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PROJECT No.

DAQ 124A

FEBRUARY 1997

Final Report for the Rural Industries Research and Development Corporation

RURAL INDUSTRIES RESEARCH & DEVELOPMENT CORPORATION

QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

DAQ-124A

EVALUATING THE RISKS OF PASTURE AND LAND DEGRADATION IN NATIVE PASTURES IN QUEENSLAND

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DEDICATION

This project is dedicated to the memory of the late Gordon Allen,
the late Graeme Lee,

and the continuing health of retired grass scientists; Bill Bisset, Joe Ebersohn, Dick Roe and Wal Scattini whose vision for the importance of quadrat cutting made this project possible.

ACKNOWLEDGMENTS

As acknowledged in the text we wish to thank the many people who have contributed to the vision and support of the project.

The project would not have been possible without the personal support of Eric Anderson, Ken Brook, Bill Burrows, David Gramshaw, John Leslie, Jim Miller, John Mott, Greg Robbins, Dick Schoorl, Barry Walker and Barry White.

We gratefully acknowledge the vital contribution of all those who have sweated in many paddocks, over many years, to cut grass and auger soil.

"Go GUNSYNpD!"

We are extremely grateful to Glenda Beard for the
preparation of the manuscript under the most difficult of conditions.

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SUMMARY

The objective of the project was to develop an approach to quantify the risks of land and pasture degradation. This objective was achieved by developing an operational model of the condition of native pastures in Queensland.

The studies presented in this report have taken us a step toward answering Dr. Joe Ebersohn's challenge as paraphrased by Greg McKeon during a presentation at the 8th Australian Rangelands Conference in Katherine, 1994:

"Unless we can calculate that x number of stock on y pasture with z rainfall will produce α liveweight, β soil erosion and γ change in grass basal cover, then we don't have a pasture science."

To meet the project's objectives , the following approach was taken:

1. Definition of land and pasture degradation

A review of literature and previous modelling studies suggested that changes in pasture composition (pasture degradation) were determined by **pasture utilisation** (**pasture eaten ÷ pasture grown**).

Land degradation (soil loss) was determined by **surface cover** which was highly correlated with **standing pasture dry matter** (also termed 'presentation yield'). Standing pasture dry matter is the net result of the addition of pasture growth, losses by animal consumption (pasture eaten by domestic, feral and native fauna) and losses by natural detachment. **Stocking rate** affects the processes of pasture growth, animal consumption and detachment.

Thus, quantification of the interaction of stock numbers (stocking rate) and pasture growth was the major goal of the project. 'Risk' can be defined as the chance of exceeding an acceptable level of pasture utilisation and that level can be derived from graziers and grazing trials.

2. Pasture growth data

To develop a model of **pasture growth** for the 46 pasture communities in Queensland (Tothill and Gillies 1992), most available data from exclosure and defoliation trials were collated including pasture yields, nutrient concentrations, and soil water measurements. Field studies were carried out during the project in pasture communities not previously studied. The collation of data was only possible through generous co-operation of officers in many institutions (QDPI, DNR, CSIRO, NTDPI, NSW Ag, University of Queensland, Qld National Parks and Wildlife Service), and included data from projects funded by other agencies (MRC, WRRDC, LWRRDC).

3. Pasture growth model

An existing soil water-pasture growth model GRASP was modified and parameterised for each site/species combination. Model parameters included plant available water capacity (PAWC), transpiration-use-efficiency and potential nitrogen uptake.

For 162 site x year combinations of pasture growth measurements, rainfall accounted for 42% of variation in peak autumn yield; a simple growth index (Fitzpatrick and Nix 1970), 45%; simulated evapo-transpiration 60%. The calibrated model accounted for 78% of variation in peak yield. For all available data (i.e. 179 site x year combinations), the calibrated model simulated soil water accurately, and the average absolute error for over 700 field measurements in soil water (mm) was similar to measurement variation. For soil layer 0-10cm, average error was 3mm; for layer 10-50cm, 8mm; for layer 50cm to bottom, 8mm; and for the whole soil profile up to 100cm depth, 18mm

The analysis of the 179 site x year combinations showed that the model could be parameterised for a wide range of pasture communities, including variation in soils and tree density, and hence, could be applied to the whole of Queensland and some other regions in northern Australia. Changes in species composition were analysed for one site only and, from this one study, future model development in this very complex area of ecology has been planned.

4. Model boundaries

Model deficiencies were documented but their solution will require further field work and major model development. Most of the model errors occur under conditions of above-average rainfall when nutrient limitations and/or phenological development are the major processes affecting plant growth. Given that the major processes involved in pasture and land degradation occur in below-average conditions, these model deficiencies are not regarded as the major limitation to the accurate simulation of degradation risks.

Previously developed models of run-off and soil loss were included in GRASP. Both sub-models are site specific, but nevertheless, provide, at least, indices or relative measures of the impact of management options such as stocking rate, pasture burning and tree/shrub control. Thus, the overall model includes sub-models of pasture growth, decomposition, nutrient uptake, changes in grass basal cover, effects of surface cover on both run-off and soil loss. The model simulates a pasture sward. However, in reality, the sward is made up of a number of species with different responses to environmental variables. Thus, the model does **not** include the effect of phenological development of individual species. As yet insufficient information is available for flowering patterns of individual species to be included in the model.

5. Modelling of grazing effects

The calculation of pasture utilisation and standing pasture dry matter require modelling the effect of grazing on growth, trampling and detachment. Historical and current grazing trials representing the major pasture communities (black speargrass, mulga, Mitchell grass) were analysed using the model. The objective was to examine how model parameters change with grazing utilisation. As expected, the pasture communities differed in the parameters that were sensitive to grazing. The most sensitive parameters for each pasture community were:- grass basal cover in mulga lands; detachment rates in Mitchell grass; soil water range, nutrient uptake and root/shoot partitioning in the black speargrass zone.

6. Analysis of safe stocking rates from graziers

The results of grazing trials are likely to be specific to site characteristics, species and climatic conditions. Graziers have experience over a wider range of land types and climatic conditions than studied in grazing trials. Four major studies (mulga lands, southern black speargrass zone and central black speargrass zone and northern black speargrass zone) have been carried out in collaboration with this project to provide grazier estimates of 'safe' stocking rates for individual properties or land types. Pasture growth was estimated using the pasture growth model above. All three studies indicated that safe utilisation rates were in the range 15-25% of average annual pasture growth. Grazing trials and simulation studies indicate that, at these utilisation rates, the risk of degradation in below average rainfall years is minimised. However grazing trial data showed that, in general, short-term animal production (per hectare) increased with higher utilisation rates (Figure 3.16). Australian Bureau of Statistics (ABS) data suggest that utilisation can be much higher than a conservative "safe" utilisation of 15% over much of Queensland, e.g. 1993/94 (Figure 5.11).

7. Operational spatial model of risks of degradation for Queensland

The operational model calculates pasture growth, pasture utilisation and pasture yield for each of 70 000 5 km x 5 km pixels in Queensland. For each pixel, pasture and soil attributes are estimated: pasture community, principal soil profile, and tree density. Tables of model parameters have been developed, initially based on pasture exclosure data (described above).

Climate inputs were from splined surfaces derived from real-time data supplied by the Bureau of Meteorology (BoM). Stock numbers were collected by ABS and reported on a Local Government Area (LGA) basis. In the operational model these are redistributed within the LGA based on the relative estimates of pasture growth for each pixel.

The spatial model was re-parameterised by J. O. Carter using a data bank of pasture yields estimated from over 220 000 ground-truth observations taken from a moving vehicle. Calibrated transpiration-use-efficiencies were similar to that derived from exclosure data. Green cover estimated from the NOAA satellite as a Normalised Difference Vegetation Index (NDVI) was used as an independent validation. Comparisons over time for individual pixels showed correlations from 0.2 to 0.8 across Queensland.

Simulations of pasture yield were also compared with reports on a LGA basis by stock inspectors (QDPI Natural Disaster Section). The spatial model compared well with drought declared areas in Queensland, thus, providing a successful independent validation of the model. Detailed examination at a half LGA-area resolution suggested the following problems and needs:

1) the real-time rainfall reporting network is not fully operational and has limited coverage in some regions;
2) interpolation of rainfall does not account for rain-shadow areas;
3) independent estimates of domestic and native animal numbers are required;
4) more accurate mapping of spinifex lands is needed; and
5) better models of landscapes with fragmented tree communities are required to simulate the non-linear effect of tree density on pasture growth.

8. Application to other states

The model has been parameterised for pasture communities in the Northern Territory and is likely to be applicable to northern WA. However, application to southern states has not yet been attempted although contacts have been established. This area of research has been reported in the LWRRDC project QPI20 National Drought Alert Strategic Information System.

9. Conclusion

The results of the project showed that:

1) historical and current pasture data can be used with models to simulate grazing lands in near real-time;
2) spatial models of production can be developed and validated with existing spatial data and monitoring systems;
3) data from graziers indicate that safe utilisation rates are 15-25% of average pasture growth;
4) relative risks of land and pasture can be quantified from simulations using actual numbers compared to safe stocking rates; and
5) case studies using the pasture growth model and models of grazing feedback on pasture and land degradation to evaluate the economic consequences of stocking rate strategies have been used in other projects (e.g. DroughtPlan: McKeon *et al.* 1996, Stafford Smith *et al.* 1996).

SECTION 1 - REVIEW: A NEED TO CALCULATE RISKS OF PASTURE DEGRADATION

1.0 INTRODUCTION

In this section we review:

1) the basis for concern with the condition of Queensland's grazing lands;
2) the reasons for preferring perennial grass species as resource indicators of good condition;
3) the causes of increased grazing pressure on the pasture resource;
4) the need for an operational forecast system of degradation alerts;
5) the methods for predicting acceptable resource use, i.e. safe stocking rate; and
6) the need for a quantitative approach to resource use.

1.1 PASTURE DETERIORATION AND DEGRADATION

The recent review on the condition of grazing lands in northern Australia (Tothill and Gillies 1992) concludes *"there is widespread deterioration in most pasture communities in Queensland; this is indicated by undesirable changes in pasture composition and soil surface characteristics such as cover and organic matter content".* Deterioration was thought to be related to increased grazing pressure resulting from below-average rainfall in the 1980s following substantial build up of livestock numbers in the 1970s, and improved husbandry practices allowing stock to better survive stress periods.

To ensure long term use of these lands, high priority was given to 'establishing guidelines for safe stocking strategies'. A major issue is the determination of a 'long-term safe stocking rate', that is, a stocking rate which 'will maintain the pasture resource in a desirable and productive condition'. Safe stocking strategies should also address the problems of decade-to-decade variation in rainfall (Willcocks and Young 1991), the varying sensitivities of pasture communities to inevitable periods of overgrazing, varying resilience of pasture species after such stresses, the possible options of strategic spelling to maintain desired pasture composition (Tothill and Gillies 1992), and the high likelihood of climate change (McKeon *et al.* 1993).

The Macquarie dictionary defines ‘degrade’ as ‘to reduce from a higher to a low rank, degree, etc.’. Thus, in applying the definition to grazing lands, it is necessary to recognise that some subjective judgement is required to rank the pasture resource in states of degradation. Tothill and Gillies (1992) distinguished between three states of pasture condition i.e.‘pristine’, ‘deteriorating’ and ‘degraded’. ‘Deteriorating’ condition was considered as ‘readily reversible through improved property management and following a return to years of average or above-average rainfall’; ‘degraded’ was a state ‘where the system can only be brought back to an acceptable steady state with difficulty’.

Most importantly Tothill and Gillies (1992) made the point that there will always be periods of deterioration due to climatic variability and that differences in resilience between pasture communities result in variation in the stability of grazing lands.

Tothill and Gillies (1992) asked groups of experts in pasture agronomy, animal production and soil conservation to estimate, for their local area, the percent of land in each of the current condition levels (Table 1.1).

Table 1.1 Condition assessment matrix - a matrix of factors x condition levels to assess the condition of a pasture (from Tothill and Gillies 1992, page 10).

Condition level	Factor		
	Soil	**Vegetation**	**Management**
A	no soil deterioration	main desirable spp. maintaining >75% dominance	sustained
B	slight soil deterioration - sheeting - rilling - pedicelling - reduced infiltration	increased presence (>25%) of undesirable pasture spp. and/or woody weeds	rehabilitation and stabilisation possible through management
C	severe soil deterioration - incision - scalding - sheeting	predominance of undesirable species	rehabilitation and stabilisation needing major works or land use change

1.2 THE NEED FOR PERENNIAL GRASS SPECIES

The key pasture attribute is the subjective term **desirable plant species**. For sustainable animal production in northern Australia a **desirable plant species** must produce plant growth suitable for animal production (meat and fibre) in variable climatic conditions; provide feed reserves through drought periods often longer than one year; provide surface cover to reduce run-off and soil loss; and be capable of recovering (either from perennial crowns or seed) from major perturbations such as drought, flood, heavy grazing and fire. Desirable plant species tend to be perennial tussock grasses which produce both leaf (necessary for animal production) and stem (suitable as a drought reserve and for soil protection). Native species are usually, but not always, well adapted to climatic extremes, and hence, form the basis of the 'desirable species' list. Introduced perennial grasses such as buffel grass and green panic have these desirable attributes and are often able to out-compete native species where some disturbance has occurred, e.g., tree clearing in brigalow and gidgee lands. Several species of perennial tussock grasses can meet the above requirements, and hence, changes in composition between these species due to pasture management (stocking rate, fire and tree control) does not necessarily result in degradation. For example, in south-east Queensland, the change from kangaroo grass (*Themeda triandra*) to black speargrass (*Heteropogon contortus*) in the 1880s is not regarded has having a major effect on beef cattle production (Tothill and Gillies 1992) but is considered to have contributed to the loss of the sheep industry in this region due to the injury caused by black speargrass awns to sheep (Shaw 1957).

The two objectives of firstly sustaining the resource in the long-term (100-1 000 years) and, secondly, maximising short-term (1-5 years) animal production are in conflict. Animal production is likely to be maximised by species which are leafy and have high concentration of nutrients (low dry matter production per unit of soil nutrient uptake) and a long growing season, i.e. species that are less restricted by low temperature especially in spring and autumn. On the other hand, the attributes of providing drought reserve, fuel for pasture burning and soil protection are likely to be increased by species which maximise dry matter production when growing conditions are suitable, i.e. when high temperatures and summer rainfall coincide, by maximising the use of limiting soil nutrients (i.e. able to achieve a high C:N ratio during growth).

Thus, fundamental to the definition of degradation is the concept of a 'desirable' species which allows a compromise between short-term and long-term goals. The major attributes are those which result in long-term resource use and necessarily involve foregoing short-term opportunities for animal production. Many perennial tussock grasses meet these requirements.

1.3 WHAT ARE THE PRESSURES THAT LEAD TO DEGRADATION?

There are several pressures that lead to the loss of desirable perennial grasses. Because the desired species are suitable for animal production they, by definition, will be grazed in preference to other undesirable species. Such differential grazing creates a vacant niche of unused light, water and nutrients, thus, providing an opportunity for undesirable species (grasses or shrubs) to grow and out-compete desired species. Continued grazing can lead to the complete utilisation of desired species.

Repeated defoliation of desired tussock species, which have a large proportion of dry matter above ground, leads to reduced root density, and as a result lower nutrient and water uptake, reduced leaf area and lower growth rates. (Howden 1988, Wandera 1993, McIvor *et al.* 1995a, Ash and McIvor 1995).

Where dry matter production is reduced more than nutrient uptake, nutrient concentration actually increases. The tussock structure of plants allows high levels of intake to occur even at low pasture yields allowing near complete defoliation of swards. For example, Ash *et al.* (1982) measured liveweight gains (0.5-1.0 kg/day) at low pasture yield (300 - 500 kg/ha) after burning black speargrass.

In some cases the undesired species, which occupy the vacant niche, continue to provide dry matter and nutrient concentrations suitable for short-term seasonal production. Degradation is only apparent during droughts when no feed reserve is present. In time, reduced surface cover may lead to increased soil erosion. Woody weeds may increase due to lack of fire (eucalypts in black speargrass) or lack of competition with perennial grass species (turkey bush in mulga lands). Thus, in these cases, there are **no short-term** feedbacks which would allow graziers to detect degradation through reduced animal production or profit.

Perennial grasses reduce the effects of drought through carry-over feed grown in previous years and through the capability of perennial tussocks to respond to rainfall amounts too small for the germination and growth of annual species. However, improvements in animal transport, management, breeds and husbandry have provided alternative drought protection to that once provided solely by the desired perennials. However, whilst droughts are no longer as devastating in terms of animal deaths, these improved practices may result in increased grazing pressure in drought and drought breaking conditions, because animals can be retained longer.

In fact, economic trends and fluctuations have resulted in pressure to increase stock numbers to compensate for declining profitability (Anon. 1995a).

"Australian agricultural industries are not profitable! Average returns to capital (for the Queensland beef industry) over the last three years have been 0.3% (91/92), - 0.1% (92/93) and 1.2% (93/94). The average Australian farm business 'profit' in 1993-94 was negative $4290. For 1994-95, ABARE estimates it will be negative $13000. Sixty-seven percent of Australian farms have a negative business 'profit'. Average farm debt as at June 1994 was $140260. Table 1.2 shows that farm debt has risen faster in the beef industry than in wool and broadacre enterprises. In eight years from 1985-1993 beef herd productivity rose about 17% and exports by a massive 72% to 802 kilotonnes. In the same period the average dressed weight **price** of export cattle fell by 18% in real terms (Anon., 1994)."

Table 1.2 Farm debt in Queensland (Anon, 1994).

	Beef $	Wool $	Broadacre $
1989/90	99 000	173 000	125 000
1990/91	120 000	210 200	134 000
1991/92	159 000	212 000	170 000
1992/93	185 000	275 000	179 000
1993/94	206 000	204 000	181 000

Thus, the major forces leading to degradation are:

1) the removal of climatic constraints on grazing pressure through better drought management;
2) financial pressure to increase stocking rate; and
3) the lack of direct short-term feedbacks on animal production to provide warning to graziers.

1.4 THE NEED TO FORECAST RISKS OF DEGRADATION

If the cycle of 'degradation → concern → goods seasons → apathy' is to be broken then there is a need to provide an alert before degradation occurs rather than after the event. Thus, this project represents a pro-active approach to land and pasture degradation in Queensland, by -

1) examining the causes of degradation;
2) quantifying the processes in simulation models using data from both research and grazier knowledge;
3) developing a computer/extension system to run models in near real-time (monthly) to provide alerts; and
4) planning links with grazier information systems.

Even in highly variable environments a proportion of graziers seek to run relatively stable enterprises by maintaining a breeding nucleus. Hence, inevitable periods of low rainfall result in heavy utilisation as feed demand exceeds pasture supply. Without benchmarks to compare with, it is difficult to determine whether the observed overgrazing during these periods is acceptable. Thus, a major component of a forecast system providing alerts is a comparison of current condition with what should be occurring if best practice was adopted. Fundamental to the concept of an alert is the concept of an acceptable land use or more specifically a **safe stocking rate**.

1.5 PREDICTING ACCEPTABLE RESOURCE USE

The review of Tothill and Gillies (1992) highlights the major need for a rational approach to estimating safe stocking rates. Public institutions, e.g. Queensland Department of Primary Industries (QDPI) and Department of Natural Resources (DNR) have some charter (e.g. implementation of Ecologically Sustainable Development [ESD] Policy) to contribute to these estimates. However, the potential role of science is not clear given the personal and financial sensitivity of the issue of stocking rates for individual graziers and consultants.

The simulation modelling approach used in this report is one of many alternative approaches to solving the stocking rate problem (practical experience, local consensus data, common sense, grazing trials, state-and-transition models, market forces). We review these alternative approaches based on ease of method, capability of extrapolation and adaptation to climate change (Table 1.3).

The major issues in comparing approaches are: participation of graziers, clarity of method, extrapolation to other properties, capacity to adapt to climate change, advantages and disadvantages in application. The “safe level of utilisation” approach attempts to overcome the major disadvantages of the other approaches, i.e. the difficulty of extrapolating to different resource units and climates. We have adopted this approach mainly because of the bias of our training. However, we suggest that simulation modelling is most likely to provide a quantitative understanding of the interaction and feedbacks in the grazing system, and hence, answer the question ‘Why?’ as well as ‘How?’. Simulation also provides a way of evaluating decade-to-decade variation in rainfall and the impact of tactical stocking rate decisions.

Table 1.3 Approaches to estimating a long term safe stocking rate.

Approach	**Long term practical experience**
Method	For an individual property or paddock accurate long term records (30-100 years) of stocking rate in combination with observations of pasture and land condition can be used to determine, in retrospect, safe long term stocking rates. The process is well understood and 'owned' by the grazier.
Extrapolation	Extrapolation is limited to the same climate, land and pasture resources.
Climate Change	Extrapolation is limited to climatic conditions within the long term experience.
Advantages	The safe stocking rate has been derived from the experience of generations of graziers specifically for individual properties. Accurate extrapolation can be made to similar situations.
Disadvantages	The approach requires long-term records, and has to account for property development, e.g., tree clearing, fencing, water improvement. It depends on the judgement of a desired state of the resource. Errors in estimating stocking rate due to short-term favourable conditions, e.g. 1970s, may cause irreversible resource damage, or in the case of unfavourable conditions, e.g. 1960s, may result in lost economic opportunities especially if climatic change occurs.
Approach	**Local consensus data (LCD)**
Method	For given pasture communities in a region, grazier groups determine long term safe stocking rates by sharing experience and knowledge.
Extrapolation	Where individual properties and paddocks have different combinations of resources, long-term safe stocking rates will need adjustment.
Climate Change	The LCD estimates may be specific to climatic condition, e.g. 1970s compared to 1980s. Re-assessment for changing climatic conditions will be required.
Advantages	This approach has the direct involvement of graziers sharing experience and knowledge, addresses the specific issues of a given region and provides well documented expert opinion.
Disadvantages	Because of variation in tree/shrub density and range of stocking rates for cleared and uncleared land, application to individual properties or paddocks may have some difficulty.

Table 1.3 continued

Approach	**Common sense tactical management.**
Method	Individual graziers have developed a set of flexible “rules” to adjust stock numbers based on: seasonal conditions (past, current and expected), standing feed; pasture composition; markets; and perceived carrying capacity.
Extrapolation	If the rules can be captured explicitly, e.g. by interviews, then they can be implemented by other graziers.
Climate Change	Where the rules contain key indicators, e.g. feed supply, then adaptation to climate change should be successful. However, where species indicators are used then climate and management effects can be confounded.
Advantages	Flexible principles and rules derived directly from grazier experience.
Disadvantages	The principles may be too intuitive to be formulated into logical rules or the rules may be specific to certain climate conditions.
Approach	**State-and-transition models**
Method	The possible states of the pasture system are defined for the specified stocking rate and fire management.
Extrapolation	This approach is restricted to the same climate-soil-plant system. Nevertheless, the biological and physical principles of the transition from state-to-state have wide power in extrapolation.
Climate Change	The principles provide a useful way to adapt to climate change as long as major climate-related shifts in plants do not occur , e.g. invasion of black speargrass into Mitchell grasslands in the 1950s.
Advantages	This approach is soundly based on a mechanistic understanding of the reasons for adopting both a stocking rate and pasture management strategy to achieve a desired vegetation state.
Disadvantages	Because of spatial variability in resources and climate, it may be difficult to develop quantitative advice for individual properties.

Table 1.3 continued

Approach	**Market forces and economic surveys.**
Method	The market already, to some extent, determines the value of grazing land based on an expected return. Estimating carrying capacity as a function of pasture and land condition would allow the effects of overgrazing to be translated into $ terms. When supported by regional economic surveys, which cover a range of stocking rates used by graziers, the regional effects of loss of pasture condition can be quantified in $ terms.
Extrapolation	Limited to region and specific pasture communities.
Climate Change	Adaptation would require constant re-assessment and relies on a range of existing management practices to assess best stocking rate.
Advantages	This approach quantifies the effects of stocking rate in $ terms allowing accurate comparison of stocking rate options in a region.
Disadvantages	A definitive comparison relies on some properties being over stocked, and hence, some regional risk of degradation. The financial comparison is likely to be confounded by variability in land and pasture resources in that the demand for land may override the effect of condition.
Approach	**Safe level of utilisation.**
Method	Pasture growth (summer or annual) is estimated as a function of soil, climate, tree/shrub density, species, and pasture condition. Safe levels of utilisation (amount eaten as a proportion of amount grown) are determined from grazing trials and/or grazier experience. Long term safe stocking rates can then be calculated for individual properties.
Extrapolation	Utilisation rates are more likely to be accurately extrapolated than actual stocking rates. Thus, a wide range of resources can be covered.
Climate Change	Where the effects of climate change and CO_2 on pasture growth can be estimated, new safe stocking rates can be calculated.
Advantages	This method incorporates the intuitively sound principle of adjusting stock numbers to match the feed available. Different approaches can be compared in terms of simple variables such as pasture growth and pasture eaten providing greater capability for handling resource and climatic variability. Graziers can assess their own properties and the concept can be applied at a range of scales, e.g. plants, patches, paddocks, properties or regions.
Disadvantages	This method involves system concepts which may not be accepted by industry. Safe utilisation rates are unknown for many communities. Errors in describing the land and pasture resource will lead to errors in the calculation with financial and legal consequences. There are no visual indicators and a calculation is required.

1.6 A SYSTEMS APPROACH TO CALCULATING RISKS OF DEGRADATION

In this section we present a systems analysis approach for calculating safe stocking rates.

Pasture growth is the major source of energy and nutrients required for animal growth. Pasture growth is a function not only of plant density but also the individual species response to light, temperature, humidity, soil moisture, nutrients and CO_2. Soils vary in nutrient supply, available water range and infiltration characteristics. Trees and shrubs can either compete with or stimulate pasture production. They can also supply browse and seeds for grazing. The removal of pasture by grazing can have a deleterious effect on the density (basal area) of desirable pasture species resulting in changes in pasture composition and soil attributes. The ratio of removal by grazing to the amount grown is often termed ‘utilisation’. ‘Utilisation’ provides an index of the grazing pressure on the soil/plant system and sets some conceptual bounds on how much can be eaten by domestic and feral stock, macropods and insects (i.e. between 0 and 100). This concept of utilisation allows the different approaches and different pasture communities to be compared with a common basis, i.e. % eaten per amount grown.

This concept of utilisation is fundamentally different to the year-to-year adjustment of stock numbers based on the expected ‘utilisation’ of observed standing pasture yield over a future time period (6-12 months). The latter concept is more appropriate to regions where there is a relatively high probability of little or no pasture growth for a year (one in four years in western Queensland). In such environments the concept of a long-term ‘safe’ stocking rate may be insufficient and more emphasis is likely to be needed on tactical (e.g. year-to-year) decisions to reduce pasture deterioration.

For the two major processes of land and pasture degradation in Queensland (Williams 1989), namely **soil erosion** and **change in species composition** to undesirable species, the risk of degradation can be calculated from **utilisation** and **% plant cover** of the surface soil.

Recent research at one location showed that damage to pastures (perennial grasses) occurred when utilisation exceeded 30% during ‘dry’ (e.g., < decile three rainfall) growing seasons (McKeon *et al.* 1990). Furthermore, the risk of soil erosion is greatest when surface cover was less than 30%, or pasture yield was less than 1 000 kg/ha of pasture dry matter (Gardener *et al.* 1990).

Computer models have been developed to simulate soil water, pasture growth and plant cover. Pasture growth can be calculated on a regional basis with the inputs of soil maps, pasture species, tree density and real-time climate data. When combined with ABS animal numbers and estimates of the density of other pasture consumers (macropods, locusts and feral animals) pasture utilisation and cover can be calculated. Forecasts of pasture growth and utilisation can be made using the seasonal rainfall forecasts provided by the Bureau of Meteorology (BoM). These forecasts are based on the behaviour of the El Niño Southern Oscillation. An operational system would be readily adapted to use climatic forecasts of General Circulation Models (GCMs) using inputs of observed sea surface temperatures.

1.7 CONCLUSION

Previous reviews of pasture condition and causes of degradation in Queensland highlighted the need to calculate safe stocking rates or pasture utilisation. The systems analysis approach adopted here requires simulation of pasture growth as described in the Section 2.

SECTION 2 - A MODEL OF NATIVE PASTURE GROWTH

2.0 INTRODUCTION

In this section we -

1) review the features of native pastures in Queensland to determine the specifications for modelling pasture growth;
2) briefly describe the simulation model GRASP;
3) describe the field methodology used to collect data for model calibration;
4) evaluate model performance for more than 150 site x year data sets;
5) report independent model validation and likely sources of error; and
6) report application of growth parameters from exclosure to grazing treatments.

Key features of native pastures

Definitive reviews of the structure and function of grasslands in northern Australia have been conducted in the last 25 years (Moore 1970, Mott *et al.* 1985, Tothill *et al.* 1985). From these reviews a systems view of the grasslands has been developed in this project (Anon. 1995a), and has been presented in Appendix 1.

