleaf). Simulations were run from 1 January 2004 to the end of the available experimental data in July 2008.

Each of the three management intensity treatments at each site was simulated. At the start of the simulations, the “fertility scalar” (a simple representation of soil fertility) for all treatments was set at a low value (0.65 on the basalt soil at Bungarby, 0.55 on the granite soil at Berridale). For the two fertilized treatments, the fertility scalars were then increased on 15 Mar 2005 and 15 Mar 2006 (the approximate date of fertilizer application) to reach final values of 0.75 and 0.90 at Bungarby and 0.65 and 0.75 at Berridale. The actual patterns of livestock movements on and off each treatment – and hence the site- and treatment-specific stocking rates – were simulated, as were the actual shearing dates.

Results of the validation simulations are presented in Figures 2-7. The general patterns of pasture growth and hence green pasture mass are quite well captured (Figures 2 and 3), although spring growth rates are somewhat too great for *Austrostipa* in 2005 and too low for *Poa* in 2005 and 2007. The model successfully captures the large stocks of standing dead herbage in the *Poa* tussocks at Bungarby; at Berridale, however, the mass of dead pasture is (on average) somewhat too high. As a result, while the regression of actual on predicted pasture masses for Bungarby is close to the 1:1 line (Figure 4), at Berridale the model over-predicts the higher dead masses, resulting in a regression slope less than 1.0. Root-mean-square prediction errors for pasture mass were 610 kg/ha at Bungarby and 285 kg/ha at Berridale; these values are in line with those obtained for other validation studies with the GRAZPLAN pasture model.

Capturing the dynamics of pasture species composition is a very difficult problem, and in this light the predictions of compositional change in Figures 2 and 3 are pleasing. First, the model correctly predicts that there is not much compositional change between the management intensity treatments. An increase in the proportion of annual plants in spring 2007 at both sites is also represented correctly by the model.

Predicted DMD values for green pasture are reasonably accurate (Figure 5), given the errors inherent in DMD measurement and the difficulty of exactly matching pasture samples to biomass pools in the model. Predictions for green *Poa* at Bungarby are better than those for other species and for the whole pasture at Berridale. The model does not, however, capture the increased pasture DMD associated with the fertiliser treatments, and predicted digestibilities for dead pasture are systematically too low (Figures 5 and 6).

While the predictions of sheep weight change are reasonable at most times during the experimental period, there are some occasions where the model and the data diverge markedly. Under-predictions of animal weight gain at Bungarby during March-April 2007 and at Berridale in late winter of 2007 are at least partly due to under-prediction of pasture growth at times when animal intake would have been highly sensitive to the green pasture mass. It may also be the case that the animals entering the trial at Bungarby were in low body condition and made compensatory growth during this period. The rapid measured weight gains at Berridale during spring 2006, on the other hand, are a mystery. The observed rates of gain (205-251 g/day during the period 19 September to 31 October 2006) require a high-quality diet, and the measured green pasture masses on the stocked treatments during this period are simply too low for any sensible model to predict rapid weight gain.

The soil-plant-animal dynamics that are leading to the observed data in Figures 5 and 6 are clearly complex and imperfectly understood. The mis-predictions of animal performance by the GRAZPLAN models in the validation data set mean that some caution should be exercised when using the model in these pasture-livestock systems. Further comparisons against data sets form other locations will be needed to understand this issue more fully.

Figure 2 Validation simulations at the Bungarby MGRDP site: comparison of actual and simulated green and total pasture mass (left) and pasture composition (right, as proportions on a total mass basis). “High”, “Low” and “Control” refer to the three management intensity treatments. In the pasture mass charts, symbols show measured data and solid lines the results of the simulations; coloured lines and symbols show green pasture mass and black symbols and lines show total pasture mass.

