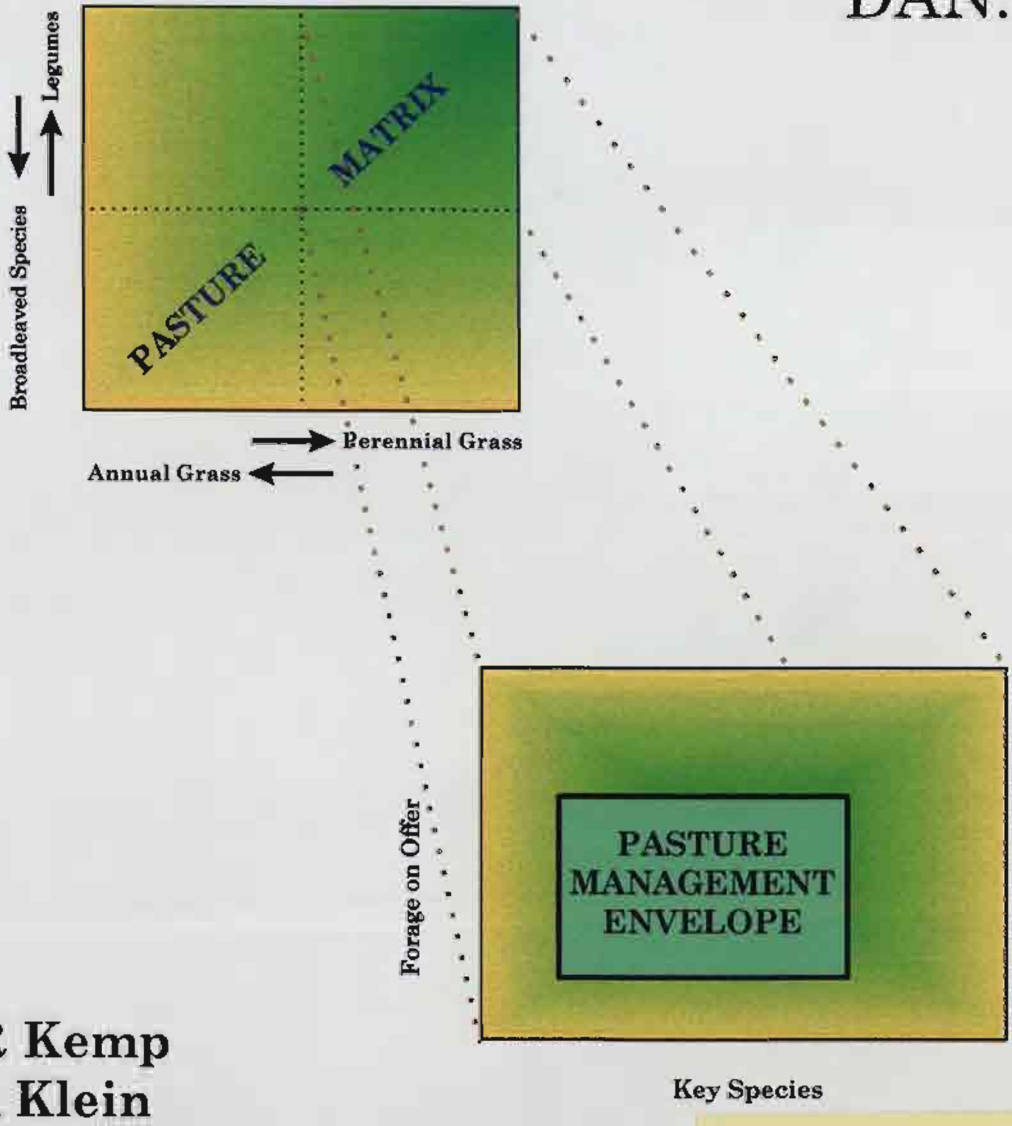
Meat Research Corporation

ADMINISTRATIVE
REPORT
DAN.078



D R Kemp
T A Klein
D L Michalk
P M Dowling

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ORIGINAL

Development of the Pasture Management Envelope

: methods for the analysis, interpretation & application of grazing management experiments

DAN.078

Final (Administrative) Report

Meat Research Corporation

July 1993 to June 1996

Research Personnel:
Dr D.R. Kemp, Principal Research Scientist
Mr T.A. Klein, Research Agronomist
Dr D.L. Michalk, Senior Research Scientist
Dr P.M. Dowling, Senior Research Scientist

NSW Agriculture, Pasture Development Group
CRC for Weed Management Systems
Agricultural Research & Veterinary Centre
Forest Rd., Orange NSW 2800
Tel: 063 913 800 Fax: 063 913 975 E-mail: kempd@agric.nsw.gov.au

ISBN:

01 September 1996

Administrative Details Report

Budget

(including contributions from NSW Agriculture)

The staff and financial budget is attached.

The estimated financial contribution from NSW Agriculture to this project has been $ 240,000 over the three years.

Intellectual property arising

No patents or other commercial products have been produced by this project. The concepts developed by NSW Agriculture on the *pasture management envelope* and the *pasture species composition matrix* have been discussed within the pasture specialists network of TPSKP.

Commercial exploitation of the project

No products have been commercialised.

Milestones

Attached.

STAFF MONTHS AND CORPORATION FUNDS Vs ACTUAL - PROJECT DAN.078 - ARVC Orange

BUDGET = CONTRACTED AMOUNTS : ACTUAL = EXPENDITURE + COMMITMENTS

DATE QUARTER BEGINNING	STAFF MONTHS		CORPORATION FUNDS							
			OPERATING COSTS		OVERSEAS TRAVEL		CAPITAL		TOTAL CASH FLOW	
	BUDGET	ACTUAL	BUDGET	ACTUAL	BUDGET	ACTUAL	BUDGET	ACTUAL	BUDGET	ACTUAL
01/07/93	1	1.5	-	-	-	-	-	-	-	-
01/10/93	2	2	10000	-	-	-	-	-	10000	-
01/01/94	2	2.5	-	2000	-	-	-	-	-	2000
01/04/94	2.5	3	-	5290	-	-	-	-	-	7290
01/07/94	2	2.5	10000	460	-	-	-	-	20000	7750
01/10/94	2	2	-	80	-	-	-	-	-	7830
01/01/95	2	2	-	4020	-	-	-	-	-	11850
01/04/95	2	2.5	-	950	-	-	-	-	-	12800
01/07/95	2.5	3	5000	5830	-	-	-	-	25000	18630
01/10/95	2.5	4	-	4320	-	-	-	-	-	22950
01/01/96	2.5	4	-	940	-	-	-	-	-	23890
01/04/96	2.5	4	-	890	-	-	-	-	-	24780
01/01/97	1.5	na	5000		-	-	-	-	30000	
TOTAL	25.5	33	25000	24780	-	-	-	-	25000	24780
								BALANCE (BUDGET - ACTUAL)	+220	

PROJECT PROGRAM

"Development of the Pasture Management Envelope & Methods for the Analysis, Interpretation & Application of Grazing Management Experiments. Subprogram 3.1, Temperate Pasture Sustainability Key program"

MILESTONES [1]	Date for Completion (dd/mm/yy)	ACHIEVEMENT CRITERIA	COMMENT
1. Evaluation of alternative methods for analysing data from grazing management experiments using old data sets. (ii)	1/01/94	Recommendations made to TPSKP Coordinator on better procedures to, initially, use. Initial protocol for statistical analysis of data.	Procedures outlined at Tamworth workshop & previously reported.
2. Budget situation as at 31/12/93 with actual against projected quarterly budgets for total staff resources and Corporation funds.	31/01/94	Budget report received by the Corporation.	Previously reported.
3. Develop framework to be used to estimate practical limits for components of a pasture. (I)	1/04/94	Draft framework circulated to TPSKP regional grazing management site researchers via Coordinator for comment.	Reported & also circulated for comment within Key Program
4. Implementation of supplementary experiments to establish response functions for the Pasture Management Envelope. Experiments to run for 2 years. (I)	1/04/94	Design reported to Corporation.	Experiments started, though limited results due to adverse season
5. Test analysis methods on data sets from the first season of the main grazing sites. (ii)	1/04/94	Analysis of compositional changes completed and methods enable effects of treatments to be established.	Initial analyses show that significant differences are detectable
6. Initial response functions to estimate boundaries for the Pasture Management Envelope for a phalaris pasture. (I)	1/07/94	Initial recommendations to TPSKP Coordinator on boundaries for a phalaris pasture for consideration at other sites.	Boundary conditions proposed and methodology to determine them outlined
7. Budget situation as at 30/06/94 with actual against projected quarterly budgets for total staff resources and Corporation funds.	31/07/94	Budget report received by the Corporation.	Reported previously
8. Initial response functions to estimate boundaries for the Pasture Management Envelope for a native grass pasture. (I)	1/10/94	Initial recommendations made to TPSKP Coordinator on boundaries for a native grass pasture for consideration at other sites.	Reported previously

MILESTONES [1]	Date for Completion (dd/mm/yy)	ACHIEVEMENT CRITERIA	COMMENT
9. Evaluation of methods for interpreting pasture response to grazing pressure in a phalaris pasture. (iii)	1/10/94	Functions to describe pasture response to grazing pressure established.	Deferred to combine with milestone 10
10. Evaluation of methods for interpreting pasture response to grazing pressure in a native grass pasture. (iii)	1/01/95	Results reported to TPSKP Coordinator for evaluation at other native grass sites.	Reported previously
11. Budget situation as at 31/12/94 with actual against projected quarterly budgets for total staff resources and Corporation funds.	31/01/95	Budget report received by the Corporation.	Reported previously
12. Methods updated for analysis of treatment effects from main grazing experiments. (ii)	1/04/95	Recommendations to TPSKP Coordinator accepted on better procedures to follow at other sites. Protocol prepared for distribution.	Sent to site managers & copy to Coordinator & copy enclosed here
13. Budget situation as at 30/06/95 with actual against projected quarterly budgets for total staff resources and Corporation funds.	31/07/95	Budget report received by the Corporation.	Reported
14. Preliminary plans to link better pasture management practices with animal production. (iv)	1/10/95	Proposals developed and reported to TPSKP Coordinator for comment.	Superseded by Phase II planning - request to cancel approved by MRC
15. Budget situation as at 31/12/95 with actual against projected quarterly budgets for total staff resources and Corporation funds.	31/01/96	Budget report received by the Corporation.	Reported
16. Develop series of response functions for pasture parameters to estimate boundaries of the Pasture Management Envelope (I)	1/04/96	Recommendations reported to TPSKP Coordinator for evaluation at other sites. More sensitive parameters defined.	Discussed in this report
17. Develop response functions between pasture parameters and grazing pressure for main grazing experiments. (iii)	1/04/96	Functions in a form that can be used to support use of the Pasture Management Envelope.	Discussed in this report
18. Link better pasture management practices with animal demands by updating plans, from 14 after comments from coordinator and site managers. (iv)	30/06/96	Recommendations on how better pasture management can be integrated with animal production tested for reasonableness with regional grazing management site producer groups.	Superseded by Phase II planning - request to cancel approved by MRC

MILESTONES [1]	Date for Completion (dd/mm/yy)	ACHIEVEMENT CRITERIA	COMMENT
19. Budget situation as at 30/06/96 with actual against projected quarterly budgets for total staff resources and Corporation funds.	31/07/96	Budget report received by the Corporation.	Included in this report
20. Completion of the Project and Final Report to the Corporation.	31/10/96	Acceptance of the Final Report acknowledged by the Corporation.	Presented to MRC
21. Final financial report and final staff resources report.	31/10/96	Receipt acknowledged by the Corporation.	Presented to MRC

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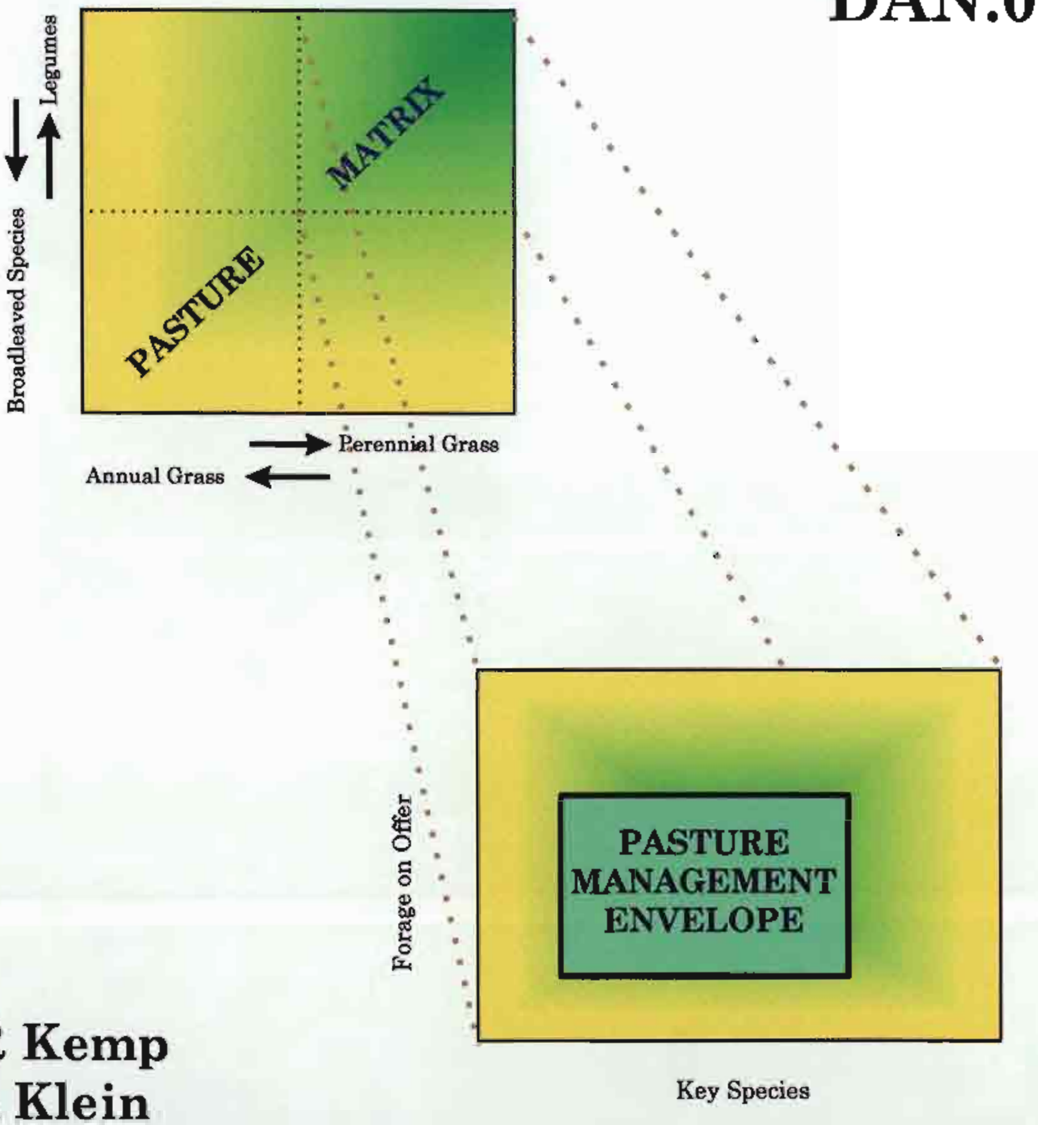
[1] The roman numeral (I, ii, iii, iv) in brackets after each milestone indicates the section of the project, as set out in the objectives in the original contract.

Meat Research Corporation

RESEARCH REPORT
DAN.078



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CRC Weed management systems

TEMPERATE PASTURE SUSTAINABILITY KEY PROGRAM

Development of the
Pasture Management Envelope

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Administrative Details Report (separate)

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Milestones

Abstract

Guidelines for pasture management need to be based upon a sound understanding of the pasture ecosystem under grazing and the results of experiments interpreted in ways that identify the relevant outcomes and can be easily translated into advisory messages for producers.