Native pastures in Queensland have the following important features:

1) native pastures grow in environments of high solar radiation, high temperatures and high evaporative demand. Rainfall occurs mainly in the warm growing season (peaking from January to March). However, evaporative demand is high (5-15mm per day), and hence, soil moisture deficits are frequent;

2) year-to-year variation in rainfall is the major source of climatic variability affecting plant growth and, in eastern Queensland, this variability is associated with phases of El Niño/Southern Oscillation (Clewett *et al.* 1991);

3) native pasture swards are often made up of many species which have different responses to major environmental and management variables, e.g. drought, frost, day length, fire, grazing and variable tree density;

4) native pastures occur across the widest range of soil types differing in many soil attributes, and landscape position;

5) soils are low in nutrients and may have low infiltration;

6) tree/shrub density varies in space and time. The woody component acts as both a competitor for water, nutrients and light and a possible stimulator by concentrating nutrients and/or providing shade;

7) the ecophysiology and autoecology of individual species has not been studied in detail (Mott *et al.* 1985), in contrast to introduced species (e.g. *Stylosanthes* spp.); and

8) nutrient cycling (carbon, nitrogen phosphorus) involves complex processes (e.g. Metherell *et al.* 1993) which are yet to be quantified for many pastures, especially the effects of management such as grazing, fire and tree clearing.

This background of high variability in all dimensions and lack of basic physiological knowledge contrasts with crop modelling in the tropics which has concentrated on a relatively few species (sorghum, wheat, sunflower, maize and peanuts) with detailed physiological knowledge of varietal differences (e.g. Hammer and Muchow 1994). Crop models show the potential capability of physiologically sound plant growth models which are calibrated to field data. For example, in an independent test, Hammer and Muchow (1994) were able to simulate 94% of the variation in sorghum biomass at five sites across northern Australia.

Model specifications

A model of native pastures must:

1) be capable of being parameterised for each pasture community in Queensland, (major parameters include available soil water range, potential nutrient uptake, water-use efficiency, potential regrowth after burning or mowing);

2) be capable of being calibrated with existing agronomic data (above-ground sward yields, presentation yields in grazing trials, grass basal cover);

3) include responses to dominating environmental and managerial variables; and

4) provide the basis for future development to improve accuracy of simulation and application to the grazing industries.

Preliminary analyses indicated that the two key model outputs were **calculation of pasture growth in years of below-average rainfall**, when risks of overgrazing are greatest, and **calculation of average or median pasture growth** which determine long-term carrying capacity. Simulation of pasture growth in years of above-average rainfall is likely to be more important for modelling animal production and demonstrating the loss of potential production due to the effects of previous degradation.

In this study we have concentrated on, as a first priority, modelling native pasture growth in years of below-average rainfall when degradation processes are most likely to occur.

Classification of pasture communities

Various classifications of pasture communities of Queensland have been made. Given that our objective is to calculate plant growth from climatic inputs, and animal consumption from known stocking rates then it is necessary to evaluate alternative resource descriptions (Table 2.1).

Table 2.1 Description of northern Australia pasture and production units.

Source	Regional Unit	Carrying Capacity	Animal Production	Soils	Pastures	Resource Status
Australian Bureau of Statistics (ABS.)	Local Government Area (114 in Qld)	Animal numbers for cattle and sheep	Branding, lambing, turn-off numbers, wool	None	Areas of pasture improvement and crops	None
Weston *et al* (1981)	35 pasture communities in Qld	Estimated beef equivalents	None	Six texture classes based on Atlas of Australian soils (Northcote *et al.* 1960-68)	Current and potential land use by soil type	Pasture condition assessed
Weston (1988)	14 pasture communities aggregated from Weston *et al.* (1981)	Estimated beef equivalents	Liveweight gain for cattle estimated by K Howard	Texture classes above	Current and potential land use estimated	Pasture condition as above
Tothill and Gillies (1992)	150 local pasture units (46 in Qld) based on Weston *et al.* (1981)	Estimated beef equivalents	None	Atlas of Australian soils (Northcote *et al.* 1960-68)	Improvement potential estimated high, medium, low	Land and pasture condition assessed
O'Rourke *et al.* (1992)	14 regions (12 in Qld)	Survey of beef producers provided property stocking rates	Liveweight estimated from age of turn-off, branding rate also surveyed	% phosphorus with phosphorus deficiency for each region	Property development clearing and improved pastures itemised	Weeds indicated but not soil erosion risk
Brook *et al.* 1992	5 km x 5 km pixels with climate surfaces and satellite data for each one km^2 pixel	Estimated from ABS and relative productivity of pasture communities	None as yet	Atlas of Australian soils (Northcote *et al.* 1960-68)	Tree basal area and cropping from satellite time series (NDVI)	None as yet
LWRRDC National Drought Alert. Brook (1996)	5 km x 5 km pixels spatial model and aggregated to O'Rourke *et al.* (1992) regions	Sheep and cattle numbers., macropods and goats	Simulated production linking grazing trials, ABS and producer data	Phosphorus map from Carter and Ahern (QDPI)	As in Brook *et al.* *(1992)*	None as yet

Each classification has a particular advantage, e.g. Local Government Areas (LGAs) provide best estimates of animal numbers; Weston *et al.* (1981) provide best resource description and condition survey; Tothill and Gillies (1992) provide the most recent condition survey; and O'Rourke *et al.* (1992) surveyed beef producers animal management and nutrition. The classification of Tothill and Gillies (1992) was used as the resource base description because of the detailed condition survey and likely continuing commitment to future surveys on status of the pasture resource.

Tothill and Gillies (1992) classified Queensland's native pastures into 46 pasture communities. In each community different grass species dominate particular condition states (A sustainably grazed, B deteriorating and C degraded). Eighty major grass species (not including ecotypes) are listed. Some species are grouped by genus, e.g. *Aristida* spp., because of the difficulties of distinguishing between individual species in the field.

The above review highlights the complexity of modelling native pasture growth. To overcome this complexity we developed:

1) a generic model of native pasture growth (Appendix 2).
2) implemented a field methodology to measure model parameters (Appendix 3); and
3) co-ordinated a network of collaborating scientists (Appendix 4) who shared the common goal of understanding native growth and who were prepared to contribute both data and intellect to model development through a project known as GUNSYNpD: Grass Under Nutritional Stability: Yield Nitrogen and phenological Development).

These three developments occurred in parallel during the project but are described as separate stages in this report.

2.2 BRIEF MODEL DESCRIPTION

Possible approaches to modelling native pastures have been reviewed by McKeon *et al.* (1990). From this review, an approach based on simulating soil water balance and linking simulated transpiration to plant growth was adopted (McKeon *et al.* 1982). For native pastures in south-east Queensland this approach proved superior when compared to alternatives (Day *et al.* 1993, Appendix 1).

The GRASP model is empirical (and unabashedly so!) in that it links known empirical relationships between plant growth and water use (Rose *et al.* 1972, McCown *et al.* 1974, Tanner and Sinclair 1983) with known empirical relationships between plant growth and growth indices (Fitzpatrick and Nix 1970, Williams and Gardener 1984). A detailed description is provided in Appendix 2.

The model includes a daily simulation of soil-water balance with four soil layers (surface 10cm, 10-50cm, 50cm to grass rooting depth, grass rooting depth to tree rooting depth). The daily soil-water balance model uses inputs of rainfall and Class A pan evaporation to calculate run-off, soil evaporation, transpiration (from grass and trees) and through-drainage.

The model simulates the processes of above-ground growth, senescence, animal consumption, detachment and decomposition. Dry matter pools of green leaf and stem, dead leaf and stem, and surface litter are included. The model does **not** simulate the dry matter pools of roots nor seeds. The model does **not** include the processes of translocation between above-ground biomass and roots, possible re-greening of previously senescenced material, nor tree canopy growth and senescence. In the following analysis we discuss the likely deficiencies in our approach.

Transpiration is calculated from simulated daily green cover and available soil-water. Daily plant growth is calculated from a transpiration-use-efficiency (kg/ha/mm of transpiration) multiplied by transpiration. Transpiration-use-efficiency is inversely proportional to daytime vapour pressure deficit which is calculated from screen measurements and adjusted for height of pasture.

Upper limits to daily growth rate are calculated from temperature, nitrogen, radiation interception and available soil water. Lower limits to growth are calculated from a growth index (Fitzpatrick and Nix 1970), nitrogen, available soil water, plant density and a potential regrowth rate.

The senescence or death of green material is calculated as a function of soil-water and frost. Detachment, the process of standing material becoming surface litter, is a function of time, rainfall and trampling due to animals.

Litter decomposition is a function of soil-water (0-10cm) and average daily temperature.

Animal intake from green and dead pools is calculated as a function of stocking rate, liveweight and type of animal. Consumption by native fauna and feral animals can be explicitly included but consumption by termites and other insects (e.g. grasshoppers) is calculated as part of the natural detachment and decomposition processes.

The model does not include phenological development of individual species because the production of a whole pasture sward, comprising many species and ecotypes, is being simulated.

Nutrient cycles of nitrogen and phosphorous are **not** simulated. As yet there is insufficient knowledge on processes (e.g. fixation, translocation) and pools (e.g. microbial biomass) to parameterise these pools and processes for each pasture community.

We will examine later the consequences of these model boundaries and limitations (Section 2.5). In all cases further model development to overcome these limitations is occurring.

2.3 DATA SOURCES AND FIELD METHODOLOGY

The most common and simplest measurement of pasture biomass is above-ground standing dry matter, which represents the net result of the addition of pasture growth and the losses of detachment, trampling and animal consumption. Where growth and detachment are occurring simultaneously it is not possible to find unique relationships between these 'opposing' processes from measurements of pasture yield alone. For example, high growth rates and high detachment rates may provide as good an explanation of a measured presentation yields as do low rates of growth and detachment.

Thus, pasture yields measured in grazing trials, where the processes are of equal but opposite sign, are not suitable for establishing relationships between environmental variables and growth rates. However, where there is little carry over of material from previous seasons due to burning, mowing or observed rapid decay (e.g. in tropical wet seasons) then growth rates can be estimated from accumulating above-ground pasture biomass.

The exclusion of grazing reduces the uncertainty regarding estimates of animal consumption and trampling. However, exclosure may change sward structure (e.g. from prostrate to upright in black speargrass) and change partitioning between roots and shoots. Burning and mowing are major interventions which may disrupt nutrient cycling (e.g. through removal of litter and previous year's material) and translocation within the plant. Hydrologic impacts include possibly increased run-off due to low cover following burning or mowing depending on duration of low cover (McIvor *et al.* 1995b).

Alternatively, defoliation may stimulate new growth since the presence of old tillers may reduce growth through shading, respiratory load or some form of apical dormancy (e.g. Scanlan 1980). Excluding grazing and regular burning or mowing can also result in substantial changes in botanical composition.

Given the complexity of pasture communities (46) and species (>80) we have adopted the approach of using exclosures despite the above reservations. Exclosures with a defined burning or mowing were used to estimate growth rates and parameterise the growth model. Where available, we have also used grazing trial data if animal consumption could be calculated and annual burning occurred (Section 3).

From exclosure studies in Queensland, soil-water, % green cover, pasture yield and N concentration data were collated from 47 localities (Figure 2.1), 89 exclosures and 179 site x year combinations. From these data a soil-water-balance/pasture-growth model (GRASP) was developed and parameterised.

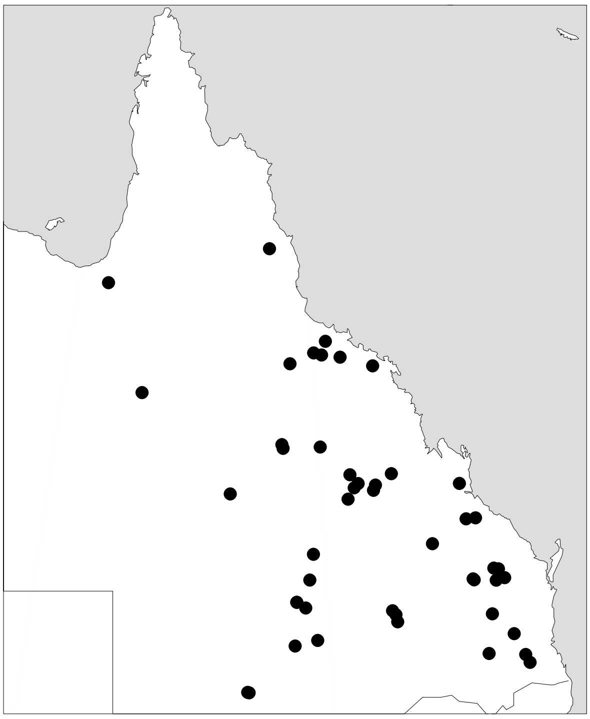


Figure 2.1 Location of native pasture exclosure data available for model parameterisation in Queensland

Field methodology for measuring model parameters and pasture growth

The model structure described above defines parameters that need to be quantified for accurate simulation. Figure 2.2 shows a typical seasonal pattern of soil water, green cover, pasture yield and N uptake measured every three weeks in an exclosure. The estimation of key parameters required to simulate the soil-water balance and pasture yield is described as well as the minimum field measurements for model calibration.

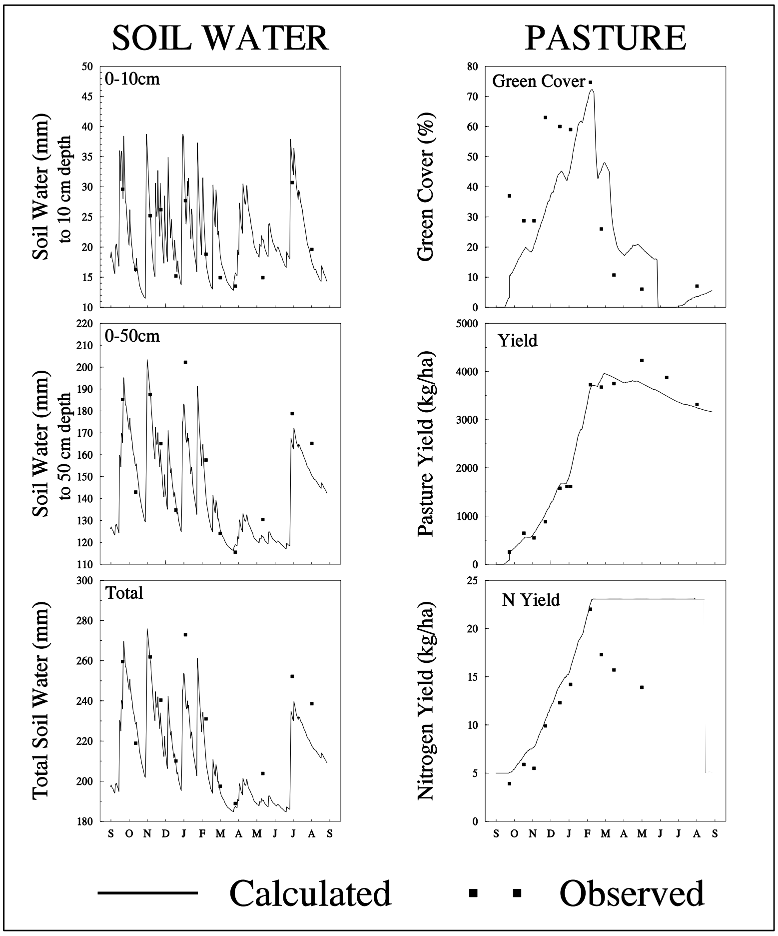


Figure 2.2 A typical seasonal pattern of plant growth, green cover, and N uptake as measured using GUNSYNpD methodology and simulated by the model GRASP. The example is for a black speargrass sward at Brian Pastures near Gayndah, south-eastern Queensland, for 1986/7 (data from D.M. Orr and G.M. McKeon).

1. Minimum soil water (permanent wilting point).

Periods of high evaporative demand (potential evapo-transpiration of 5-15mm/day) are common during the summer growing season, and hence, minimum soil water contents can be measured either opportunistically or as part of a regular (e.g. three weekly) sampling procedure. Varying soil evaporation rates due to cracking or high temperature gradients may contribute to errors in estimates derived from single seasons.

2. Maximum soil water (field capacity).

Soil moisture sampling after periods of high rainfall (50-100mm) provides estimates of maximum soil water (field capacity). Access to sites is not often possible until several days after such events. We have found that the daily water balance model accurately estimates evapo-transpiration when green cover in high (>30%) and soil moisture is high, and hence, maximum soil water can be determined from selected high soil moisture measurements and estimates of evapo-transpiration since rainfall.

The alternative of direct field determination using infiltration rings and water cartage is not feasible unless dedicated staff and water are available. For sites where measurements of the drained upper limit of soil water were made values are usually lower than estimated by 'back calculating' with the model (Figure 2.3). This possible source of error remains an area for further research although sensitivity studies with the model suggest that other factors have greater effects on pasture production.

3. Relationship between cover and yield.

Observations of percentage green cover are related to green yield (Figure 3.2, Appendix 2). The model parameter, yield at 50% green cover, varies with species, grazing history and water stress. Percentage green cover can be reproducibly estimated after a few hours training or measured directly from photographs. Similar relationships between projected cover and total standing dry matter are used in the calculation of run-off.

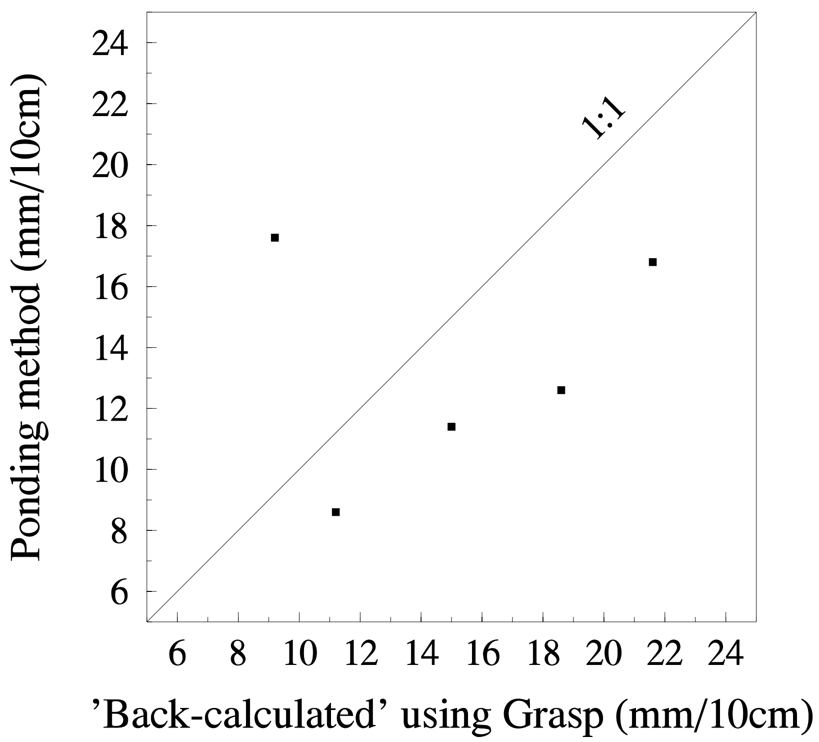


Figure 2.3 Comparison of estimated plant available water capacity (PAWC mm/10cm being the difference between field capacity and wilting point) in the top 50cm by: 1) calibrating GRASP to selected soil water measurements and; 2) measured by field ponding and soaking for seven days (E. Thomas *pers. comm.*).

4. Relationship between model green cover and available soil-water.

The model calculates a maximum possible green cover based on available soil-water. Species vary in their tolerance of water stress and ability to maintain green cover at low soil water levels (Figure 4.2 of Appendix 2). The threshold soil water index required to support full cover is derived from estimates of green cover at the end of the growing season when soil water is usually declining.

5. Relationship between height of pasture and yield.

Species vary in growth habit which is expressed as the relationship between height and yield. Plant height alters the vapour pressure deficit (VPD) environment surrounding transpiring surfaces. Tropical tall grass species rapidly escape the zone of high VPD near the soil surface. In contrast stoloniferous species remain in the surface zone, and hence, may be less efficient in water use.

6. Temperature response

General relationships between temperature and potential growth for C_4 and C_3 species are used. Since the growth of the sward is being modelled, general relationships have been preferred even though individual species have specific relationships between temperature and growth. We have found that the equations of McCown *et al.* (1981) for C_4 species and Fitzpatrick and Nix (1970) for C_3 species are adequate general relationships.

7. Effect of frost

Observations of death of green material associated with frosts allow relationships with screen minimum temperatures to be developed. Species differ in sensitivity to frost, especially C_4 compared to C_3 species. However, parameterisation from field data using nearest available screen minimum temperatures will also include landscape and microclimate effects. In most cases one general relationship has been used. More accurate parameterisation will require daily minimum temperatures which more accurately describe the pasture observation site.

8. Relationship between potential regrowth and grass basal cover

The initial pasture growth rate measured for 3-6 weeks after burning, mowing or heavy grazing is simulated as a function of:

1) plant density (i.e. measured as % grass basal cover);
2) a model parameter, potential regrowth rate; and
3) environmental variables expressed as a growth index (after Fitzpatrick and Nix 1970, Appendix 2).

The model parameter, potential regrowth, is calculated by model calibration with yield measurements in the first 3-6 weeks of growth. Further model development will be required to account for variation in N availability, and possible translocation of nitrogen and carbohydrates to shoots from roots and crowns.

9. Transpiration-use- efficiency

The model parameter, transpiration-use-efficiency (TUE), standardised at a near coastal day-time VPD of 20hPa, is derived by calibration with all observed yield measurements throughout the growing season. The parameter varies with species and fertility. Whilst a general response to VPD is used based on Tanner and Sinclair (1983), further model development will examine the possibility of different relationships between VPD and TUE for different species.

10. Soil-water content at which above-ground growth stops

Yield and soil-water observations from many sites confirm that **no** increase in above-ground yield occurs when soil-water declines below a particular value. For perennial pastures this generally occurs when the ratio of actual transpiration to potential transpiration is less than 0.4. Values derived from model calibration with data from heavily grazed pastures suggest higher thresholds up to 1.0 which occurs at approximately 40% available soil water (Figure 2.6 of Appendix 2). This increased sensitivity to soil-water deficit with grazing may indicate reduced root activity.

In the case of annuals (e.g. forbs in central Australia) growth continued to the lowest observed soil water either indicating no threshold on growth or that lowest observed soil water represented the limited capability of annual species to extract soil water in contrast to perennials.

11. Nitrogen uptake

Nitrogen uptake is assumed to be related directly to transpiration flow. Maximum possible uptake of N represents the annual capacity of the soil-plant system to mineralise and recycle nitrogen. The experimental methodology involving burning or mowing to remove previous season's material, prevents any N mineralisation from litter or carry-over material, and hence, model parameters may underestimate N availability. Alternatively, burning and mowing may cause rapid root death providing a source of readily mineralised material. Filet (1990) found no difference between N uptake in burnt and unburnt pastures.

Initial N yield is likely to reflect the above effects as well as environmental (surface moisture and temperature) effects on mineralisation during the winter/spring season. Insufficient data (e.g. soil nitrate measurements) are available to model these processes for all sites at present.

12. Detachment rates

Detachment rates are calculated from changes in pasture yield and estimated pasture growth. Since exclosures have been initially burnt or mown, the detachment rates represent that of ungrazed material which is less than one year old, and hence, may not be directly applicable to grazing and older material (see Section 3). Detachment rates after peak yield in autumn were approximately 0.002 kg/kg per day (i.e. 30-40% in six months). Forbs detached at a much faster rate (0.010 kg/kg per day) than perennial grasses.

Some sites showed evidence of rapid decline in yield immediately following seed production although it is not possible to quantify this accurately because of the low frequency of sampling and high spatial and temporal variability in flowering typical of native pasture plots.

The model has been designed to simulate different rates of detachment for leaf and stem. However, insufficient data are available to parameterise all communities at present.

Summary

Field data collection allows estimates of most parameters to be made **before** running the model. Thus, model calibration concentrates on the main growth parameters **potential regrowth rate** and **transpiration-use-efficiency**.

2.4 MODEL CALIBRATION AND ANALYSIS OF NATIVE PASTURE PRODUCTION

Model calibration

The manual calibration procedure was necessarily iterative and subjective using both accumulating experience in the possible range of parameters and subjective judgement about data quality and consistency. Table 2.2 summarises the model's fit to all available data and measured variables (soil water, yield, green cover and N uptake). Appendix 4 presents simulated and observed variables for the 94 exclosures in Queensland.

Each site varied in quality of climate input. We would expect variation in some parameters to be reduced with standard climate. We have now (February 1997) generated uniform climate data for all sites (as described in Section 5) and the analyses presented in this section will be repeated with this new, standard climate data.

For most exclosures there were two to three years data. The calibration procedure aimed to provide **one** set of parameters which represented the best fit to all data measured at that exclosure. Thus, the high correlations presented in Table 2.2 show that the model provides a reasonably consistent interpretation of the processes affecting plant growth rather than just the capacity to fit 'n' values with 'n' parameters.

Table 2.2 Comparison of simulated and observed pasture and soil variables for all 179 site x year combinations of pasture exclosure data (One site/year was accidentally omitted in analysing standing dry matter). Regression is for x = observed, y = simulated. Mean error is calculated as the average of the absolute value of observed less simulated.

VARIABLE	MEAN OBSERVED	MEAN SIMULATED	NUMBER OF OBS.	CORRELATION (r)	SLOPE	INTERCEPT	MEAN ERROR
Total Soilwater (mm)	**159**	**155**	**728**	**0.975**	**0.941**	**5.6**	**15.2**
Standing Dry Matter (kg/ha)	**1698**	**1754**	**993**	**0.911**	**0.949**	**143**	**357**
% green cover	**33**	**32**	**715**	**0.657**	**0.669**	**10**	**14**
N uptake kg/ha	**12**	**11**	**719**	**0.770**	**0.625**	**4**	**4**
% N in dry matter	**0.84**	**0.83**	**704**	**0.619**	**0.718**	**0.2**	**0.29**
Standing dry matter (log transform)	**7.02**	**7.04**	**993**	**0.907**	**0.925**	**0.5**	**0.29**
Standing dry matter at end of autumn (kg/ha)	**2476**	**2542**	**178**	**0.903**	**0.934**	**230**	**445**

Comparison with all measurements across all sites and in all seasons showed high correlations with soil water and low absolute errors similar to sampling variation (Table 2.2). Average absolute errors in simulated soil water by layer were 3 mm for the 0-10 cm layer, and 9 mm for both the 10-50 cm layer and bottom layer (50 cm to limit of grass roots). Overall the average error in total soil water was only 15mm suggesting that the processes of flow between layers could be better modelled. The lowest correlations were with observed green cover and N uptake and percent N in dry matter (Table 2.2). The lower correlation in the green cover are to be expected as most cases the values were visually estimated and, as yet, not all data has been corrected for operator bias. In the case of N uptake, models of N decline after peak yield have not yet been parameterised for each site, and hence, a substantial improvement is expected.

For 89 site x year combinations, yields were available for both autumn and the following winter/spring. In most cases, 80% of maximum observed yield had occurred by the end of autumn, confirming that there are many limitations to growth after this time (water, temperature, nutrients and phenological maturity). Thus, warm season growth (spring to autumn) is the major determinant of feed availability for year-round grazing (Figure 2.4).

The model simulated the above limitations to growth well and, when winter detachment rates were included, simulated yields follow the seasonal pattern closely (Table 2.2). The calibrated model accounted for 86% of the variation in the end of autumn yield (Table 2.2, Figure 2.5) with an average error of 445 kg/ha or 18% of mean yield for 178 site x year combinations.

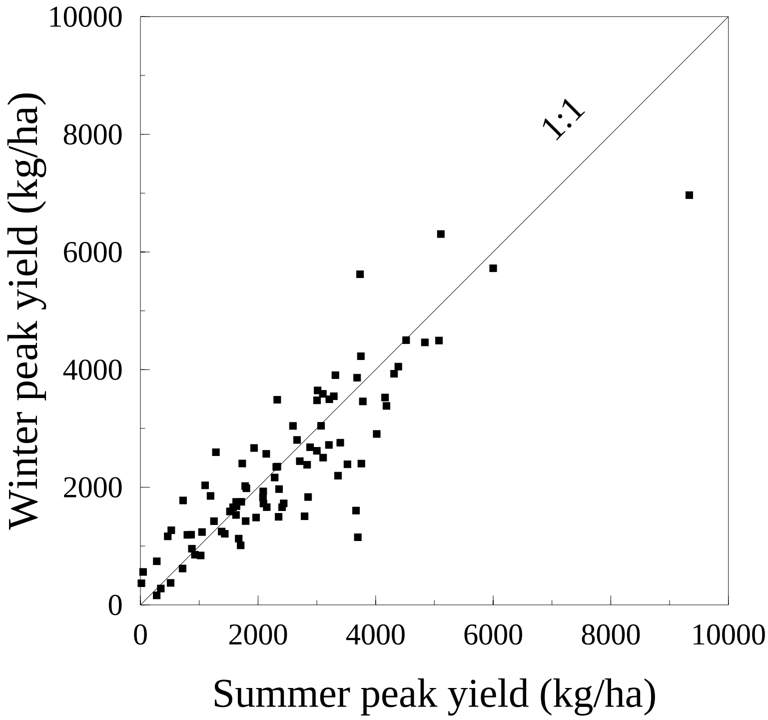


Figure 2.4 Comparison of peak yield measured in autumn with subsequent maximum yield occurring in winter/spring for the 89 native pasture exclosures in Queensland where measurements were available in both seasons.

Sources of variation in warm season pasture growth rate

From 179 site x year combinations available, a subset of 162 sites x year combinations was selected to analyse sources of variation in warm season pasture growth. Sites were rejected which:

1) did not have a similar measurement period (>100 days and < 1 year);
2) were not within a range of nitrogen uptake expected for native pastures (Autumn N yield <35 kg/ha); and
3) had significant carry-over dry matter from the previous season.