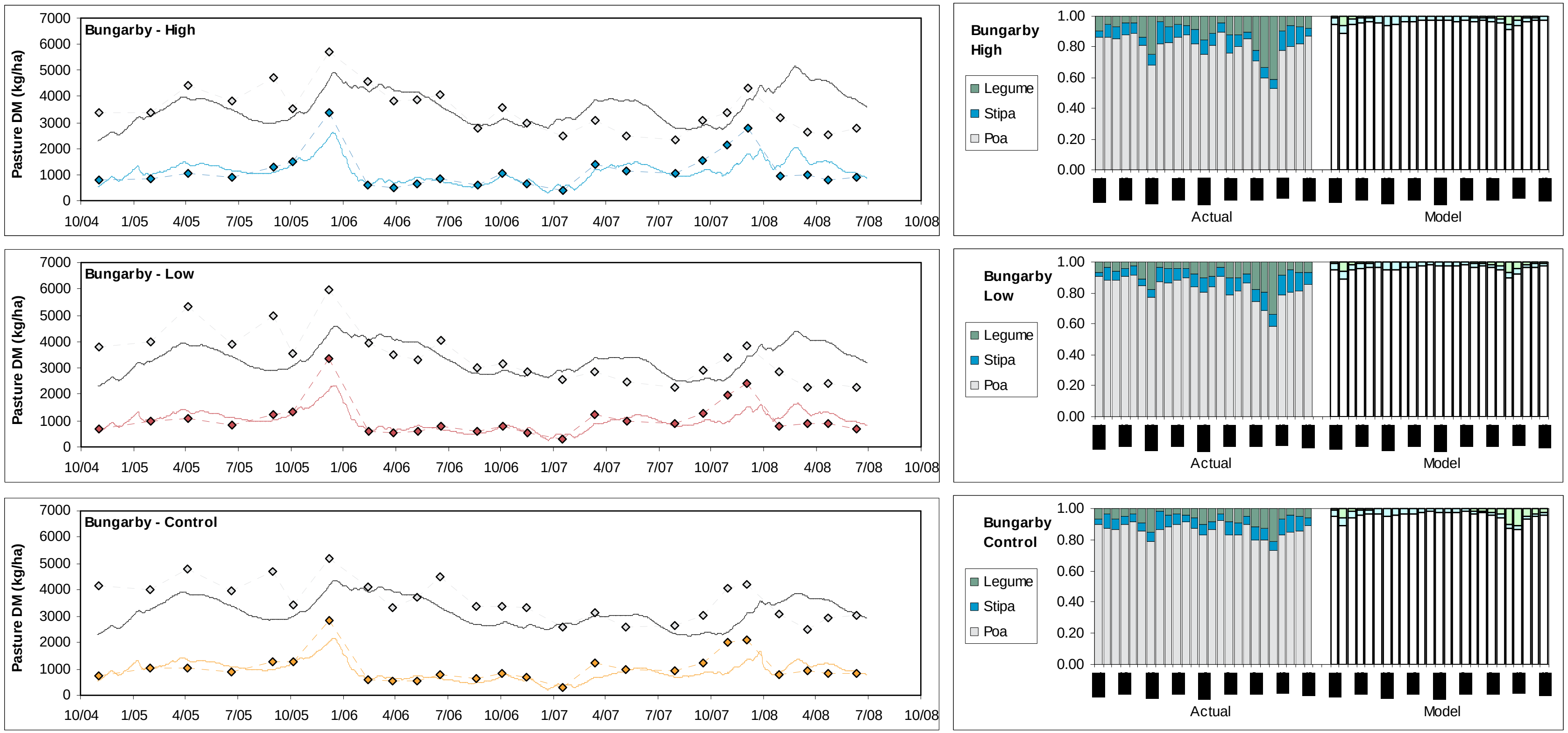


Figure 3 Validation simulations at the Berridale MGRDP site: comparison of actual and simulated green and total pasture mass (left) and pasture composition (right, as proportions on a total mass basis). “High”, “Low” and “Control” refer to the three management intensity treatments. In the pasture mass charts, symbols show measured data and solid lines the results of the simulations; coloured lines and symbols show green pasture mass and black symbols and lines show total pasture mass. Note that the vertical axis in the pasture mass charts differs from that in Figure 2.