This project investigated the use of the ***pasture management envelope*** *which embodies the concept that pastures should be managed within boundaries rather than to fixed points and builds on concepts of 'benchmarks'. In the envelope a priority is attached to benchmarks and only two are used at any one time, and both lower and upper boundaries are set where management needs to intervene to correct any adverse trends. The boundaries used in the envelope are for key (desirable) species (% dry weight) and for the forage-on-offer (FOO - t (green)DM/ha). Secondary boundaries can be set for forage allowance per animal unit to enable estimation of stocking rates.*

Data from four grazing experiments were used to define boundaries and tested for one independent site. For these pastures it was considered that the lower and upper boundaries for total (desirable) perennial grasses or total legumes, should be 15 to 60%. The FOO boundaries for a phalaris pasture were 1.5 to 3.5 tDM/ha and for cocksfoot and naturalised native grass pastures 1 to 3 tDM/ha. The lower boundaries were considered more important than the upper ones. Each boundary in reality has some flexibility about it. The better management treatments met the boundary conditions for one parameter often, but less so for two parameters, highlighting the problems in expecting producers to meet a list of benchmarks. The envelope provided a valuable procedure for evaluating treatments and to portray extension messages, but is a sophisticated tool that requires knowledge of pasture assessment and is more appropriate when pastures are in a reasonable state and production and sustainability goals can be set. Further development and use of the envelope is justified.

The ***pasture species composition matrix*** *was developed as a simpler way of describing all the common states that most temperate pastures can exist in. This enabled a concise description of pasture trends under different management practices, from which advisory messages could be deduced and the limitations of some practices identified. It should provide a useful vehicle to use with producers to identify their goals in pasture management.*

Statistical procedures for the analysis of the grazing management experiments were also developed in collaboration with biometricians. Multivariate biplot techniques were used to identify overall treatment effects and the major components influencing a treatment. New splining procedures now enable a general description of time trends in individual pasture components.

The development of rules for pasture management requires that better management practices be evaluated against relevant criteria, rather than simply testing only the statistical significance of results. The framework used for such evaluation needs to embody key concepts for pasture management and provide a means of translating the results through a 'common language' into advisory messages for producers.

The *Pasture Management Envelope* was developed as a concept to guide the work being done within the *Temperate Pasture Sustainability Key Program* funded by the Meat Research Corporation. In broad terms the *envelope* proposes that it is better to manage a pasture within boundaries than to fixed points, such as the 'ideal' legume : grass ratio of a pasture. Management to fixed points is not really practical.

Boundary conditions for the *envelope* relate to the 'benchmarks' being developed for pasture management. However, rather than having a list of benchmarks the *envelope* defines the more important benchmarks and the priority in their application. The boundary conditions for the *envelope* are based on upper and lower limits for key species e.g. perennial grasses and, or legumes, and for the forage on offer. Ideally the later should be determined as green dry matter, though this is not always practical. During the main growing season the majority of the vegetation is usually green. In addition boundaries can be established for the forage allowance per animal unit (e.g. dry sheep equivalents - dse) from which it is then possible to estimate stocking rates. The species and forage boundaries are not considered absolute, but have some flexibility around them and serve largely to highlight when management should intervene to correct any adverse trends.

The boundary conditions for the *envelope* need to consider interactions between species and between species and pasture biomass, as well as implications for pasture growth rates and animal requirements. Data were used from four grazing management experiments to estimate boundaries and then to test the value of the better treatments. Boundaries were first estimated for a well established phalaris pasture and then tested and modified if necessary against degraded and newly sown cocksfoot pastures and a naturalised native grass pasture.

It was found that the better starting point for the consideration of boundaries was the legume content. A minimum of 15% legume was considered necessary to sustain a pasture and it was found that the legume content of pastures often recovered from this level, but if it was lower the legumes were often a minor part of the sward for that growing season. The maximum legume content was that beyond which the stability of the pasture was considered to be a problem. It was set at 60%, though this was rarely reached in experiments.

The minimum perennial grass content was considered the level from which the grass content could increase to a significant component of the pasture in a season or two. This was mostly defined from the perspective of changes in biomass. Experiments have provided insufficient data on the grass content necessary to establish effective recruitment of new plants, to insure the longer-term stability of the pasture. After considering the available data it was decided that 15% perennial grass was an appropriate minimum. The maximum perennial grass content (60%) was established as the level that enabled legumes to be at or above 15%. The boundary levels of 15 and 60% for both legumes and perennial grasses were considered appropriate for the four pasture types studied.

The minimum forage on offer required was considered to be the level that kept legumes above 15%. This varied considerably, around an average of 1.5 tDM/ha for the phalaris pasture. The maximum forage level was assessed as that where the legumes often failed to exceed 15% of the pasture. For the phalaris pasture this was 3.5 tDM/ha. These boundary values were reduced to 1 to 3 tDM/ha for the other three pasture types.

The ability of management treatments to meet these criteria was assessed. The better treatments on any pasture type often met one criteria e.g. legume boundaries, but had less success meeting a second criteria at the same time. This was in part due to the experiment design which only aimed to test tactics rather than complete systems. The tactics tested were often simple contrasts to the control. Theses tactics could be modified to better achieve management targets. The evaluation against criteria though, often suggested where treatments could be modified to improve pasture management. For example on the phalaris pasture the better treatment was one where the pasture was kept short (100-300 mm) during spring. This treatment was often outside boundaries in autumn, suggesting that additional grazing pressure could also be applied in good autumns to minimise rank growth.

The progressive decline in ability to meet increasing numbers of criteria highlight the problem of suggesting lists of benchmarks to producers without any priority attached to them. The proposed *envelope* boundaries were further examined to decide which ones were the more important. It was decided that the lower boundaries were more important than the upper. For instance, in the phalaris pasture the legumes did recover if the perennial grass content reached 70% or the forage on offer exceeded 3.5 tDM/ha. There are still limits, but the upper boundaries could be regarded as having more flexibility than the lower.

The phalaris boundaries were tested against data from a mature phalaris pasture at Tamworth. Under continuous grazing the phalaris failed to persist, but did so under a spring and autumn rest treatment. In that latter treatment the forage on offer was within the proposed boundaries (1.5-3.5 tDM/ha). This raised the query as to whether the effectiveness of the treatment was simply a case of maintaining the pasture above the lower forage boundary or if there is a specific requirement for rests within the seasonal phenological cycle. Similarly in a newly sown pasture at Four Mile Creek there were no treatment effects, but due to the conservative stocking rates used, all treatments kept forage above the lower boundary of 1 tDM/ha. This may have been enough to insure persistence of the cocksfoot during the drought, though additional data suggested there may have been some effects from a declining frequency that plants would have been grazed.

Pasture composition would be influenced by grazing pressure. Various ways of estimating grazing pressure were then considered for a pasture where change had been minimal. Several of these criteria showed too much variation to be useful and all had some theoretical limitations. The better criteria may be to use the available forage per dse.

Limited data on the changes in composition over time were considered. This showed that the composition in autumn or spring remained similar for the ensuing six weeks, but thereafter the relationships gradually broke down and could in fact become inverse six months later. This suggests further management work may need to consider strategies designed to correct any potential longer-term trends.

The *pasture management envelope* is a sophisticated tool that, while simple in concept, does require some knowledge of how to assess pastures and of management options to employ. It does not consider all components in a pasture, or cover all the likely *states* that can exist within a pasture and may be best applied once the more desirable species are a significant part of the pasture and emphasis can be placed on production and sustainability goals. The *envelope* can be easily used to illustrate extension messages.

State and transition models have been developed for rangelands as an alternative and simpler approach, to guiding management decisions, but difficulties were experienced when applying them to higher rainfall zones due to the continuous distributions found. A new *pasture species composition matrix* model was developed based on the four main functional groups that commonly exist within temperate pastures. This matrix plots the ratio of annual to perennial grasses i.e. less desirable to desirable species, against the legume to other broadleaf species (forbs) ratio.

The *pasture matrix* was able to illustrate the composition changes in a pasture over time and the effect of different management treatments. These effects could then be readily simplified for advisory messages. The *matrix* could also be used with producers to help them define their goals in pasture management and to appreciate tactics they could use to get there. Both the *envelope* and the *matrix* could be further refined by applying statistical analyses to them.

When the Temperate Pasture Sustainability Key Program started, procedures for the statistical analysis of treatment effects within grazing experiments were limited. This project was also involved in reviewing and developing procedures for data analysis. The analysis of compositional data has the difficulty that if significant differences are found between treatments for one component but not others, it is not certain if a Type II error has occurred. Multivariate biplot techniques were used to analyse treatments and establish which components were having the major influence on a treatment and how that changed over time. This was the first time such techniques have been applied to grazing experiments. This approach needs further development to establish how it may be applied to the *envelope* or the *matrix*. New techniques developed by biometricians were then used to fit splines to individual components and to provide an analysis of significant differences in trend over time. Details are to be reported separately by Ms H Nicol. These procedures need some further development to provide a statistical analysis of short-term effects within long run data sets.

This work has established how some of these techniques can be used and shown the benefits. They need to be applied to other data sets from TPSKP and then tested in SGSKP.

1. Introduction and Objectives

The Temperate Pasture Sustainability Key Program (TPSKP) was established by the Meat Research Corporation (MRC) to improve the productivity and persistence of perennial pastures in the high rainfall zone of south-eastern Australia. Surveys Many (Kemp & Dowling, 1991; Quigley, 1991) indicate that pastures are inadequate for meat production, as the proportion of desirable species (grasses with high nutritive value and legumes) found in surveys is often low. The low level of perennial grasses (10% in surveys, *loc cit*) is also a problem for ecosystem stability and better management of soil water and nitrogen fluxes, causing concern about the future sustainability of existing pasture ecosystems. The first phase of this Key Program commenced in July 1993 with emphasis on screening grazing management options for better pasture management systems, supported by sustainability and drought studies and some ancillary work (see the Preparation Report for TPSKP for further details). The project reported here is Part 3.1 of Component 3, "Principles, Sustainability and Ecological Studies" within the Temperate Pasture Sustainability Key Program.

Grazing management became a major focus in TPSKP because it has an important influence on the composition and productivity of pasture systems, but little information was available to formulate better tactics and strategies for producers (Kemp & Michalk, 1994). Since considerable information is available on species and cultivars, fertilisers, herbicides and other management tactics for producers to use, there was not the same need for research on these issues as for grazing tactics. However, to achieve the goal of more sustainable, productive and persistent pastures, all these tactics will need to be integrated into pasture / grazing management systems. This integrative role will become the focus of phase II of the Key Program, scheduled to commence in July 1996.

The development of grazing tactics and strategies to improve the productivity and persistence of perennial pastures needs to have a theoretical basis derived from principles. The grazing tactics screened in TPSKP were based on a consideration of the general patterns of phenological development in pastures i.e. regeneration from seeds or buds in autumn, limited development over winter - especially for legumes, flowering and seed set in spring and then survival over summer - particularly in the more winter rainfall dominant regions. The experiments were expected to show significant differences between treatments, but that evaluation of significance also needs to consider what those effects mean from an agricultural perspective. It is important to know if the changes in composition are large enough and rapid enough, to have an impact on productivity and sustainability of the pasture and if the available biomass is sufficient for optimal animal performance.

Management within agricultural boundaries

The *pasture management envelope* project was developed to mesh with the main grazing studies of TPSKP and develop procedures to analyse experiment results for their relevance to 'desirable' pastures and then show how that analysis could be used to provide advisory messages for producers. This was based on the concept of a *pasture management envelope* where the aim is to manage pastures within boundary conditions rather than aim for a fixed point. The boundary conditions need to be based on an understanding of pasture ecosystems, optimising pasture growth rates and also optimising the system for animal performance. Determination of the procedures to define relevant boundaries and the provision of initial estimates for subsequent review became the first aim of this project.

Over recent years 'benchmarking' has become a common practice in many industries including agriculture. Benchmarks have been developed for pasture management and grazing practices. However these are often limited in scope (e.g. Allan, 1994) with no priority attached to the long list of benchmarks proposed, put forward with no guidance for producers on their relative importance. Many of the proposed 'pasture' bench marks have been derived solely from animal production considerations without any acknowledgement of implications for pasture performance. This has arisen because the benchmarks were first derived in environments such as New Zealand where pasture persistence and productivity are not major problems. One of the aims of the *pasture* *management envelope* is to identify key benchmarks, understand how they may interact and assess their implications for commercial use. Implementation does require that producers are familiar with the basic benchmarks being proposed.

When the Key Program was proposed the *pasture management envelope* was used as a concept of what TPSKP aimed in part to achieve. As this concept had not been explored in great depth an additional aspect of this project was to make a judgement as to the usefulness of the *pasture management envelope* in technology transfer. Should it remain as a concept to emphasise the aim of managing pastures within boundary conditions, or should there be a continuing effort to quantify those boundaries for the most common pasture conditions? This is a separate issue from using the *envelope* to evaluate research results.

The development and place of the *pasture management envelope* was the main component of this project, but several other components were also involved.

Filling the data gaps

The main data sets available to develop the boundary conditions for the *pasture management envelope* were those from the grazing studies. These studies employ an open communal grazing design at a common stocking rate, on established pastures. Initial variation in pasture composition across the sites was often limited and only developed with time. One of the important boundary conditions for managing pastures is the grass : legume ratios as this forms the basis of sustainable productive pastures. To supplement the data sets from the main studies, additional experiments were designed to produce variation in the grass : legume ratio and then follow in the short-term (three months) any impacts on subsequent pasture growth and composition. These studies were also used to provide a test of the resilience of the pasture to change and to assess if there was a wide tolerance in the grass : legume ratios that were acceptable in a pasture.

Response to grazing pressure

Sustainable grazing management involves managing the interaction between animals and the pasture. Many producers only adjust stocking rate based on the condition of their animals, but this often means that pastures have suffered an adverse impact before the animals have. It is important to be able to describe animal impacts on pastures in terms of the effect on pasture composition and productivity. The impact of animals is usually managed through adjusting stocking rate. However this does not take into account that both animal requirements and pasture growth rates will vary through the year. An additional aim of this project was to develop procedures to estimate grazing pressure, to understand how that would influence pasture responses and thence the management boundaries and to assess how that information can be used in the transfer of pasture management information to producers.

New data analysis methods

When TPSKP was being established it was acknowledged that existing statistical analyses were inadequate and that new techniques would need to be developed for the analysis of results from the grazing studies. Procedures available at that time had considerable limitations. The better procedures routinely used, involved standard analyses of variance on individual components at single harvests, or over time. With this approach interpretive problems can arise. For instance, an analysis may show significant treatment differences for one component in a pasture, but not for others, it is then uncertain if a type II statistical error has occurred. The role of spatial analysis in analysing compositional data had also not been resolved.

The grazing studies involved repeated measures over time, but the time-series analyses available when TPSKP was initiated, did not use functions with enough flexibility to cope with the common seasonal patterns in pasture production. The development of better statistical procedures could also help decide on boundary conditions for pasture management by distinguishing significant effects. A further aim of this project was then to develop a strategy for the analysis of data from the grazing management experiments. Subsequently a project was organised with Ms Helen Nicol, Biometrician at Orange, to do the statistical analyses for the grazing studies. These two projects then worked cooperatively towards this end.

Plans for linking pasture management with animal production

The ultimate goal of TPSKP was to develop improved pasture management practices which enhance pasture production and sustainability, reduce the costs of maintaining productive pastures and to show how this information can be used to improve animal production. The data analyses discussed above aimed to integrate the information on how to manage pastures for improved plant performance. The final part of this project was to consider how to integrate that information with animal production practices aimed at optimising per animal performance for meat production. However during 1995, planning for Phase II of this Key Program took over this role and it was decided with MRC approval, to drop this component of this project. Each grazing experiment in Phase II will need to consider the animal production system in relation to pasture management strategies.

Changes to the original plans

As discussed, this project was designed to work in closely with the grazing studies in TPSKP. Those studies did not start as early as planned and this then meant that the additional experiments, designed to investigate in more detail the effects of legume : grass ratios on pasture performance were also delayed. These experiments were established at the same sites as the grazing studies so that data from the two experiments could be combined. The initial delay was not a major problem except that it then coincided with a significant drought and legume growth was much poorer than would normally occur. The data obtained is discussed in this report, but in general the information obtained from these studies was less than expected.