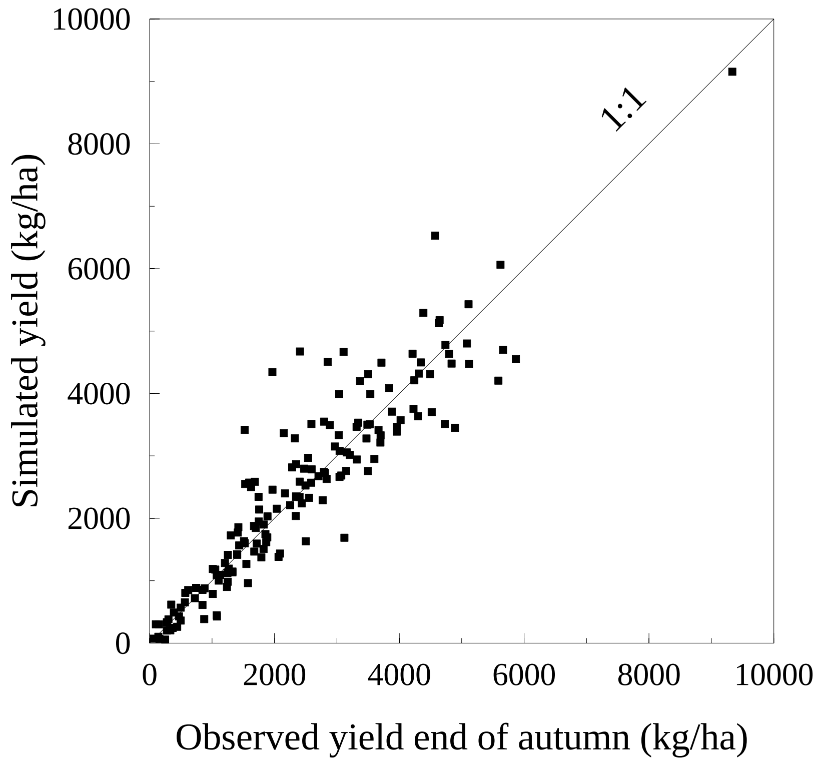


Figure 2.5 Comparison between observed yield at the end of autumn and simulated yield from the model GRASP. The model was parameterised as described in the text with parameters calibrated using all pasture data (993 points). The autumn yields represent a subset of these data, and hence, are not independent of calibration procedure.

The basis for rejecting sites from this analysis could be refined in future studies, in particular, to include only sites where parameters are well defined from field studies (e.g. potential N uptake may not be attained in a dry year). This should serve to reduce variability in some parameters. Four site/years were accidently omitted from the analysis and these and more recently measured sites (since 1995) together with sites from other states could be included in future studies.

Table 2.3 and Figure 2.6 show the correlation between measured pasture growth rate (from spring to autumn) and various environmental variables. Soil variables (% organic carbon, or available water range expressed as mm/10cm) accounted for only 8-19% of variation in measured pasture growth. Similarly, biological/soil variables such as grass basal cover and potential N uptake accounted for a small proportion of variation (8-10%). The major source of variation was rainfall (40%) with simulated climatic indices accounting for higher proportions: simulated growth index, 46%, and simulated evapo-transpiration, 60%. Simulated growth with the subjectively calibrated model accounted for 80% of the variation in measured pasture growth

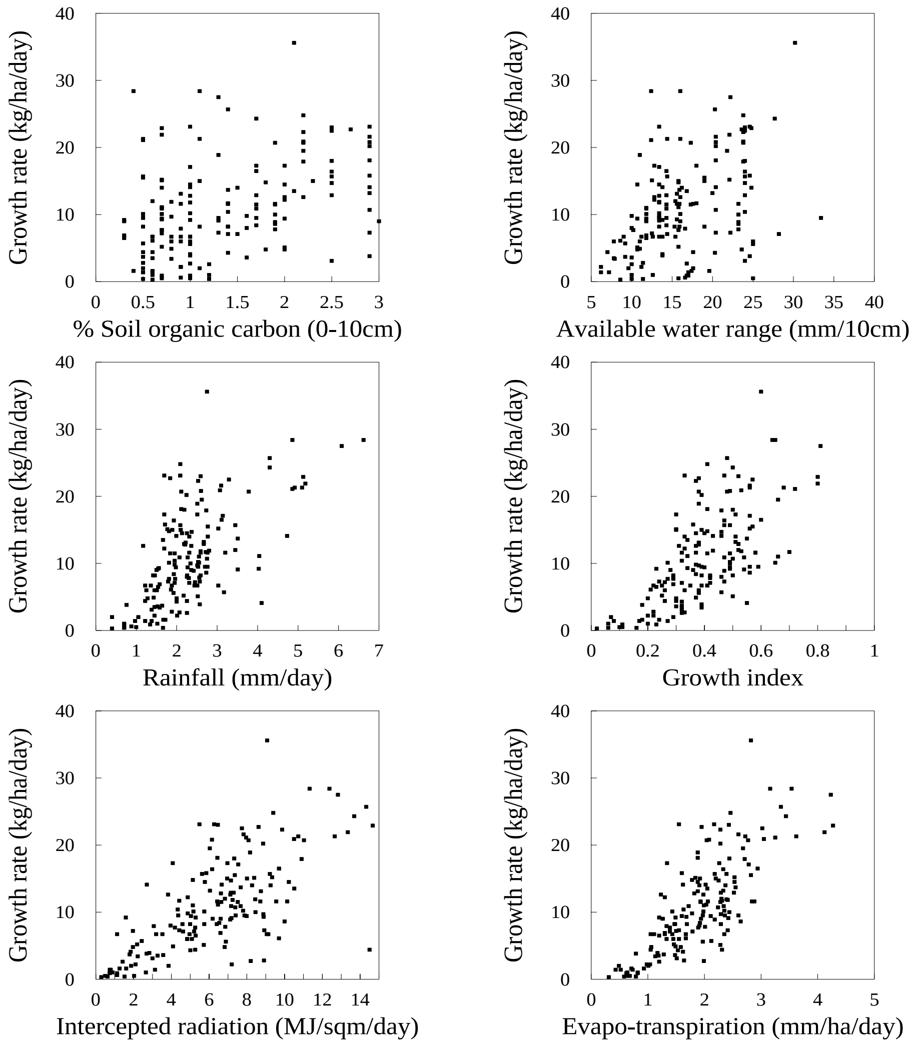


Figure 2.6 The relationship between measured pasture growth rate (from burning/mowing in spring to end of autumn) for 89 native pasture exclosures in Queensland (162 site x year combinations) and (1) % organic carbon 0-10cm; (2) soil available water range, mm/10cm for 0-50cm layer; (3) rainfall; (4) growth index (after Fitzpatrick and Nix 1970); (5) simulated radiation interception; and (6) simulated evapo-transpiration.

Table 2.3 Relationship between measured and simulated environmental variables, and pasture growth rate (kg/ha/day), calculated from mowing/burning in spring until the end of autumn, for 162 site x year combinations of native pastures.

VARIABLE	REGRESSION	CORRELATION
Vapour pressure deficit (hPa)	y = 22.05 - 0.5572x	r^2 = 0.086
Potential N uptake (kg/ha)	y = 5.844 + 0.229 x	r^2 = 0.081
Grass basal cover (%)	y = 4.683 + 1.192 x	r^r = 0.104
Soil organic carbon (%)	y = 5.808 + 3.820 x	r^r = 0.164
Available water range (mm/10cm)	y = 1.647 + 0.566 x	r^2 = 0.191
N mineralisation index (0-1)	y = -0.446 + 0.280 x	r^2 = 0.392
Rainfall (mm/day)	y = 0.801 + 4.36 x	r^2 = 0.405
Growth index (0-1)	y = -1.476 + 31.4 x	r^2 = 0.459
Radiation interception (MJ/m^2/day)	y = 1.266 + 1.549 x	r^2 = 0.478
Evapo-transpiration (mm/day)	y = -2.941 + 7.306 x	r^2 = 0.604
Transpiration (mm/day)	y = 2.586 + 8.031 x	r^2 = 0.602
Simulated growth (kg/ha/day)	y = 0.594 + 0.806.x	r^2 = 0.803

Analysis of model errors

The model was readily parameterised for sites covering a wide range in rainfall, geography, species and tree density. The calibration procedure allows consistent simulation of a wide range of processes; hydrology, plant growth, N uptake, plant senescence and detachment.

An analysis of situations where there were large errors between observed and simulated indicated the following problems:

1) sub-surface lateral drainage including outflow springs in plots (two sites on granite landscape);
2) spinifex sites had moisture extraction below one metre but no measurements were available (two sites);
3) slow drainage in saturated soils (one site);
4) intermittent high green cover estimates during periods of frost or drought;
5) rapid growth under ideal conditions (especially low VPD) probably due to high allocation of photosynthate to tiller growth before seed production;

6) low growth compared to model prediction under 'ideal' growth conditions possibly due to phenological maturity or limitations imposed by previous heat stress on tiller bud number (Brian Pastures in 1993/94);
7) rapid initial growth following drought conditions, probably due to high nitrogen availability and seedling establishment (Indian couch site);
8) rapid senescence and detachment of early flowering grass (Queensland blue grass and Indian couch) during growing season; and
9) possible re-greening of stem tissue due to winter rainfall and mild temperatures (Mitchell grass site at Biddenham).

Modification of the generic model to account for these individual site, year or species effects has not be attempted. Most errors occurred under conditions of above average rainfall, and hence, are likely to have less impact on simulation of drought effects

2.5 MODEL VALIDATION

The major objective in developing the model GRASP and field methodology was to design a model which could simulate year-to-year variation in pasture growth with a constant set of parameters which were derived from field measurements.

Only a limited number of sets of exclosure data are available which have more than five years of observations. Most of the 179 combinations of sites and years included only two to three years at one site. A major problem was that exclusion of grazing changed botanical composition. Section 3 deals with model evaluation for grazing trials run over five to ten years.

Case study 1: Black speargrass, forest blue grass and kangaroo grass at Gayndah

Of four exclosures established in 1986 at Brian Pastures, Gayndah, three remained relatively stable in terms of botanical composition (black speargrass, forest blue grass and kangaroo grass). Model parameters were derived mainly from season 1986/87 when frequent (three weekly) measurements were available. Parameters for nitrogen availability limiting growth were derived from autumn 1990 although the parameters were consistent with measurements in other years. Figure 2.7 and Table 2.4 show that a constant set of calibrated parameters accounts for a high proportion of both within year and between year variation in pasture yield.

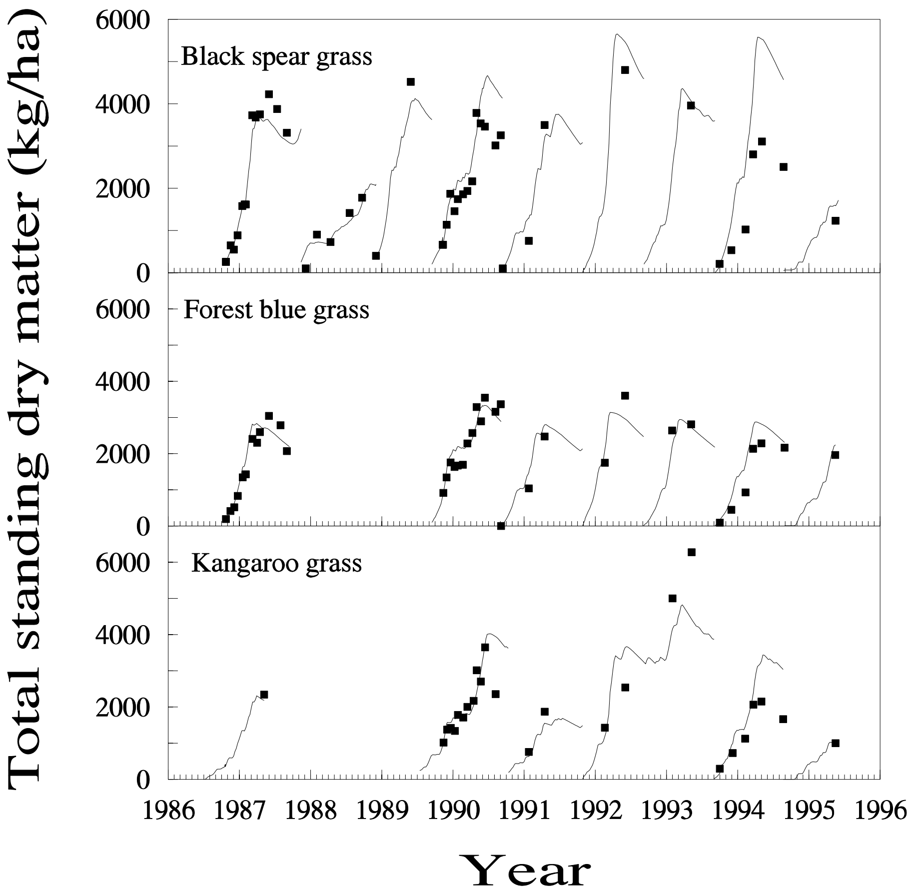


Figure 2.7 Comparison of observed and simulated pasture yields from 1986 to 1995 for three sites at Brian Pastures with relatively stable botanical composition. Model parameters were derived from years 1986-87 and peak yield in 1989-90. The other data points are independent of calibration procedure. Data for 1993-94 and 1994-95 were collected **after** model parameterisation. January 1994 included a week of highest VPD on record since 1957 at Brian Pastures.

Table 2.4 Comparison of observed and simulated pasture yields for five sites with over five years data at Brian Pastures, Gayndah.

SITE	MEAN OBSERVED	MEAN SIMULATED	NO. OF OBS	CORRELATION (r)	SLOPE	INTERCEPT	MEAN ERROR	RANGE OBSERVED	RANGE SIMULATED
Black speargrass mown three weekly 1964-70	700	778	32	0.892	1.35	-166	253	155-1475	136-2040
Black speargrass mown six weekly 1964-70	976	959	20	0.973	1.15	-160	170	209-2214	177-2446
Black speargrass burnt annually 1986-95	2018	2296	47	0.908	1.01	254	456	200-4799	105-5530
Forest blue grass burnt annually 1986-95	1957	2087	38	0.936	0.83	464	308	93-3602	169-3330
Kangaroo grass burnt annually 1986-95	2068	2172	26	0.849	0.75	624	457	297-6278[1]	174-4422

[1] Pasture was not burnt in 1992, and hence, 6 278 kg/ha is the accumulation of two years of growth (Figure 2.7).

Case study two - Black speargrass defoliation trial 1963-1970 (Scattini 1981)

Plots of black speargrass and other species were mown every three or six weeks each summer from 1963 to 1970 (Scattini 1981). Yields after mowing were measured or estimated and, in the simulation, the model's starting yield was reset at each mowing to these values. The good agreement between observed and simulated (Figures 2.8 and 2.9) for both cutting regimes indicates that the model simulates yield over a wide range in seasonal rainfall and defoliation intensities.

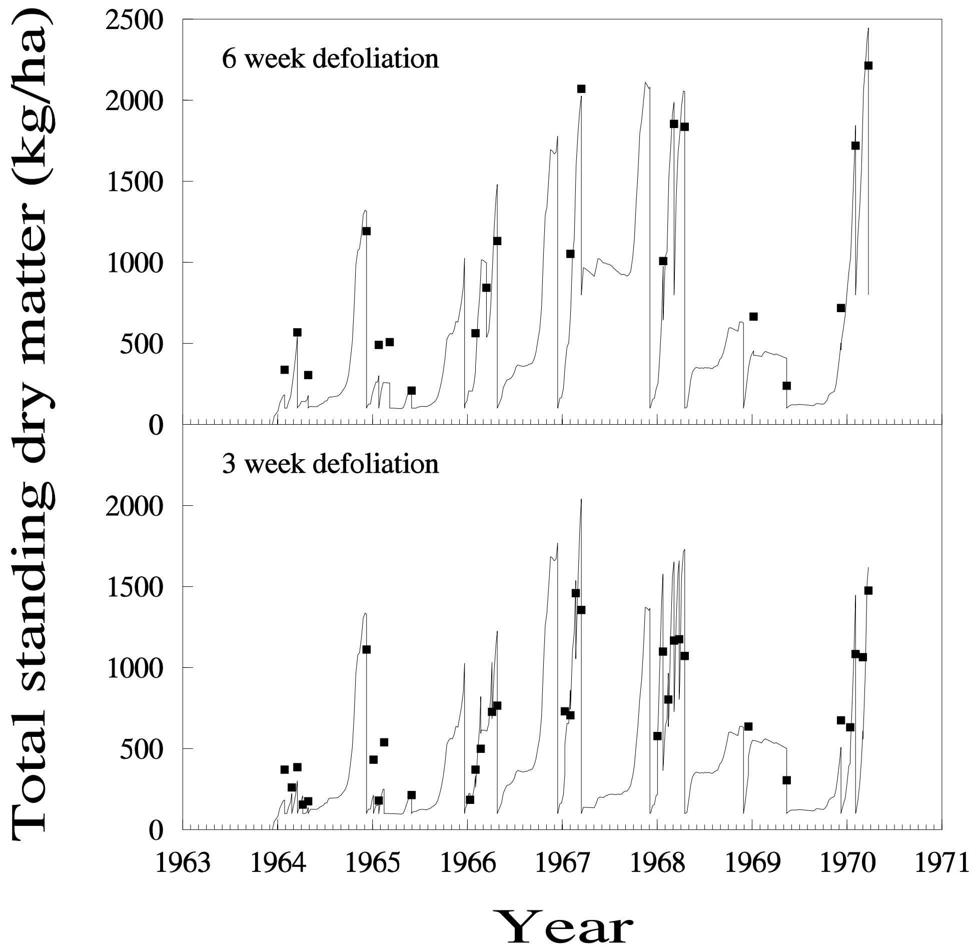


Figure 2.8 Time series comparison of observed and simulated pasture yields for black speargrass defoliation trial (Scattini 1981). Swards were mown either three weekly or six weekly during the growing season.

Of particular importance is the successful independent validation of the model at the three sites in 1994/95 (black speargrass, forest blue grass and kangaroo grass). These sites had relatively constant botanical composition for the period 1986-1995, and model parameters, especially those related to drought, were derived in the 1986/87 season. However, observed production at other sites (Ladies Mile and Lena) was over-estimated by 50%. These sites had substantial changes in botanical composition after exclosure. The over-estimates of growth in 1994/95 suggests that parameters for potential regrowth rate and transpiration-use-efficiency were too high. This may result from either increased growth rate due to invading species using resources of nitrogen and water not used by existing species, or over-estimation of growth parameters during calibration for the favourable season of 1989/90. During this season rapid tiller elongation occurred in autumn (Figure 2.7) and may have contributed to over-estimation of growth parameters.

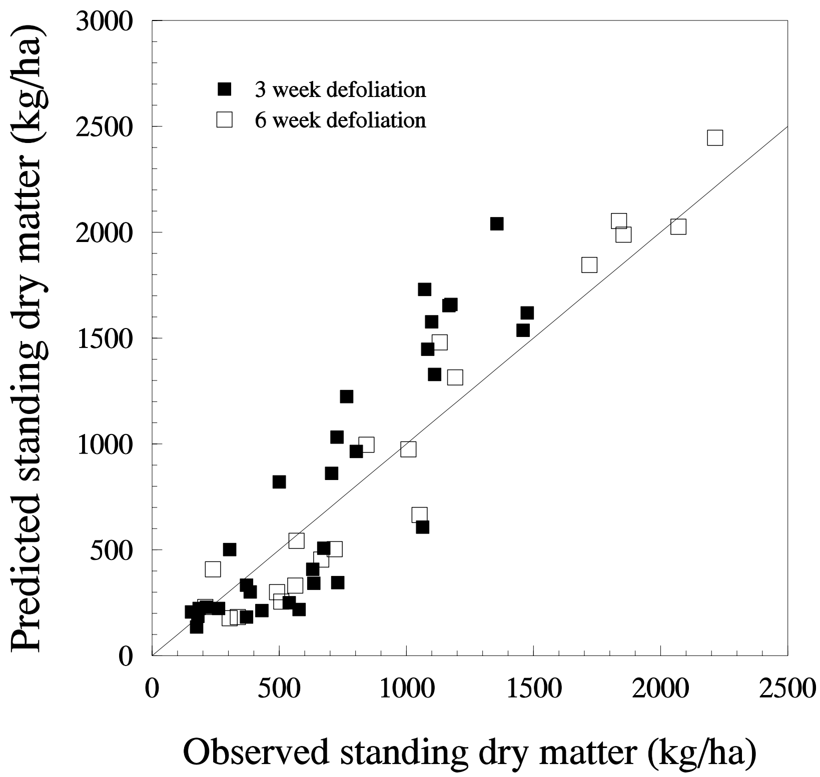
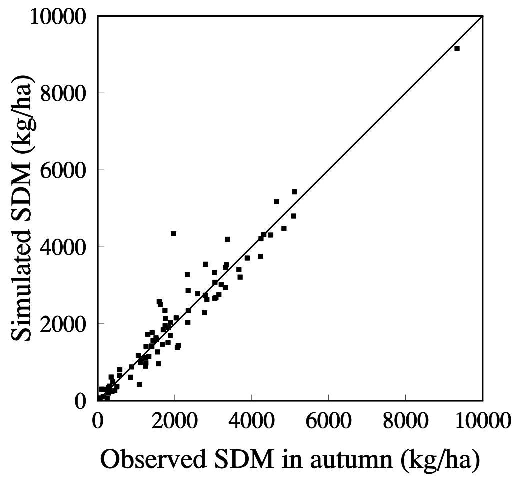


Figure 2.9 Comparison of observed and simulated pasture yields for black speargrass defoliation trial (Scattini 1981). Swards were mown either three weekly or 6six weekly during the growing season.

Simulation of year-to-year variation in growth

The exclosure data set used in model development also allows some assessment of the ability of the model to simulate year-to-year variation. For those sites where there were measurements in several years the model was compared for first year (Figure 2.10a) and subsequent years (Figure 2.10b). Model calibration was strongly weighted to the use of first year data including every 3-6 weekly harvests. Not surprisingly a high proportion of peak yield variation (r^2 =0 92) was explained. Data from subsequent years were used sparingly in calibration although in some cases, parameters such as critical %N and soil water attributes have been more correctly derived from these years. In these subsequent years, the model performed well under low growth conditions with most of the errors being associated with high growth conditions (Figure 2.10b). The success of the model in these subsequent years (r^2 =0 72) provides only a partial validation since we emphasise that these data are **not** completely independent of the calibration procedure. The errors under high growth conditions suggest that a better model will be required of leaf/stem partitioning, and hence, a variable critical % N for sward growth.



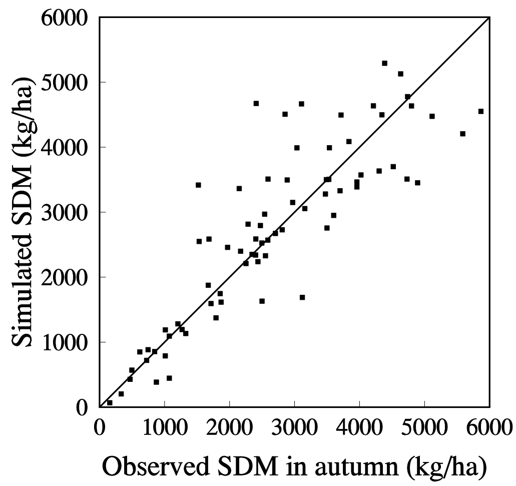


Figure 2.10a (left) & Figure 2.10b (right) Simulation of observed year-to-year variation in peak autumn yield in exclosures for the first (Figure 2.10a) and subsequent (Figure2.10b) years of measurement.

2.6 SUMMARY: EVALUATION OF THE MODEL ON NON-GRAZED PASTURE

In evaluating the model's capability we have found:

1) the model was readily parameterised from data measured at each site;
2) there were no simple soil measurements which could be used to predict parameters accurately indicating strong species x soil interactions;
3) the major sources of variation in calibrated transpiration-use-efficiency were species suggesting variation in root/shoot partitioning;
4) the model accurately represented the major effect of tree competition for water. Future improvement should also include competition for nutrients (Table 3.7, Scanlan and McKeon 1993);
5) constant model parameters were relatively successful in simulating pasture yield in below average seasons for sites with stable pasture composition;
6) care has to be taken when parameterising the growth model using data from the 'grand phase' of plant growth, i.e. rapid tiller elongation just prior to seed production. It is likely that this period involves a major change to root/shoot partitioning of growth and growth parameters. Transpiration-use-efficiency derived from these periods is likely to over-estimate growth at other times; and
7) as yet we have not developed a simple approach to modelling the variety of phenological responses that occur in a sward. In swards which are monospecific due to management, e.g. regularly burnt black speargrass, the phenological development of individual species has a much larger impact on pasture growth and has proved a major source of error in modelling.

2.7 ANALYSIS OF GROWTH PARAMETERS

The model was parameterised for all available pasture exclosure data resulting in 84 different parameter sets. The 84 parameter sets described for each site both soil and plant parameters which were either measured (e.g. minimum soil water) or calibrated (e.g. transpiration-use-efficiency). The 84 parameter sets were classified by a range of attributes to examine variation in the major plant growth parameters as follows:

1) pasture community either based on Tothill and Gillies (1992) or Weston *et al.* (1981);
2) dominant grass species in sward;
3) photosynthetic pathway including C_3 and C_4 variants, NADP-ME, NAD-ME and PCK (Hattersley and Watson 1992);
4) growth habit of dominant species (erect, prostrate or clumped);
5) plant size either as % basal cover per kg of yield (<1% per t/ha; 1-2% per t/ha or > 2% per t/ha), or assessed subjectively as small; medium; or large biomass per tussock; and
6) plant available water range expressed as mm of available water per 10cm of depth averaged over top 50 cm (<13mm/10cm, 13 to 17mm/10cm, or >17mm/10cm).

From one-way Analysis of Variance, the statistical significance of variation between groups means is shown for each parameter in Table 2.5.

Pasture community and species had a strong effect on all important parameters with differences between groups being statistically significant (Table 2.5). Photosynthetic pathway had significant effects on all important parameters except potential regrowth rate and potential regrowth rate per unit basal area. Although growth habit (subjectively classified) had significant effects on all important parameters except potential regrowth rate and potential regrowth rate per unit basal area, more quantitative measures of growth habit, i.e. tussock size and basal cover per yield had significant effects on fewer parameters. Measured soil attributes had a significant effect on only one parameter, viz. the soil water at which growth stops.

The 84 parameter sets provide the opportunity to summarise average plant parameters for a pasture community or for a species. At this stage it is not possible to determine which approach (community or species) is best for spatial modelling because, at a pasture community level, measured differences in growth parameters of species are averaged, eg. Wandera (1993). Alternatively, species parameters have been derived from so few sites that soil x species effects are difficult to determined.

Table 2.5 Statistical significance of different classification groups (e.g. species, pasture communities) on sward growth parameters.

	TUE (kg/ha/mm Transpiration-use-efficiency (kg/ha/mm at 20hPa)	**Potential N uptake (kg N/ha)**	**Sward potential regrowth (kg/ha/day)**	**Potential regrowth per unit basal cover (kg/ha/day)**	**Soil water index at which growth stops**
Pasture Community:					
Weston *et al.* (1981)	***	***	***	***	***
Tothill & Gillies (1992)	***	***	***	***	**
Dominant Species	**	**	**	***	***
Photosynthetic pathway	**	***	NS	NS	**
Growth habit	***	***	NS	NS	***
Tussock size	NS	*	NS	NS	*
Basal cover/yield	NS	NS	NS	NS	*
Plant available water range	NS	NS	NS	NS	*

* means group effect is significant at $P<0.05$
** means group effect is significant at $P<0.01$
*** means group effect is significant at $P<0.001$

Transpiration-use-efficiency (TUE)

Table 2.6 shows the comparison between sward TUE averaged either for species or for pasture communities. There were large differences between communities ranging from 7 kg/ha/mm for mulga to 20-25 kg/ha/mm for Mitchell grass and brigalow lands. Species TUE had less variation ranging from 7 to 18.5 kg/ha/mm. Other possible sources of variability yet to be examined are:

1) soil structural attributes;
2) site variation in humidity;
3) "rare" phenological effects on TUE, e.g. rapid stem elongation during a warm autumn in 1990 or the effect of the January 1994 heat wave; and
4) the impact of other species in the sward on sward TUE.

The effect of soil fertility on transpiration-use-efficiency is highlighted by the results for *Cenchrus ciliaris* (buffel grass) which has low TUE (5 kg/ha/mm) in the *Aristida-Bothriochloa* lands and high TUE (26 kg/ha/mm) in the brigalow lands. However, an analysis of TUE for black speargrass sites did not show any relationship with measured soil attributes. Furthermore, on the same soil types, both Wandera (1993) and McIvor *et al.* (1995) measured species differences on plant growth. Thus, the resolution of soil and species effects will require further field work and analysis. The spatial model described later in the chapter uses pasture community as a basis to estimate TUE for each 5 km x 5 km pixel.

Potential nitrogen uptake

Potential nitrogen uptake (kg N/ha) was estimated for each site although not all sites had received sufficient rainfall for nutrient limitations to be fully expressed. Nevertheless, potential N uptakes (Table 2.7) were lower for those species associated with poor pasture condition, e.g. *Aristida* spp. and *Chrysopogon fallax,* supporting the findings of McIvor *et al.* (1995). The potential fertility of brigalow lands was twice that of other grasslands (Table 2.7).

Table 2.6 Transpiration-use-efficiency (TUE) of pasture species and pasture communities. Transpiration-use-efficiency was calibrated for each site and expressed at a standard VPD (20hPa).