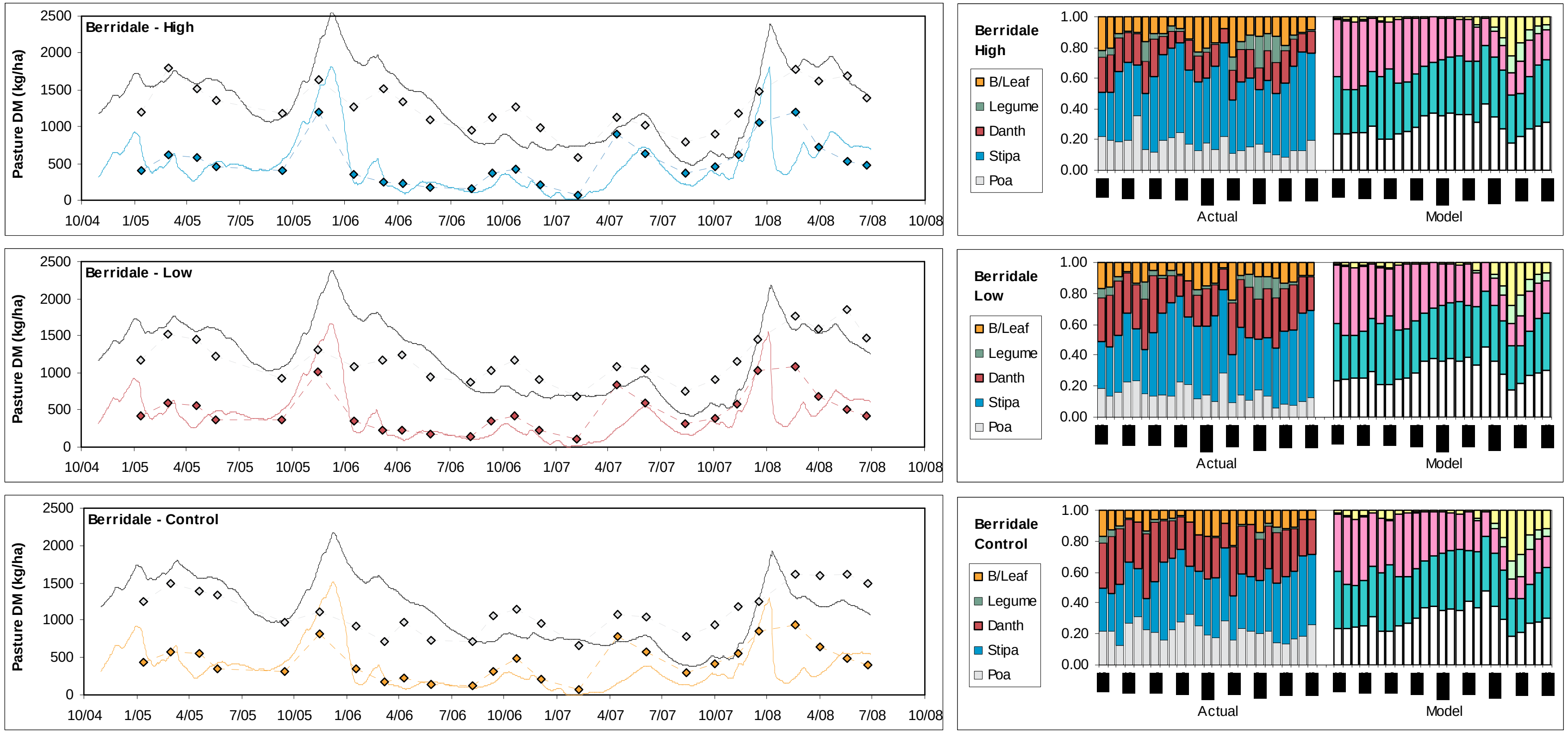


Figure 4 Validation simulations at the two MGRDP sites: comparison of actual and simulated green pasture mass (solid symbols) and dry pasture mass (open symbols). ◆ High management intensity; ◆ low management intensity; ◆ low-fertility control. Dashed lines show linear regressions of actual on modelled pasture masses, calculated over all green and dry mass measurements (Bungarby: y = 91x + 219; Berridale: y = 0.50 x + 293). Solid lines show a 1:1 relationship. Note that the axis scales are different.

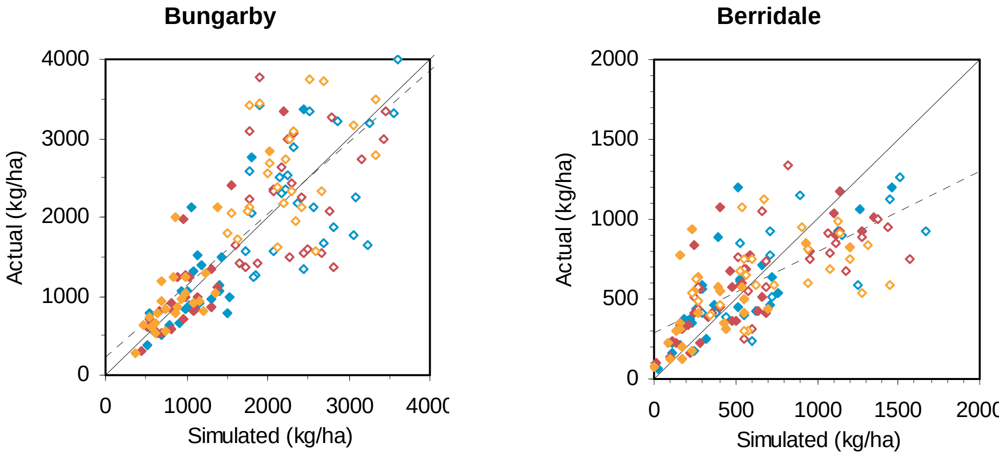


Figure 5 Validation simulations at the two MGRDP sites: comparison of actual and simulated dry matter digestibility (DMD) of *P. sieberiana* and of other species at Bungarby, and the total pasture at Berridale. Green pasture DMD is shown as solid symbols and dry pasture DMD as open symbols. ◆ High management intensity; ◆ low management intensity; ◆ low-fertility control.

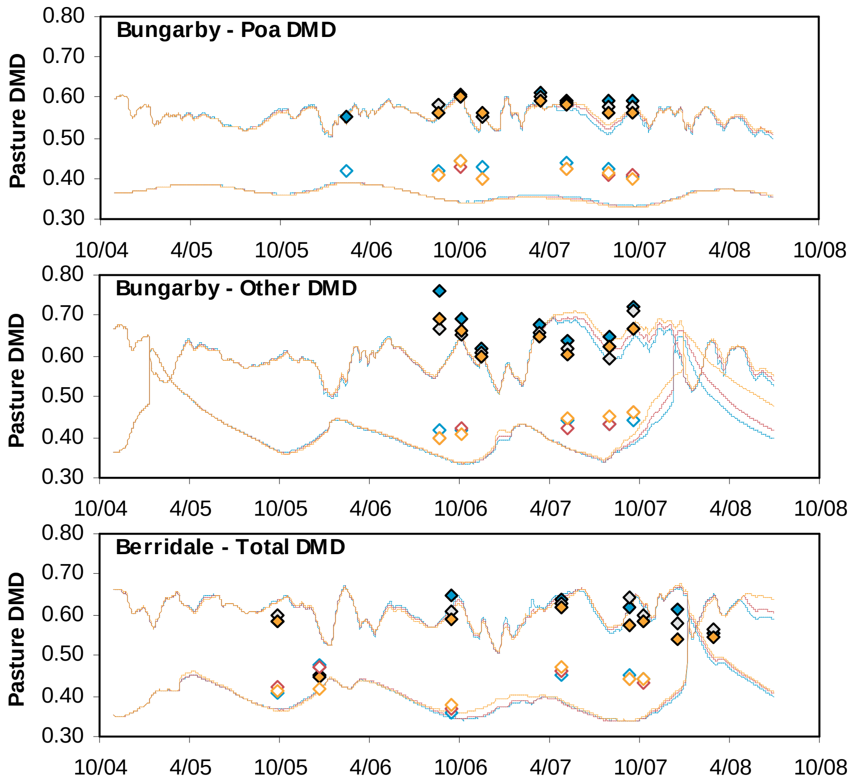


Figure 6 Validation simulations at the two MGRDP sites: comparison of actual and simulated green pasture DMD (solid symbols) and dry pasture DMD (open symbols). ◆ High management intensity; ◆ low management intensity; ◆ low-fertility control. Note that the axis scales are different.