During 1995 the MRC commenced planning for Phase II of the Key Program. This rendered unnecesary some components of this project, especially the proposal to develop plans to link pasture management with animal production as outlined above. The MRC also decided to hold a review into this project in late 1995 which changed the direction of the project. Some preliminary work on a *pasture species composition matrix,* designed to provide a broader view of pasture *states* and *transitions* was presented at that review and it was decided to develop those ideas further. After considering the outcomes from that review and the timing of developments in Phase II the MRC decided in early 1996 to dispense with the remaining milestones in this project and requested that a final report be prepared earlier than planned. This was done so that any recommendations for future directions in this area of work would be available as plans are developed for Phase II. Originally a final report was not due until the end of 1996. These later changes added extra components, curtailed some other activities and lessened the amount of work in a few areas.

During the course of this project progress reports were circulated to those involved in the TPSKP grazing management studies. This was done to elicit responses to the direction and outcomes from this research. Less response was obtained than anticipated. This was attributed to the limited data analyses that other sites had done at those times and that they had not started to evaluate their own data in terms of agricultural relevance. This emphasised a need to assist and encourage the compilation of results to ensure that the objective consideration of results commenced at all sites as soon as possible. Many site managers probably won't consider their results until after the TPSKP grazing studies conclude in late 1996.

In the original proposal, the Research Officer employed under DAN.074 (Trevor Klein) was to be responsible for much of the work in this project as well as assisting in the management of the main experiments at Orange. This was done, but the emphases among these duties did change due to requests from the pasture research network in TPSKP. The Research Officer became the resource person able to provide advice to others within TPSKP on a range of issues concerned with data handling, processing and analysis. He visited all the grazing management sites in TPSKP to help with data organisation and was then very closely involved in processing that data with the Biometrician at Orange. This became a larger task than originally envisaged due to the limited biometrical knowledge and support at some sites, but was worthwhile as data analysis for most sites is now well advanced and when Phase I concludes in late 1996 the final data analyses will proceed very efficiently. Data analysis in TPSKP is arguably more advanced than often the case with other large projects. There have been clear benefits from having a research officer available to assist with data, helping develop the methodology and communicating with Biometricians, while providing a valuable link across all field sites.

Structure of this report

This report contains three main chapters. The first deals with the *pasture management envelope,* the second with the *pasture species composition matrix* and the third with the statistical analysis of data from the grazing studies. Recommendations are summarised in a concluding chapter. Appendices summarise the budget and list the milestones and other information.

2. Pasture Management Envelope

INTRODUCTION

Pasture management aims to maintain a ‘desirable’ pasture for animal production over the short- to long-term. The definition of a ‘desirable’ pasture will vary with pasture type, season, region and animal production systems, but in general encompasses the need for a reasonable proportion of desirable species producing a suitable amount of quality biomass to sustain pasture growth rates and animal intake. Pastures are complex and can be monitored at different levels. These levels influence the growth and development of the pasture as well as how animals respond to the forage produced. Within this project an objective was to simplify the complexity of a pasture to easily monitored and understood components.

The *pasture management envelope* (PME, Figure 1 & TPSKP Preparation Report) has been devised as a means of evaluating the results from research and of focusing on when to make pasture management decisions, in order to maintain a desirable pasture. The central concept is to manage a pasture within boundaries rather than to a fixed point. It has similarities to the use of benchmarks (e.g. Allan, 1994), but establishes a priority among them and links two or more, important management criteria. Management treatments that keep a pasture largely within the boundaries are considered satisfactory. However, once the state of the pasture reaches an envelope boundary, or is outside the envelope then management becomes more important. The concept of a *pasture management envelope* was first proposed by Spain *et al* (1985) for the management of tropical legume cultivar experiments and then subsequently developed for temperate pastures by Kemp (1991). The use of the *pasture management envelope* applies more to paddock than property management as this is often the unit for decisions on pasture management used by producers.

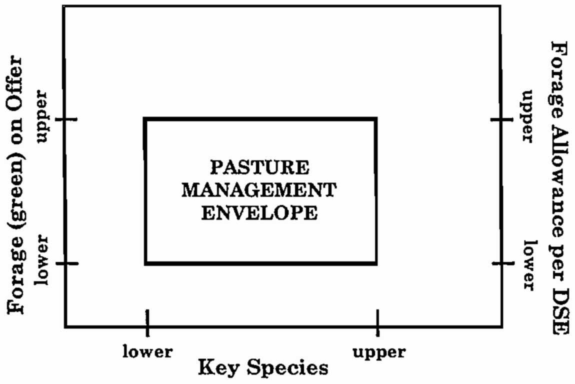

Figure 1: The Pasture Management Envelope as a function of limits for key species and green forage on offer. Forage allowance enables the envelope to be tailored for different classes of livestock and to estimate stocking rates.

The optimal characteristics of a desirable pasture will vary throughout the year. The main focus of the *pasture management envelope* is on periods when active pasture growth is possible (usually autumn to spring inclusive across southern Australia), and to a lesser extent on dry seasons when the aim can be to simply maintain ground cover and, or soil seed reserves. The boundary conditions considered for the *pasture management envelope* were the biomass i.e. ideally the *green* Forage-On-Offer (FOO), and composition of key species required to optimise pasture growth, long-term development and sustainability and animal intake and production. The *envelope* provides a simple way of achieving some integration between these components, but more sophisticated tools may ultimately be needed. It also aims to define objective values rather than relying on subjective terms e.g. that a component is too low or too high. This section of the report considers the basis for defining boundaries for pasture managment, the criteria used and examples of their application. Changes in pasture composition and forage-on-offer are often in response to grazing pressure and procedures for defining the grazing pressure are also considered.

The boundaries of the pasture management envelope

The concept of a *pasture management envelope* was developed around monitoring two components of a pasture; first the key species which may have a major influence on pasture productivity, and second the pasture biomass.

These two components remained as the major factors after further development of the *envelope*, though often it was found useful to use two species defining overlapping *envelopes* to better appraise trends. Several issues which needed to be considered when defining these components are discussed below.

In practice, boundaries are unlikely to be absolute or narrow, but would have some variation about them. Their main use is to define the tolerable limits for a pasture and identify when management decisions are needed. The boundary conditions for management of a pasture are not absolute as mostly we are dealing with continuous distributions.

Pasture species: The *pasture management envelope* concept assumes that for many pastures one or two species have the largest influence on the growth, development and sustainability of the pasture. These key species should then be monitored in experiments, or paddocks on farms, to assess if the pasture is being managed effectively. The key species could be a single species such as phalaris, or a functional group such as all the legumes. Initially, it is suggested that pastures be analysed in terms of the four functional pasture species groups common to most temperate perennial pastures : desirable perennial grasses, annual grasses, legumes and other broadleaf species. Most of the important species in temperate pastures can be categorised into these four groups, the main exception being the less-desirable perennial grasses such as serrated tussock and wire grass. Other ways of handling these functional species groups are discussed in the chapter on the *pasture species composition matrix*.

The original concept (Kemp, 1991) considered that the legume content is the driving variable. This was based on the evidence that many pastures have low growth rates or are dominated by weeds, unless the legume content is adequate. Other species could though, be the key for different circumstances. For example; perennial grasses have a major role in stable, sustainable pastures and can be the more productive component, once fertility levels are reasonable. Perennial grasses may be a better primary key species as evidence from TPSKP suggests that they are influenced as much by management as the climate, whereas legumes seem to be driven more by the climate than management practices, in the medium-term.

The use of one species as the key in the *pasture management envelope*, does not necessarily mean that other species are ignored. There is often a complementary relationship between species. For example; legume proportions can be inversely related to those of the grasses, such that as legumes increase, grasses decrease and *vice versa*, unless the pasture is very weedy. At this stage we have limited information on how the competitive relationships operate between the main functional groups within pastures. When these are better defined it should then be possible to use a single species to define the *envelope* and have a reasonable understanding of the likely trends in other components. The chapter on the *pasture matrix* investigates one procedure for evaluating interactions between the major components of a pasture. Experiments in TPSKP were not established to derive such relationships, but when the grazing studies conclude it should be possible to explore some of the general relationships between pasture species using the available data. Further work in this area should be done in Phase II. We need to establish the consequences of changes in a key species. What happens to the proportions of other species when the key species increases or decreases? Are the paths the same?

It is important to define both an upper and a lower limit and hence the desirable species should be the key species when using the *pasture management envelope*. For less-desirable species the main interest is usually to confine them below an upper limit which can be tolerated. Consideration of what this limit should be for less-desirable species will influence the limits chosen for the desirable components.

Boundary conditions for key species are defined using the percent composition on a dry weight basis, rather than population criteria such as plant densities etc. Expressing the data on a biomass basis enables direct linkages to be made to pasture growth rates and animal performance. Measurements of species biomass can also be more efficiently done using procedures such a Botanal (Tothill *et al*, 1992) which producers can readily understand and use, than the more tedious techniques for basal cover and plant, tiller or stolon densities.

The upper and lower limits (as percent composition) for key species to sustain a productive pasture in the short- and long-term, would include some judgement of the constraints they may place on rehabilitation e.g. what is the lower limit for perennial grasses below which it is not practical to consider rehabilitating the pasture by grazing management, what is the minimum legume content required to fix enough nitrogen to sustain pastures, or what would be the upper limit of annual grasses and weeds before pasture productivity declines and cannot be reclaimed? These limits could be decided on rates of change relative to initial starting conditions as it is unlikely that models based on thresholds and step changes (e.g. *state & transition* models - see chapter on the *pasture species composition matrix*) would apply.

The available literature to define boundary conditions, is very limited except for perennial ryegrass and white clover. Data from New Zealand and the United Kingdom can help to provide suitable values. There are very little data available for most of the pasture types being studied within TPSKP.

As this project and most of the experiments were short-term, it was decided to emphasise key species and the short-term responses of the pasture e.g. within a season, or year. Some longer-term data were available from two studies started at Orange some years earlier than TPSKP.

Pasture biomass: The biomass of a pasture influences it's performance and animal production in several ways. Absolute biomass determines ground cover and the *space* available for competing species. However from a functional perspective the amount of green biomass is more important. The growth rate of a pasture is directly related to the amount of green tissue, especially the leaf biomass. Animal production is also determined more by the amount of digestible green tissue in the pasture than total biomass. In developing functions to aid pasture management the amount of green biomass is preferred as an independent variable, though it is not always available and as found in TPSKP visual estimates of the percent green are one of the more problematic measurements. The main exception to the use of green biomass is in dry seasons when total biomass is important for maintaining ground cover and it's impact on factors like seedling regeneration and erosion. The main focus of the *pasture management envelope* is on periods of active growth because it is at this time that grazing tactics have the most impact on pasture composition.

Pasture growth rates: Pasture growth rates depend upon both species composition and green biomass. In an ideal pasture the growth rate should be maintained near optimal for the environment for most of the time, while also retaining the desirable species as major components. The optimal range in biomass and key species to sustain higher pasture growth rates needs to be assessed when considering the boundary conditions for the *pasture management envelope*. In practice, data on pasture growth rates are though, used as a check on the composition and biomass boundaries to establish if the range in boundaries has any adverse implications for pasture growth.

We need to examine how the pasture growth rate, biomass and species composition vary with season, in the pastures commonly used. Are there any common elements and how far can we go in using general relationships to define the optimal *pasture management envelope*? Some accounting is needed to allow for climatic effects. A simple plot of pasture growth rates against biomass or composition often results in a cloud of points due to variation in temperatures and moisture conditions during the different periods of measurement. However such data can still be useful for estimating the general relationships with pasture growth rates. The upper boundary for such a plot of points represents the relationship between growth rates and pasture parameters when other constraints are minimised.

Animal requirements: In most cases, pastures are grown and managed to feed animals. An ideal pasture maximises the growth rates of the animals e.g. for elite lambs, or maximises the value of the animal product e.g. fine wool. In this project and the first phase of TPSKP animal output was not measured. However, animal performance does need to be considered when defining the boundaries for pasture management.

Animal requirements and performance on some pasture types e.g. perennial ryegrass / white clover, are reasonably well understood. Published data from those sources can be used to help define the pasture state needed to satisfy animal requirements. Criteria to be used include the pasture composition and forage-on-offer to optimise intake and animal growth rates. These values can then be overlaid on those derived from consideration of pasture parameters, as outlined above, to see what compromises are needed. The work done in setting up the original *envelope* suggested that in general, there may not be any major conflicts. Conflicts may arise more where the aim is to ration stock by keeping pasture biomass low as this could have adverse affects on some species. Similarly when high values of FOO are required for some classes of livestock e.g. cows and calves, as this could lead to dominance of taller, more aggressive perennial grasses. These circumstances will need to be defined.

Assessment of grazing pressure

A major part of the Key Program is concerned with gaining a better understanding of the interaction between grazing and pasture composition when different grazing tactics are used. There have been previous studies of this interaction and some general effects are known. At low grazing pressure animals graze selectively which can adversely effect desirable components of the pasture, particularly if they are only a small proportion of the sward or grazed at a sensitive stage in their phenological cycle. As grazing pressure increases, selectivity decreases as does the amounts of Forage-on-offer (FOO) available for animals and for producing the substrates necessary for plant growth. Shorter pastures tend to have a higher legume content than tall pastures. While these general effects are known, our understanding is not sufficient to enable reliable predictions of the outcomes of grazing interactions. The Key Program includes some measurements that can be used to assess grazing pressure and its interactions with pasture performance. This section outlines those measurements and suggests how they can be used.

Grazing pressure can be defined in several ways:

1) One simple way is to consider the stocking rate expressed in some common units e.g. dse/ha (i.e. dry sheep equivalents) or animal grazing days. This definition does not take into account that at a constant stocking rate the grazing pressure on the pasture can vary enormously with fluctuations in pasture growth rates and FOO.

2) A second definition is to link stocking rates with resource availability e.g. dse per kg of available dry matter (total, or preferably green), or the inverse (kg DM per dse), to correct for the variability in available FOO. This definition is quite workable within simple systems and is suitable for analysis of the control treatments within the grazing management experiments. It could also be used for other treatments where there is independent evidence that animals were grazing those treatments at the same intensity and frequency as the control. Where that is not possible, grazing pressure needs to be estimated from data collected within a treatment. This definition does not specify if the pasture is producing sufficient forage to meet current needs as the available FOO may be more a consequence of carry-over from previous seasons. A modified index is to express available FOO as the pasture growth rate per dse (kg DM per ha per dse) to assess if current stocking rates are above or below current pasture production rates. This index does not then consider the total amount of forage available.

3) Peter Doyle (Doyle *et al*, 1994) proposed a definition of grazing pressure which can be estimated from using cages within plots or paddocks, and which provides an estimate of current pressure from animals on a pasture.

Grazing Pressure (GP) = Pasture Consumption Rate (PCR) / Pasture Growth Rate (PGR) (i)

This definition provides an index of GP. When $GP < 1$ the pasture is 'lightly' grazed and FOO increases, when $GP > 1$ the pasture is 'heavily' grazed and FOO decreases.

This method of estimating GP is attractive and fits within the protocols for the grazing management experiments. Cage data is collected to estimate pasture growth rates so little extra work is involved in obtaining and analysing data to estimate GP. For each estimate of GP plot and cage FOO for that harvest (H_{t2}) and for the previous harvest (H_{t1}) are available.

To estimate GP using equation (i), from this data the calculations are:

$$\textbf{PGR (Pasture Growth Rate)} = [\textbf{Cage FOO}(H_{t2}) - \textbf{Cage FOO}(H_{t1})]/\textbf{days} \qquad \text{(ii)}$$

and;

$$\textbf{PCR (Pasture Consumption Rate)} = [\textbf{PGR} - [\textbf{Plot FOO}(H_{t2}) - \textbf{Plot FOO}(H_{t1})]]/\textbf{days} \qquad \text{(iii)}$$

The calculation of GP can sometimes exclude the division by time, as all harvests are over the same time period, though it usually makes more sense to express this data on a daily basis. GP needs to be plotted etc., for the mid point of the time interval between harvests.