SPECIES	NO. OF SITES	TE	COMMUNITY	NO. OF SITES	TE
Heteropogon contortus [1]	28	11.4 [cd]	Black speargrass	50	11.4 [d]
Bothriochloa bladhii	7	12.3 [bcd]	*Aristida-Bothriochloa*	11	12.3 [cd]
Bothriochloa pertusa	4	10.0 [cd]			
Chrysopogan fallax [1]	4	10.5 [cd]			
Aristida spp.[2]	4	14.1 [abc]			
Bothriochloa ewartiana	4	15.8 [abc]			
Dicanthium sericeum [1]	4	14.5 [ab]	Queensland Blue Grass	3	16.7 [bc]
Cenchrus ciliaris [3]	9	17.0 [ab]	Gidgee	2	16.0
			Brigalow	5	25.4 [a]
Astrebla spp.	6	18.5 [a]	Mitchell Grass	5	19.8 [b]
Mulga C_3 grasses	5	7.2 [d]	Mulga lands	5	7.2 [e]

a,b,c,d,e: values with same letter are not significantly different at $P<0.05$

[1] One site in *Aristida-Bothriochloa* community
[2] Two sites in *Aristida-Bothriochloa* community
[3] Three sites in *Aristida-Bothriochloa*, four in Brigalow, two in gidgee

Table 2.7 Pasture growth parameters for GRASP derived from calibration with exclosure data grouped by dominant species or pasture community

Species	Potential N uptake (kg N/ha)	Sward Potential Regrowth		Soil water index at which growth stops (0-1)
		(kg/ha/day)	(kg/ha/day per % basal cover)	
Heteropogon contortus	21^{bc}	16^{b}	2.9^{c}	$.24^{bcd}$
Bothriochloa bladhii	23^{bc}	14^{b}	2.4^{c}	$.31^{abc}$
Bothriochloa pertusa	27^{ab}	30^{a}	5.8^{ab}	$.25^{abcd}$
Chrysopogan fallax	14^{cd}	7^{b}	2.0^{c}	$.03^{e}$
Aristida spp.	13^{d}	11^{b}	3.2^{bc}	$.18^{cde}$
Bothriochloa ewartiana	19^{bcd}	17^{ab}	4.7^{ac}	$.20^{bcde}$
Dicanthum sericeum	19^{bcd}	11^{b}	2.0^{c}	0.35^{ab}
Cenchrus ciliaris	31^{a}	30^{a}	6.4^{a}	$.17^{de}$
Astrebla spp.	23^{b}	21^{ab}	4.2^{bc}	$.31^{abc}$
Mulga C_3 grasses	16^{cd}	8^{b}	3.2^{bc}	$.40^{a}$

Community	Potential N uptake (kg N/ha)	Sward Potential Regrowth		Soil water index at which growth stops (0-1)
		(kg/ha/day)	(kg/ha/day per % basal cover)	
Black speargrass	20^{b}	15^{b}	2.9^{c}	$.26^{sbc}$
Aristida-Bothriochloa	21^{b}		5.2^{b}	$.13^{d}$
Queensland Blue Grass	18^{b}	13^{b}	2.0^{c}	$.40^{a}$
Brigalow	43^{a}	42^{a}	10.4^{a}	$.20^{bcd}$
Mitchell Grass	24^{b}	21^{b}	4.0^{bc}	$.29^{sb}$
Mulga lands	16^{b}	8^{b}	3.2^{hc}	$.40^{a}$

a,b,c,d: values with the same letter are not significantly different at $P<0.05$

Sward potential regrowth rate

Sward potential regrowth (kg/ha/day) was calibrated from yield measured early in the growing season. During this phase, growth is mainly simulated by the equation:

growth = grass basal cover*potential regrowth rate*growth_index.

The combined variable of grass basal cover multiplied by potential regrowth rate is termed Sward Potential Regrowth (SPR). Species-averaged SPR (Table 2.7) was significantly ($p<0.001$) correlated with potential N uptake (PNU); SPG = -10.9 + 1.33 * PNU (n = 10, r^2 =0.83). Sward potential regrowths were variable, and hence, only the main effects of fertility (brigalow lands) and stoloniferous species (*Bothriochloa pertusa*) were significant. When potential growth per unit of grass basal cover was calculated the above differences were also significant (Table 2.7). The two communities black speargrass and *Aristida-Bothriochloa* (AB) had similar sward potential regrowths (15-17 kg/ha/day). However, when expressed per unit of percent grass basal cover, the AB community had significantly higher potential regrowth rates suggesting that some compensation for lower grass basal cover occurs by increasing regrowth per plant.

Soil Properties

Soil properties such as % organic carbon, nitrogen, phosphorus, pH, soil moisture at 15 bars and particle size distribution were measured at each site in 1994. There were no major correlations (Table 2.8) between measured soil properties and the model parameters, transpiration-use-efficiency, potential N uptake, and sward potential regrowth rate suggesting that the interaction between species and soils is a major source of variation.

Table 2.8 Correlation (r) between bulk surface (0-10cm) soil analyses and GRASP parameters. Correlations are based on 94 sites except particle size analyses based on 82 sites (correlations greater than 0.21 are significant at $P<0.05$) and Total P,K & S based on 53 sites (correlations > 0.27 are significant at $P<0.05$).

Analysis	Method	Transpiration -use-efficiency (kg/ha/mm) at VPD= 20hPa	Potential N uptake (kg/ha/day)	Sward potential regrowth (kg/.ha/day)	Potential regrowth per unit basal cover (kg/ha/day)	Soil water index at which plant growth stops
pH (H20)	20:100, Soil:H20	0.57	0.34	0.45	0.26	-0.07
Electrical Conductivity	20:100, Soil:H20	0.58	0.46	0.31	0.27	0.05
Chloride (C1) extractable	20:100, Soil:H20	-0.03	0.12	-0.10	-0.11	0.07
Nitrate/Nitrogen (N) ext.	20:100, Soil:H20	0.08	-0.04	-0.03	-0.07	0.15
Phorphorus (P) bicarb ext	1:100, Soil:0.5M NaHC03 Colwell	0.14	0.22	0.14	0.04	0.10
Phorphorus (P) acid ext.	1:200, Soil:0.005M H2S04 (BSES)	0.07	0.01	0.03	-0.04	0.02
Potassium (K) replaceable	5.200, Soil:0.05M HC1	0.32	0.36	0.20	0.16	0.14
Sulphur (S) extractable	20:100, Soil:0.01M CaHP04	0.04	0.03	-0.22	-0.07	0.44
Calcium (Ca) pH 7.0	5:100, Soil:1M NH4CI @ pH 7.0	0.56	0.35	0.23	0.13	0.22
Magnesium (Mg) pH 7.0	5:100, Soil:1M NH4C1 @ pH 7.0	0.20	0.10	-0.09	-0.18	0.34
Sodium (Na) pH 7.0	5:100, Soil:1M NH4C1 @ pH 7.0	0.22	0.08	0.09	-0.00	0.202
Potassium (K) pH 7.0	5:100, Soil:1M NH4C1 @ pH 7.0	0.27	0.25	0.11	0.19	0.39
ECEC	Exchangeable (Ca+Mg+Na+K)	0.46	0.28	0.12	0.02	0.29
Organic Carbon (OC)	Walkley & Black	0.26	0.37	0.09	-0.03	0.30
Total Nitrogen (N)	Kheldahl digest	0.36	0.48	0.16	0.11	0.25
Air dry moisture content	Air Dry Moisture content	0.39	0.27	0.10	0.01	0.33
PSA-Coarse sand fraction	gravimetric	-0.15	-0.38	-0.09	-0.02	-0.12
PSA-Fine sand fraction	gravimetric	-0.26	0.05	-0.09	-0.02	-0.12
PSA-Silt fraction	hydrometer	0.06	0.08	-0.16	-0.24	-0.38
PSA-Clay fraction	hydrometer	0.36	0.39	0.15	0.11	0.36
Moisture Cont. @ 1500 Kpa	pressure plate	0.32	0.23	0.03	-0.06	0.37
Total phosphorus (P)	pressed powder, XRF	0.29	0.43	0.40	0.42	0.37
Total potassium (K)	pressed powder, XRF	-0.05	-0.01	0.04	-0.06	-0.04
Total sulphur (S)	pressed powder, XRF	0.48	0.54	0.31	0.34	0.15

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Photosynthetic Pathway

An alternative approach to examining differences in growth parameters between species is to consider lumping of physiological types based on alternative photosynthetic pathways i.e. C_3, C_4 NADP-ME, C_4 NAD-ME and C_4 PCK and other sub categories (Hattersley and Watson 1992).

Whilst such an approach shows statistical differences between groups (Table 2.9) the representation of type is biased by either a single species (e.g. *Astrebla* spp. as the sole representative of NAD-ME on our data set) or soils (C_3 and NAD-ME *Triodia* type occur on low P soils).

2.8 EFFECT OF PREVIOUS GRAZING ON PLANT GROWTH PARAMETERS

Of major importance for calculating the risks of degradation is the effect of grazing on plant growth parameters. Excluding grazing allows some of the previous grazing effects to be immediately reduced. Hence, even the data collected in the first year of exclosure of previously heavily grazed pastures does not necessarily provide correct estimates of plant growth parameters to be used in simulating grazed pastures. Nevertheless, the calibration of the model across years indicated some change in the following parameters:

soil moisture content at which growth stops. Previously grazed swards were found to be more sensitive to soil moisture deficit; and

yield-height and yield-cover relationships. Swards of black speargrass were more prostrate and had higher cover for the same yield compared to swards which had not been grazed.

Table 2.9 Pasture growth parameters for GRASP derived from calibration with exclosure data grouped by photosynthetic pathway.

Photosynthetic Pathway	Species	Transpiration -use- efficiency (kg/ha/mm) at VPD= 20hPa	Potential N uptake (kg/ha)	Sward potential regrowth (kg/ha/day)	Potential regrowth per unit basal cover (kg/ha/day)	Soil water index at which plant growth stops
C_3	*Monochather paradoxa* *Thyridolepis mitchelliana*	7.2 ^{d}	16 ^{bc}	8	3.2 ^{b}	.40 ^{a}
NADP-ME	*Cenchrus ciliaris* *Dicanthium* spp. *Heteropogan contortus* *Bothriochloa* spp. *Chrysopogon fallax* *Themeda triandra*	12.6 ^{bc}	22 ^{ab}	17	3.5 ^{b}	.24 ^{b}
NADP-ME (*Aristida* type)	*Aristida* spp.	14.1 ^{abc}	13 ^{c}	11	3.2 ^{b}	.18 ^{bc}
NAD-ME	*Astrebla* spp.	18.5 ^{a}	23 ^{ab}	21	4.2 ^{ab}	.31 ^{ab}
NAD-ME (*Triodia* type)	*Triodia* spp.	7.0 ^{d}	7 ^{c}	13	4.5 ^{ab}	.01 ^{c}
PCK	*Urochloa* spp. *Enneapogon* spp. *Panicum maximum* *Chloris gayana*	15.5 ^{ab}	29 ^{a}	24	7.4 ^{a}	.25 ^{ab}

a,b,c,d: values followed by the same letter are not significantly different at $P<0.05$

Different grazing pressures result in large variation in species composition. Species, although growing in essentially the same soil/climate environment, have large differences in flowering time, dry matter production and N uptake. (Ash and McIvor 1995, Wandera 1993). Previously published work indicates a variety of growth responses to grazing. The most important responses were reduced yield and nutrient uptake (McIvor *et al.* 1995a, Wandera 1993), earlier flowering time and a greater percentage of annuals in the sward. These responses can be simulated by reducing potential N uptake for grazed swards.

Examination of growth parameters for swards which were nearly monospecific showed large differences between species regarded as representing degraded condition, e.g. *Aristida* spp. and *Chrysopogon fallax*. For example, *Aristida ramosa* at Brian Pastures has high above-ground growth probably due to partitioning of growth to shoots rather than roots. In contrast, *Chrysopogon fallax* and *Aristida* spp. dominated patches at Narayen had low above-ground production. Thus, different species attributes can have considerable impact on growth parameters independent of the ranking of the desirability of the species (Section 1, Wandera 1993), and hence, it is difficult to generalise on parameters which would represent a given pasture condition class. However, the methodology and modelling procedure described above demonstrated that these species attributes can be parameterised and pasture growth simulated for a given botanical composition.

SECTION 3 - MODELLING GRAZED PASTURES

3.1 INTRODUCTION

In this section we describe:

(1) data sources available for modelling grazed pastures;
(2) model development and parameters to model animal consumption, trampling; natural detachment and decomposition;
(3) parameterisation of the model for eleven native pasture grazing trials;
(4) model development of grass basal cover of desirable perennial grasses; and
(5) calculation of the effect of stocking rate on utilisation rates and animal production.

3.2 DATA SOURCES FOR GRAZED PASTURES

Assessment of risks of degradation requires simulation of grazed pasture using long (30-100 years) time series of climatic data. Validation of the model GRASP for time series of exclosure data (burnt or mown each year) was demonstrated in Section 2. However, the simulation of grazed pastures requires models of the other dry matter flow processes: consumption by animals; detachment; trampling; and litter breakdown. Few of these process have been measured independently, and hence, pasture yields are the primary source of data.

The potential sources of pasture yield data from grazed pastures include:

1) grazing trials with regular (seasonal/yearly) measurement of pasture yield;
2) remote sensing indices such as NDVI;
3) stock inspector or other governmental reports, e.g. drought declaration reports;
4) graziers' diaries and observations; and
5) photographic time-series.

Of these potential data sets only remote sensed data were available in a computer compatible form. Hence, in this project we had to first establish a procedure for storing historical grazing trial data in a form that allows rapid model calibration and validation testing (e.g. Cowan. 1994, Appendix 1). At present, data from six cattle trials in eastern Queensland and five sheep trials have been stored in a form suitable for modelling. Not only are all observational data stored but management changes (e.g. changes in stocking rate, dates of burning) are coded in a form that allows a simulation of each paddock in the trial. Tables 3.1 and 3.2 summarise the major native pasture grazing trials analysed in this project, and highlight the wide range in rainfall, soils, nutrients and locations (Figure 3.1) used in developing the following analysis of the effects of grazing.

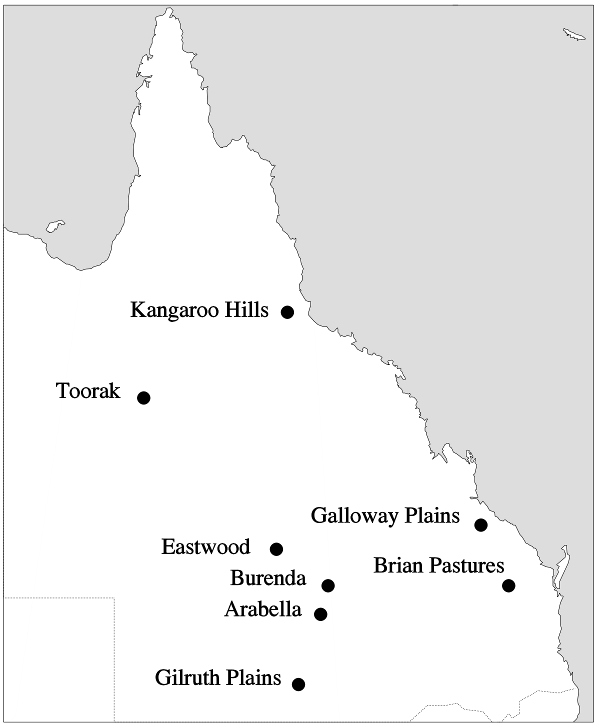


Figure 3.1 Location of grazing trials analysed in this report.

Table 3.1 Grazing trials in eastern Queensland simulated with GRASP model.

GRAZING TRIAL	NEAREST TOWN	PASTURE COMMUNITY	YEARS	TREATMENTS
Brian Pastures P55-1	Gayndah	southern black speargrass (cleared)	1961-1970	three stocking rates in summer-autumn
Brian Pastures P55-2	Gayndah	southern black speargrass (cleared)	1970-1979	three stocking rates in either summer-autumn or winter-spring
Brian Pastures P55-3	Gayndah	southern black speargrass (cleared)	1980-1984	as above in P55-2 with/or without burning in spring
Ladies Mile	Gayndah	southern black speargrass (cleared)	1989-1994	five periods of deferring grazing
Galloway Plains	Calliope	central black speargrass (cleared)	1988-1995	six stocking rates
Kangaroo Hills	Seaview Range (W of Ingham)	northern black speargrass (oversown with Townsville stylo)	1965-1975	two stocking rates with or without clearing and phosphorus

Table 3.2 Grazing trials in western Queensland simulated with GRASP model.

LOCATION	NEAREST TOWN	PASTURE COMMUNITY	YEARS	TREATMENTS
Toorak	Julia Creek	Mitchell grass	1985-1995	five levels of utilisation*
Eastwood	Blackall	buffel grass	1967-1983	three to four constant stocking rates
Burenda	Augathella	Mitchell grass	1976-1989	five levels of utilisation
Arabella	Charleville	Mulga pastures	1977-1986	four levels of utilisation
Gilruth Plains	Cunnamulla	Mitchell grass flood plains	1941-1954	three constant stocking rates

* Utilisation levels were treatments where stocking rate was changed each year at end of growing season to consume a proportion of standing pasture yield over next 12 months. Utilisation levels were constant for each paddock (e.g. 10, 20, 30, 50, 80 % of standing pasture yield.

We are extremely grateful to our colleagues and funding agencies who have allowed access to the unpublished data from these grazing trials. Such an analysis could only occur with the generous scientific spirit of those involved in data sharing. As will be described in Section 4 this ethos of information sharing and interpretation through models is as relevant to graziers as it is to scientists.

The objectives of the following analyses were to:

1) quantify the dry matter flow processes of consumption, detachment and trampling;
2) evaluate the constancy of model parameters over time;
3) develop models simulating the effects of grazing on growth and other model parameters; and
4) develop a model of grass basal cover of desirable perennial grasses.

3.3 CATTLE GRAZING TRIALS IN EASTERN QUEENSLAND

Tables 3.3 to 3.7 and Figures 3.2 to 3.5 summarise findings for cattle grazing trials in the black speargrass community in eastern Queensland.

The grazing trial 'P55' (black speargrass, SE Queensland) provides the basis for examining the impact of grazing on growth. Each year pastures were burnt in spring when yield was sufficient to carry a fire (≈1 000kg/ha). As a consequence, carry-over yield from year-to-year was not likely to be a major component of measured yields. Consumption was estimated from equations developed by McKeon and Rickert (1984). These estimates are compatible with Minson and McDonald (1987). The three stocking rates used resulted in a wide range of utilisation rates (23-77% on average). In the first three years most of the effect of grazing on reducing yield could be accounted for by animal consumption. However, following the drought of 1963/64, the decline in pasture yield was greater than could be accounted for by just consumption alone. This decline in yield could be simulated by changes to model parameters following seasons of high utilisation (75%). Large reductions in desirable perennial grass basal cover occurred as a result of drought and heavy utilisation which allowed stoloniferous and early flowering grasses to invade.

The required changes to model parameters indicated that parameters derived from ungrazed sites would over-estimate yields under grazing. Once these effects were included a high proportion (86%) of yield variation for season x year x stocking rate combinations could be accounted for by the model. (Figure 3.2, Table 3.4).

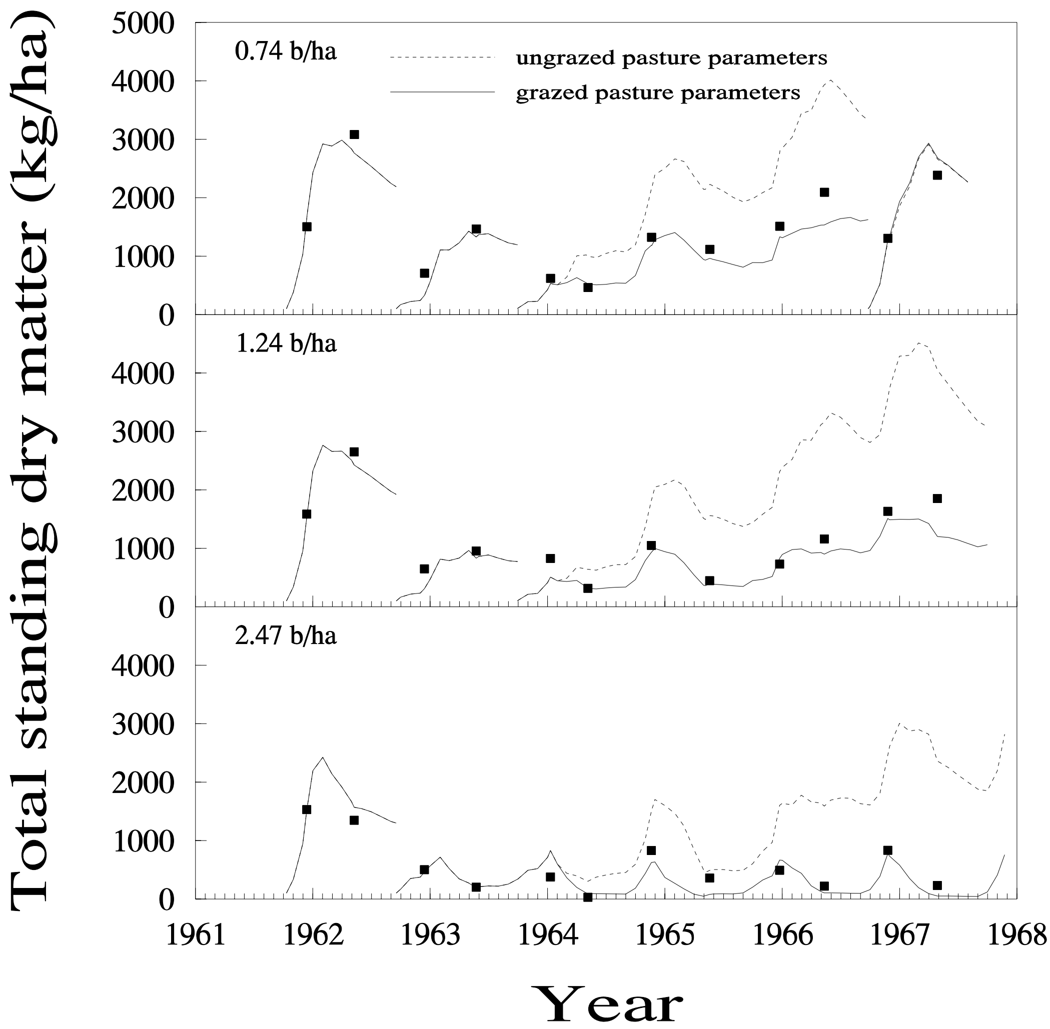


Figure 3.2 Comparison of observed and simulated pasture yield data for Brian Pastures P55 grazing trial phase one (see Table 3.3 for treatments).

Independent validation was carried out using data collected for these paddocks 1975 - 1984. Although, on average, the simulated and observed were very close, correlation was not as good as the calibrated period (r^2 =0.36). From 1975 yields were visually estimated rather than harvested and could be subject to larger errors especially where regressions are used to transform low visual estimates to yields. Subsequent studies (1995/6) have indicated large variation in N uptake between soil types across the grazing trial. Future modelling work will concentrate on parameterising individual paddocks using this information.

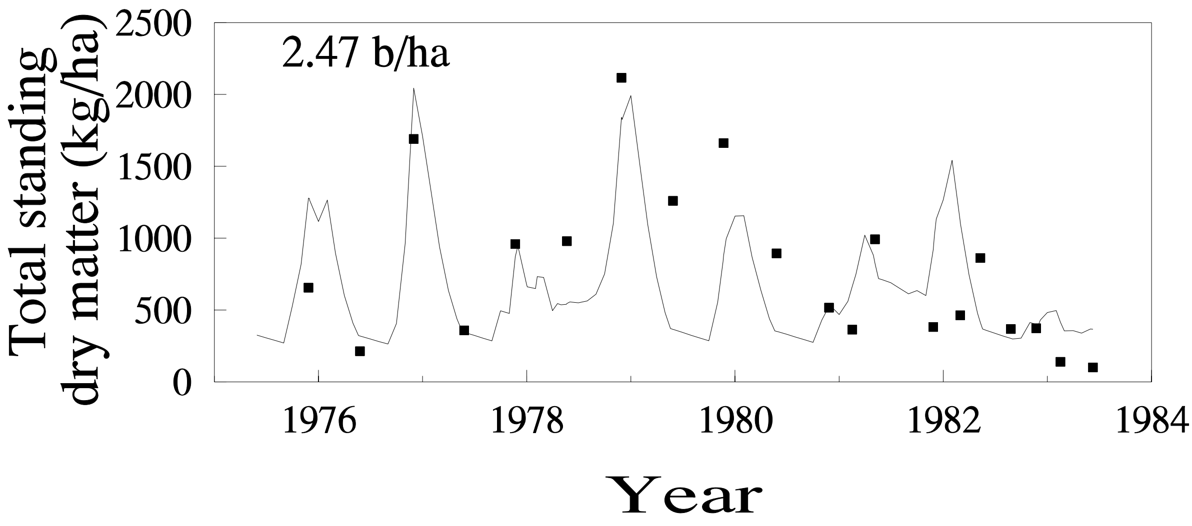


Figure 3.3 Comparison of observed and simulated pasture yield data for Brian Pastures P55 grazing trial phase two and three heaviest stocked treatment (see Table 3.4 for treatments).

3.4 SHEEP GRAZING TRIALS IN WESTERN QUEENSLAND

Five grazing trials in western Queensland using sheep were analysed. Two trials, buffel grass at Eastwood (Table 3.8) and mulga grasses at Arabella (Table 3.9) represented extreme cases of high and low fertility in a semi-arid environment, and hence, provide an excellent test of a model's capability in semi-arid highly variable climatic environments. The other three trials Gilruth Plains (Table 3.10), Burenda (Table 3.11) and Toorak (Table 3.12) were all on Mitchell grass but were spread over 1 000 km on a north-south gradient.

Table 3.3 Summary of "P55" grazing trial in south-eastern Queensland (1961-69).

Name	Brian Pastures "P55" phase 1
Community	Southern black speargrass
Location	Brian Pastures Research Station, 16 km SE of Gayndah
Period and soil	1961 to 1969, on variable clay soils. Site had been cleared of eucalypt regrowth
Desirable Perennial Grass Species	*Heteropogon contortus, Bothriochloa bladhii, Dicanthium sericeum*
Principal Investigator	W J Scattini *et al.*
Grazing Treatments	Three stocking rates (0.74, 1.24, 2.47 per ha) of weaner steers during summer (December to May). Pastures were burnt when possible.
Main Findings	• Large decline in basal area of desired perennial grass species occurred at the high stocking rate and during drought (soil water index <0.3), e.g. 1968/69. • Pasture composition shifted to stoloniferous grasses and early flowering species.
Modelling Findings	• Growth parameters were derived from one GUNSYNpD exclosure in a treatment which had been annually burnt since 1980 and grazed only in winter and spring since 1970. Growth parameters were derived from 1986/87 season and simulated initial years (1961-1965) reasonably well. The following changes were required to model other years. • Heavy utilisation resulted in more leaf and less stem, and hence, higher % N would be required for growth to occur. However, there was no measured decline in potential N uptake from 1962-1967 (Scattini 1973). Further measurements were not taken after 1967. • Heavy utilisation resulted in lower root density, and hence, increased sensitivity to water stress and reduced available water range. • More prostrate sward structure occurs under heavy grazing. Hence, there is a higher VPD where the plants are actually

	growing, and hence, lower water use efficiency.

Table 3.4 Summary of "P55" grazing trial (1970-84) in south-eastern Queensland

Name	Brian Pastures "P55" phases two and 3
Community	Southern black speargrass
Location	Brian Pastures Research Station, 16 km SE of Gayndah
Period and soil	1970 to 1984 on variable clay soils
Desirable Perennial Grass Species	*Heteropogon contortus, Bothriochloa bladhii, Dicanthium sericeum*
Principal Investigator	D.G. Cooksley, C. Paton *et al.*
Grazing Treatments	Previous treatments (Table 3.4) were either continued, i.e. summer-autumn grazing at three stocking rates or grazed only in winter spring at three stocking rates. In 1980 treatments were split again (either burnt or not burnt) resulting in 12 treatments in all.
Main Findings	Winter/spring grazing allowed desirable perennial grasses to return
Modelling Findings	• GUNSYNpD parameters derived in 1986 - 1995 underestimated maximum N availability or critical %N, and hence, pasture yield in high rainfall years (1970s) was under predicted. • growth in the drought year 1982/83 was simulated well - an independent test of the model. • pasture under heavy grazing was reasonably well simulated using parameters derived in phase one - an independent test of the model. • subsequent field work (1995/6) has shown wide variation in N availability between soil types, and hence, paddocks (K.A. Day).