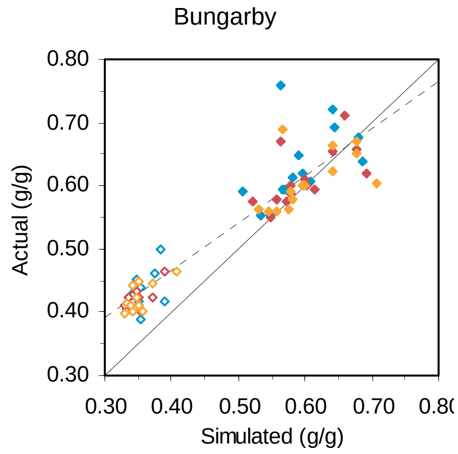
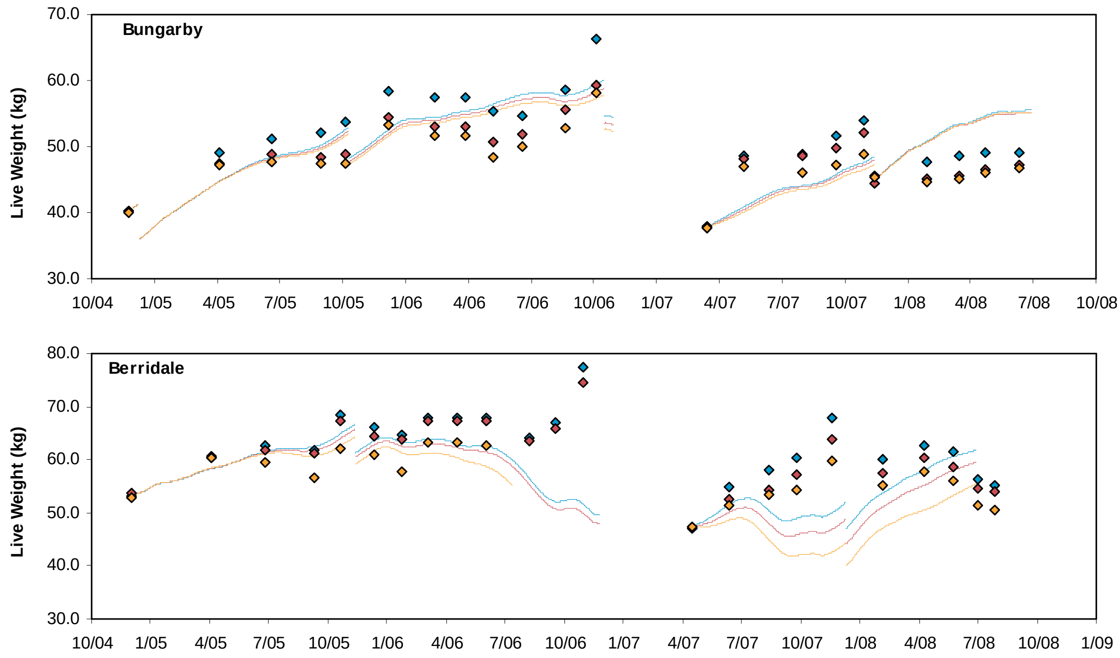


Figure 7 Validation simulations at the two MGRDP sites: comparison of actual and simulated sheep live weights on each treatment. ◆ High management intensity; ◆ low management intensity; ◆ low-fertility control. The variations in stocking rate in the experiment have been taken into account in the simulation. Gaps in the simulated lines show points where stock were shorn or replaced, or where the experimental plots were destocked owing to drought.