The main problem with the use of this third definition of GP is sampling. Cages only sample a very small proportion of a pasture within a plot and are subject to high variability. Animals range across the whole area and do not always graze evenly. Patch grazing is often evident. In the grazing management experiments the control stocking rate was set in collaboration with local producers, which often meant that stocking rates were conservative. Under these conditions animals grazed selectively for a large part of the growing season. One would then expect estimates of GP to fluctuate over time and early analyses of the data from experiments at Orange showed that was often the case. Consideration of GP then needs to be in terms of the medium to longer-term trends e.g. relative to the control, and probably averaged over seasons. The interval between cage measurements also needs to be short enough that the pasture inside the cage does not change substantially from the pasture on the plot, but long enough to obtain a meaningful estimate of net pasture growth. If intervals are too long climatic conditions and, or phenological development, can change and cause losses in FOO that result in negative estimates of pasture growth rate which pose problems for interpretation.

The use of cages to estimate consumption rates is difficult because of the sampling problems discussed. An alternative approach is to predict consumption rates based on the estimated animal requirements using standard tables, or programs such as Grazfeed. This is likely to show less variability and would be useful to explore general trends over time on a paddock scale, but would still not overcome the problems of estimating consumption on plots in the short term, due to the grazing patterns of animals.

A limitation of this procedure is that GP does not provide much information about animal pressure in relation to available forage. Animal intake will depend upon the total amount of forage available. The main use of this measure of GP is to assess the amount of 'pressure' the pasture is under and the proportion of new growth that is likely to be utilised.

Data on estimated grazing pressure provides supplementary information that is useful for understanding the impact of treatments. The grazing pressure estimates can indicate when pastures were under significant pressure from livestock and when there were opportunities for selectivity. Measurements of FOO without considering animals are not always the best guide for animal impact as they measure total biomass, which can include the carryover from earlier periods. Grazing pressure is a short-term estimate of the ability of the pasture to provide current animal requirements for green forage.

METHODS

Two approaches were used to define the boundary conditions for management. The first was to take an overview of the results over time from an experiment, consider which treatments resulted in the better, or worst pastures and use the data on biomass and composition to define boundaries for management. The second method was more complex and sought to use the variation generated among treatments to define internal relationships within different pasture types. These relationships were explored to see if it was possible to predict trends in the pasture e.g. if legumes are low in autumn, will they be so in six months time given a specified management, what were the levels of biomass and, or composition that sustained reasonable pasture growth rates? The investigation of these relationships was supported by supplementary experiments.

This project estimated boundary conditions for management using data from a high-input, productive phalaris pasture experiment at Orange, a degraded cocksfoot pasture at Newbridge, a newly sown cocksfoot pasture near Four Mile Creek and a *Danthonia, Microlaena* pasture near Cargo, within the Central Tablelands of New South Wales. The first two experiments had been established for some years prior to the start of TPSKP and provided an opportunity to also assess some longer-term trends, though in general because of the nature of this project emphasis was on short-term effects.

Supplementary experiments

Experiments were located on the same pastures and sites as used for the two new TPSKP grazing experiments in Central NSW (DAN.074) i.e. Four Mile Creek and Cargo. These experiments started in autumn 1994 on a newly sown cocksfoot based pasture and one based on native perennial grasses. In each season of the year an area of pasture adjacent to the main experiment was managed to try and create variation in biomass and composition, particularly grass : legume ratios.

In the supplementary experiments the aim was to create a range in proportions of key species * biomass and then measure the effects of these different base conditions on pasture growth rates and composition through the following season. An area of pasture was selected for study where the perennial grass proportion was from below to above that for the control treatments. Plots (2 * 2 m) were marked out and the proportions of perennial grass then estimated. Legume seed was broadcast in autumn to plots in inverse proportion to the perennial grass components. This was to create a series of treatments where the legume content decreased as the perennial grass content increased. The aim being to establish at least three levels of composition i.e. 10, 30 and 50% legume with 50, 30 and 10% perennial grass respectively. If necessary the perennial grass and, or legume content was to be reduced using a herbicide wand (& glyphosate). As it would not be easy to rapidly increase the perennial grass proportions, the sites selected included some areas with above average proportions. Two of these sites were established at each grazing experiment, to be used alternately over seasons e.g. the first site being used in winter, the second in spring, then the first again in summer and so on. Unfortunately as already mentioned the drought had a large impact on these experiments. Legume establishment was considerably less than expected and reduced the amount of useful information.

To achieve differences in biomass, plots were excluded from grazing for about six weeks, before the start of an experiment. This was to increase pasture biomass above the control treatments, then just prior to starting the experiment, plots were to be mown to different heights (meter readings were taken before and after mowing) to establish differences in starting biomass. The lower levels of biomass established aimed to be below the concurrent control treatments on the main experiment. The variation in biomass was to be established in a factorial arrangement with the variation in composition. The number of heights that plots were mown to depended upon season. Unfortunately the dry seasons made it impossible to establish more than two heights at best, even in spring where provision had been made for up to five mowing heights. The target heights for mowing proposed were 2, 5, 10, 20 and 30 cms. There were two replicates for each composition * biomass (i.e. mowing height) treatment i.e. 30 plots per experiment. Measurements and samples were taken every three weeks, during periods of active growth and six weeks when pasture growth rates were low, within each 12 week cycle to describe the changes in composition and pasture growth rate that occurred. Botanal and destructive sampling procedures were used to estimate composition while yield estimates were done with the falling plate meter. Within the 2 * 2 m plots five sample positions were used. Sampling times coincided with the measurements of pasture growth etc., on plots and in cages on the main (adjacent) experiment. These experiments were repeated in each season for two years.

Mowing was used to establish differences in biomass for each of these experiments as it was difficult to effectively achieve different levels of grazing in the required patterns across a range of plots of different compositions. The results could (potentially) differ from the responses of a grazed pasture. To check for any such effects, the data from these experiments were compared with those from the main experiment to see if there are any significantly different trends. As there were no significant differences the data were then combined for subsequent analyses.

RESULTS

Boundaries for management of a productive phalaris pasture (Orange)

The data obtained in the WRDC/IWS project DAN 28 and continued under TPSKP have been used to assess the boundary conditions for management of a productive phalaris pasture. The values derived from considering boundary conditions appropriate to maintain a more desirable composition in the pasture i.e. a reasonable proportion of perennial grass and legumes, represent an initial first step that will require modification for different pasture types. In phase II it will be important to consider these boundaries in relation to optimal animal production, though an initial analysis suggests there may not be any conflict.

The values considered here are based on a review of the trends in composition and standing biomass across a range of treatments. The aim was in part, to establish rules that could assist in the analysis of data from other experiments. The values suggested were put forward to participants in TPSKP to see if they apply to other data sets. No alternatives have been suggested to date.

Key species limits

Pasture phases: Within the phalaris pasture studied, the key desirable species were white clover, subterranean clover and phalaris. The pasture has gone through several stages in the experiment to date. Stage I was when the pasture was young, white clover was the dominant legume and the proportion of phalaris was expanding on most treatments. Stage II was a period of short term drought when subterranean clover became the dominant legume and phalaris developed larger plants. Stage III saw a return to higher rainfall, especially over summer and the return of white clover as the dominant legume, while phalaris increased to 80% of the pasture on some treatments. During this third stage, pasture production was high and usually in excess of utilisation. Stage IV has been during the 1995 drought with subterranean clover as the major legume. Stage V has seen a return to

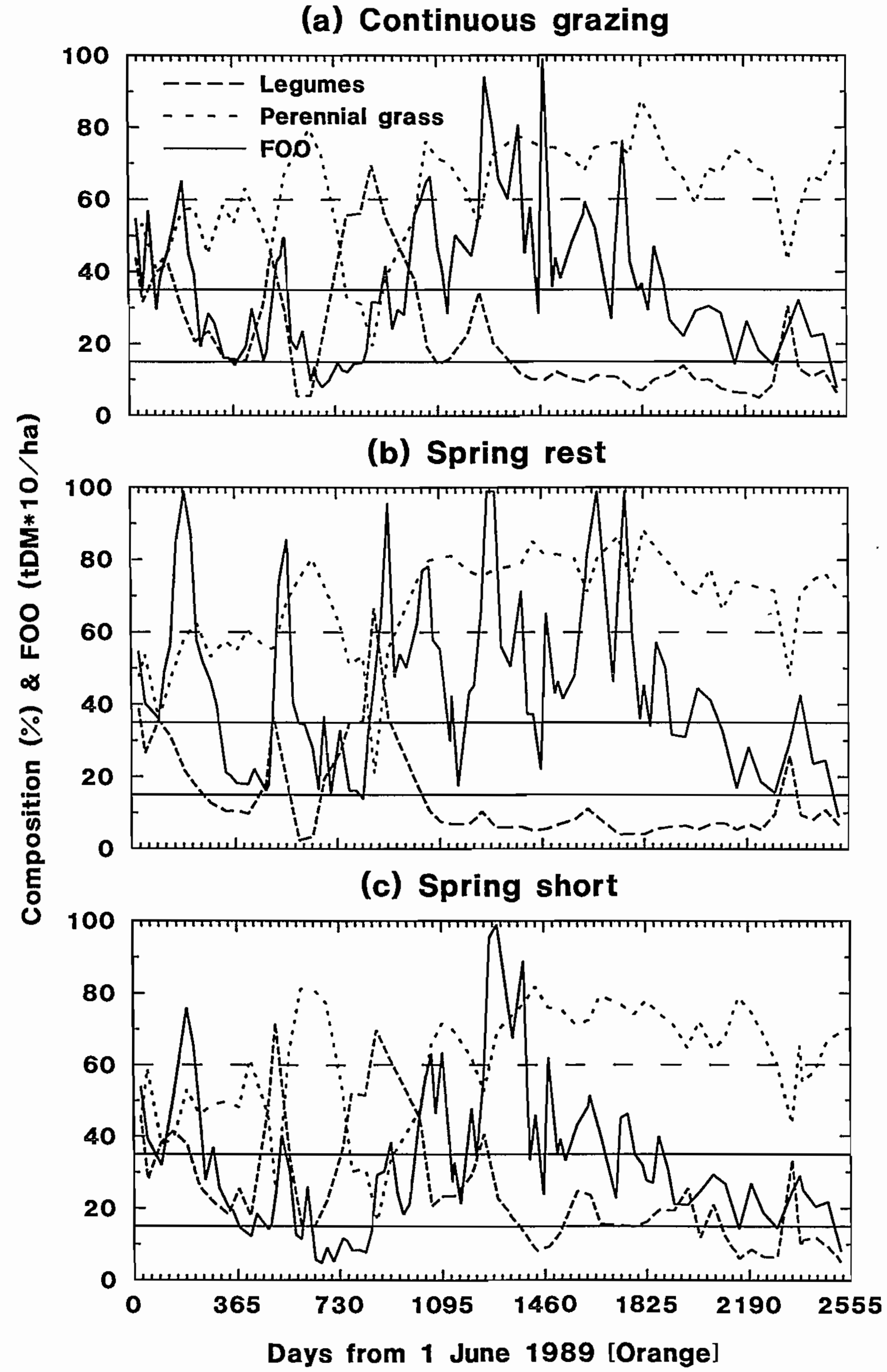

Figure 2: Perennial grass and legume content and forage on offer (FOO) over seven years for a phalaris pasture at Orange. The solid lines denote upper and lower boundaries for management of FOO. The lower solid line denotes the lower management boundary for species and the dashed horizontal line the upper species management boundary. Data are for three treatments.

better rainfall, more white clover in the pasture and the phalaris content on all treatments continuing to increase to a high proportion (> 60%). These different stages in the life of the pasture have been used to consider appropriate limits for key species.

The changes in perennial grass, legumes and FOO over seven years are shown in Figure 2 for the control and two contrasting treatments. The general increase in perennial grass and decrease in legumes under continuous grazing is evident. FOO followed the seasonal patterns in rainfall being at a minimum during the droughts of 1991 and 1995. The legumes were often at a minimum in early autumn prior to the germination of subterranean clover and that data was discounted when considering boundaries.

Legume minimum: An overview of the data showed that when either legume species accounted for 5-10% of the pasture they could in some years, increase their proportion under conservative stocking rates, provided other conditions were suitable for growth. These low levels often applied in autumn and it was considered that a legume content below 15% by the end of winter, early spring would not be adequate for nitrogen supply and could also be selectively grazed, further reducing their ability to contribute to pasture production. When above 15% during the growing season, the legumes made an important contribution to the pasture for some months. *A lower limit of 15% was then set as the value for minimal legume content that should trigger a management response.*

The main treatment that kept legumes near or above this lower limit (lower solid line in Figure 2) was the spring short and this particularly applied during the later years when legume contents were low. This treatment involved keeping pasture growth in spring between 100 and 300 mm in height by using extra livestock when required. A key part of the treatment was to apply extra grazing pressure before pastures became rank and this often doubled the legume content in spring, especially for white clover. There was less effect on subterranean clover.

Legume maximum: There were not many occasions where the legume content was very high. Legumes did reach 50-60% of the pasture a few times in the early years (Fig. 2) in the spring short and herbicide treatments where weed invasion was minimal. It was considered though, that if the legumes exceeded 60%, the pasture would become unstable and would be liable to significant invasion by nitrophilous weeds. *For legumes in a phalaris (or other vigorous perennial grass) pasture, the maximum limit proposed was set at 60%.* Management at this limit (upper dashed line on Fig. 2) may not, be as critical as at the lower limit, provided the phalaris component is within its limits. Management to limit legumes below 60% would probably only apply for pastures other than those dominated by phalaris.

Phalaris minimum: Phalaris was the dominant species in the pasture. In some cases phalaris was reduced to around 20% and recovered to higher levels (Fig. 2c). This recovery was attributed to the associated high legume content which presumably fixed a substantial amount of nitrogen that the phalaris was able to effectively use for growth. A limit of 20% is close to the 15% set for legumes. *It is proposed that a minimum limit for phalaris of 15% would be the boundary to activate management decisions in a productive phalaris pasture.* Recruitment of phalaris has been difficult to achieve in TPSKP and it could be difficult to improve the proportion of phalaris in a reasonable time if the proportion fell below 15-20%. However, data from the degraded cocksfoot pasture (discussed later) suggests that other perennial grasses can recover from this low level in less productive pastures.

Phalaris maximum: Phalaris was clearly able to dominate the pasture, reaching 80% in some treatments, if management allowed (Fig. 2). The maximum limit for phalaris was set by determining the proportion of phalaris in the pasture that allowed the legumes to exceed 15%, particularly early in the growing season. Examination of the data indicated that in most treatments, both white and subterranean clover often only exceeded 15% when phalaris was around 60% or less. *It was proposed that the maximum limit for phalaris be 60%, at which stage management should intervene.* Above this limit the legumes are unlikely to be significant contributors.

In the spring short treatment the legumes accounted for 15-20% of the pasture when phalaris was around 70% in the later years of this experiment (Fig. 2). In contrast the control had a similar phalaris content, but 5-10% less legume. FOO was lower on the spring short treatment which suggests the interaction between all components is important to achieve satisfactory management of a phalaris pasture. If FOO is adequately managed then some tolerance in the upper limit for phalaris may be possible.

Species limits: The review of the data for the phalaris pasture from DAN 28 has suggested the key species limits of 15% to 60% for white and subterranean clover and phalaris. The similar values for these different species was derived from independent evaluations for each species, but having common boundaries does provide some convenience. The broad limits allow some flexibility in the management of composition in the pasture.

FOO limits

The *envelope* concept is two dimensional, combining the percent composition and forage yields (standing biomass or Forage-On-Offer, ideally as green DM) required to sustain a desirable composition. It was considered that the more important boundary conditions for FOO should be set first in relation to the lower limit for key legume species, then take into account any effects on the perennial grass.

FOO minimum: The minimum FOO was set at the level required for legumes to exceed 15% of the pasture. Emphasis was placed on the measurements taken during the earlier part of the growing season (autumn). Values ranged from 1 to 3 t DM/ha with a median of 1.5 tDM/ha. *It was proposed that the minimum FOO for management of a phalaris pasture be 1.5 tDM/ha.* Lower values could be possible, but pasture growth rates and ground cover, would be less. This lower limit is shown in Figure 2.