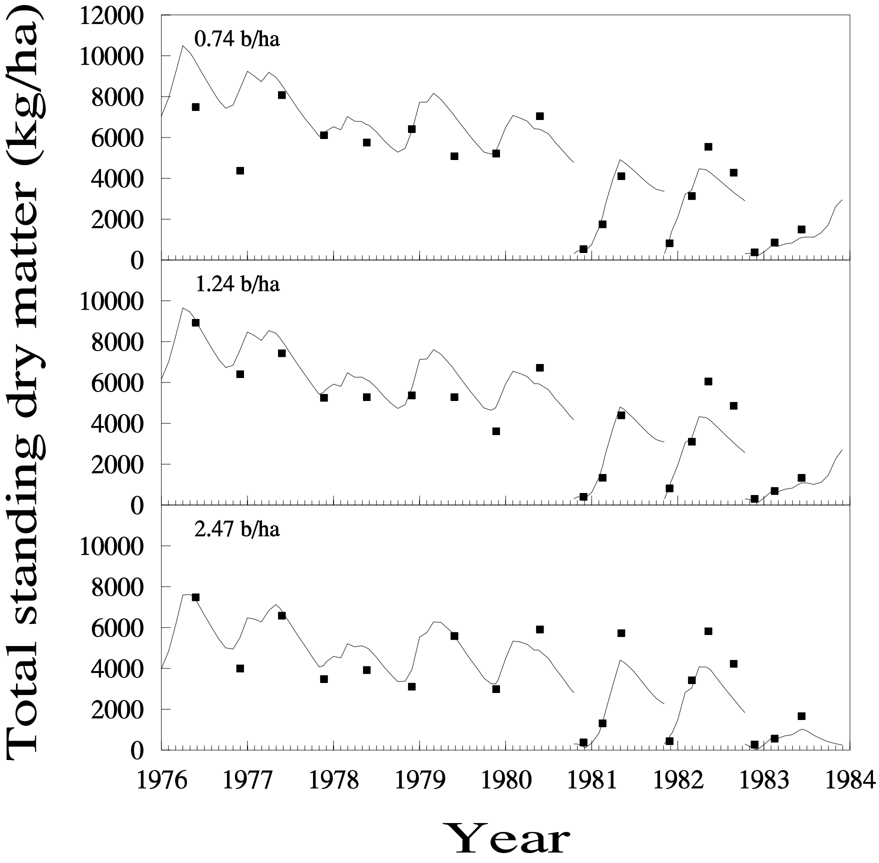


Figure 3.4 Comparison of observed and simulated pasture yield data for Brian Pastures P55 grazing trial phases two and three: winter/spring grazed and burnt when possible after 1980 (see Table 3.4 for treatments).

Table 3.5 Summary of Ladies Mile grazing trial in south-east Queensland (Orr *et al.* 1997 a,b).

Name	Ladies Mile Grazing Strategies Trial
Community	Southern black speargrass
Location	Brian Pastures Research Station, 16 km SE of Gayndah
Period and soil	1989-1994 on duplex and fertile alluvial soils
Desirable Perennial Grass Species	*Heteropogon contortus, Bothriochloa bladhii*
Principal Investigator	D M Orr, C Paton *et al.*
Grazing Treatments	Previously degraded pastures with a high content of *Aristida* spp. were burnt annually and grazed with variable deferment of start of grazing following burning. The two treatments simulated were: (1) no rest after burning and stocked at 0.67 weaner/steers per ha; and (2) six months rest after burning before stocking
Main Findings	• Burning and deferred grazing resulted in a return to a high proportion of desirable perennial grass species
Modelling Findings	• Growth parameters were available from two sites adjacent to the trial but the exclosure caused pasture composition to change to desirable perennial grasses and growth parameters derived from the exclosure over-estimated pasture growth under grazing • Sensitivity test with the model showed that grazing effects could be best represented by increased sensitivity to drought (as found in P55 phase 1) and reduced N uptake (as found by Ash and McIvor 1995). This model analysis supports the previous findings from the analysis of P55.

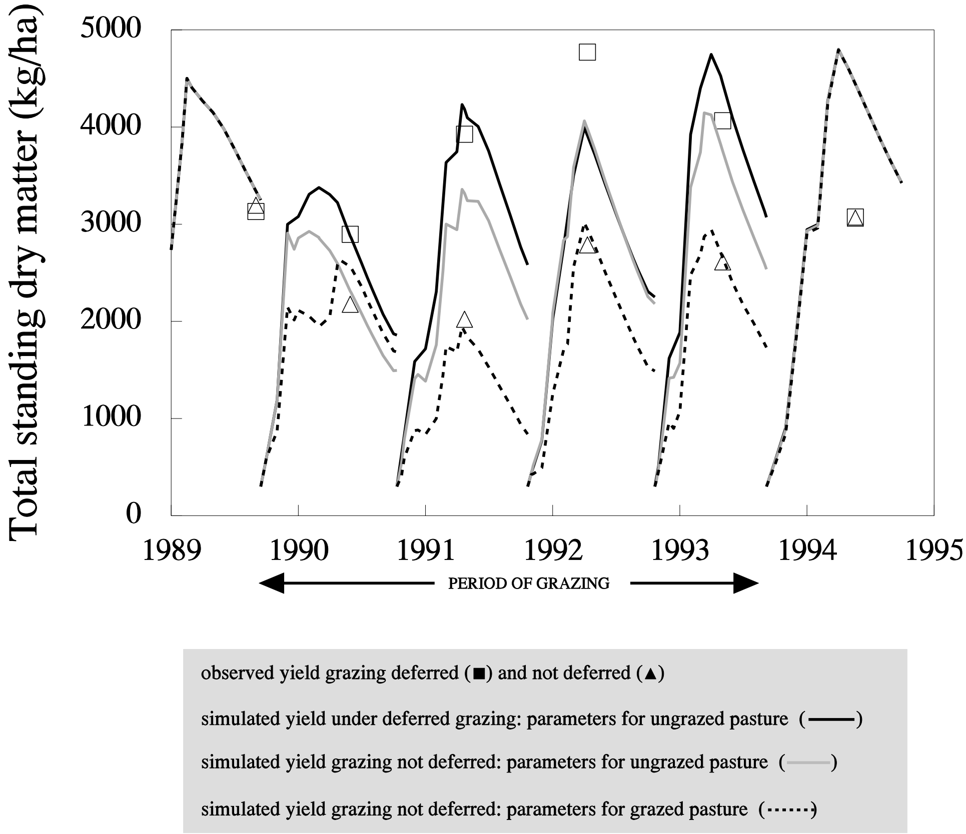


Figure 3.5 Comparison of observed and simulated pasture yield data for Brian Pastures Ladies Mile grazing strategies trial (see above legend and Table 3.5 for treatments).

Table 3.6 Summary of Galloway Plains grazing trial in central Queensland (1988-1994).

Name	Galloway Plains (west replicate)
Community	Central black speargrass
Location	Galloway Plains, 25 km west of Calliope, Central Queensland
Period and soil	1988 - 1994, alluvial clay
Desirable Perennial Grass Species	*Heteropogon contortus, Bothriochloa bladhii*
Principal Investigator	W.H. Burrows, E Anderson, R. Clem, D.M. Orr, M. Salloway *et al.*
Grazing Treatments	Five constant stocking rates and a sixth ungrazed (control) treatment were simulated. Other treatments were not simulated. Fire treatments were introduced later but not included in the simulation study for this project. Stocking rates ranged from 0.125 yearling steers per ha to 0.5 yearling per ha.
Main Findings	• Pasture composition did not change with increasing stocking rate. • Soil loss increased with stocking rate.
Modelling Findings	• The GUNSYNpD site had relatively low growth parameters to some extent reflecting the previous grazing history of the site. • Grazing effects on yield were able to be solely accounted for by consumption. • A higher proportion of the variation in yield could be accounted for by relating potential N uptake to seasonal rainfall suggesting that N mineralisation was enhanced by warm and wet conditions. However, no measurements of N yield had been made. Alternative hypotheses based on variable critical %N are yet to be explored.

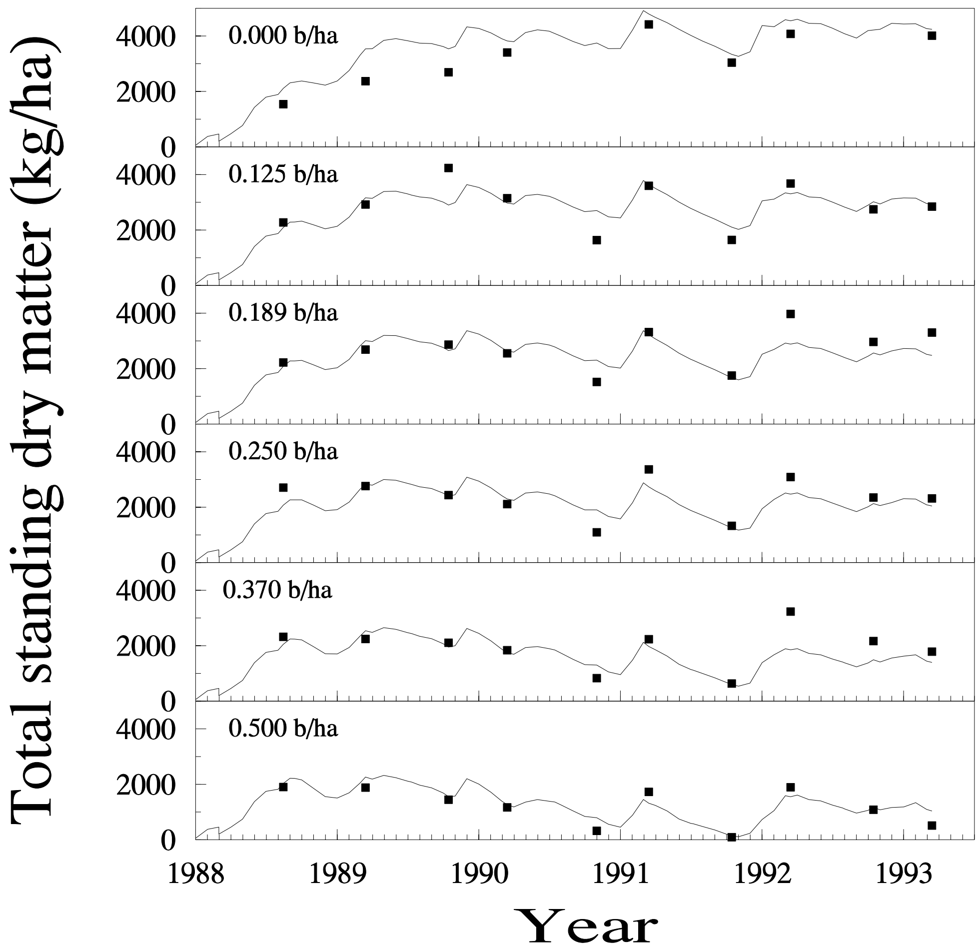


Figure 3.6 Comparison of observed and simulated pasture yield data for Galloway Plains grazing trial: western replicate (see Table 3.6 for treatments).

Table 3.7 Summary of Kangaroo Hills grazing trial in northern Queensland (1965-1976).

Name	Kangaroo Hills
Community	Northern black speargrass
Location	Kangaroo Hills, 100 km west of Ingham on Seaview Range
Period and soil	1965 - 1976
Desirable Perennial Grass Species	*Themeda triandra, Heteropogon contortus*
Principal Investigator	P. Gillard and R. Rebgetz
Grazing Treatments	Two stocking rates (0.21 and 0.42 steers per ha); with and without trees; with and without phosphorus. All treatments were oversown with Townsville stylo.
Main Findings	• Removal of trees increased dry matter yields, little effect of stocking rates or phosphorus
Modelling Findings	• A GUNSYNpD site was not available so the model was calibrated using data from one season following burning (1975). • Trees were assumed to compete for nutrients by reducing maximum N uptake as indicated by N yield in above-average rainfall years (1968). With these changes the model adequately accounted for the effects of stocking rate and trees on pasture yield. • Constant parameters explained yields in below-average rainfall but not yields in the high rainfall year 1974 suggesting a range of hypotheses: reduced detachment due to stem accumulation; or greater availability of nitrogen due to more favourable mineralisation conditions or increase in legume component; or changes in critical %N for growth. Measurements of nitrogen concentration and uptake were available only for one year.

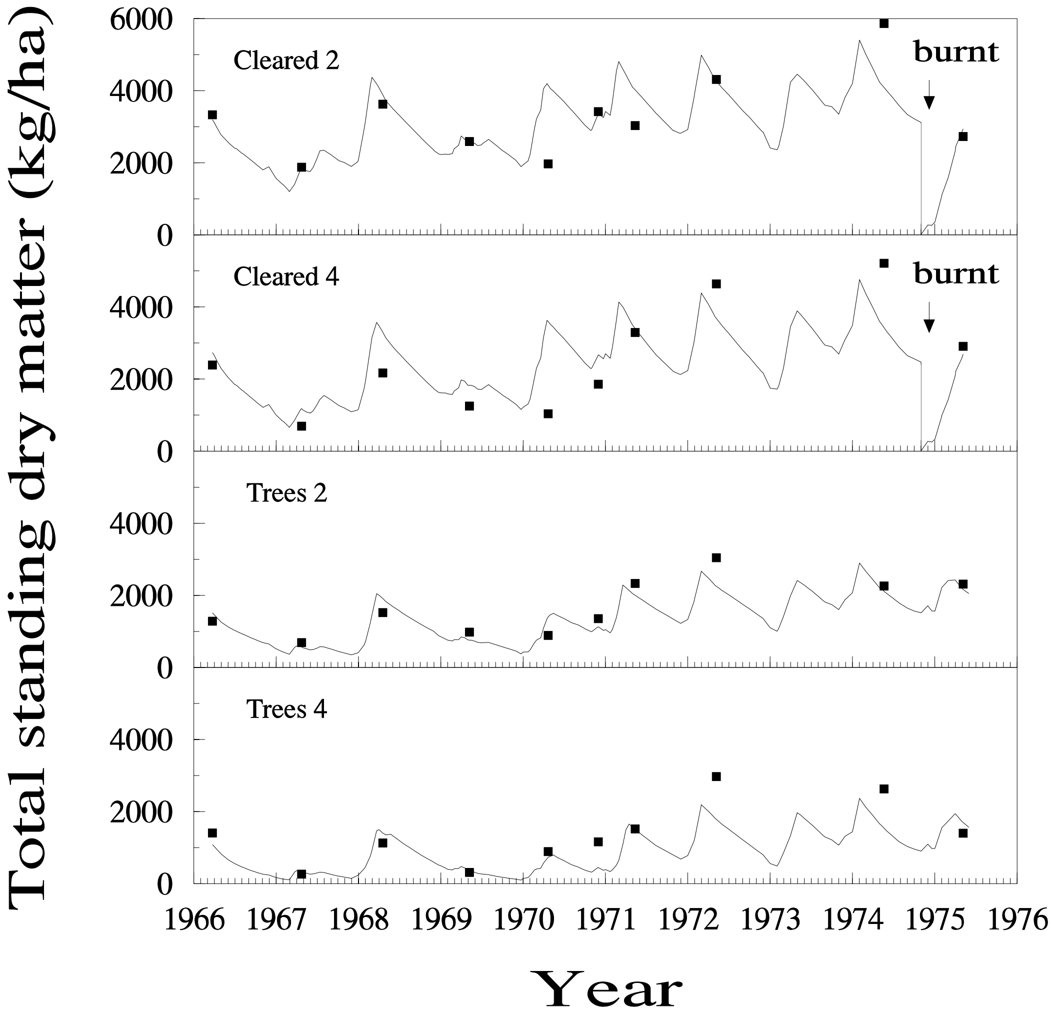


Figure 3.7 Comparison of observed and simulated pasture yield data for Kangaroo Hills grazing trial (see Table 3.7 for treatments).

Table 3.9 Summary of Eastwood grazing trial in western Queensland

Name	Eastwood Buffel grass trial
Community	Buffel grass on cleared gidgee
Location	Eastwood Station, 40 km south of Blackall
Period and soil	1967-1974, on clay soil. The gidgee woodland was pulled and burned in 1961.
Desirable Perennial Grass Species	*Cenchrus ciliaris* (buffel grass)
Principal Investigators	the late G.R. Lee, G. Payne, D.M. Orr, *et al.*
Grazing Treatments	Four rates set stocked sheep (10, 5, 2.5, 1.25 per ha). Sheep in the heavier stocking rate treatment were supplemented.
Main Findings	• Buffel grass was very resilient to heavy grazing • Highest stocking rate was destocked after four years and, in later years, had higher yields and less woody regrowth than other treatments • There was large variation in grass basal cover between the two paddock replicates when the highest stocking rate treatment collapsed indicating that small topographical effects can have large ecological outcomes
Modelling Findings	• Model growth parameters were calibrated for 1967 and showed good consistency across all stocking rates except in 1974 when the high stock treatment had greater yield than simulated. This 'error' could be explained by the observed patch grazing that occurred in this high growth year (D.M. Orr *pers. comm.*). • Sheep intake parameters were calibrated using observed green yields and these values were used in the other grazing trials. • Rapid decline in standing pasture yield in 1969 could not be simulated with the existing model. Further model development may be required to incorporate dry matter pools of leaf, stem and seed and independent detachment rates for each pool.

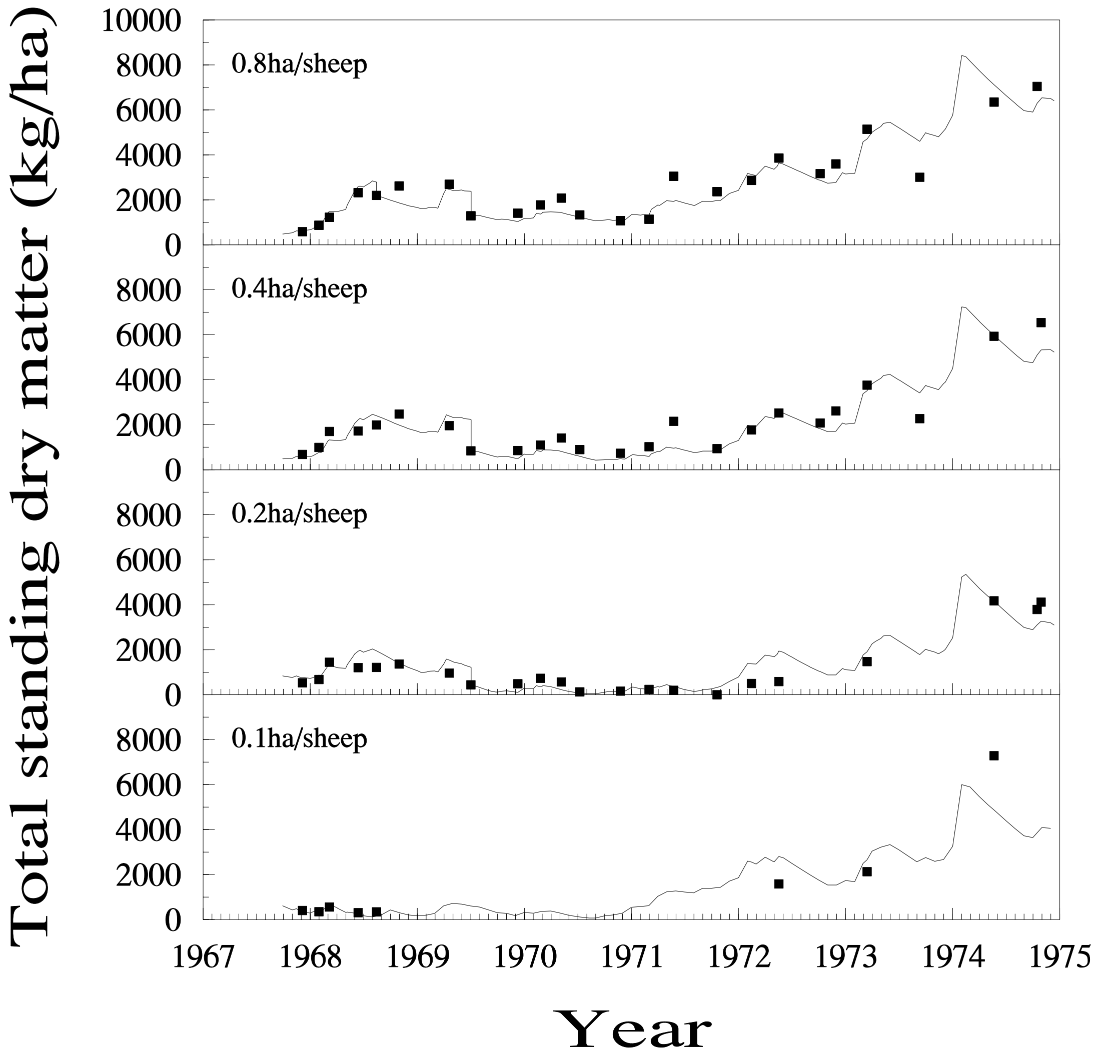


Figure 3.8 Comparison of observed and simulated pasture yield data for Eastwood buffel grass grazing trial (see Table 3.8 for treatments).

Table 3.9 Summary of Arabella grazing trial in south-western Queensland (1977-1986).

Name	Arabella utilisation trial
Community	Soft mulga
Location	Arabella, 20 km east of Charleville
Period and soil	1977 - 1986, on soft mulga
Desirable Perennial Grass Species	*Monachather paradoxa, Thyridolepis mitchelliana, Digitaria* spp.
Principal Investigators	I.F. Beale, D.M. Orr, *et al.*
Grazing Treatments	Four levels of utilisation by sheep (20, 35, 50, 80%). Stock numbers were adjusted each May. Treatments had different tree densities.
Main Findings	• Paddocks were variable in soil texture and tree/shrub density. • Loss of DPG species occurred at 50% and 80% utilisation after 1980 drought. • DPG species were replaced by *Aristida* spp. and bare ground at high utilisation rates. • 80% treatment had to be destocked for 18 months out of the 7 years.
Modelling Findings	• Growth parameters were derived from a site at Charleville (P W Johnston 1986/87). • Reasonable simulation was achieved without further calibration. • Basal area was related to growth in previous season or yield at end-of-season suggesting that accounting for animal intake alone was sufficient to simulate grazing effects. • Although species composition varied from C_3 to C_4 grasses, adequate simulation was achieved with C_3 parameters. • Future model development would require models of annuals (e.g. forbs)

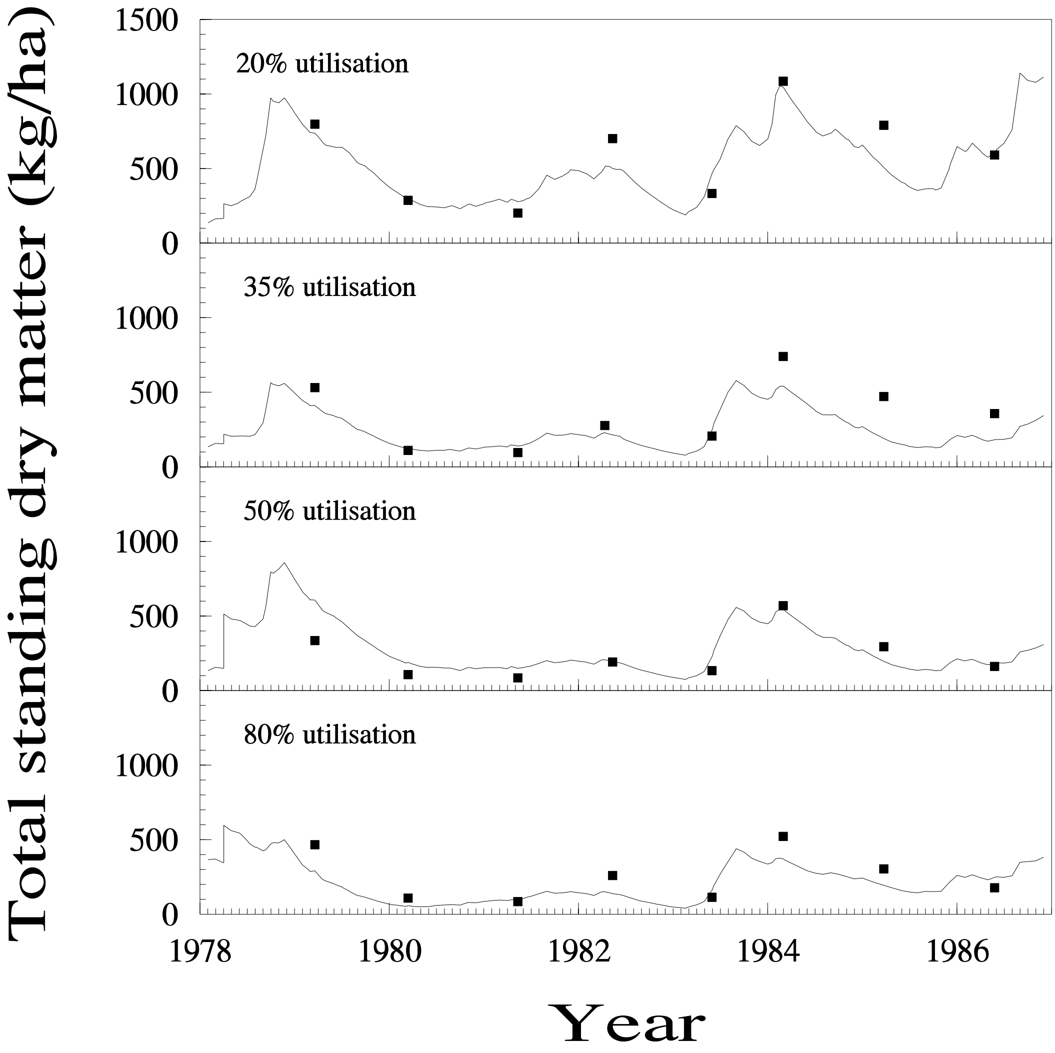


Figure 3.9 Comparison of observed and simulated pasture yield data for Arabella utilisation trial (see Table 3.9 for treatments).

Table 3.10 Summary of Gilruth Plains grazing trial in south-western Queensland (1941-1952).

Name	Gilruth Plains grazing trial
Community	Mitchell grass flood plain
Location	Gilruth Plains, 20 km east of Cunnamulla
Period and soil	1941 - 1952 on clay soil
Desirable Perennial Grass Species	*Astrebla* spp.
Principal Investigators	R. Roe and the late G.H. Allen
Grazing Treatments	3 stocking rates of sheep (1:3ha, 1:2 ha, 1:ha). Other treatments which were not simulated included rotational grazing.
Main Findings	• Mitchell grass could be grazed at high grazing pressure (1:2ha) while maintaining *Astrebla* spp. Pasture stability was adversely affected at the heaviest stocking rate.
Modelling Findings	• Growth parameters were derived from first year data using other parameters from a recent exclosure site ('Airlie' via Wyandra, 1990) • Pasture yield at all stocking rates was simulated using the same parameters.

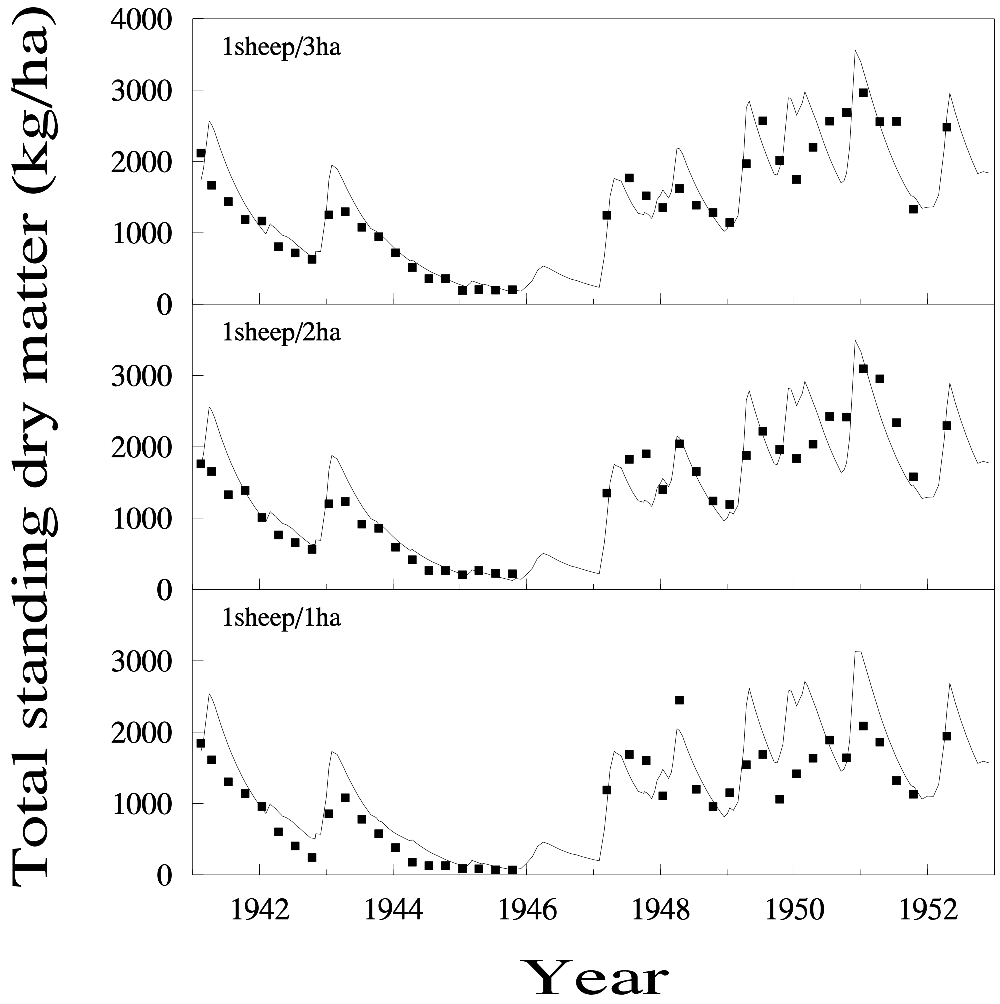


Figure 3.10 Comparison of observed and simulated pasture yield data for Gilruth Plains grazing trial (see Table 3.10 for treatments).

Table 3.11 Summary of Burenda grazing trial in south-western Queensland (1975-1989).