3.3 Long-term simulations

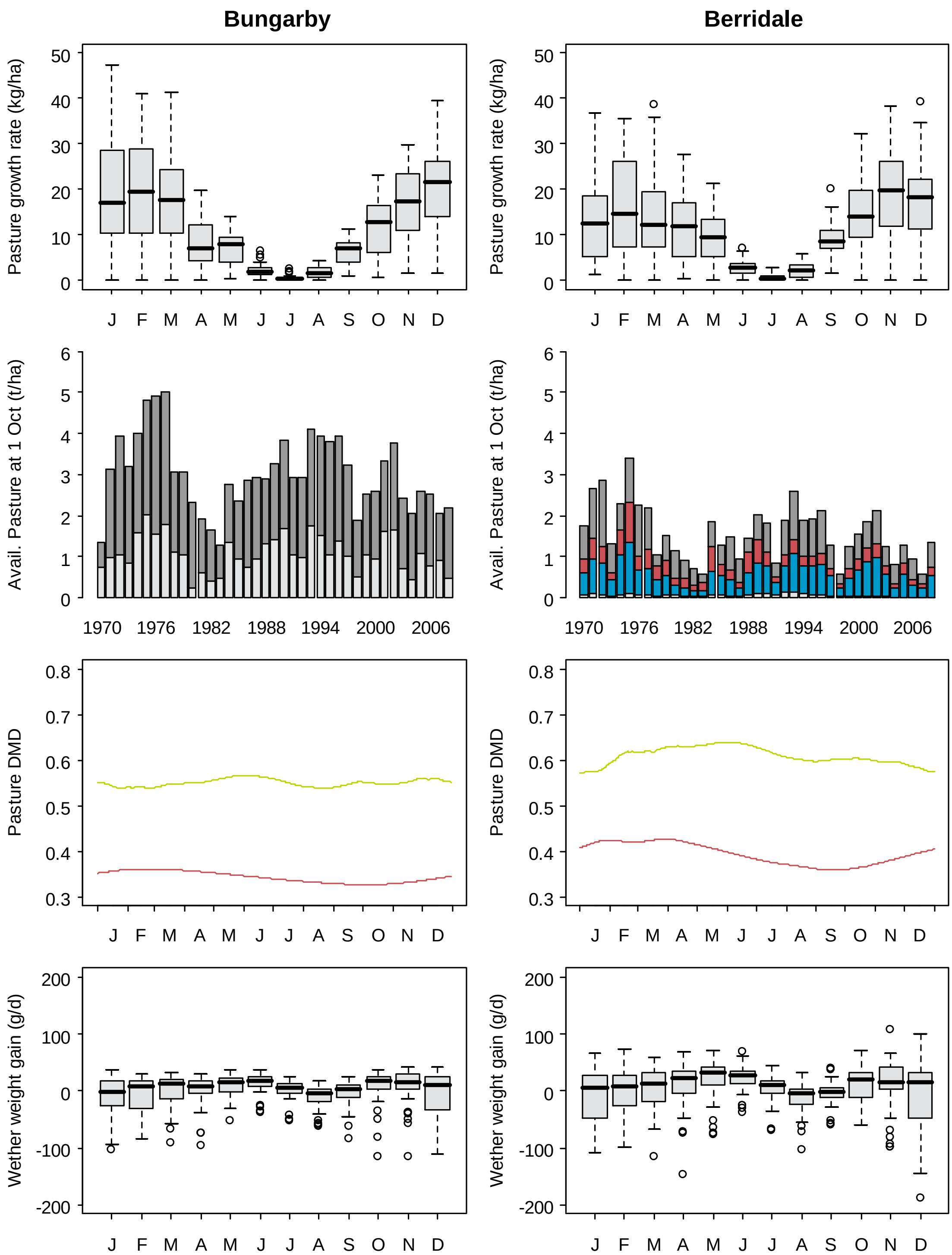
Long-term simulations for the Bungarby and Berridale sites were carried out using the GrassGro decision support tool (version 3.1.3). The simulation models, soil physical attributes and genotypic parameters used in the validation simulations were also used in the long-term runs. Since weather data for the two sites were only available from the start of the MGRDP in 2004, weather records from 1970-2008 were extracted for the nearest point in the Data Drill, which provides weather data on a 3-minute grid across Australia.

Because the long-term simulations were intended to be evaluated by Monaro graziers, they were set up to approximate district practice. The soil fertility was set to the same low levels used for the control treatment in the validation simulations (i.e. the “fertility scalar” was set to 0.65 at Bungarby and 0.55 at Berridale), and a low stocking rate was used (3.5 wethers/ha at Bungarby and 2.5 wethers/ha at Berridale).

The simulated pastures were simplified for the long-term runs, with only the major constituent species being included in the pasture mix (i.e. *Poa* at Bungarby, and *Austrostipa*, *Austrodanthonia* and *Poa* at Berridale). A fine-wool medium Merino wether enterprise was simulated (breed standard reference weight 50 kg; average simulated fleece fibre diameter 19 micron). Replacement wethers were bought at 18 months of age and old wethers sold at 78 months of age on 1 January each year, following a 15 December shearing. Sheep were fed wheat to maintain their body condition score when it fell below 1.0.

A sample of the results from the long-term simulations is presented in Figure 8. A severe limitation to growth in the winter and highly variable rates of growth at other times of the year can be seen clearly, as can the high ratio of dead to green forage in *Poa*-dominant pasture. The simulation at Berridale retains all three perennial grasses over a 39-year simulation, with roughly equal amounts of *Austrostipa* and *Austrodanthonia* and a smaller proportion of *Poa*. Long-term average digestibility of green *Poa* pasture never reaches a high value, with the result that rapid growth by wethers is not seen. Nonetheless, the sheep maintain their weight on average, with relatively infrequent periods of rapid weight loss being balanced by longer periods of modest weight gain (very little supplement was fed in either long-run simulation). Rates of sheep weight gain are more variable in the Berridale simulation, with higher quality of green pasture enabling greater gain when pasture mass is high, but lower overall pasture productivity (constrained by fertility) resulting in periods of pasture shortage.

Figure 8 Long-term simulations (1970-2008) at the two MGRDP sites. First row: box plots of monthly average pasture growth rates. Second row: changes in pasture composition, as shown by green and dry pasture masses on the 1st October each year. ☐ Green *Poa sieberiana*; ■ green *Austrostipa* spp.; ■ green *Austrodanthonia* spp. ■ dry pasture. Third row: long-term average dry matter digestibility of green (—) and dry (—) pasture. Fourth row: box plots of monthly average weight change of wethers.