FOO maximum: The maximum FOO was assessed as the values across treatments where the legumes failed to exceed 15% of the pasture. Again emphasis was placed on measurements early in the growing season. The data from stage III, when pasture utilisation was less, was very useful for setting this upper boundary. A range of values was obtained and it was decided that a value at the lower end of the range was more relevant, because the higher values suggested by a few treatments were clearly out of range for other, more desirable treatments. *The maximum FOO proposed for a phalaris pasture was 3.5 t (green) DM/ha.* Pastures at this level were able to sustain legume contents within the desirable range. This upper limit was derived from a well fertilised phalaris pasture in a higher rainfall site, where the legume content was often high. If the legumes and, or fertility of a site are low then a slightly higher limit may be necessary in spring, especially with the more winter active phalaris cultivars. Such modifications could be established by considering other data sets.

FOO limits: The limits for FOO derived from this analysis (1.5-3.5 t DM/ha, Fig. 2) are greater than those usually suggested for perennial ryegrass, white clover pastures (0.5-2.5 t DM/ha, e.g. Nicol *et al*, 1987). In drier climates with less dense swards some lower values may apply. Total dry matter is shown on Figure 2, but this was often 70-80% green.

FOO and composition effects on pasture growth rates

The data from the experiment was used to assess the impact of FOO and composition on pasture growth rates. A generally flat response surface was found over the range in boundary conditions proposed above. It was concluded that the suggested range was appropriate to optimise pasture growth rates.

FOO and composition for animal production

Animal intake increases as the available biomass per head increases up to a limit determined by physical capacity and pasture digestibility and then remains constant. The *pasture management envelope* can be constructed to include a forage allowance for livestock (Figure 1). This is useful for estimating stocking rates based on current FOO. The boundaries in FOO and composition, where animal intake could be sustained over the likely range from maintenance to *ad-lib* feeding were considered in relation to the available, limited literature. Most of the available data is for perennial ryegrass / white clover pastures in New Zealand and the UK. This information (e.g. Nicol *et al*, 1987; Dove, 1995) suggested that a range in FOO of 500-1,500 kg (green) DM per ha would be suitable as would the range in legumes and perennial grass from 15-60% for each. However the structure of a phalaris pasture is different to perennial ryegrass, with lower leaf densities and often, a more upright canopy. The range in FOO proposed (1.5-3.5 t (green) DM / ha) was not seen as posing any constraints on animal production, as animal intake would be close to the maximum in most circumstances. This would fit with the apparent desire of many producers to have a high per head performance from their livestock, rather than simply maximising per hectare output. Lower values for the range in FOO could still sustain productive livestock systems but it was considered that would be very difficult to achieve in spring and may not be achievable at the conservative stocking rates employed by most producers.

Grazing pressure

For the phalaris based pasture at Orange cages were used in several treatments prior to the commencement of the TPSKP program. The GP (equation I) was shown to vary from very low in spring to two during mid winter and late summer periods, for continuously grazed treatments. The dynamic growth of phalaris on a fertile soil, in spring, from a set stocked pasture insured that there was a low PCR during this growth period, relative to PGR, hence a low GP. The spring short and herbicide treatments resulted in similar effects (DAN 28 Report). Following the incorporation of this Phalaris site, into the TPSKP program cage data was collected from all plots.

Dry conditions resulted in low pasture growth rates after spring 1993. However, as previously noted for the data collected from Orange, GP oscillated quite markedly between treatments and the continuously grazed plots from harvest to harvest. But, when means for each season were considered, a more consistent relationship was observed. These relationships though, have indicated that there is little difference between treatments. The site was conservatively stocked (in line with district practice) so that animals did not place extensive pressure on the pasture. From the beginning of 1995 GP was greater than one, which resulted in a general reduction in FOO across the site.

Evaluation of boundaries

The boundary proposals discussed above were developed from examination of the treatments using graphs such as Figure 2. Data for all treatments were then pooled to examine the interaction between perennial grass, FOO and legumes (Fig. 3). This showed that contours for percent legumes were around 15-20% when the perennial grass content averaged 60% and the FOO was 1.5-3.5 tDM/ha. There were very little data for low grass contents making it hard to evaluate the lower boundaries. However the few points available did show that 60% legumes were associated on average, with 15-25% perennial grass and 2-3 tDM/ha, both close to the limits proposed.

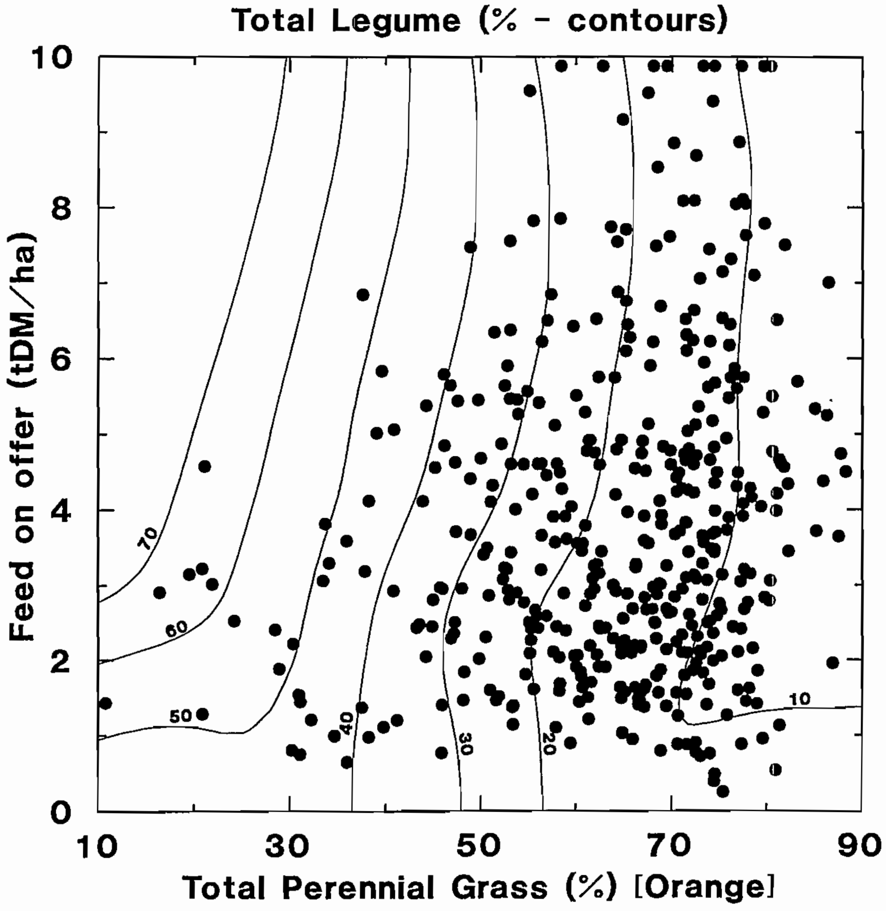

Figure 3: Relationship between total perennial grass (phalaris) content, forage-on-offer and mean total legume (white plus subterranean clover) content (contours) for an established productive phalaris pasture at Orange. Proportions were calculated on a dry weight basis. Data from eight management treatments over seven years.

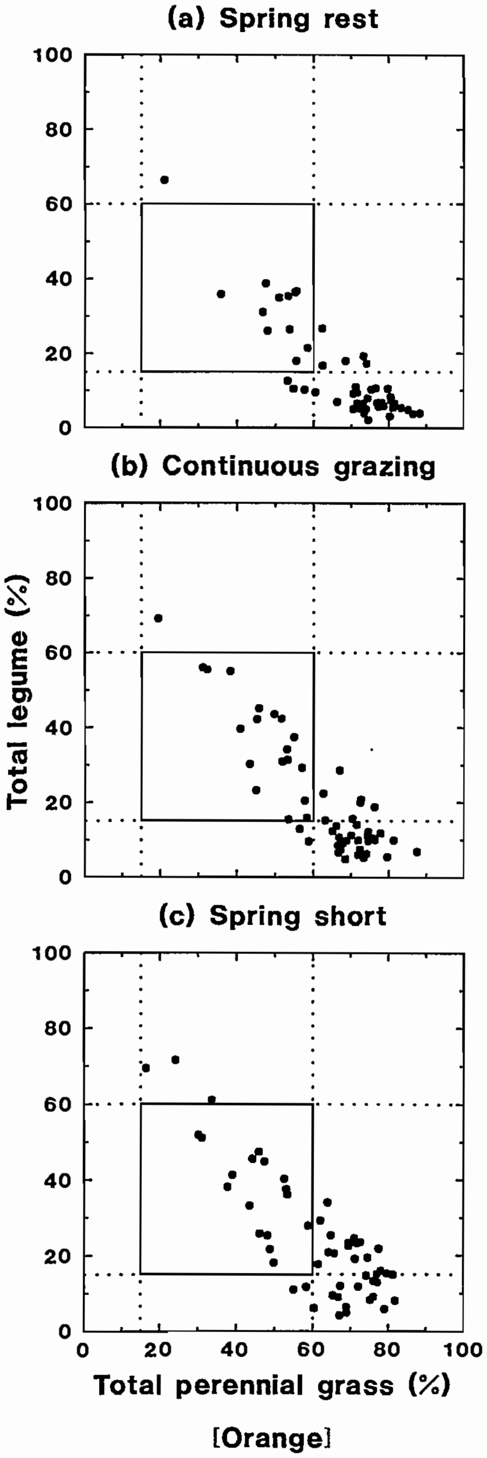

Figure 4: Relationship between total legumes and perennial grass content for three treatments from a phalaris pasture over seven years. Data are from harvests taken every six weeks. Dotted lines show the management boundaries proposed (see text).

The data from all measurements for each treatment were compared with the individual and paired envelope boundaries for perennial grasses, legumes and FOO (Figures 4 & 5). The spring rest treatment tended to have the highest perennial grass and lowest legume contents, the spring short had the lower perennial grass and higher legumes, with the control somewhat intermediate. Comparison of the perennial grass and legume contents (Fig. 4) showed that each treatment resulted in more occasions when one criteria was satisfied than for both. The same applied for FOO with perennial grass or legumes (Fig. 5). The percentage of occasions that different criteria were satisfied is shown in Table 1. These results include points from dry seasons when active pasture growth was minimal.

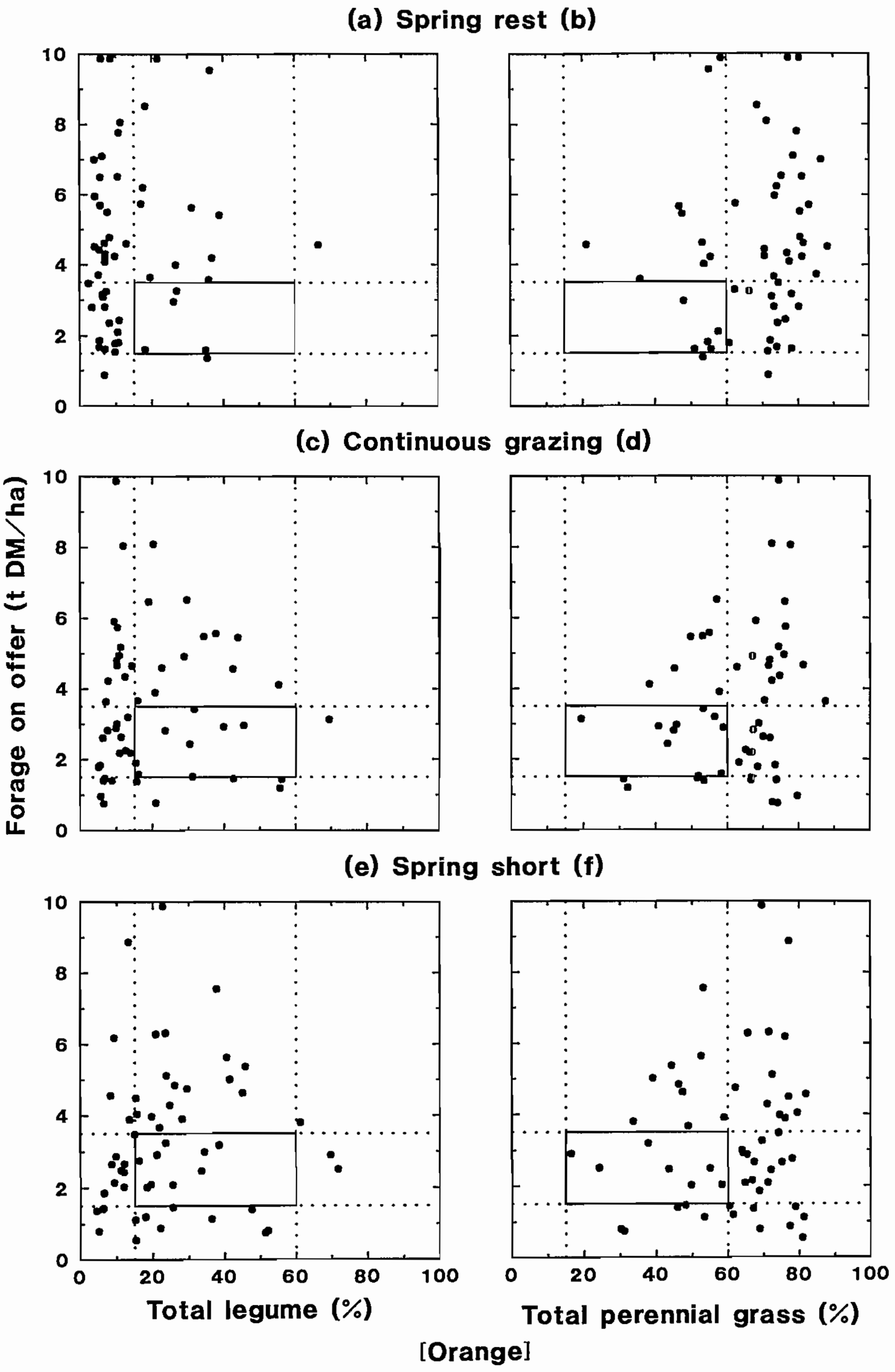

Figure 5: Relationship between forage on offer and the legume or perennial grass content of a phalaris pasture under three management treatments. Data from six weekly harvests over seven years. Dashed lines outline the proposed management boundaries (see text).

Table 1: Percentage of observations, over seven years from three grazing management treatments applied to a phalaris pasture at Orange, that met one or more criteria for the boundary management conditions.

Criteria	Spring rest	Control	Spring short
Total perennial grass (TPG) 15-60%	29	38	48
Total legumes (TLG) 15-60%	31	46	67
Forage-on-offer (FOO) 1.5-3.5 t DM/ha	35	37	46
TPG & TLG within limits	21	35	43
TPG & FOO within limits	10	24	22
TLG & FOO within limits	8	15	28

These results suggest that it is easier to satisfy one criterion than two or more and highlights the difficulties of having a list of benchmarks that need to be satisfied. The *envelope* also allows a visual impression of whether all components are within their benchmarks. Overall the spring short treatment was more in line with the proposed envelope than the other treatments. The major difficulties encountered were in limiting phalaris dominance and reducing the FOO. These difficulties are the aspects of phalaris pasture management needing further development.

Across treatments, there were more times that the combined perennial grass and legume boundary conditions were satisfied than either of those components and FOO. This suggests that there could be more flexibility in the criteria for FOO than proposed here, for the management of phalaris pasture composition. High legume contents were measured at FOO's above 3.5 t DM/ha (Fig. 3), especially in the earlier years of this experiment (Fig. 2). Lower legume contents could be maintained in a mature phalaris pasture than proposed here provided nitrogen supply is adequate to sustain pasture growth. Unfortunately, there are no adequate models of grass, legume interactions available to estimate the required proportion of legume. In this report it is only suggested that 15% would be the minimum to sustain nitrogen supply in a pasture. The important criteria for FOO in a phalaris pasture is arguably the minimum necessary to insure desirable species have the opportunity to grow and animal intake is maintained. This needs to be considered in future studies. The difficulties of keeping FOO below the upper limit emphasise the problem of avoiding rank phalaris pastures under conventional stocking policies.