Name	Burenda utilisation trial
Community	Southern Mitchell grass
Location	Burenda, 100 km NE of Charleville
Period and soil	1975 - 1989, on cracking clay
Desirable Perennial Grass Species	*Astrebla* spp.
Principal Investigators	I.F. Beale, D.M. Orr, *et al.*
Grazing Treatments	Five levels of utilisation by sheep (10, 20, 30, 50, 80%). Stock were changed in May with stocking rates chosen to eat a proportion of existing pasture yield.
Main Findings	• A large decline in DPG species occurred at 80% utilisation leading to destocking of this treatment • High year-to-year variation in yields was probably associated with changes in species composition
Modelling Findings	• Biddenham GUNSYNpD sites were used to estimate growth parameters. • High detachment rates in summer were required to simulate observed pasture yields. • These rates were consistent with those observed for forbs and seed heads. • Yields could be adequately simulated by assuming that the perennial grass component was replaced by a rapidly growing and detaching annual component.

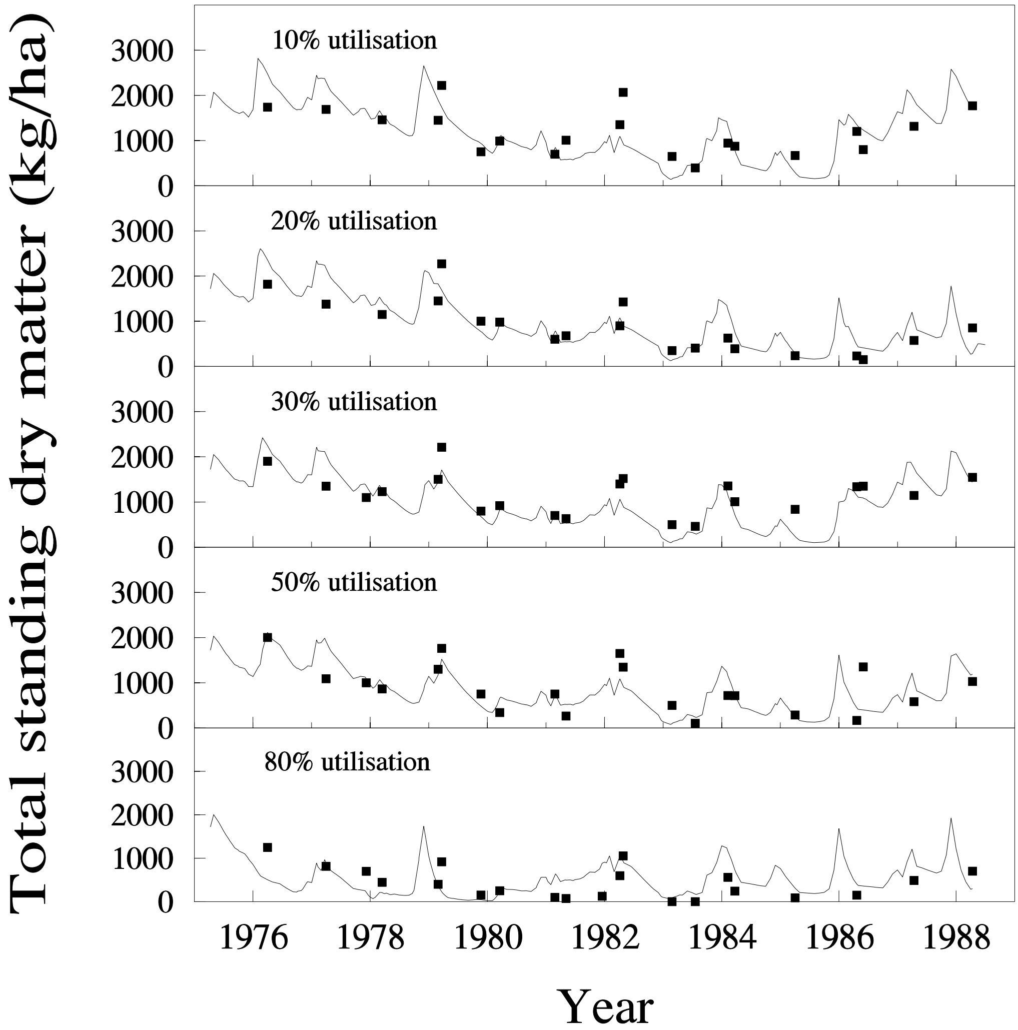


Figure 3.11 Comparison of observed and simulated pasture yield data for Burenda utilisation trial (see Table 3.11 for treatments).

Table 3.12 Summary of Toorak grazing trial in western Queensland (1984-1993 period).

Name	Toorak utilisation trial
Community	Northern Mitchell grass
Location	Toorak Research Station, 50 km south of Julia Creek
Period and soil	1984 - 1993 on cracking clays
Desirable Perennial Grass Species	*Astrebla* spp.
Principal Investigators	D.G. Phelps, D.M. Orr, *et al.*
Grazing Treatments	Five levels of utilisation by sheep (10, 20, 30, 50, 80%). Stock were changed in May/June with stocking rates chosen to eat a proportion of existing pasture yield.
Main Findings	• Initially there was no relationship between utilisation level and proportion of *Astrebla* with year-to-year rainfall variability having a larger effect than grazing treatments in the first four years (1984-88). However, treatment effects were beginning to appear in 1989 and 1990 with the 80% treatment not responding to rainfall as much as the lightly grazed treatments.
Modelling Findings	• Simulation with growth parameters derived from the GUNSYNpD site was successful for the initial period until a two year drought reduced perennial grass basal cover to near zero (J.O. Carter and D. Cowan *pers. comm.* 1986-87). • The model was not successful in simulating the high pasture yields observed in 1991 in the low utilisation treatments

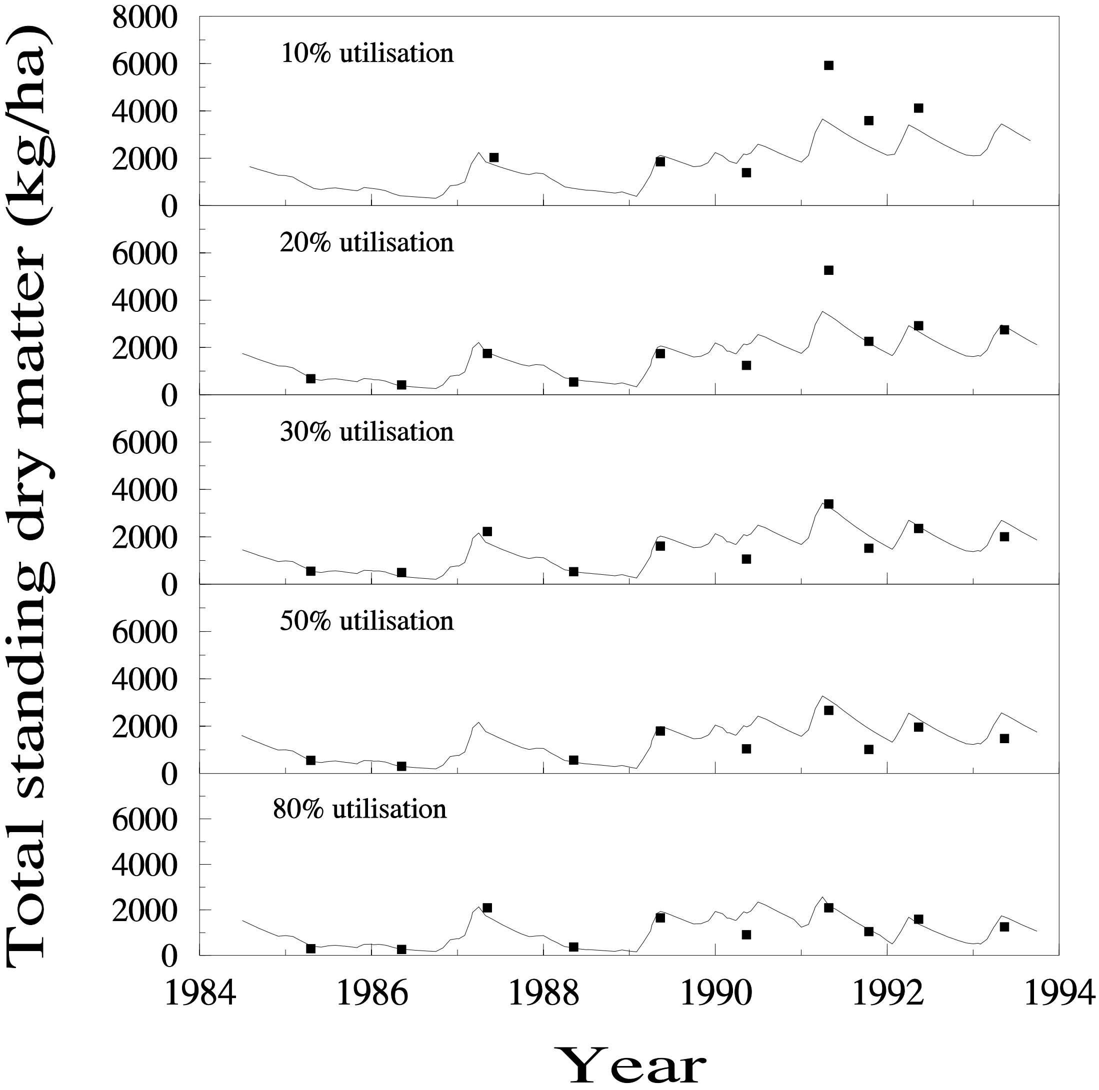


Figure 3.12 Comparison of observed and simulated pasture yield data for Toorak utilisation trial (see Table 3.12 for treatments).

3.5 SUMMARY OF GRAZING TRIAL EFFECTS

The analysis of grazing trials was carried out to develop parameters for detachment, consumption and trampling. When combined with plant growth parameters derived either from GUNSYNpD or from single years in the grazing trial, a high proportion of variation in observed pasture yield could be accounted for in most trials (Table 3.13).

Derivation of model parameters

Where model growth parameters were derived from exclosures which had not been grazed (P55, Ladies Mile), the effects of increasing grazing pressure on pasture yield were modelled by reducing N uptake and increasing the sensitivity of plant growth to soil water deficit (e.g. Figures 3.2 and 3.4). For trials where growth parameters were derived from previously grazed exclosure or lightly grazed paddocks (Galloway Plains, Kangaroo Hills), the simulated yields over time were highly correlated with observed data for a range of stocking rates and tree densities and no change in model parameters was required. Thus, some care has to be taken in choice of site for derivation of the growth parameters which best represent the grazed situation.

A major problem in the simulation of pasture yield in Mitchell grasslands is the suppression of new growth by existing tillers on new growth (Scanlan 1980). As a result growth could be over-estimated by model parameters derived using data from mown exclosures. These problems of simulating Mitchell grasslands will only be resolved by a model of botanical composition which allows individual species to be simulated to account for large differences in species parameters (cover/yield, N use, detachment rates) (Orr 1986).

Table 3.13 Comparison of simulated and observed pasture yields for grazing trials in Queensland. Regression slope and constant are for x=observed and y=simulated. Mean difference is average absolute error, i.e. absolute difference between observed and simulated.

TRIAL	MEAN OBSERVED	MEAN SIMULATED	NO. OF OBSERVATIONS	CORRELATION	SLOPE	CONSTANT	MEAN DIFFERENCE	RANGE IN OBSERVED	RANGE IN SIMULATED
Toorak 1984-1993	1555	1634	56	0.863	0.69	588	406	125-5929	79-3495
Eastwood 1967-1974	1923	1901	78	0.921	0.85	271	476	0-7285	84-7123
Burenda 1976-1988	913	939	103	0.757	0.81	198	327	0-2270	45-2478
Arabella 1977-1986	359	396	32	0.845	0.77	118	109	85-1085	103-1046
Gilruth Plains 1941-1954	1287	1409	120	0.889	0.93	215	288	69-3093	70-3271
Kangaroo Hills 1965-1976	2214	2251	40	0.781	0.69	729	544	267-5864	335-4255
Galloway West 1988-1994	2351	2346	58	0.859	0.81	449	389	91-4417	141-4783
Brian Pastures[1] 1961-1967	1067	998	36	0.949	0.93	1	194	31-3081	14-2761
Brian Pastures[2] 1975-1984	3903	4041	57	0.926	1.02	63	695	276-8928	58-8701
Brian Pastures[3] 1975-1984	768	738	40	0.610	0.48	369	396	14-2763	303-2044
Ladies Mile 1989-1994	3143	3382	12	0.799	0.78	919	393	2022-4771	1945-4450

[1] all three stocking rates
[2] light and medium stocking rate (independent validation)
[3] heavy stocking rate (independent validation)

Detachment processes

Detachment processes are not well understood and are difficult to measure unless growth can be accurately estimated. Field observations suggest a strong seasonal component since detachment is likely to be faster under good growing conditions and high intensity rainfall.

The GRASP model includes pools of leaf and stem to allow for future model development to include variable leaf to stem ratio between species, different leaf and stem detachment rates, and effects on quality and diet selection. As yet insufficient data are available to parameterise a leaf/stem model. Similarly, the separate dry matter pools of forbs and seed heads, which are likely to be transient, are not simulated in the model but are included as part of the total pasture yield. Thus, at this stage of model development, parameters describing detachment rates have been developed for the whole sward:

1) for black speargrass communities in the southern zone, detachment rates were near zero in the season immediately following burning; and the overall rate of 0.002 kg/kg/day has been derived from pastures which have not been burnt for >5 years and was consistent with detachment rates in exclosures;
2) in the northern zone (e.g. Kangaroo Hills), a more rapid rate of 0.005 kg/kg/day appeared appropriate and was consistent with other studies, e.g. McCaskill and McIvor (1993). Similarly, at Galloway higher rates were found (0.004 kg/kg/day)
3) for buffel grass (Eastwood, western Queensland), different rates for leaf and stem were assumed based on observations that old stems remained for several years. Pasture yield data showed periods of rapid decline. This could be due to sampling variation, translocation of carbohydrates to roots or dispersal of seed heads;
4) for mulga pastures, losses of dry matter could occur due to unspecified grazing by kangaroos, termite and grasshoppers. For pasture yields measured in the grazing trial an average detachment rate of 0.003 kg/kg/day was found. This

relatively high rate of detachment may reflect the possible role of native fauna and termites in pasture disappearance; and

5) for Mitchell grasslands high variability was found in detachment rates. When pastures were dominated by *Astrebla* spp. detachment rates were low, i.e. 0.002kg/kg/day. However, after the loss of tussocks of *Astrebla* spp. due to heavy grazing and/or drought, higher detachment rates (0.010 kg/kg/day) were found reflecting higher rates of detachment associated with forbs and annual grasses.

Trampling and effects of utilisation on consumption

For sheep, the buffel grass grazing trial provided the most reliable data to estimate trampling rates as the growth and detachment parameters appeared consistent across the 17 years of study (Figure 3.8). Sensitivity studies indicated that a ratio of trampling to consumption of 1:3 was the best estimate. This value was applied to other grazing trials by sheep. Similarly for parameterising the effect of increasing utilisation on reducing individual animal intake, the buffel grass trial provided the best data with clear stocking rate effects on liveweight change. The parameters reflected the ability of sheep to graze to appetite at very low pasture availability (200-300kg/ha).

For cattle, utilisation/intake parameters had been previously determined by McKeon and Rickert (1984) at Brian Pastures in south-eastern Queensland. No litter was observed in the pasture one year after a burn (W.J. Scattini *pers. comm.*) indicating that trampling rate was low and that natural detachment processes could account for yield losses.

3.6 APPLICATION TO CALCULATING RISKS OF DEGRADATION

Grazing trials lasting 5-10 years, although long-term in terms of scientific study are relatively short-term relative to producer experience. Thus, with the view of estimating safe stocking rates for long-term (30-100 years) sustainable grazing, relatively short-term trials may not include sufficient cycles of deterioration and resilience to reveal the long term effects of a particular stocking rate policy as discussed in Section 1. Nevertheless, grazing trials provide measurements that allow the mechanism of degradation to be modelled.

The calculation of risks of degradation requires models of -

1) the relationship between grass basal cover and pasture yield;
2) the relationship between pasture yield and soil loss; and
3) the relationship between utilisation and animal production.

Perennial grass basal cover and pasture yield

For a particular location, relationships have been established between perennial grass basal cover (including both desirable and undesirable species) and pasture yield in autumn (Christie 1978), or rainfall over the previous two years (Scattini 1969).

During this project a survey of currrently and previously exclosed sites was conducted. Plant basal cover was measured on 56 sites where sites were, at the time, protected from grazing. A relationship was found between pasture yield and grass basal cover measured at the same time (Figure 3.13 and Table 3.14). Figure 3.13 and Table 3.14 show a strong link between perennial grass basal cover and previous pasture growth for the total grass sward, species groups and individual species. The relationship between yield and basal cover varied between species (Table 3.14).

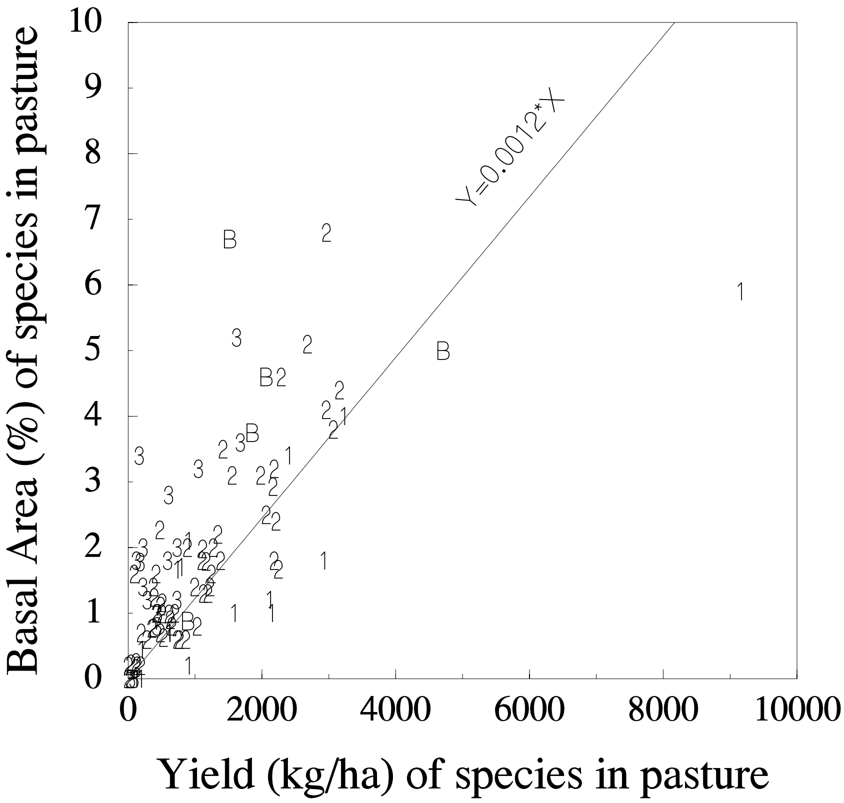


Figure 3.13 The relationship between species yield (kg/ha) and basal area as (%) as measured in autumn 1994 in GUNSYNpD exclosures. Species are divided into three groups (1-3) according to Table 3.14 and a remaining group (B) which is buffel (*Cenchrus ciliaris*).

Species were classified into three groups according to basal cover to yield ratio except for buffel (*Cenchrus ciliaris*) which varied in basal cover to yield ratio between sites (Table 3.14 and Figure 3.13). Species with a high basal cover to yield ratio (group 3) tended to be small and, in the case of *B. pertusa, E. bimaculata* and *C. fallax*, prostrate species. These species may also be regarded as indicators of poorer condition pasture (Tothill and Gillies 1992). An exception in all of the above cases is *Themeda triandra*, which is a moderate sized tussock grass which declines with heavy grazing (Shaw 1957). In the case of *T. triandra* we suspect that this observed high basal cover to yield ratio could be attributed to a suspected highly competitive root system and a high root to shoot ratio in *T. triandra*. A highly competitive root system is suspected from field observations in exclosures at Gayndah where distinct rings can be noted around individual plants forming a zone which is devoid of other grasses (K.A. Day). Such "zones" are not evident in other species such as *H. contortus*, *Aristida* spp. and *B. bladhii* which are prevalent in the area.

Table 3.14 Relationship between grass basal cover and pasture yield from exclosures throughout Queensland (April/May1994).

SPECIES GROUPING	BASAL COVER TO YIELD RATIO	LINEAR REGRESSION			
		SLOPE	INTERCEPT	(r^2)	No.
All swards	0.0013	0.0006	2.63	0.31	56
All species	0.0012	0.0009	0.85	0.50	96
Group 1	0.0007	0.0006	0.48	0.75	16
Group 2	0.0015	0.0014	0.23	0.75	57
Group 3	0.0029	0.0021	0.78	0.56	18
Cenchrus ciliaris	0.0015	0.0006	2.97	0.15	5
Heteropogon contortus	0.0016	0.0016	0.15	0.76	25
Astrebla spp.	0.0012	0.0010	0.36	0.79	14
Bothriochloa bladhii	0.0008	0.0006	0.76	0.80	9
Aristida spp.	0.0014	0.0009	0.62	0.61	8
Monochather paraoxa	0.0020	0.0019	0.07	0.73	6
Themeda triandra	0.0032	0.0033	-0.14	1.00	3
Bothriochloa pertusa	0.0021	0.0023	-0.19	1.00	3

Group 1: *Bothriochloa bladhii* (9), *Chloris Gayana* (1), *Dichanthium* spp.(5), *Panicum maximum* (1)
Group 2: *Aristida* spp.(8); *Astrebla* spp.(16); *Bothriochloa ewartiana* (3), *Heteropogon contortus* (25), *Monochather paradoxa* (6), *Triodi*a sp. (1)
Group 3: *Bothriochloa decipiens* (3), *Bothriochloa pertusa* (3), *Chrysopogon fallax* (2), *Enneapogon* spp. (2), *Eremochloa bimaculata* (4), *Eragrostis eriopoda* (1), *Themeda triandra* (3)

Species with a low basal cover to yield ratio (group 1) tended to be from more fertile sites (brigalow soils in the case of *C. Gayana* and *P. maximum* (sown grasses) and black earths and heavy textured soils in the case of *B. bladhii* and *Dichanthium* spp.). The production of a high amount of above ground dry matter per unit basal cover could be an advantageous trait in competitive conditions resulting from high fertility and low to moderate disturbance.

Species basal cover is commonly measured on grazing trials as a key indicator of pasture condition. Using modelled pasture growth and grass basal cover data from grazing trials where perennial grasses dominated composition even under heavy grazing (P55, Galloway Plains, Arabella, Burenda and Eastwood), a general relationship has been established (Figure 3.14) between average pasture growth (t/ha/year) over the previous two seasons (GROWTH), pasture yield (kg/ha) at the end of April (YIELD) and percent grass basal cover (%GBC):

%GBC = (3.576 x - 0.458 GROWTH ^{2}) * (0.83 + 0.25 * YIELD) (n=150, r^2=0.66)

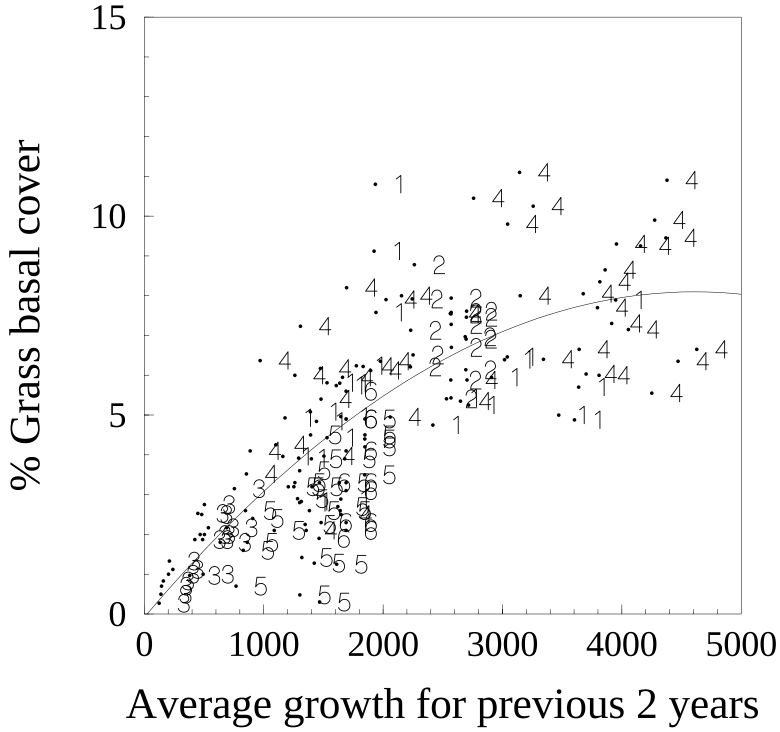
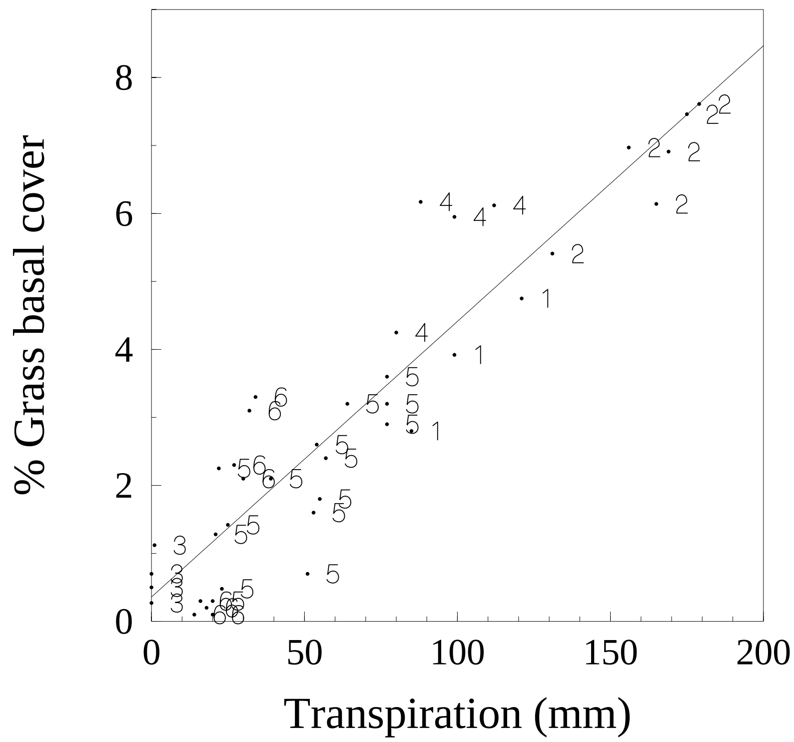


Figure 3.14 Relationship between between average growth over the previous two years and perennial grass basal cover (%) for six grazing trials. Data points are labelled according to grazing trial: (1) P55; (2) Galloway Plains; (3) Mulga; (4) Eastwood; (5) Burenda and; (6) Toorak.

This relationship does not fully account for the over-riding effect of severe drought on perennial grass basal cover. For each grazing trial, the worst year was selected on the basis of soil moisture deficit. In such years, for some trials, grass basal cover (%GBC) was reduced with increased utilisation in the previous season (P55, Arabella, Burenda) whilst for other trials there was little effect of previous utilisation on %GBC (Eastwood, Galloway Plains). For all sites and stocking rates, %GBC during drought was related to total seasonal transpiration (T) from November to April (Figure 3.15).

$$\% \text{ GBC} = 0.36 + 0.0405 \text{ T} \quad (n = 40, r^2 = 0.86)$$

Figure 3.15 Relationship between seasonal transpiration during the worst (drought) year



in each of six grazing trials and perennial grass basal cover (%). Data points are for different stocking rate treatments and are labelled according to grazing trial: (1) P55; (2) Galloway Plains; (3) Mulga; (4) Eastwood; (5) Burenda; and (6) Toorak.

Mechanism for loss of perennial grasses

Detailed measurements of plant survival and grass basal cover by D.M. Orr (Galloway Plains, Arabella, Burenda, Toorak) provide the basis for examining the effect of utilisation on the survival of desired perennial grass species. These studies on young cohorts of black speargrass at Galloway Plains showed that mortality of perennial plants increased rapidly where soil moisture deficit and heavy utilisation occurred together during the growing season.

Grass basal cover at the Eastwood buffel grass grazing trial on cleared gidgee showed the least sensitivity to increasing stocking rate. Although in a semi-arid environment, with similar rainfall to Arabella and Burenda, buffel grass pasture sustained high utilisation rates from 1967 to 1983 without large changes in perennial grass basal cover (G.R. Lee, G. Graham and D.M. Orr unpublished data), complete utilisation with supplemented sheep was necessary to 'crash' the pasture. These results support the conclusion of McIvor *et al.* (1994) that pastures on low nutrient soils are most at risk of over-grazing.

Thus, general equations have been developed to calculate %GBC as a function of grazing and drought, allowing the loss of perennial grasses to be assessed.

Pasture yield and soil loss

Site specific models of run-off and soil loss has been included in GRASP (e.g. Scanlan *et al*. 1996). Run-off has been calculated as a function of soil water deficit, rainfall intensity and cover (calculated directly from standing pasture yield). GRASP simulates a litter pool as the net result of gains through trampling and detachment and loss through decomposition. However, insufficient data were available to parameterise potential litter decomposition. Litter and standing yield are likely to be strongly correlated, and hence, it is appropriate to use pasture yield as an estimate of surface cover for calculating run-off and soil loss (e.g. Scanlan and McIvor 1993, Scanlan *et al.* 1996, McIvor *et al.* 1995b). GRASP also includes the effect of tree density on surface cover using data from J O Carter. Trees contribute litter whilst reducing cover from grass production. Hence, the simulation of pasture yield under grazing allows at least the relative effects of run-off and soil loss to be simulated.

The run-off model was developed in northern Queensland for a site in the Burdekin catchment (Scanlan *et al.* 1996). Successful independent validation was carried out in central Queensland (Springvale, M Silburn). A full report has been presented elsewhere (Yee Yet 1994).