In each box plot, the box shows the middle 50% of values (the interquartile range). The horizontal line inside the box shows the median value. Beyond the "whiskers", outlying values are shown by circles (an outlier is a value that lies more than 1.5 times the interquartile range beyond the upper or lower quartile).

3.4 Assessment of simulation results by Monaro graziers

The modelling process and results described in sections 3.1-3.3 were presented to a meeting held by the Monaro Farming Systems producer group on 14 September 2009. Attendance was somewhat smaller than expected (four producers and three officers of NSW Industry & Investment), but the feedback from the meeting was straightforward and positive. The graziers agreed that the genotypic parameters developed in this project were of a quality sufficient for GrassGro to be applied to the native pastures of the Monaro region.

The native grass genotypic parameter sets have since been distributed to a GrassGro user (Doug Alcock, NSW Industry & Investment, Cooma) and will be made available on request to other trained GrassGro users.

REFERENCES

Archer KA, Robinson GG (1988) Agronomic potential of native grass species on the Northern Tablelands of New South Wales. II. Nutritive value. *Australian Journal of Agricultural Research* **39**, 425-436.

Jeffrey SJ, Carter JO, Moodie KM and Beswick AR (2001). Using spatial interpolation to construct a comprehensive archive of Australian climate data. *Environmental Modelling and Software*, **16**, 309-330.

Lodge GM, Whalley RDB (1983) Seasonal variations in the herbage mass, crude protein and in-vitro digestibility of native perennial grasses on the north-west slopes of New South Wales. *Australian Rangeland Journal* **5**, 20-27.

Moore AD, Donnelly JR, Freer M (1997) GRAZPLAN: decision support systems for Australian grazing enterprises. III. Pasture growth and soil moisture submodels, and the GrassGro DSS. *Agricultural Systems* **55**, 535-582.

Moore AD (2001) FarmWi$e: a flexible decision support tool for grazing systems management. Proceedings of the 19th International Grassland Congress, Sao Pedro, Brazil (Eds JA Gomide, WRS Mattos, SC Da Silva) pp. 1045-1046.

Robinson GG, Archer KA (1988) Agronomic potential of native grass species on the Northern Tablelands of New South Wales. I. Growth and herbage production. *Australian Journal of Agricultural Research* **39**, 415-423.

Tothill JC, Hargeaves JNG, Jones RM (1992) BOTANAL – a comprehensive sampling and computing procedure for estimating pasture yield and requirements. I. Field sampling. CSIRO Division of Tropical Crops and Pastures, Tropical Agronomy Technical Memorandum No. 78, Brisbane.

ACKNOWLEDGEMENTS

This work would not have been possible without the preceding years of experimental work carried out by staff of NSW Industry & Investment (particularly Jo Powell, Luke Pope and Doug Alcock). Their willingness to share their experimental results, to provide me with an introduction to the MGRDP experiments and to assist with soil sampling is greatly appreciated. I would also like to thank the members of the Monaro Farming Systems group who participated in the evaluation exercise.

APPENDIX – LISTING OF THE PASTURE GENOTYPIC PARAMETERS

Parameter	Meaning	Units	*Poa sieberiana*	*Austrostipa* spp.	*Austrodanthonia* spp. (tableland)
Grass	TRUE for grasses		TRUE	TRUE	TRUE
Legume	TRUE for legumes		FALSE	FALSE	FALSE
Annual	TRUE for annuals, FALSE for perennials		FALSE	FALSE	FALSE
Long Day	TRUE if long days required to induce reproductive growth		TRUE	TRUE	TRUE
K_{V1}	Vernalisation rate at 0ºC	/d			0.05
K_{V2}	Effect of temperature on vernalisation rate	/ºC			0.20
K_{V3}	Base temperature for degree-day computations	ºC	0.0	0.0	0.0
K_{V4}	Day length for commencement of reproductive growth	hr	12.5	11.0	10.3
K_{V6}	Degree-day sum for commencement of flowering	ºd	1300	800	200
K_{V9}	Degree-day sum beyond which the reproductive phenostage can end	ºd	2200	1500	2800
K_{V10}	Value of the soil moisture growth-limiting factor that defines "drought" for the senescence calculations	0-1	0.25	0.25	0.25
K_{V15}	Reduction in the rate of development due to water stress in pre-flowering, reproductive plants	0-1	0.00	0.00	0.00
K_{V16}	Temperature threshold for the onset of winter dormancy	ºC	-99.9	-99.9	-99.9
K_{V20}	Length of the drought period required to induce senescence when DD(j)= KV9j	d	5.0	4.0	
K_{V21}	Value of DD(j) at which senescence occurs in the absence of drought	ºd	2500	2000	4200
K_{I1}	Reference specific leaf area (ratio of leaf area index to leaf weight)	m^2/g	0.017	0.016	0.016
K_{I2}	Reference specific stem area	m^2/g	0.003	0.003	0.005
K_{I3}	Curvature factor for effect of light on specific area	$MJ/m^2/d$	13.5	13.5	13.5
K_{I4}	Temperature threshold for maximal specific area	ºC	15	15	15
K_{I5}	Relative specific area at 0ºC	0-1	0.6	0.6	0.6
K_{I7}	Apparent light extinction coefficient under ungrazed conditions	0-1	0.45	0.50	0.55
K_{I8}	Apparent extinction coefficient under heavily grazed conditions	0-1	0.65	0.65	0.80
K_{I9}	Apparent extinction coefficient of standing dead	0-1	0.60	0.70	0.70
K_{I10}	Apparent extinction coefficient of litter	0-1	1.00	1.00	1.00
K_{WU1}	ASW threshold for growth limitation	0-1	0.35	0.35	0.35
K_{WU2}	Proportion of any transpiration deficit that can be recovered from moist layers	0-1	1.00	1.00	1.00
K_{RU1}	Radiation use efficiency under reference conditions	g/MJ	1.65	1.7	1.6
K_{RU2}	Effect of radiation intensity on radiation use efficiency	$MJ/m^2/hr$	0.6	0.6	0.6
K_{RU3}	Relative photosynthetic efficiency of stems	0-1	0.6	0.6	0.6
K_{BT1}	Biomass-transpiration coefficient	kPa g/kg	6.0	6.0	6.0
K_{BT2}	Relative increase in biomass-transpiration coefficient at twice reference [CO2]	-	0	0	0
K_{T1}	temperature for 5% of maximum assimilation rate	ºC	5	5.5	6
K_{T2}	temperature for 95% of maximum assimilation rate	ºC	12	13	13
K_{W1}	Transpiration ratio below which assimilation rate decreases	0-1	0.5	0.3	0.4
K_{WL1}	WFPS threshold for waterlogging	0-1	0.85	0.85	0.85
K_{WL2}	Curvature of growth limitation by waterlogging	-	23	23	23
K_{TL1}	Threshold growth-limiting factor for translocation from belowground reserves	-	0.2	0.2	0.2