The general decline in legume content over the years and increase in phalaris without any apparent decline in productivity (Fig. 2) suggests that a legume content of 15-20% was adequate to sustain this pasture. In addition the content of minor species was low. This further indicates that some tolerance of the upper boundary for phalaris may be appropriate. In such circumstances a phalaris content of 70% may not pose any problems. The *envelope* boundaries aim to alert managers to when some action is needed and are considered to have some flexibility. These considerations do suggest that in well established phalaris pastures the upper boundary for phalaris could be from 60-70%.

Boundaries for a degraded cocksfoot pasture (Newbridge)

The boundary conditions derived for the phalaris pasture were used as the first estimates to evaluate management boundaries for the pasture at Newbridge, which was dominated by annual grasses and had a low perennial grass content. Cocksfoot was the main perennial grass.

This experiment commenced prior to TPSKP and six years of data were available for analysis. At this site a high stocking rate (15 dse/ha) was used by the cooperator for the first three years and was then reduced (to 10-12 dse/ha) for the next three. The design was different to that used in TPSKP. Half the experiment was fertilised at a base level, using the current practices of the cooperator. Due to the adverse economic and seasonal conditions over recent years this meant that no fertiliser was applied to the base treatment. The other half of the experiment was fertilised at recommended rates based on soil tests, which were 250 kg superphosphate / ha per year plus 2 t lime / ha (surface applied) in each of the first two years. In addition to strategic rests a herbicide (carbetamide) treatment for annual grass control was included. After four years this treatment was modified; herbicide applications ceased after 1993, cocksfoot seed (5 kg/ha) was broadcast in autumn 1994 and then summer rests were imposed in subsequent years.

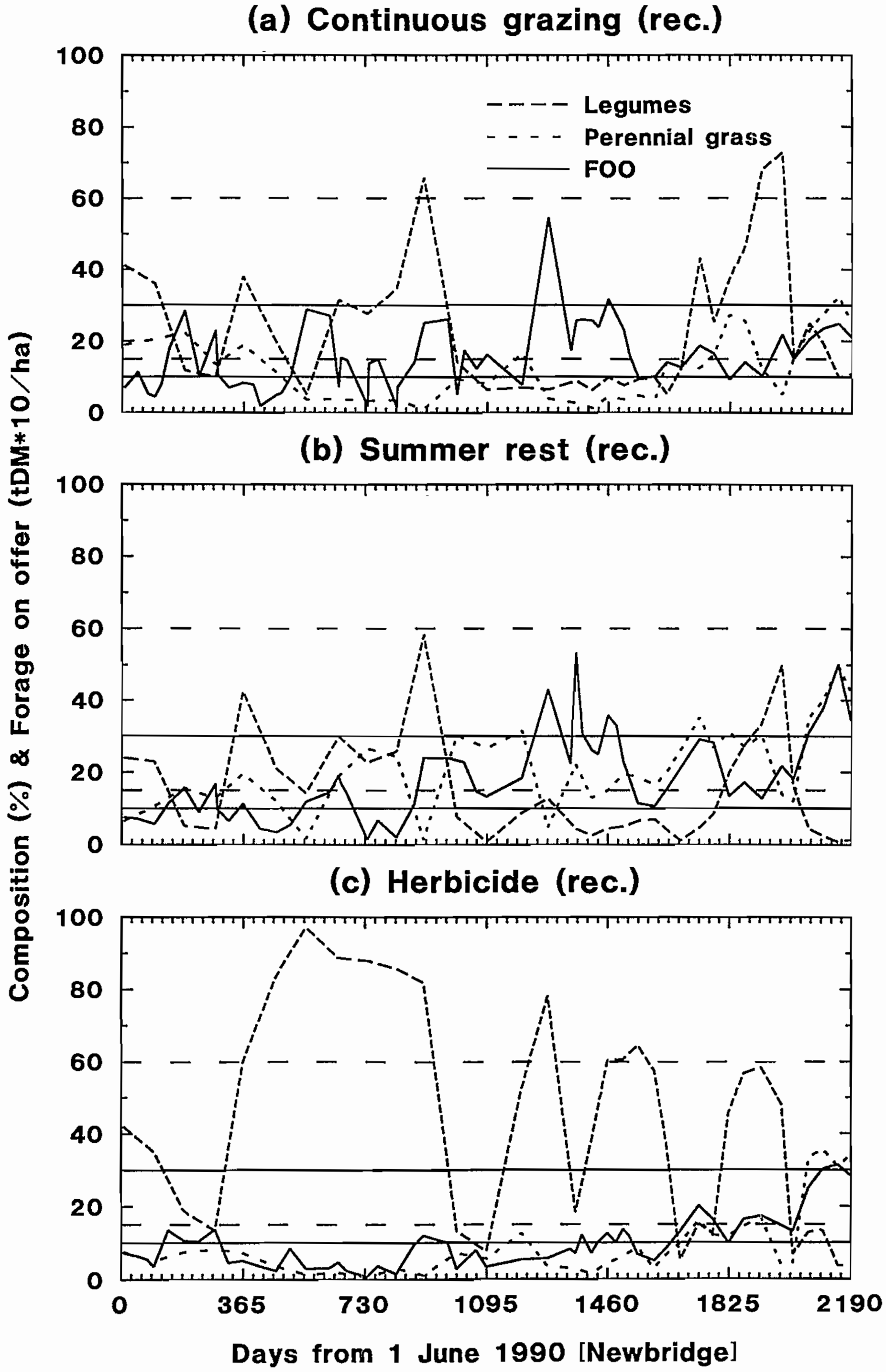

Figure 6: Legume and perennial grass content and forage on offer for three treatments applied to a degraded cocksfoot pasture at Newbridge. Data are for six years. Horizontal lines as per Fig. 2.

Key species limits

Legume limits: The dominant legume at this site was subterranean clover. The legume content was often between 15 and 60% during the season of active growth (Fig. 6), the exception being the dry season of 1994. The herbicide treatment had the highest legume contents in most years (Fig. 6c), but very little else and was not considered a stable sward, hence the modifications to this treatment in 1994. After reviewing the results it was decided that the limits of 15 and 60% previously proposed were appropriate for this pasture.

Perennial grass (predominately cocksfoot) limits: Cocksfoot was a minor component in the control treatments at Newbridge and declined from 10 to below 5% where no fertiliser was applied. With fertiliser there was an increase in cocksfoot from 1995 under continuous grazing (Fig. 6a). This treatment had the highest initial cocksfoot content which did decline substantially under the higher stocking rate of the first three years. Cocksfoot increased under the summer rest treatment and on the herbicide plots after the inclusion of a summer rest in that treatment and did recover on these treatments from low contents of 10-15%, as measured in autumn. These results indicate that perennial grasses can recover from very low levels when appropriate grazing tactics are used. However it was considered that a minimum of 15% was still appropriate to insure recovery within a reasonable time (e.g. Fig. 6b). Cocksfoot never reached the proposed upper limit of 60%, but it was still considered appropriate for the reasons outlined earlier for the phalaris pasture.

FOO limits

The high grazing pressure during the early years of this study resulted in low levels of FOO. It was apparent that the minimum (derived from the phalaris pasture) of 1.5 t DM/ha was too high as in the summer rest treatment the cocksfoot content was able to increase during the period when FOO declined to 1 t DM/ha. This was in the later phase of the experiment when the stocking rate had been reduced. A lower FOO minimum of 1 t DM/ha could be appropriate for this pasture as the structure is different to the phalaris pasture. Cocksfoot has smaller crowns than phalaris. This pasture rarely exceeded 3 t DM/ha, but when this occurred the legume content approached the minimum of 15% (e.g. in 1994 Fig. 6). Based on these data it was decided to modify the boundaries for FOO to 1-3 t DM/ha for this pasture.

Pasture growth rates

The low base fertility and high grazing pressure at this site resulted in low pasture growth rates throughout the six years. Desirable species were present in the pasture, but the low growth rates limited opportunities for large changes in composition.

Evaluation of boundaries

The general relationship between perennial grass (90% cocksfoot), FOO and legume for all the measurements in the Newbridge experiment, shown in Figure 7a, provides a check on the lower boundary proposals. At 15% perennial grass and 1-3 t DM/ha FOO, the legume content ranged from 10-30% and similar legume contents applied as the perennial grass content increased. This is a different pattern to that observed for the phalaris pasture (Fig. 3) and is probably due to an interaction with the high annual grass content at Newbridge. Further work will be needed to establish the mechanism behind this interaction, but as shown with the herbicide treatment (Fig. 6c) control of the annual grasses resulted in higher legume contents. Below 15% perennial grass, the legume content increased and this was associated with higher levels of FOO. These points were often from the summer rest treatment. The data in Figure 7a suggest that the legumes were not competing with perennial grasses as the perennial grasses increased from 15 to around 35%.

Comparison of the perennial grass, legume and FOO contents for the control, summer rest and herbicide treatments at one or two fertility levels (Figures 8 & 9) showed that data was within the perennial grass boundaries when fertiliser was applied and summer rests used. The percentage of occasions when different criteria were satisfied is shown in Table 2. This was a degraded pasture at the start of the experiment and few of the early measurements could be expected to come within boundary conditions.

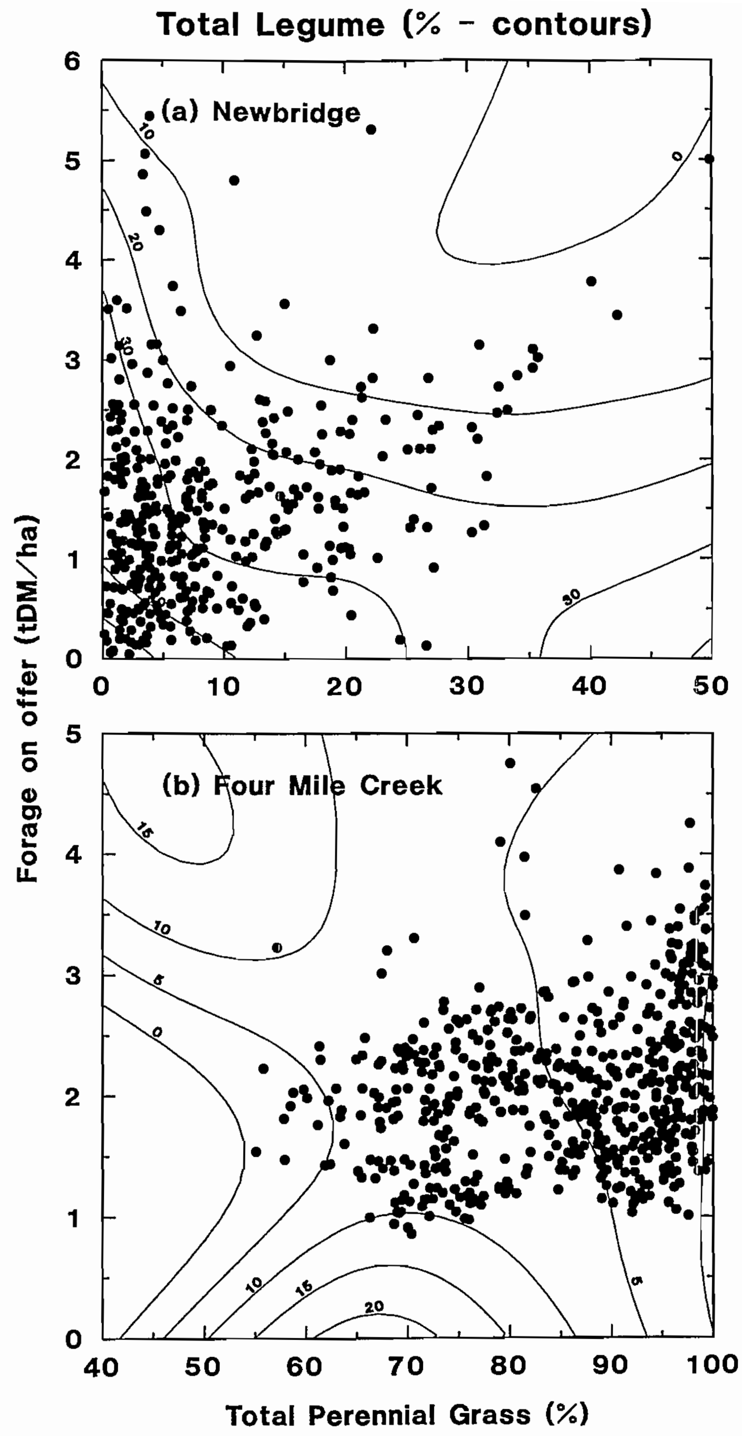

Figure 7: Distribution of forage on offer, perennial grass and average legume content (contours) for a degraded cocksfoot pasture at Newbridge and a newly sown cocksfoot pasture at Four Mile Creek. Data for six and three years respectively, harvests every six weeks.

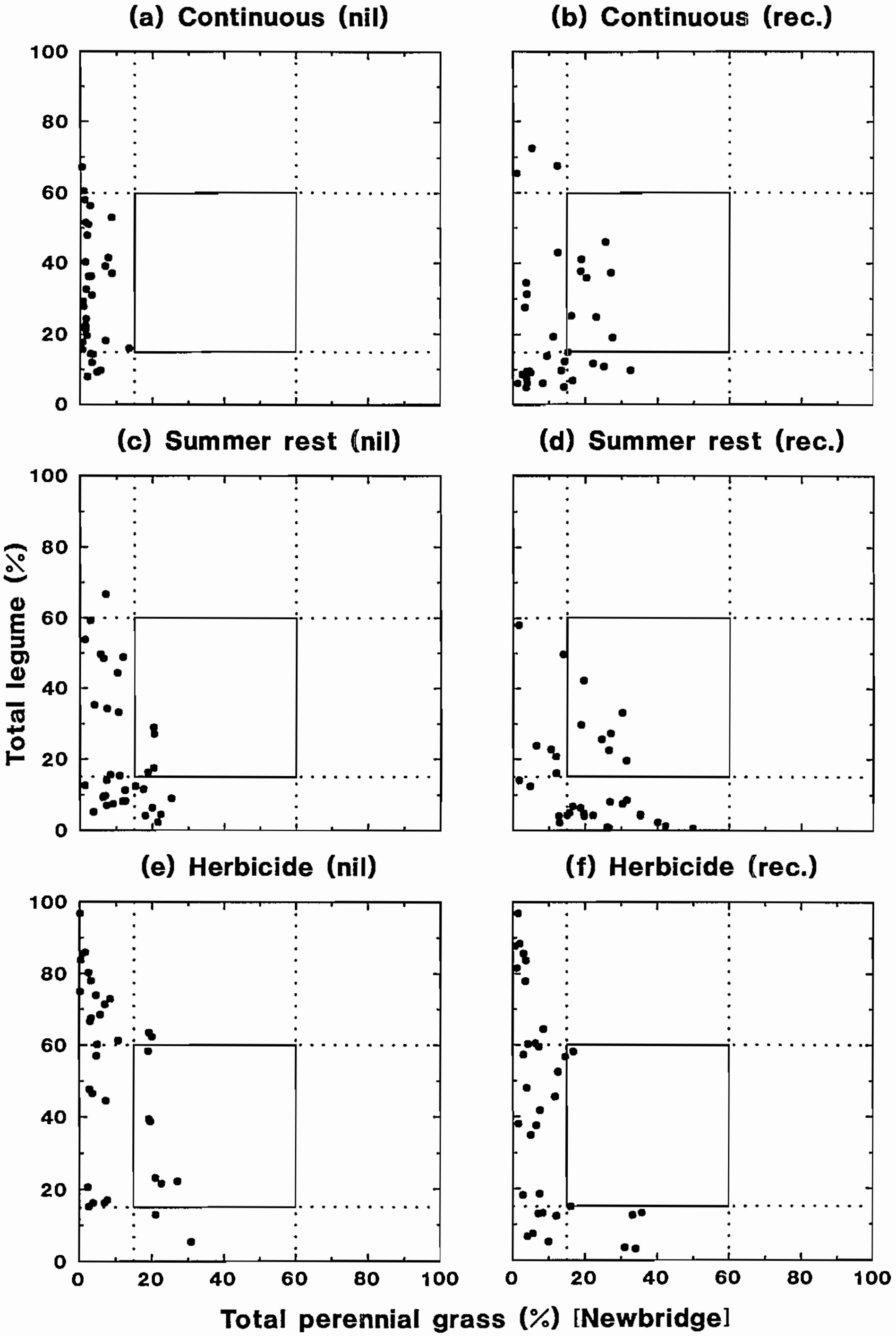

Figure 8: Relationship between total legume and total perennial grass for a degraded cocksfoot pasture at Newbridge. Data for three management treatments at nil or recommended levels of fertiliser. Dotted lines indicate the proposed management boundaries.