For the purposes of assessing risks, a general soil loss model (Rose 1985) was included in GRASP. The model has been parameterised for the Springvale data (M. Silburn). Soil loss is a direct linear function of slope angle and soil erosivity, and exponential functions of cover and run-off. It is expected that maps of slope will be used to indicate areas most at risk, i.e. high slopes. Soil erosivity as yet has not been mapped although maps of surface soil attributes (e.g. texture) have been prepared and could be used as inputs once other soil loss data have been analysed (M. Silburn, LAMSAT project, LWRRDC).

Effect of utilisation on animal production, management and the pasture resource

The analysis of grazing trials (Figure 3.16, Tables 3.15-3.23) shows higher levels of animal production per unit area (wool or liveweight gain per ha) can be achieved over 5-10 years at utilisation rates higher than a conservative safe rate of 15-20% (usually lowest stocking rate in trial). However, the trials also showed that:

1) risk of animal death in drought increased with average utilisation (Toorak >25% average utilisation; Brian Pastures 55% average utilisation; Gilruth Plains 24% average utilisation);
2) heavily utilised pastures had to be destocked after loss of perennial species during droughts (Arabella >40% average utilisation; Burenda >37% average utilisation); and
3) risk of soil loss increased rapidly with increasing utilisation. For example, at Galloway Plains soil movement at 50% average utilisation was ten times that for low utilisation rates (Salloway *et al.* 1993). Similarly, at Kangaroo Hills observed run-off was substantially greater in treatments with high utilisation rates (P. Gillard *pers. comm.*).

Thus, native pasture grazing trials, although conducted for relatively short periods (5-10 years), show that heavy utilisation rates (35-50%) cause major problems in maintaining animal numbers and/or resource productivity.

For the native pasture trials (i.e. excluding the Eastwood buffel grass trial) maximum production (value per hectare) over the short term (generally 5-20 years) occurred at an average utilisation of 30-60% (Figure 3.16). To achieve sustainable production most authors (e.g. Johnston *et al.* (1996), Orr *et al.* (1994), Roe and Allen (1993), D. Cooksley *pers. comm.*) recommended stocking rates or treatments which resulted in lower levels of utilisation (15-25%). At these recommended stocking rates, relative production (Figure 3.16) was 30-65% of maximum production per hectare. Correct analysis of the effect of stocking rate strategies on production consequences requires detailed economic analysis (including dynamic flock/herd models and premiums received for quality of production), and models of pasture and land degradation. Preliminary studies have been carried out using some of the above grazing trial information (e.g. McKeon *et al.* 1997, Stafford Smith *et al.* 1997a). However such studies are yet to include the long term effects of soil loss and woody weed invasion, and hence, are unable to simulate the long term consequences of different stocking rate strategies.

Nevertheless, the analysis of relative production (Figure 3.16) highlights the contrast between levels of pasture utilisation which maximise short term production and those levels perceived by experienced scientists to be sustainable in the long term.

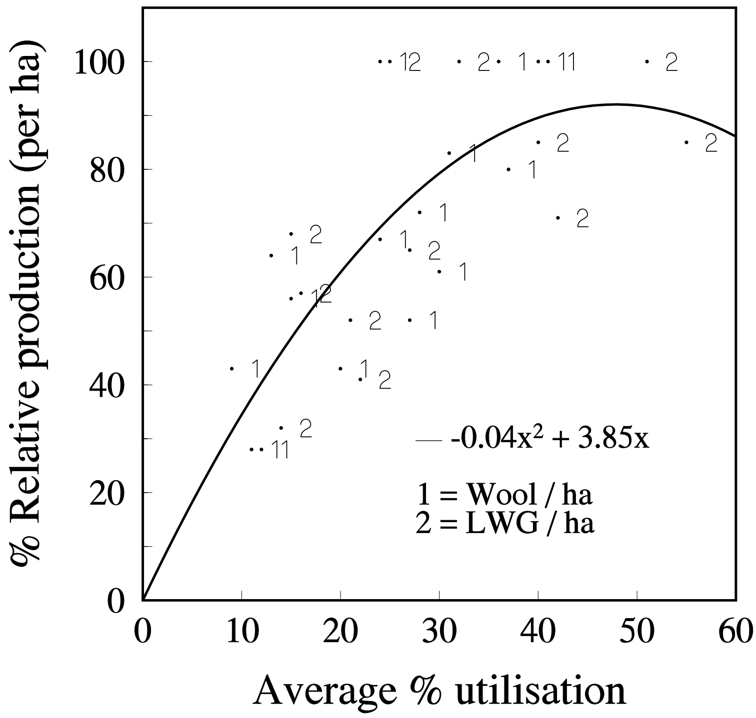


Figure 3.16 Relationship between pasture utilisation and animal production for sheep and cattle grazing trials on native pasture (i.e. excluding Eastwood trial on buffel grass). Production is relative to the "best" treatment as described in Tables 3.16 to 3.23).

Table 3.15 Simulation of Eastwood buffel grass stocking rate trial. Treatments had constant stocking rates of sheep with initial Merino weaner ewes. Animal production data are from the late G. R. Lee, G. Payne and D.M. Orr. The effect of continuous stocking rates on sheep and *Cenchrus ciliaris* (buffel grass) productivity in central-western Queensland (paper in preparation).

TREATMENT	SIMULATED GROWTH .(kg/ha/year)	SIMULATED EATEN (kg/ha/year)	EATEN / GROWTH (%)	GREASY FLEECE (kg/ha) RELATIVE TO "BEST" TREATMENT (%)	DESTOCKED
0.8 ha/sheep	1890	430	23	30	
0.4 ha/sheep	1730	830	55	59	
0.2 ha/sheep	1600	1280	80	100	
0.1 ha/sheep	1540[1]	1560	>100	2	Destocked August 1970

[1] For three years only (1967/8 to 1970/1 0.1 ha/sheep treatment was supplemented to maintain sheep and was destocked after three years. For one year only, 1967-1968, wool per ha was double that which occurred at 0.2 ha/sheep.

Table 3.16 Simulation of Burenda Mitchell grass utilisation trial (1976-1983). Stocking rates of sheep were changed each year (May) to eat a constant proportion of pasture yield present in May. Animal production data are from Beale (1985).

TREATMENT	SIMULATED GROWTH (kg/ha/year)	SIMULATED EATEN (kg/ha/year)	EATEN / GROWTH (%)	GREASY WOOL (kg/ha) RELATIVE TO "BEST" TREATMENT (%)	DESTOCKING
10%	1350	160	12	28	-
20%	1330	260	20	43	-
30%	1270	380	30	61	-
50%	1240	460	37	80	Insufficient pasture to restock after summer 1983
80%	1060	390	36	100	Insufficient pasture to restock after summer 1983

Table 3.17 Simulation of Arabella mulga lands trial 1979-1986. Stocking rates of sheep were changed each April/May to eat a constant proportion of pasture yield present in May. Ewes were used in years 1985 and 1986. Animal production data from Beale (1985).

TREATMENT	SIMULATED GROWTH (kg/ha/year)	SIMULATED EATEN (kg/ha/year)	EATEN / GROWTH (%)	GREASY WOOL (kg/ha) RELATIVE TO "BEST" TREATMENT 1979-1984 (%)	DESTOCKING
20%	580	90	15	56	-
35%	290	80	27	52	-
50%	305	85	28	72	-
80%	230	90	41	100	Destocked in 1980 and not restocked until April 1981

Table 3.18 Simulation of Gilruth Plains Mitchell grass grazing trial (1941-1952). Treatments were grazed for two periods of constant stocking rates (1941-45 and 1947-51) with a period of destocking between grazing periods (1946-1947). Relative net values (wool produced minus cost of supplements) are from Roe and Allen (1993).

TREATMENT	SIMULATED GROWTH (kg/ha/year)	SIMULATED EATEN (kg/ha/year)	EATEN/ GROWTH (%)	'NET' VALUE ($/ha) RELATIVE TO "BEST" TREATMENT (%)	COST OF SUPPLEMENTARY FEED 1st PERIOD ($/ha)
1 sheep/3ha	1364	121	9	43	0.14
1 sheep/2ha	1362	176	13	64	0.32
1 sheep/1ha	1363	324	24	100	2.98

Table 3.19 Simulation of Gilruth Plains Mitchell grass grazing trial: utilisation and production for each grazing period (1941-45 and 1947-51).

	Period 1942 - 1945			Period 1947 - 1952	
TREATMENT	EATEN / GROWTH (%)	WOOL GROSS VALUE ($/ha)	COST OF SUPPLEMENTS ($/ha)	EATEN / GROWTH (%)	WOOL GROSS VALUE ($/ha)
1 sheep/3ha	25	2.16	0.14	7	3.24
1 sheep/2ha	36	3.23	0.32	10	4.96
1 sheep/1ha	50	5.31	2.94	21	9.96

Table 3.20 Simulation of Toorak Mitchell grass grazing trial (1985-1993). Stocking rate of sheep changed each year (May) to eat a constant proportion of pasture yield present in May. Animal production data from Phelps *et al.* (1994).

TREATMENT	SIMULATED GROWTH (kg/ha/year)	SIMULATED EATEN (kg/ha/year)	EATEN / GROWTH (%)	CLEAN WOOL (kg/ha) RELATIVE TO "BEST" TREATMENT 1985-93 (%)	DESTOCKING OR SUPPLEMENTATION IN DROUGHTS
0%	1620	0	0	0	-
10%	1600[a]	170	11	28	5 and 15% "mortality[b]" in 1987 and 1988 droughts
20%	1600	290	18	-	-
30%	1590	380	24	67	15% "mortality" in 1987 drought
50%	1580	490	31	83	40% "mortality" in 1987 and 1988 drought
80%	1570	640	40	100	60% and 100% "mortalities" in 1987 and 1988 drought

[a]: Simulated growth under-estimated observed yields in 1991 in this treatment
[b]: Animal liveweights have been measured every three months. During dry periods, sheep weighing less than 30kg liveweight were removed to avoid unnecessary mortalities. These sheep have been treated as deaths in subsequent calculations.

Table 3.21 Simulation of "P55" (Brian Pastures) grazing trial (1971-1979). At each stocking rate two paddocks were rotationally grazed with weaner steers for summer-autumn (S-A) and then winter-spring (W-S). Liveweight data is from D. Cooksley (*pers. comm.*).

TREATMENT	SIMULATED GROWTH (kg/ha/year)	SIMULATED EATEN (kg/ha/year)	EATEN /GROWTH (%)	LIVEWEIGHT GAIN (kg/ha) RELATIVE TO "BEST" TREATMENT
0.37 b/ha	3679	549	15	68
0.62 b/ha	3663	910	25	100
1.24 b/ha	2702	1489	55	85

Table 3.22 Galloway Plains black speargrass stocking rate trial (W. Burrows) 1988-1993. Treatments were grazed at constant stocking rate with 300kg steers. There was a small increase in stocking rate in 1990-1 and 1992-3. Animal production data were supplied by W. Burrows (1994). Milestone report to Meat Research Corporation: Effects of stocking rate, legume augmentation supplements and fire on animal production and stability of native pastures (DAQ080).

TREATMENT	GROWTH (kg/ha/year)	EATEN (kg/ha/year)	EATEN / GROWTH (%)	LIVEWEIGHT GAIN (kg/ ha/ year) RELATIVE TO "BEST" TREATMENT (%)
1/8 ha	2596	364	14	32
1/5.3 ha	2591	539	21	52
1/4.0 ha	2587	707	27	65
1/2.7 ha	2577	1022	40	85
1/2 ha	2513	1290	51	100

Table 3.23 Kangaroo Hills black speargrass stocking rate, and tree clearing trial (P. Gillard) 1966-1975. Native pasture was cleared or trees not removed, stocked at two rates with weaner steers. All treatments were oversown with Townsville stylo and half of the replicates had phosphorus applied. Data from Gillard (1979).

TREATMENT	GROWTH (kg/ha/year)	EATEN (kg/ha/year)	EATEN / GROWTH (%)	LIVEWEIGHT GAIN (kg/ ha/ year) RELATIVE TO "BEST" TREATMENT (%)
0.21 b/ha cleared	2970	488	16	57
0.21 b/ha trees	1981	439	22	41
0.42 b/ha cleared	2886	934	32	100
0.42 b/ha trees	1832	762	42	71

SECTION 4 - CALCULATING SAFE STOCKING RATES

4.1 INTRODUCTION

The analysis of grazing trials reported in Section 3 showed:

1) the short-term (2-10 years) advantage of higher stocking rates on animal production; and
2) the potential mechanisms for degradation.

In most publications from the grazing trials the principal investigators commented that although the trial showed increased production (per hectare) with increased stocking rate, lighter stocking rates were preferable due to a variety of reasons, e.g. lower variability in production, less impact of drought or dry seasons, reduced need for buying and selling, less risk of damage to desirable perennial grass composition, fewer opportunities for weed invasion and soil erosion. The advantages of light stocking rates are likely to be difficult to quantify from short-term grazing trial results because of the low frequency of events which can have major impact on pasture composition and soil loss. Thus, grazing trials have limitations for estimating long-term (30-100 years) sustainable stocking rates, i.e. 'safe' stocking rate. Estimates of safe stocking rate are better derived from grazier experience which, for an established grazier, is more likely to cover the range of climatic and economic events that show the consequences of a chosen grazing regime.

There are likely to be a range of stocking rates used within a region due to individuality of graziers and their circumstances, e.g. property size, financial history, duration of land ownership, expertise in trading and drought management. Thus, the range of stocking rates in a region provides a spatial 'experiment' on the consequences of different stocking rate strategies, although only subjective judgements can be made.

Given this wealth of personal and regional experience, it is not surprising that graziers (either as individuals or as groups) are prepared to nominate safe stocking rates for their own property or, more generally, for different types of land. The problem with this approach, as discussed in Section 1, is how to extrapolate across a range of climates, soils, tree densities and pasture condition.

It was hypothesised, in Section 1, that expressing safe stocking rate as a safe utilisation rate (pasture consumption ÷ pasture growth) was one approach to compare and extrapolate across environments. Thus, four sets of grazier data (south west, south east, central and north eastern Queensland), in conjunction with other projects, have been examined to estimate safe levels of utilisation.

4.2 CASE STUDIES

For each case study, graziers or grazier groups estimated safe carrying capacity for land types or whole properties. Intake was calculated from these estimates of carrying capacity. Because of regional differences, different approaches were used to estimate pasture growth inititally. The approaches adopted are discussed below. Intake was estimated by assuming that a beef cattle adult equivalent (AE) consumes 10kg/head of dry matter per day during the growing season (180 days), and 5kg/head for dormant season; and that a dry sheep equivalent (DSE) consumes 400kg/head/year. Variation in intake from this assumed level is considered in Section 4.3.

Potential utilisation was calculated as intake (above) divided by potential pasture production, i.e. pasture growth in the absence of grazing. Potential pasture growth was estimated independently by relating land types with pasture growth derived from the GUNSYNpD pasture production studies. Land types were either ranked relative to known GUNSYNpD study sites, or matched to an analogous soils/pasture grouping of GUNSYNpD sites for which average pasture growth parameters had been calculated. Extrapolation from GUNSYNpD sites were made either on the basis of a simple rainfall-use-efficiency or on the basis of actual GRASP pasture growth parameters such as potential nitrogen uptake and transpiration-use-efficiency.

Pasture growth was discounted for the effect of trees and pasture condition. One of the disadvantages of using consensus data from grazier groups is that, in the case of treed land types, it is difficult to estimate "average" tree density from ground surveys. For this reason, only safe stocking rates for land types in cleared condition have been examined with respect to consensus data. Where carrying capacity was estimated for individual properties DPI officers were able to survey tree density. Pasture condition was accounted for either by selecting properties in good condition (benchmark properties) or, where pasture condition was likely to be variable between properties, i.e. in the case of the regional survey presented (Scanlan *et al.* 1994), pasture condition was estimated for each property.

Case study 1: Central Queensland: local best practice data (K A Day)

Grazier groups estimated safe stocking rates for 20 pasture communities in central Queensland (R. Clark *pers. comm.*). Stocking rates ranged from 14 to 62 AE/100 ha. Average pasture growth was calculated using regional rainfall and the GRASP model with pasture growth and soil parameters derived from a data bank of ungrazed pasture production trials (GUNSYNpD project). Potential utilisation for the summer growing season was calculated as described above. Potential utilisation rates ranged from 10-19% utilisation over the growing (September-May) period. Whether or not such stocking rates are implemented is debatable.

Case study 2: South-east Queensland: benchmark property data (K A Day et al.)

Four graziers in the Central Burnett region were selected by a local property planning officer to provide experienced views of safe carrying capacity both for their properties and the component land types. Safe utilisation was calculated by the methodology presented above for 40 individual land units representing 18 different land types. Annual utilisation levels were, on average, 27% calculated both on a land type and property basis. The range in utilisation was 9-52% across the 40 land units and 23-29% across the four properties. Twenty-seven percent utilisation of annual growth translates to 23% utilisation over the **growing** season (September to May). This study is reported in full in Stafford Smith et. al. (1997b).

Case study 3: South-west Queensland: benchmark property and consensus data (Johnston et al. 1996)

Safe stocking rates (as DSE) for nine land types on four benchmark properties were nominated by graziers. The properties were regarded as being in good condition based on surface cover, and lack of erosion and woody weed invasion. Johnston *et al.* (1996) measured pasture growth using field methodology described in Appendix 3 and calibrated GRASP to each site. From simulation over 30 years, simple relationships between rainfall and growth were established for the whole south-western region allowing estimates to be made for the benchmark properties. Across the range of communities, average safe utilisation was 15% of annual pasture production. The major differences were associated either with highly productive and more resilient land types (e.g. Mitchell grass) or for land types where mulga was likely to be an important source of browse

Case study 4: Northern speargrass: regional survey (Scanlan et al. 1994)

In Dalrymple shire, northern Queensland, a survey of 45 properties was conducted (Scanlan *et al.* 1994) which provided information on both actual stocking rates over three years of the study (1987-89), and safe carrying capacity estimated by each grazier). For all pasture communities on each property, estimates of grazing area, tree basal area, pasture condition, and rainfall were made. Rainfall-use-efficiencies (kg/ha of pasture per mm of rainfall) were estimated for each community as a function of fertility, and VPD which was dependent on distance from the coast and type of year. Pasture growth was calculated for each property and each year. Utilisation was calculated for summer period (182 days) based on an estimated potential intake of 10kg of dry matter per day for an adult equivalent (AE).

For the 45 properties over the three years of the study (1987 to 1989), pasture utilisation ranged from 5% to 45% with the majority (85% of property x year combinations) having between 15 and 30% utilisation over the summer period.
Estimated safe stocking rates ranged from three to 23 AE/100 ha. Eighty percent of these estimated safe stocking rates were less than 35% utilisation of decile three pasture growth, i.e. the growth that occurs in at least 70% of years. Despite the wide range of rainfall, land resource units, pasture condition and tree density, the majority

(58%) of graziers' estimates translated into a relatively small range of utilisation (25%-35% utilisation of decile three production). For the Dalrymple Shire, decile three pasture growth as simulated using the GRASP model was approximately 50-65% of average summer growth (McKeon *et al.* 1994). So, on this basis, 30% utilisation of decile three pasture growth translates to 17% utilisation in an average six month growing period. To allow further comparison with the findings of Johnston *et al.* (1996), 30% utilisation of decile three pasture growth translates to an average annual utilisation of 30%.

The change in actual stock numbers from 1987 to 1989 was compared to property utilisation rates. Properties with greater than 25% utilisation over the summer period were reducing stock numbers, while those with less than 15% utilisation were increasing stock numbers. The 1987/88 season was below average in terms of simulated pasture growth (decile two) and the 1988/89 season was above average (top 30% of years). The two year period, as a whole, was close to median pasture growth

Summary of the four case studies

Across a tenfold range in pasture productivity (500 to 5 000 kg/ha/year) the nominated safe stocking rates represent approximately 15-25% utilisation of average pasture growth during the **growing period**. However, there are some regions where 15-25% utilisation is likely to be too high, although detailed survey data are not available. For example, Newman (1992) in a survey of 19 properties in the Julia Creek - Mitchell grass region (north-western Queensland, a region with severe droughts) found an average stocking rate of 0.51 DSE/ha (range 0.37-0.59 DSE/ha) for the 1985 to 1990 five year period. Based on an average pasture growth of 1 600 kg/ha/year estimated at Toorak (Section 3) this average stocking rate represents 12.7% utilisation. Low safe utilisation rates have similarly been calculated for tropical tall grass communities in northern Australia, where the growing season is short and nutrients such as phosphorus are likely to be major limitations on animal production (Norman 1963, Winter 1987, McIvor *et al.* 1994).

4.3 INTERPRETATION OF A LOW (15-25%) SAFE UTILISATION

For each of the case studies safe levels of utilisation were low, typically 15-25% utilisation in the growing season. This level of utilisation (15-25%) seems low and not intuitively obvious given the large areas of bare ground often observed in drought. We consider here the possible sources of variation and explanation.

Animal intake and pasture growth

The calculation of utilisation requires estimates of components of **safe stocking rate** in adult equivalents, **animal intake** and **pasture growth**.

Estimates of safe stocking rate derived from local best practice and from benchmark properties (case studies one and 2) may be more conservative than for land types because property values include unproductive areas (ridges, areas of high tree density). Better estimates of this source of variation will require property survey data. Animal numbers although referred to as adult equivalents or dry sheep equivalents do not necessarily include other components of the herd and flock (e.g. weaners, lambs, horses). In estimating intake we have adopted estimates at the upper end of the range. For sheep we have adopted 400kg/DSE/year and, for cattle, 1800kg/AE/180 days during the pasture growing period and 900kg/AE/180 days in the period of lower quality forage.

Estimates of pasture growth have been derived from exclosures placed on representative land types. It is possible that site choice may have resulted in a biased sampling of the landscape and pasture condition. Sites were readily accessible and uniform and, unless specifically chosen otherwise, they were representative of good condition and reasonable soil depth.

Section 5 examines in greater detail how representative of the grazing lands the exclosures data were. However, the success of using growth parameters derived from exclosures in the simulation of grazing trials suggests that exclosures are generally representative of grazed pastures, for the purposes of deriving pasture growth parameters.

The difference between 'potential' and 'actual' utilisation.

Pasture growth estimated from exclosures must be regarded as potential growth. As discussed in Section 3, grazing reduces growth through different plant and hydrological processes: reduced light interception; increased run-off; higher nitrogen requirements; and change in pasture composition to less productive species. We presented a case study based on a simulation of grazing strategies in the mulga lands. When the above factors are included in simulation models, simulated pasture growth declines with increasing stocking rate. A projected 15-20% utilisation of potential (exclosure growth) represents 20-30% of actual growth (Figure 4.1). Increasing stocking rate reduces growth to such an extent that a **projected** utilisation of 25-30% would result in 50-60% utilisation of **actual** pasture grown and, as such, low pasture yields. Thus, in the case of the mulga lands, 15-20% utilisation represents a use of pasture where there is minimal damage to pasture growth and low run-off.

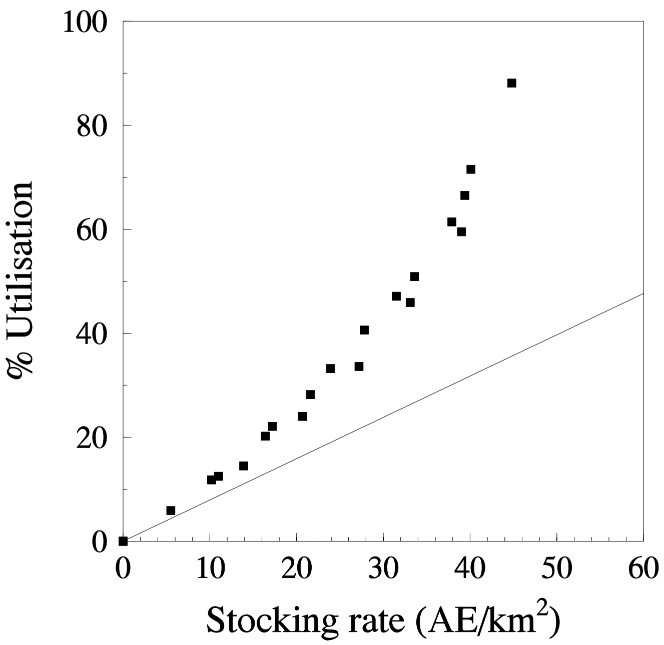


Figure 4.1: A simulation of pasture growth and animal intake for a sheep grazing trial at Arabella in south-west Queensland shows that actual utilisation (■) increases exponentially with increased stocking rate. This exponential increase is due to pasture growth being reduced with increased stocking rate. Thus, utilisation calculated on the basis of potential pasture growth (—) is lower than that simulated on the basis of actual pasture growth.

Thus, we suggest that the apparently low utilisation derived from grazier estimates of safe stocking rates can be explained for some pasture communities by the rapidity with which actual pasture growth declines with increasing stocking rate.

What does 'safe' mean to graziers?

Pasture communities are likely to differ in sensitivity to grazing according to frequency of drought, nutritional limits on animal production, and type of desired enterprise (breeding, finishing). Grazier-estimated safe stocking rates are likely to include all these factors and do not necessarily exclude a flexible approach to buying and selling to take advantage of favourable seasons.

Analysis from the grazing trials in Section 2 showed that the use of lower utilisation rates substantially reduces the impact of drought on herd/flock management (Beale 1985, Phelps 1994) and the risk of financial losses through reduced need to trade at inopportune times. Thus, it is likely that the nominated safe utilisation rates reflect a view of stock management designed to reduce the impact of drought. Where droughts have been perceived to be less frequent or severe (coastal Queensland and south-eastern Queensland), then higher safe stocking rates would be expected to be nominated on an economic basis alone. Given that a low utilisation rate has desired effects of reduced impact of drought as well as longer term consequences for resource management, e.g. desired fire frequency, botanical composition and soil cover, it is difficult to attribute the grazier's conservative estimates of safe stocking rate to any one factor.

Constant versus variable stocking rate

The concept of an average safe constant stocking rate is fundamentally different to varying stocking rate in response to variation in standing pasture yield (e.g. as in the treatments used in the utilisation trials in western Queensland). The use of flexible stocking rates to consume a constant proportion (20-30%) of end-of-season yield over the next six to 12 months, may provide increases in long-term animal production per ha but is likely to increase variation in income and place more emphasis on management skills such as livestock trading (Stafford Smith and Foran 1988). In the case presented for Dalrymple, graziers who were stocking such that 15-20% of the pasture growth was eaten, did not change their stocking rate over the two years of study.

Experimental comparisons between constant and flexible stocking rate strategies are now being carried out. The current development of seasonal rainfall forecasts using SOI (Stone and Auliciems 1992) raises the possibility of a third stocking rate strategy based on consuming a safe proportion (e.g. 20-30%) of future pasture yield. At present it is not possible to determine which stocking rate strategies are best. For the purposes of calculating risks we have taken a constant safe utilisation rate of 15% over the growing season as a baseline to simulate expected run-off, pasture yields, cover and other hydrological/pasture/animal attributes. However, it is possible that flexible stocking rate strategies may be better for resource management and profitability especially in adapting management to climatic variability on a decadal and generational time scale. The issue is currently being evaluated in the projects DroughtPlan (Stafford Smith *et al.* 1997, McKeon *et al.* 1997)) and RIRDC DAQ 139.

What are the visual indicators of 15-25% utilisation?

The concept of an average safe level of utilisation is a mathematical construction rather than the result of direct measurement. The calculation requires estimates of two **rates** (i.e. animal consumption and pasture growth) while graziers and agronomists can observe only **pools** (e.g. presentation yield and animal liveweight), and hence, the rates of the driving processes are not readily apparent.

It is reasonable to ask what does the result 15-25% average utilisation look like on a pasture. However, high year-to-year variation in pasture growth (due to climatic variation), in combination with constant stocking rates, results in large year-to-year variation in pasture yield and surface cover. For example, simulated yields for a black speargrass pasture grazed at a constant 15% utilisation ranged from 500 to 3300kg/ha.

Thus, **there is no simple visual indicator of safe average utilisation** other than relative observations such as drought or frequency of burning across a range of stocking strategies. The assessment of average utilisation from snapshot observations requires knowledge of previous rainfall and a further calculation of expected pasture yield. In fact, it is on the basis of such a procedure, that we have developed the operational spatial model described in the following section (Section 5).

An alternative approach to providing visual pasture indicators of a safe stocking rate is to determine the expected frequency of important management events, e.g.. frequency of burning, requirements of woody regrowth control, destocking due to drought, supplementation requirements, presence of indicator species or variability in animal turn-off. The process of documenting the production and managerial consequences of using safe stocking rates is only just beginning but it will become the most important approach for individual graziers to assess directly the relative consequences of their own stocking policy.

4.4 FUTURE DEVELOPMENTS

The concept of an average safe utilisation rate has been developed here for the purposes of simulating risks of land and pasture degradation. Other QDPI projects (e.g. Drought Plan) are testing these concepts in estimating safe stocking rates for individual properties (e.g. Scanlan *et al.* 1994, Johnston *et al.* 1996, Day *et al.* 1996).

Use of grazier knowledge of safe stocking rates

The use of grazier knowledge in estimating safe stocking rates is the forum for future developments. Nominated "safe" stocking rates can be extrapolated to other locations/communities provided pasture growth can be estimated and, thus, safe utilisation rates calculated. As more knowledge becomes available, sources of variation in safe levels of utilisation will be examined.

These projects will provide the basis for examining -

1) the variation between pasture communities and landscape units which are likely to differ in sensitivity to grazing; and
2) the economic implications of adopting more conservative stocking rates.