Parameter	Meaning	Units	*Poa sieberiana*	*Austrostipa* spp.	*Austrodanthonia* spp. (tableland)
K_{TL2}	Relative rate of translocation from belowground reserves	/d	0.005	0.005	0.005
K_{RE1}	Maintenance respiration rate at 10ºC (g DM/g N/d)	g/g/d	0.40	0.40	0.40
K_{RE2}	Q10 factor for maintenance respiration	-	1.75	1.75	1.75
K_{RE4}	Growth respiration rate	g/g	0.25	0.25	0.25
K_{A1}	Target root:shoot ratio during vegetative growth	-	1.80	1.20	1.20
K_{A2}	Target root:shoot ratio during reproductive growth	-	1.00	1.00	1.00
K_{A4}	Maximum value of the ratio (leaf allocation):(shoot allocation)	0-1	0.7	0.8	0.8
K_{A5}	Minimum value of the ratio (leaf allocation):(shoot allocation)	0-1	0.5	0.5	0.6
K_{R1}	Maximum rooting depth under optimal soil conditions	mm	1000	1000	1200
K_{R2}	Maximum rate of root front extension	mm/ºd	2.0	2.0	2.0
K_{R3}	Base temperature for root front extension	ºC	0.0	0.0	0.0
K_{R4}	ASW below which root extension is reduced	0-1	0.25	0.25	0.25
K_{R5}	Threshold bulk density for reduced root extension in 100% sand	Mg/m^3	1.4	1.4	1.4
K_{R6}	Threshold bulk density for reduced root extension in 0% sand	Mg/m^3	1.2	1.2	1.2
K_{R7}	Rate of decrease in root extension with increasing bulk density	m^3/Mg	2	2	2
K_{R8}	Minimum value of the bulk density effect on root extension	0-1	0.1	0.1	0.1
K_{R9}	Specific root length	m/g	200	200	140
K_{R10}	Average radius of effective roots	m	0.00015	0.00015	0.00013
K_{D1}	Thermal age at which death of shoots commences	ºd	500	500	500
K_{D2}	Background death rate of old shoots in seedlings & established plants	/ºd	0.005	0.005	0.005
K_{D3}	Additional death rate of all shoots in senescing plants	/ºd	0	0.001	0.001
K_{D4}	Temperature for 5% mortality at the first frost	ºC	-5	-5	-5
K_{D5}	Temperature for 95% mortality at the first frost	ºC	-11	-11	-11
K_{D6}	Frost-hardening factor	ºC	1	1	1
K_{DR2}	Specific root loss rate at 10ºC	/d	0.002	0.002	0.002
K_{DR4}	Q10 for root aging and loss	-	1.5	1.5	1.5
$K_{F1,leaf}$	Fall of standing dead: reference rate for leaf	/d	0.001	0.0025	0.0025
$K_{F1,stem}$	Fall of standing dead: reference rate for stem	/d	0.0004	0.0012	0.0012
K_{F2}	Fall of standing dead: maximum relative effect of precipitation	-	40	40	40
K_{F3}	Fall of standing dead: curvature of precipitation effect	/mm	10	10	10
K_{F4}	Fall of standing dead: trampling effect	/kg/d	30	30	30
$K_{BR1,leaf}$	Background rate of breakdown of leaf litter	/d	0.1	0.1	0.1
$K_{BR1,stem}$	Background rate of breakdown of stem litter	/d	0.02	0.02	0.02
K_{BR2}	Litter breakdown: trampling effect	/kg/d	10	10	10
K_{BR3}	Rate of litter incorporation under dry soil conditions	/d	0.02	0.02	0.02
K_{BR4}	Rate of litter incorporation under wet soil conditions	/d	0.05	0.05	0.05
$K_{Q,leaf,1}$	Average digestibility of newly-produced leaf	g/g	0.75	0.75	0.85
$K_{Q,leaf,2}$	Minimum digestibility of green leaf during vegetative growth	g/g	0.55	0.55	0.7
$K_{Q,leaf,3}$	Minimum digestibility of green leaf during reproductive growth	g/g	0.55	0.5	0.65
$K_{Q,leaf,4}$	Thermal time during which green leaf maintains its digestibility	ºd	200	200	200