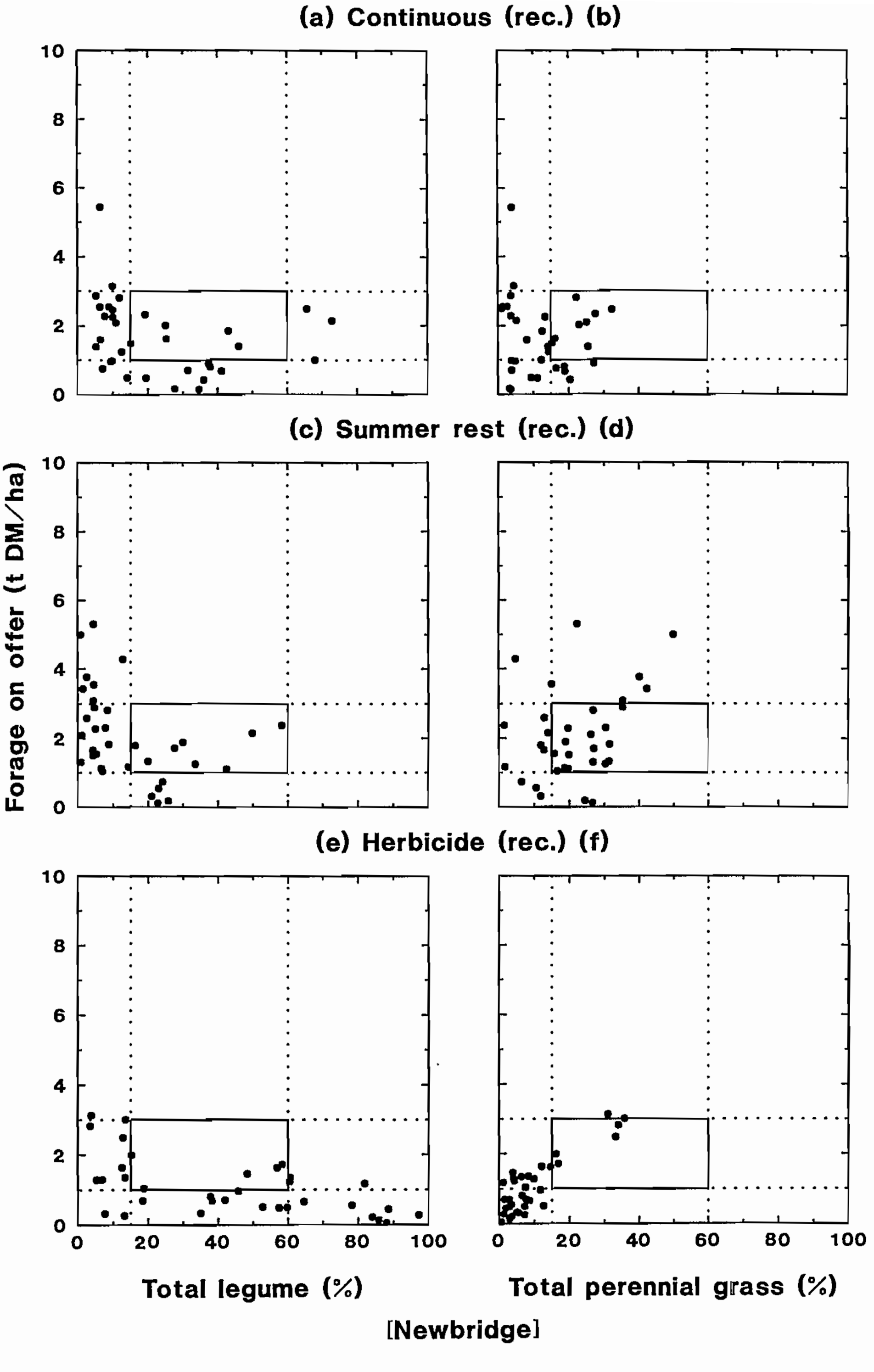

Figure 9: Relationship between forage on offer and total legume or total perennial grass content at recommended fertiliser levels for three management treatments applied to a degraded cocksfoot pasture at Newbridge over six years. Dotted lines are the proposed management boundaries as explained in the text.

Table 2: Percentage of observations, over six years from six grazing management treatments applied to a degraded cocksfoot pasture at Newbridge, that met one or more criteria for the boundary management conditions. Results are for base / recommended fertiliser treatments. Values in brackets are those where data was above the upper limit. The herbicide treatment included a summer rest after four years. Stocking rates were higher for the first three years.

Criteria	Control	Summer rest	Herbicide
Total perennial grass (TPG) 15-60%	0(0) / 38(0)	32(0) / 68(0)	29(0) / 18(0)
Total legumes (TLG) 15-60%	76(6) / 38(9)	44(3) / 38(0)	44(47) / 41(29)
Forage-on-offer (FOO) 1-3 t DM/ha	53(3) / 59(3)	62(12) / 65(21)	53(0) / 44(3)
TPG & TLG within limits	0 / 24	0 / 24	44 / 15
TPG & FOO within limits	12 / 21	26 / 47	21 / 24
TLG & FOO within limits	18 / 6	29 / 15	29 / 15

These treatments frequently satisfied boundary conditions for legumes and FOO and to a lesser extent for perennial grass. The perennial grass content was initially low and then increased over time in this experiment hence there was a lower expectation that boundary conditions would be met. These data reinforce the result that under continuous grazing and no fertiliser, cocksfoot goes out of the pasture, while adding fertiliser was only as good as applying a summer rest.

When two criteria were used the percent success was less than for one criterion. When fertiliser was applied the percent success was often lower than for the base fertility treatment. This was due to the FOO content being above the upper boundary, which did not appear to have any long term consequences for the pasture (Fig. 6). The best combination within envelope boundaries, was for perennial grass and FOO for the fertilised summer rest treatment, which included data from the early part of the experiment before the treatment had had any effect.

Boundaries for a newly sown cocksfoot pasture (Four Mile Creek)

In contrast to the site at Newbridge, the experiment at Four Mile Creek was on a newly sown pasture dominated by cocksfoot. The pasture had very few other perennial grasses or annual grasses, and a low legume content. The experiment started in 1993 and only three years data were available for analysis. During this period a drought severely restricted pasture growth and opportunities for compositional change. To date there have been no consistent differences between treatments. Emphasis in this report will be on the control treatment. Stocking rates were conservative due to the seasonal conditions.

The boundary conditions developed for the degraded cocksfoot pasture at Newbridge were evaluated against the data for this experiment.

Key species limits

Legume limits: Subterranean clover was the dominant legume at Four Mile Creek. The legume contents was generally low at this site (Fig. 10), only exceeding 15% in 1995. As there was limited data, the boundary conditions of 15-60% were retained for this pasture.

Perennial grass limits: Cocksfoot was the dominant grass and started at 60% of the pasture and increased over time (Fig. 10). The only time legumes increased was when the cocksfoot content declined to 70%. It was decided that the boundaries previously proposed (15-60%) were appropriate for this pasture.

FOO limits

Due to the dry seasons FOO remained within the proposed boundaries of 1-3 t DM/ha (Fig. 10). The higher legume contents occurred when FOO was 1-1.5 t DM/ha. It was decided that 1-3 t DM/ha boundaries for FOO were suitable for this pasture as the cocksfoot persisted throughout the dry years when the pasture was maintained within those limits (Fig. 11).

Pasture growth rates

This site suffered substantially from the dry conditions and consequently stocking rates had to be reduced. Growth rates were very low throughout the experiments and cage data was too variable to detect any differences between treatments. Visual evidence indicated that there was a tendency for sheep to avoid the fodder cut treatment following the first cut, possibly due to the nature of the remaining stubble which resulted in slightly higher amounts of green leaf and growth rates. We will need further data from this site as while no major changes have occurred the cooperating producer expects the pasture to deteriorate over time.

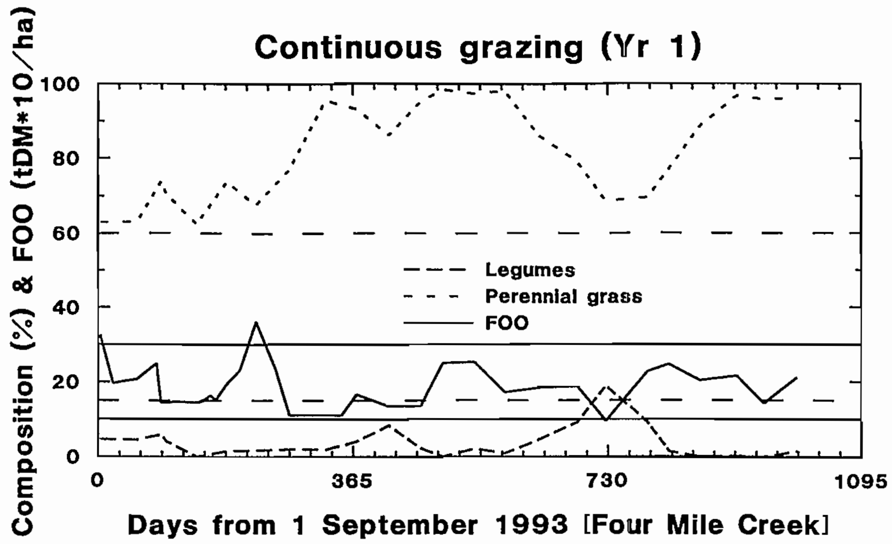

Figure 10: Changes in the perennial grass and legume contents and the forage-on-offer (FOO) in a new cocksfoot dominated pasture under continuous grazing at Four Mile Creek over three years from September 1993. The solid horizontal lines mark FOO boundaries of 1 and 3 t DM/ha and the dashed lines species limits of 15 and 60%.

Evaluation of boundaries

The dominance of cocksfoot and low legume content has meant that most of the data collected has been at perennial grass contents above 60% and legumes below 10% (Fig. 7). Many observations were within the FOO boundaries of 1-3 t DM/ha and within that range legumes were below 5% once the perennial grass exceeded 80%. There was a small tendency for legumes to increase as FOO declined from 3 to 1 t DM/ha. The main implication from these results to date is that cocksfoot will evidently persist in an established cocksfoot pasture, when FOO is maintained within the proposed boundaries of 1-3 t DM/ha, without the need for any specific management treatment. The low legume content in this pasture is attributed more to the poor seasons than to any view that legumes and cocksfoot are not compatible.

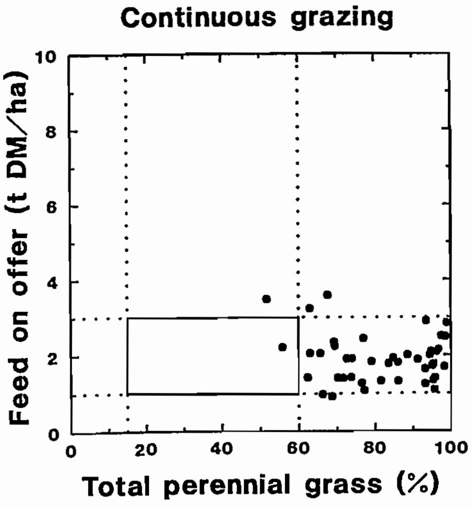

Figure 11: Relationship between total perennial grass percent and forage-on-offer for an established cocksfoot pasture under continuous grazing at Four Mile Creek. The box and dotted lines indicate boundary conditions for each axis. Data over three years from 1993.

Boundaries for a native grass pasture

The native grass grazing management experiment commenced in June 1993. The same procedure was used as outlined for defining boundary conditions for the phalaris and cocksfoot-based pastures discussed above. For this analysis, the data obtained so far was reviewed to assess if the boundaries suggested for the cocksfoot-based pasture are appropriate for this different pasture, or needed modification. The two dominant perennial grass species were *Microlaena* and *Danthonia.* The major non-desirable annual grass species at this site was *Vulpia.* Fertility at this site is low and pasture growth rates and rates of change, have also been low. At this site the initial total biomass (which the owner reported was typical for that time of year i.e. 2 t DM/ha at the end of winter and included a high proportion of dead material carried over from previous seasons) suggested that there was under-utilisation of total Forage-on-offer (FOO) (Fig. 12). The pasture at the commencement of the experiment was very rank and unpalatable and was only slowly reduced over the first year. The slow removal of dry FOO was due to the low stocking rate employed in the early part of the experiment. Grazing through the drought resulted in the reduction of this material and then allowed treatment contrasts to develop in the second year.

Key species limits

Legume limits: The legume content in this experiment was generally low except during 1995 (period marked by dotted lines in Fig. 12). Under continuous grazing the legume content rarely exceeded 15%, whereas the autumn rest and fodder cut treatments had approximately twice the legume content, reaching 20-30% in 1995. Data for these treatments for the second year of start (i.e. first applied in 1994/95) are shown in Figure 12 as they were managed similar to the control during the first year and then had treatments applied just prior to 1995 when legume growth was better. Over the three years if the legume content was not above 15%, soon after the break of season in autumn, it remained low during the next six months. This limited evidence supported the view that a legume content of 15% was an appropriate minimum. This pasture did not have legume contents near the proposed upper boundary of 60% so it was not possible to evaluate that condition.

Perennial native grass limits: The initial perennial grass content was around 40% and increased over time (Fig. 12). Under continuous grazing it had increased to above 60% by 1995 and remained high until the end of the study. This restricted space for legume regeneration and growth. The autumn rest and fodder cut treatments reduced the perennial grass content during 1995 to around the upper boundary of 60% and maintained a higher legume content. This supports the view that an upper limit of 60% is appropriate for perennial grasses. There was very little data to evaluate the lower 15% boundary.

FOO limits

Total FOO rarely exceeded the 3 t DM/ha proposed for the upper boundary, indicating that this level is not readily attainable given the current composition of the pasture and fertility at the site. On the control treatment FOO was generally 1-3 t DM/ha throughout the three years and this was associated with a high perennial grass content and low legumes and no change in the amount of bare ground. The relationship is not simple though, as the autumn rest and fodder cut treatments were also within those limits yet had a lower perennial grass and higher legume contents, especially in 1995.

We propose that a range of 1 to 3 t DM/ha would be feasible boundaries for a native grass pasture. At higher total FOO unpalatable seed heads of annual grasses reduce forage quality. The upper limit of 3 t DM/ha emphasises the need to act positively to restrict seed head development when such pastures approach that upper boundary. This upper boundary may still be a little high and could be reduced to 2.5 t DM/ha as further information is obtained on the functioning of this pasture ecosystem, especially adjustments for the different species.

Pasture growth rates

FOO at the native grass site was high at the start of the experiment. Much of this FOO was mature vulpia with unpalatable seed heads. In addition the site was also understocked for the first four months of the experiment. Because of this initial high FOO, stock numbers were not adjusted during the drought. Pasture growth rates were low throughout the study. Grazing pressure was light for the first year or so of this experiment, allowing animals to be selective and which may have been one reason for the low legume contents. Estimates of grazing pressure for individual treatments suggested that it was higher on those treatments where rank growth had been removed and legume contents were higher. This probably had an additional effect of maintaining a more desirable composition in those treatments after the period when treatments had been applied.