From a modelling viewpoint, process models of carbon and nitrogen flow, and plant competition are yet to be developed which would allow ecophysiological support for nominated safe stocking rates.

Use of ABS animal numbers to estimate safe stocking rates

An alternative to grazier estimates would be the use of historical animal numbers reported to the Australian Bureau of Statistics (ABS). Historical periods could be identified when resource degradation was not apparent, e.g. 1945 - 1965. Following closer examination of the issues involved we decided not to use historical ABS data for the following reasons:

1) historical numbers may not reflect true stocking rates due to previously poor mustering efficiencies;
2) historical changes in tree densities and woody weeds would have had a large impact on pasture growth but have not been documented;
3) the pasture resource may have been under-used before the introduction of *Bos indicus* cattle and use of supplements; and
4) doubts on accuracy of animal numbers have been expressed based on measured turn-off rates and lack of impact of drought on year-to-year variation in reported stock numbers.

Although ABS numbers represent the only readily available historical data source, their interpretation requires analysis of selected individual property data in conjunction with herd/flock models (the subject of two current (1997) PhD projects, W Hall and D Mayer QDPI/University of Queensland).

4.5 CONCLUSION

Analysis of four grazier surveys in three regions indicated that a safe utilisation rate of 15%-25% of potential (exclosure) growth provides a general and conservative view of pasture use. The surveys indicate that some graziers are likely to stock above this level. Grazing trial data and economic analysis suggests that short-term (5-10 years) financial returns are likely to increase with increasing stocking above 15% utilisation. However, at such stocking rates the risks of land and pasture degradation, feed shortages and animal losses are likely to increase. The following section describes the simulation of these risks.

SECTION 5 - AN OPERATIONAL MODEL FOR QUEENSLAND

5.1 INTRODUCTION

In this section we describe a spatial model developed for Queensland and prototyped for other states. We provide examples of how the findings from DAQ124A as presented in Sections 1 to 4 of this report can be extended through a spatial modelling framework to assess risks of pasture and land degradation.

The spatial model for Queensland, initiated in this project by RIRDC and QDPI, became part of a national drought alert system funded by LWRRDC (QPI 20). A full description of the spatial model including development, validation and use has been documented in the final report for the LWRRDC project QPI20 (Brook 1996). Volume 1 of the above final report (Research Summary) is appended (Appendix 1). The following description complements these reports and highlights the role of the spatial model in assessing risks of pasture and land degradation. The spatial model uses a version of GRASP which is essentially the same as reported in Section 2. The version of GRASP used in the spatial model will be improved from the findings presented in Sections 2 and 3 of this report.

5.2 INPUTS TO THE SPATIAL MODEL

An operational spatial model of pasture growth and utilisation has been developed running in near real-time (monthly) with output a few days after the end of each month. The model is run on a 5 km grid across Queensland (ca. 70 000 5 km x 5 km pixels). It has also been run for the continent but is not operational or well validated at this scale.

The main inputs to the operational system are:

1) climate;
2) soil;
3) geographic information such as LGA boundaries;
4) animal numbers;
5) pasture communities; and
6) tree density.

The organisation of this input data in a form suitable for spatial modelling and rapid visual assessment has been a major achievement of the spatial modelling process. Maps of tree density, soil attributes, sheep and cattle stocking rates and NDVI, have not previously been available at the resolution now prepared for the spatial model. These products have been sought by a diverse range of clients for use in activities ranging from bushfire control to greenhouse gas inventories.

The development of an operational drought alert model is dependent on the supply of products from other organisations, e.g. real time climate data from the Bureau of Meteorology (BoM), animal numbers from Australian Bureau of Statistics (ABS) and pasture condition maps from the Meat Research Corporation (MRC). Changes in policy and computing systems by other organisations can seriously limit QDPI's capacity to maintain an operational system. These issues are discussed in relation to climate data in the following section.

1. Rainfall and climate: Daily meteorological surfaces available for Australia

<u>Daily climate data</u>

There are approximately 500 meteorological stations in Australia which keep daily or hourly climatic records and report to BoM. Daily climate data (**temperature, vapour pressure, evaporation, radiation),** as supplied by the Bureau, have been interpolated to a 0.05 degree grid over the whole of Australia. The interpolation used a technique developed by Dr Mike Hutchinson at ANU's Centre for Resource and Environmental Studies (CRES). This technique is well accepted and accounts for elevation as well as horizontal position. It also takes account of the long-term climate variability at each station to assess how representative a particular value is. Thus, at each pixel there is an estimate of each climate variable: maximum and minimum temperature, evaporation and vapour pressure, for each day since 1957, (1964 in the case of evaporation). This represents the earliest daily data available in complete form from BoM. Daily radiation data have been estimated from daily cloud cover.

Daily rainfall data

In Section 2 we determined that seasonal rainfall accounted for 40% of the variation in measurement of pasture growth across Queensland. The daily rainfall record for the whole of Australia is fairly complete from 1889 onwards. Over 6 000 rainfall stations have been reporting monthly totals from approximately 1910 onwards. However, there has been a sharp decline in reporting stations in the last 25 years from a peak of over 8 000 stations in the early 1970s to approximately 5 000 stations currently. Monthly rainfall totals have been interpolated using Hutchinson's spline technique (above). As daily values of rainfall are spatially "noisy", daily values were reconstructed by re-distributing the interpolated monthly totals by the daily pattern of the nearest rainfall stations.

In summary, for each pixel across Australia, we have daily rainfall estimates from 1889 onward, daily estimates of maximum daily temperature, and minimum 9.00 am vapour pressure and daily solar radiation from 1957 onwards, and daily evaporation from 1964 onwards. These data provide the opportunity to re-analyse all production data using standard climatic inputs.

Interpolation of data from the near real-time rainfall network

Rainfall data described in the above section can be up to three months old before being made available by BoM. However, near real-time monthly rainfall data is received from BoM's telegraphic station network and this the only near-real time data available before 'paper' reports, from a wider number of stations, are made available by BoM. As such this data is critical to an alert system operating in near-real time.

As this rainfall station network is a much smaller sub-set of rainfall data that is eventually received by BoM, a different technique to that described above was required to interpolate this rainfall data . A Krigging and rainfall normalisation spline method has been developed but research on interpolation methods for the near real-time rainfall network is still continuing. Comparison of model output with reports from QDPI stock inspectors showed occasional large errors in rainfall interpolation in rain shadow regions (e.g. Nebo shire) and areas of low station density. Such errors highlight the need for an accurate high resolution rainfall reporting system. Preliminary research indicates that Geostationary Meterological Satellite (GMS) data can probably address some of these problems.

Operation of BoM's real-time agrometeorological system

Near real-time climate data is supplied by BoM via the Internet. Rainfall data from the telegraphic network, temperature and humidity data are supplied from a smaller number of climate stations, and radiation estimates are provided from a solar insolation model on a point only basis.

The continuing operation of the spatial model in near real-time is dependent on accurate real-time data. Many problems exist with the operation of BoM's near-real time system: missing data; inconsistent totals; inconsistent lists of rainfall stations between Melbourne H.Q. and each state; and intermittent data availability. Lack of quality real-time data can present a major problem in the operation of the drought alert model. Initial problems are being resolved with many meetings between QDPI and various representatives from both the Brisbane and Melbourne offices of BoM. The matter has also been raised at the Standing Committee's Agrometeorology forum by QDPI. A joint project Specific Information for Land Owners (QNR3) with the BoM, QDNR, QDPI and others is now funded by RIRDC (1997).

2. Soil databases and soil water parameters

The Atlas of Australian Soils (Northcote *et al.* 1960-68) was procured as an ARC-INFO coverage. Various unlabelled polygons have been corrected and the coverage has been rasterised into the spatial model format.

While large amounts of effort have been expended in mapping soil boundaries at various resolutions and describing soils in a taxonomic sense, very little information is available on parameters to 'attach' to the mapped soil polygons. Considerable development has been required to derive estimates of soil depth, plant available water holding capacity, infiltration, erosivity, bulk density, and nutritional parameters such as pH, phosphorus, nitrogen and organic carbon.

J.O. Carter, has analysed a database of soil profile morphology covering 24 000 samples. Mean soil water capacity for all principal profile forms has been derived from the texture and structure descriptions. Comparison with 0.33 and 15 bar water contents in QDPI's soil chemistry database still remains to be completed. Other scientists in QDPI are developing predictive equations that relate plant available water to 15 bar measurements (M. Littleboy *pers. comm*., K.A. Day unpublished GUNSYNpD data).

As yet no map of slope or soil erosivity is available to allow simulations of soil erosion in absolute terms. Nevertheless, approaches to predict these parameters from digital elevation models and soil variables is being explored (M. Littleboy *pers. comm.*).

3. Local government boundaries and land use maps

QDPI has rasterised the national maps of local government boundaries, national parks, ungrazed lands and military training lands. In Queensland cultivated areas have been mapped from Landsat TM for the wheat modelling component of the LWRRDC project QPI20, and cane lands has also been completed. In other states, cultivated land has been mapped from National Oceanographic and Atmospheric Administration's (NOAA) images.

4. *ABS stock densities and total grazing pressure*

QDPI has Australian Bureau of Statistics (ABS) animal number information available from 1952. From 1987 onwards, a spatial raster of animal numbers has been developed for each year. The ABS data have been apportioned across the shire pixels according to pasture type, tree cover and indices of potential pasture productivity.

The ABS have intimated that they are considering reducing the coverage and frequency of producer surveys. QDPI have had a number of discussions with the ABS during 1993-95 about the drought alert project and future environmental uses of animal number information. The annual update of accurate animal numbers is fundamental to the operation of the degradation alert system. However, changes in scope of the census (based on estimated value of agricultural operations) and exclusion of herd and flock composition items from the annual census are likely to increase the difficulty of accurately calculating pasture utilisation.

The grazing pressure of uncontrolled grazers (feral animals and native fauna) is a major issue in calculating the risk of degradation. Graziers in western Queensland report major impacts due to the presence of uncontrolled grazers. J.O. Carter has produced prototype density maps in a spatial mode. Some reparameterisation of pasture losses (e.g. detachment rates) will be necessary once these data sets are available.

5. *Native pasture community maps*

QDPI has incorporated Tothill and Gillies' (1992) classification of pasture types in Queensland. A lookup table of various pasture parameters derived from parameterising GRASP on GUNSYNpD datasets has been produced for each pasture class. The lookup table is being modified as a result of work with the field validation data produced by this project. However, data on land and pasture condition status (i.e. A,B or C) are not yet available from MRC.

6. *Tree Density*

Danaher *et al.* (1992) developed relationships between tree basal area and remote sensing attributes, e.g. mean and variance of NOAA NDVI images. Within a 5 km x

5 km pixel, trees are unlikely to be uniformly distributed. Given the non-linear relationship between tree density and pasture growth, large errors in modelling pasture growth are possible. For each pixel, a synthetic tree basal area was calculated to overcome the non-linear effects of tree density and still allow simulation at a pixel resolution. Field surveys during 1995 examined alternative approaches to calculating the effect of trees. Tree density for the state is currently (1997) being remapped at high (30 m x 30 m) resolution using Landsat Thematic Mapper data as part of the Queensland Government funded project State Land Use and Trees Study (SLATS).

5.3 VALIDATION OF THE SPATIAL MODEL

Validation against NOAA imagery

NDVI data for Queensland (89 images, 1988-1994) were averaged from 1 km x 1 km pixels to 5 km x 5 km pixels and registered to the spatial modelling grid. The NDVI data were, at the time of the following analysis (1995), radiometrically uncorrected but had improved cloud masking. All images were corrected for sensor drift and speckle lines were removed. The analysis screened out very low cover situations where soils are the main source of reflectance.

Satellite data were analysed in two ways to best reflect spatial and temporal variability. Firstly, a spatial correlation map was produced in which the output image pixels contained a Pearson r value. This was carried out on a pixel by pixel basis giving a maximum of 89 paired data points for each pixel. Maps containing slope, intercept and the number of observations were also produced. The second analysis was, for each date, to calculate the correlation across Queensland. This provided 89 correlations between entire NDVI images and simulated NDVI since 1988 (Figure 5.1). The correlations were of a similar magnitude to the correlation between NDVI and direct field measurement of the green cover, and similar or better than those obtained by Coughenour (1992) for a similar scheme in Kenya.

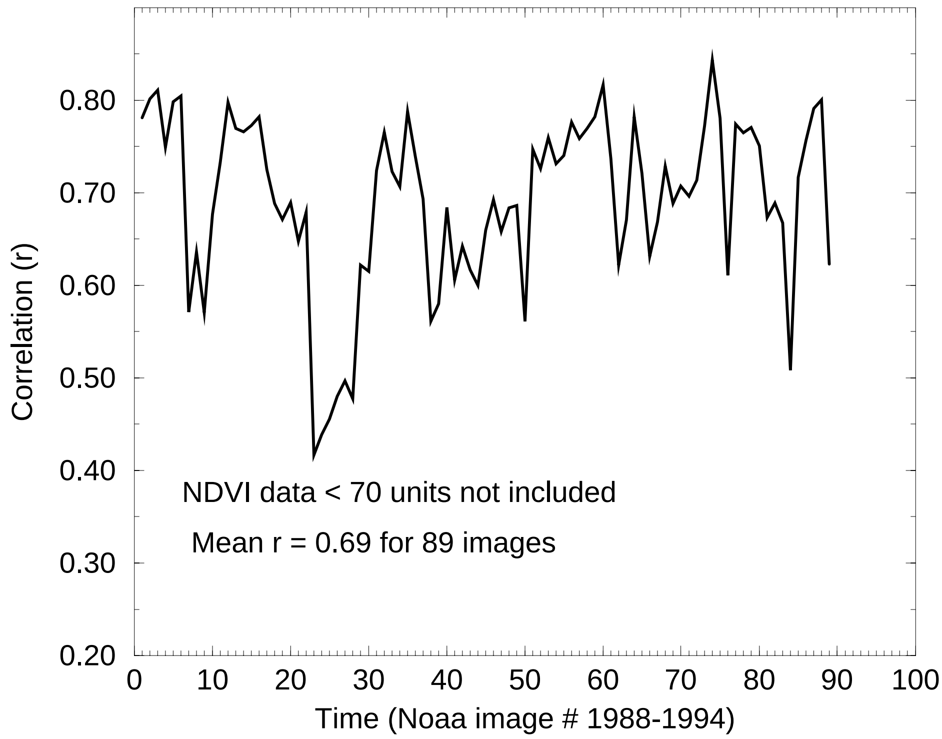


Figure 5.1: Temporal correlation between 89 image pairs for NOAA satellite NDVI and model derived NDVI

Future improvements may include:

1) better cloud masking (especially for those areas having soils with a high reflectance in the visible band);
2) correction of reflectance for adsorption by ozone;
3) correction for sensor geometry i.e. sun - target - sensor angles;
4) correction for water vapour and aerosols;
5) use of soil adjusted NDVI to achieve better results at low cover levels;
6) inclusion of a dynamic rather than static tree canopy model, where tree foliage projected cover responds dynamically to available soil moisture and air temperature, thereby, improving water balance and the "synthetic" (model derived) NDVI; and
7) use of a subset of satellite data to calibrate certain model parameters

Field validation using visual assessment

As part of the LWRRDC project QP120, two officers were employed to carry out field data collection (Brook 1996). The process involved visual estimation of pasture yields from a moving vehicle. These estimates were corrected by 10 calibration harvests per day. Over 220 000 visual estimates of yield were made. The data were collected in transit and entered into a notebook computer, automatically time stamped and geo-referenced by an attached global positioning instrument (GPS). Custom software, "Trackman", has been modified specifically for this purpose. The team have also collected a large number of tree basal area measurements for validation of the tree map. This map was derived by syntheses of 1 km x 1 km resolution imagery from the NOAA satellite.

Software has been written to calibrate yield measurements; average data to 5 km x 5 km pixels in the modelling grid; and compare the data with the model output.

Spatial model parameters were calibrated for each pasture community (Table 5.1). The calibrated model explained a high proportion (r^2=0.77) of the variation between shires (Table 5.2) which had at least nine pixels of field observations.

Table 5.1 Predicted and field estimated yield (kg/ha) for various pasture communities as at 20 April 1994 (where observations cover more than nine pixels).

Pasture community	Observed	Predicted	No. pixels
Black speargrass	1670	1799	133
Channel pastures	646	419	41
Brigalow pastures	1388	1008	39
Queensland bluegrass	1671	2113	10
Mitchell grass (ashy downs)	329	319	30
Spinifex on sand dunes	1565	1625	28
Mulga on residuals	624	652	48
Mitchell grass (northern)	1114	1052	83
Blady grass (southern)	1477	1400	12

Table 5.2 Predicted and field observed trials (kg/ha) for various shires as at 20 April 1994 (where observations cover more than nine pixels).

Shire	Observed	Predicted	No. pixels
Banana	1299	828	33
Barcoo	857	750	137
Bauhinia	1442	1573	19
Blackall	1307	1500	44
Caboolture	1253	1010	10
Diamantina	267	256	38
Duaringa	1352	933	19
Gayndah	1825	1241	18
Hervey Bay	1486	1598	10
Isisford	954	482	17
Kilkivan	1570	1621	16
Kolan	1807	2420	10
Miriamvale	2128	2728	11
Monto	1616	1866	16
Nanango	1514	1638	12
Tiaro	1904	2485	11

In April 1994 the model under-estimated shire yields less than 1 500 kg/ha by 30% but over-estimated by up to 25% shire yields greater than 2 000 kg/ha (Figure 5.3).

Data from the field survey at some locations appear to vary less between pixels than does the simulated model output. In northern speargrass communities, the real world is smoother than simulated by the model. Poor parameterisation for the effects of tree density, stock distribution, and fragmented patches of trees in the landscape, are all potential contributing factors. However, in spinifex communities, the real world is more variable than simulated by the model, possibly due to inadequate mapping of heterogeneous pasture communities, and inability to map burnt areas. These problems could be solved with use of better resolution vegetation maps and use of satellite (NOAA) imagery.for operationally mapping fire scars.

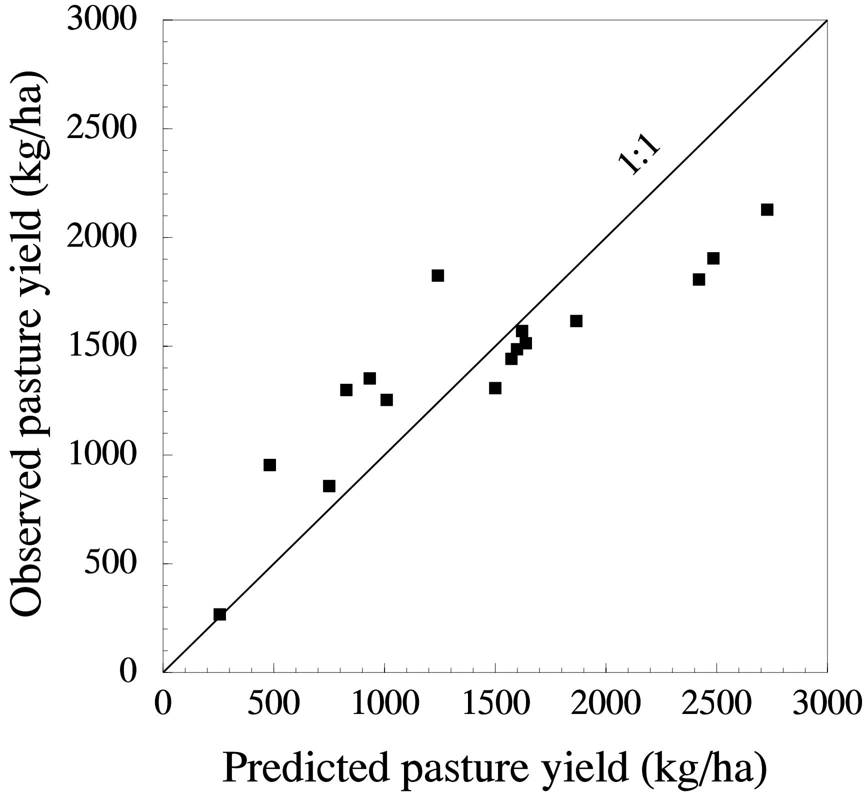


Figure 5.3: Comparison of pasture biomass predicted by the spatial model and observed pasture biomass for Queensland shires.

Validation against exclosure data

The major pasture parameters, transpiration-use-efficiency and detachment rates were calibrated from the extensive field data described earlier in this section using the first 50 000 observations. High correlation (Figure 5.4) was found between TUE for each pasture community and TUE derived from the GUNSYNpD data set (Section 2). This result suggests that the GUNSYNpD data set is representative of the major grasslands of Queensland. The major outlier was the mulga lands of higher TUE in the extensive data, This may indicate a build-up of nitrogen due to drought prior to field sampling and/or, a shift in composition to species with higher transpiration-use-efficiencies such as forbs and *Aristida* spp.

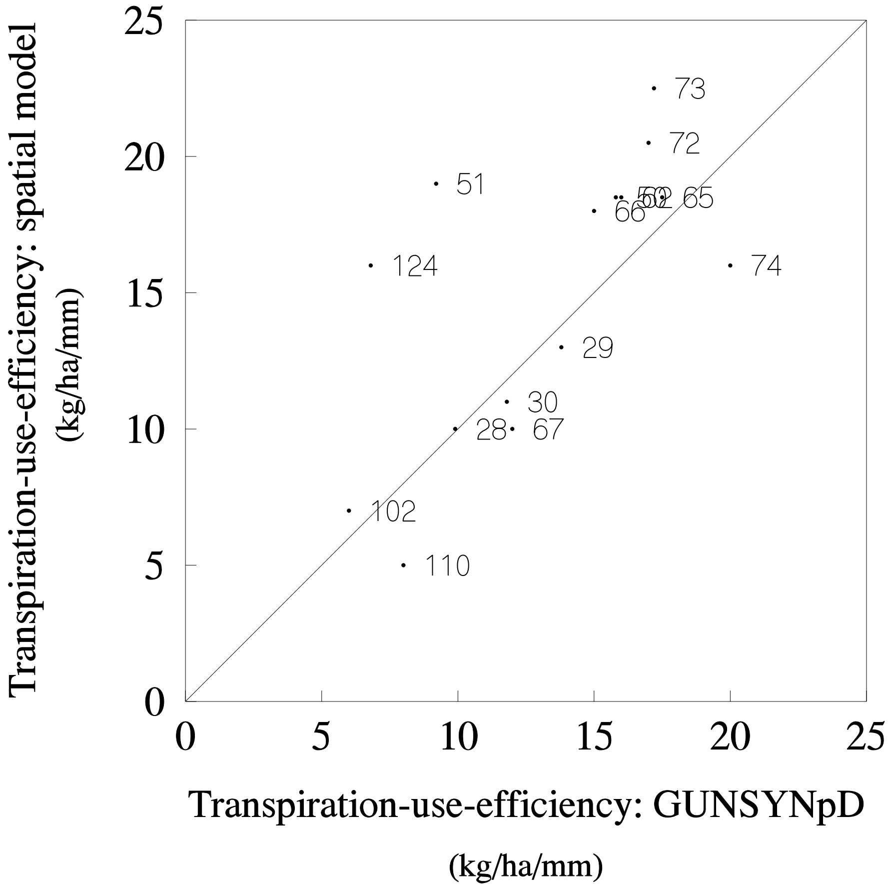


Figure 5.4: Comparison of transpiration-use-efficiency for pasture communities in Queensland as used in the spatial model with transpiration-use-efficiency determined independently from field measurements (GUNSYNpD). Numbers indicate pasture community from Tothill and Gillies (1992).

5.4 DEGRADATION ALERT PRODUCTS

The spatial model has been used to produce a range of products that have proved useful to a wide range of clients. As discussed, the organisation of this input data in a form suitable for spatial modelling and rapid visual assessment has, in itself, been a major achievement of the spatial modelling process. For example maps of rainfall percentiles have been used by both the Queensland and Federal Cabinets to assess the extent and intensity of the 1991-1996 drought in Queensland (Figure 5.5). However, the primary aim of organising this data was to monitor and forecast, in near real-time, risks of land and pasture degradation. While most products are still experimental they are gradually released for use on the "Long Paddock" Internet site (URL: http://www.dpi.qld.gov.au/longpdk)

Pasture growth

The major output of the spatial model is pasture growth incorporating the effects of climate, soil, stock, species and trees. When each seasonal map is expressed as a percentage of average pasture growth (1956-1996), areas of likely feed deficiency and potential degradation are quickly highlighted (Figure 5.6). These maps were used during 1996 to assess the intensity of the drought situation in Queensland. Shire drought declarations (e.g. September 1996, Figure 5.7) correspond well with calculated percentile pasture growth (Figure 5.6) and less well with percentile rainfall. (Figure 5.5).

In broad agreement with the extent and intensity of low relative pasture productivity (Figure 5.6) is the average NDVI for August 1996 ranked relative to the previous 15 Augusts since measurements began in 1981 (Figure 5.8, N. Flood, DNR, Climate Impacts and Applications). However the meaning of a low relative NDVI for one location to the next is not well understood. This new methodology requires further evaluation on a month-to-month and location-to-location basis as anything that effects green cover will effect the ranking of NDVI (e.g. reduction in tree canopy cover in response to soil water deficit, variable occurrence of frost).

Preliminary forecasting of future condition has been attempted using the 'analog year method' of the Bureau of Meteorology Climate Outlook Bulletin allowing six monthly forecasts of feed deficit. However, a better approach based on SOI phase forecasting (Stone and Auliciems 1992) using up to 10 historical years has been operationalised.

The legends below describe figures presented on the facing page.

Figure 5.5 Queensland rainfall for the 12 months up to and including August 1996 ranked against previous records for the same period since 1956. Data is from the Bureau of Meteorology, Melbourne. Contours are subject to interpolation error. Areas with insufficient data e.g. the far south-west and north of the state are left blank.

Figure 5.6 Pasture growth expressed on the same basis as rainfall in Figure 5.5 i.e. for the 12 months up to and including August 1996 ranked against previous records for the same period since 1956. Pasture growth is calculated by the pasture model GRASP on a 5 km x 5 km grid using rainfall presented in Figure 5.5.

Figure 5.7 Drought declared shires and IDP status in Queensland as at September 1, 1996.

Figure 5.8 NDVI calculated from NOAA AVHRR imagery for August 1996 ranked relative to NDVI for previous Augusts since 1981 in Queensland.

Actual utilisation relative to safe utilisation

The calculation of pasture growth (e.g. Figure 5.6) provides an ability to better account for climatic impacts. A further step is to account for grazing impacts. This we have achieved through comparing actual levels of pasture utilisation with safe levels of utilisation (Section 4). To make such a calculation with the spatial model involved a number of steps. As detailed in Section 4, the benchmark stocking rate chosen for sustainable resource management is that which results in 15-25% utilisation of potential (i.e. exclosure) pasture growth. Potential pasture growth is simulated as if each pixel was an annually mown exclosure. “Safe” stocking rates are calculated as a conservative, constant rate which results in 15% utilisation of average growth since 1986. ‘Safe” stocking rates are used to simulate pasture production, run-off, soil loss and grass basal cover as a base line of acceptable resource use (Section 1). Figure 5.9 shows the range of utilisation levels across Queensland for the nine months to June 1994 based on a constant “safe” stocking rate which results in 15% utilisation of average pasture growth in the longer term (1986-94).

The spatial model is then run with animal numbers using the time series of actual stock numbers supplied by ABS to calculate utilisation, e.g. June 1994 (Figure 5.10). For each pasture and resource variable, e.g. cover and run-off, the ratio of actual to safe allows assessment of the risks of degradation. Given the current lack of maps of slope and soil erosivity the risks of degradation can only be calculated, at present, in relative rather than absolute terms. For example, Figure 5.11 shows the areas where reported ABS stocking rates exceed the calculated safe stocking rate. The consequences of the stocking rates for run-off, for example, are shown relative to a safe stocking rate (Figure 5.12). For the example shown in Figure 5.12, in areas where stocking rates exceeded the calculated “safe” stocking rate, run-off was greater than that simulated for a “safe” stocking rate, in some areas by up to 100%.

The legends below describe figures presented on the facing page.

Figure 5.9 Utilisation (pasture eaten/ pasture grown) for Queensland for the nine months to June 1994. Pasture eaten is based on a calculated "safe" stocking rate as defined in the text.

Figure 5.10 Utilisation (pasture eaten/ pasture grown) for Queensland for the nine months to June 1994. Pasture eaten is based on shire stock numbers reported to the Australian Bureau of Statistics.

Figure 5.11 The ratio of ABS shire stock numbers for Queensland for 1993/1994 to a calculated long-term "safe" stocking rate as defined in the text. (This figure is the same as that obtained by "dividing" Figure 5.10 by Figure 5.9)

Figure 5.12 An example of the type of calculation which can be made to assess the risk of land degradation in Queensland: simulated run-off based on shire stock numbers reported to the Australian Bureau of Statistics relative to run-off simulated for a calculated long-term "safe" stocking rate as defined in the text.

5.5 CONCLUSION

The operation of the spatial model shows that it is possible to model pasture growth and utilisation at a resolution sufficient to allow new debate of risks of drought and feed deficit occurring. The calculation of a relative utilisation using grazier estimates of safe stocking rate provides for the first time a link between expert knowledge, grazing science, seasonal forecasts and computer power. The benefits of such calculations will be assessed as drought and degradation alerts become operational in near real-time. Re-analysis of past events and real-time assessment of current and forecast conditions will refine and build confidence in these calculations. Improvements to the spatial model will come from improved spatial inputs, improved model functions and parameterisation derived from detailed "point" studies.

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