Parameter	Meaning	Units	*Poa sieberiana*	*Austrostipa* spp.	*Austrodanthonia* spp. (tableland)
$K_{Q,leaf,5}$	Rate parameter for decline of DMD of green leaf	/ºd	0.006	0.006	0.006
$K_{Q,leaf,6}$	Base temperature for maturation & senescence of green tissue	ºC	4	4	4
$K_{Q,stem,1}$	Average digestibility of newly-produced stem	g/g	0.75	0.75	0.8
$K_{Q,stem,2}$	Minimum digestibility of green stem during vegetative growth	g/g	0.5	0.4	0.4
$K_{Q,stem,3}$	Minimum digestibility of green stem during reproductive growth	0	0.35	0.35	0.35
$K_{Q,stem,5}$	Rate parameter for decline of DMD of green stem	ºd	0.004	0.003	0.003
K_{Y1}	Dead & litter decay: reference rate of microbial decomposition of digestible DM	/d	0.010	0.015	0.015
K_{Y2}	Dead & litter decay: factor for Q10 of decomposition	-	4.7	4.7	4.7
K_{Y3}	Dead & litter decay: factor for Q10 of decomposition	ºC	32	32	32
K_{Y4}	Dead & litter decay: minimum value of the moisture factor for standing dead	-	0.05	0.05	0.05
K_{Y5}	Dead & litter decay: maximum moisture content of standing dead	g/g	7	7	7
K_{Y6}	Dead & litter decay: ASW for 5% of maximum decomposition	-	-0.2	-0.2	-0.2
K_{Y7}	Dead & litter decay: ASW for 95% of maximum decomposition	-	0.85	0.85	0.85
K_{Y8}	Dead & litter decay: relative rate of decomposition of indigestible DM	0-1	0.1	0.1	0.1
K_{CP1}	Crude protein content of 80-85% digestible herbage	g/g	0.270	0.270	0.270
K_{CP2}	Crude protein content of 75-80% digestible herbage	g/g	0.230	0.230	0.230
K_{CP3}	Crude protein content of 70-75% digestible herbage	g/g	0.195	0.195	0.195
K_{CP4}	Crude protein content of 65-70% digestible herbage	g/g	0.165	0.165	0.165
K_{CP5}	Crude protein content of 60-65% digestible herbage	g/g	0.135	0.135	0.135
K_{CP6}	Crude protein content of 55-60% digestible herbage	g/g	0.105	0.105	0.105
K_{CP7}	Crude protein content of 50-55% digestible herbage	g/g	0.080	0.080	0.080
K_{CP8}	Crude protein content of 45-50% digestible herbage	g/g	0.060	0.060	0.060
K_{CP9}	Crude protein content of 40-45% digestible herbage	g/g	0.040	0.040	0.040
K_{CP10}	Crude protein content of 35-40% digestible herbage	g/g	0.020	0.020	0.020
K_{CP11}	Crude protein content of 30-35% digestible herbage	g/g	0.020	0.020	0.020
K_{CP12}	Crude protein content of 25-30% digestible herbage	g/g	0.020	0.020	0.020
K_{DG1}	Degradability of protein in 80-85% digestible herbage	g/g	0.925	0.925	0.925
K_{DG2}	Degradability of protein in 75-80% digestible herbage	g/g	0.875	0.875	0.875
K_{DG3}	Degradability of protein in 70-75% digestible herbage	g/g	0.825	0.825	0.825
K_{DG4}	Degradability of protein in 65-70% digestible herbage	g/g	0.775	0.775	0.775
K_{DG5}	Degradability of protein in 60-65% digestible herbage	g/g	0.725	0.725	0.725
K_{DG6}	Degradability of protein in 55-60% digestible herbage	g/g	0.675	0.675	0.675
K_{DG7}	Degradability of protein in 50-55% digestible herbage	g/g	0.625	0.625	0.625
K_{DG8}	Degradability of protein in 45-50% digestible herbage	g/g	0.575	0.575	0.575
K_{DG9}	Degradability of protein in 40-45% digestible herbage	g/g	0.525	0.525	0.525
K_{DG10}	Degradability of protein in 35-40% digestible herbage	g/g	0.475	0.475	0.475
K_{DG11}	Degradability of protein in 30-35% digestible herbage	g/g	0.425	0.425	0.425
K_{DG12}	Degradability of protein in 25-30% digestible herbage	g/g	0.375	0.375	0.375
K_{HR}	Height ratio: also governs the size of the ungrazeable portion of the pasture	-	2.5	3.0	1.5
K_{SF}	Parameter controlling the relationship between DMD and relative quality	-	0.0	0.0	0.0

Contact Us
Phone: 1300 363 400
+61 3 9545 2176
Email: enquiries@csiro.au
Web: www.csiro.au/flagships

CSIRO and the Flagships program

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills. CSIRO initiated the National Research Flagships to address Australia's major research challenges and opportunities. They apply large scale, long term, multidisciplinary science and aim for widespread adoption of solutions.