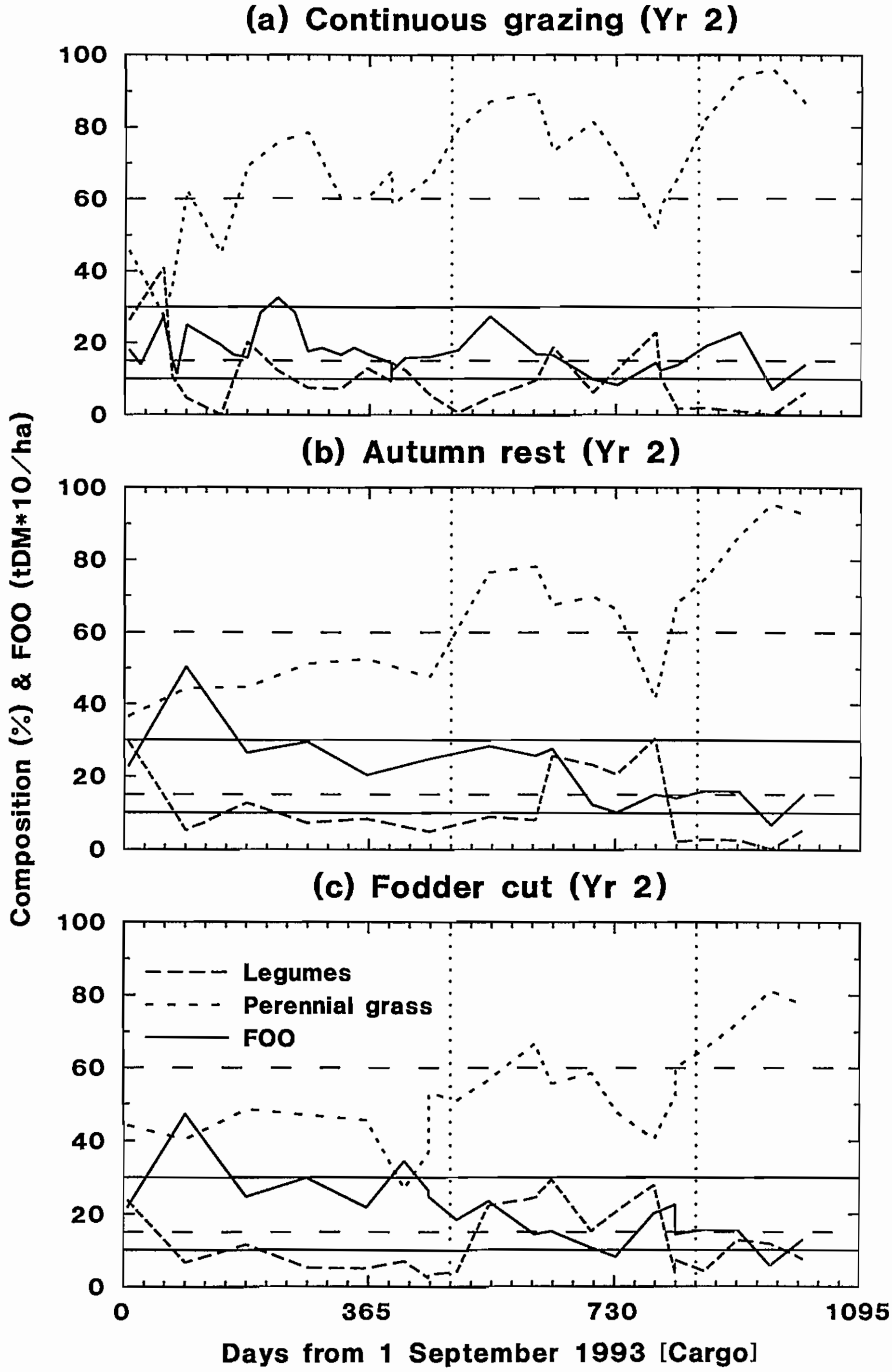

Figure 12: Trends in total legumes and perennial grass content and forage on offer over three years for three management treatments applied to a naturalised native grass pasture at Cargo. Dashed horizontal lines indicate the boundary limits for species and solid lines those for forage on offer. The dotted vertical lines indicate 1995 when legume growth was above average. Treatments started in late 1994.

Evaluation of boundaries

The legume content in this native grass pasture tended to decline as the perennial grass content and FOO increased (Fig. 13). At the upper boundary of 60% perennial grass and 1-3 t DM/ha the legume content was 5-

15%. This supports the view that a higher perennial grass content would be detrimental to legumes, though the full interaction with annual grasses needs to be explored. Legume contents of 15% or more were generally at FOO levels of 1-1.5 t DM/ha. This could be a function of season and competition from annual grasses, but may also suggest that in native grass pastures at low fertility levels, low levels of FOO may need to be maintained to increase the legume content. *Microlaena* can form thick mats that exclude other species. The upper boundary for FOO of 3 t DM/ha will need further evaluation for these pastures. Tactics to increase the legume content will also need development.

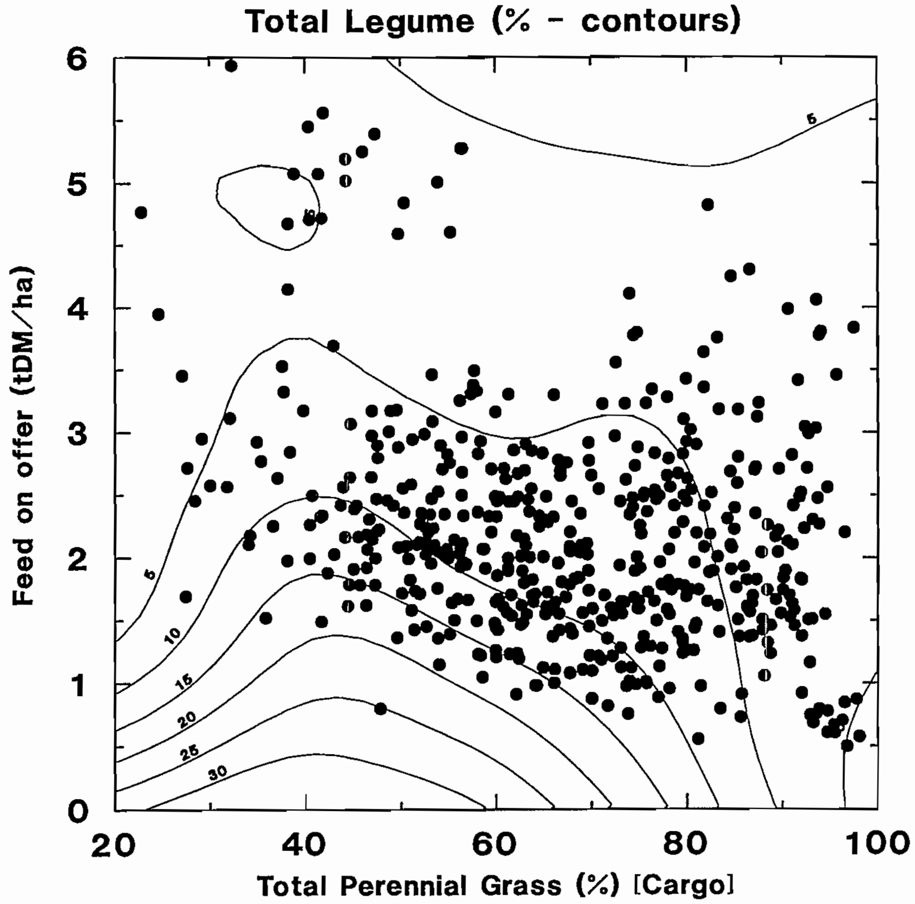

Figure 13: Relationship between total perennial grass (*Danthonia & Microlaena* spp.), forage-on-offer and total legume content (contours of mean percent) for a native grass pasture at Cargo. Data from twenty management treatments over three years.

Assessment of the ability of better treatments to manage the pasture within boundaries (Figures 14 & 15), showed that as with earlier examples, one criteria was often met but two criteria were more difficult to satisfy. These effects were not quantified as the experiment had only being going for a short period during a drought and treatment effects were only starting to be exerted as the stocking rate used was conservative. Similar results have been obtained so far from those treatments started in different years (Figures 14 & 15).

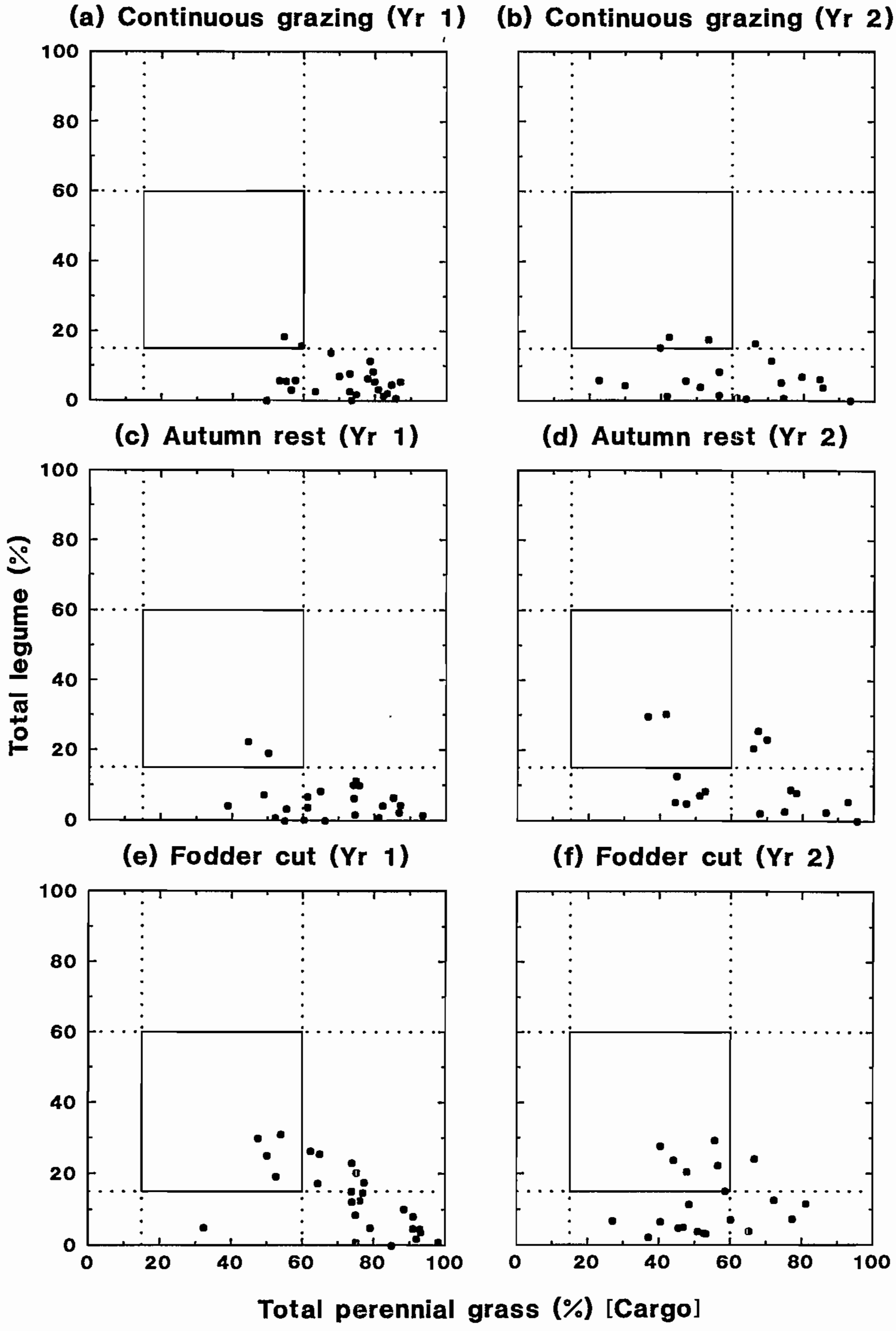

Figure 14: Total legume in relation to total perennial grass content of a naturalised native grass pasture at Cargo. Data from three treatments started over two years. Dotted lines indicate the proposed management boundaries.

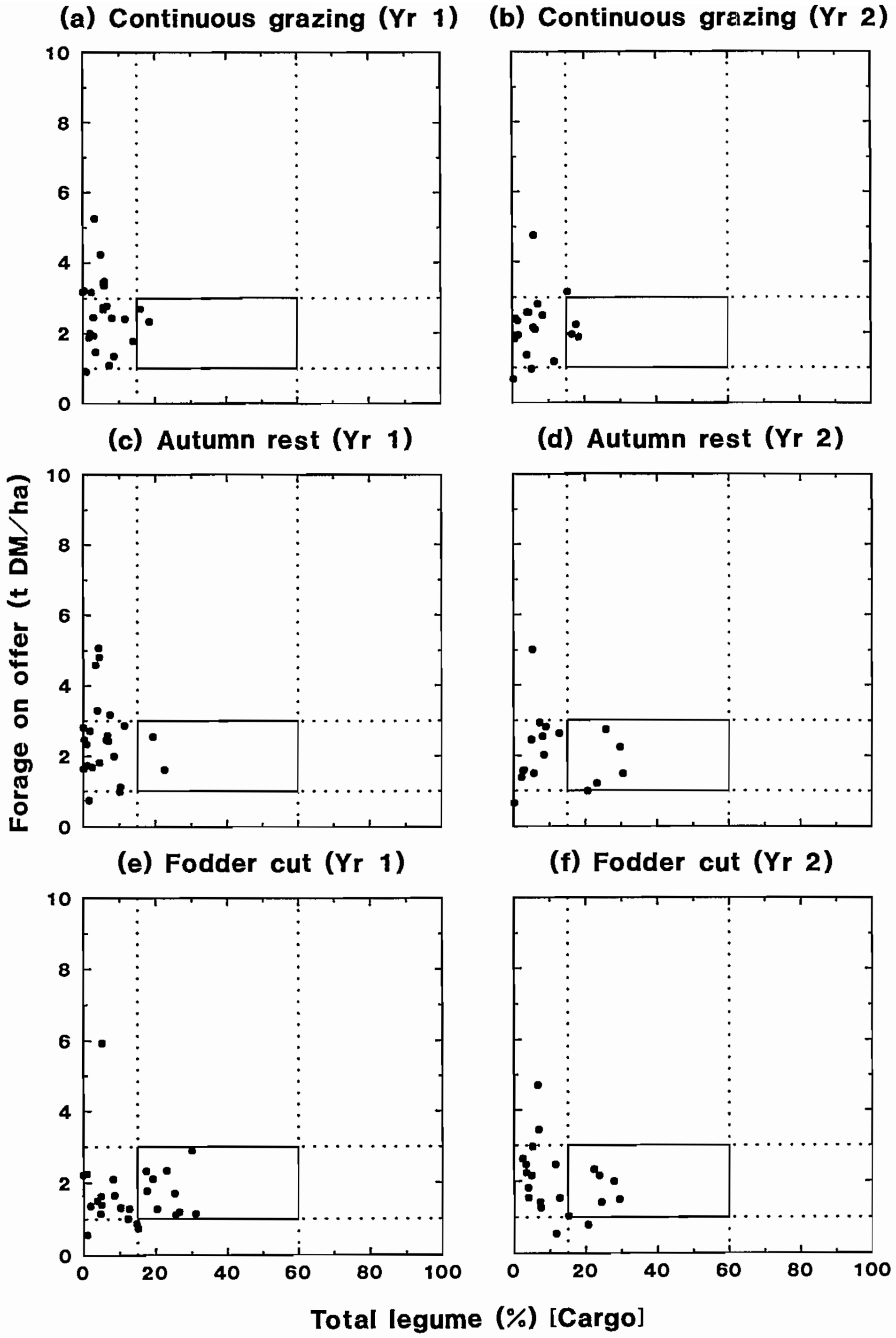

Figure 15: Forage on offer in relation to total legume for three treatments (started in two years) applied to a naturalised native grass pasture at Cargo. Dotted lines indicate the proposed management boundaries.

Assessment of grazing pressure

Assessment of the grazing pressure on a pasture can help in the analysis of pasture responses and determine when pasture growth rates were in excess of animal requirements or *vice versa*. Procedures to estimate grazing pressures were outlined earlier in this chapter. Data from the newly sown cocksfoot pasture at Four Mile Creek, were used to calculate various indices for grazing pressure (Figures 16, 17). Data from this site was used as there were only a few species and change in the pasture was limited during the experiment. The results for this site, as discussed earlier, showed that cocksfoot was able to persist at this site under a range of treatments and this was attributed to the minimum FOO being maintained above the lower boundary suggested for this pasture (Fig 16c). Grazing pressure effects are considered here to assess if they offer any alternative or additional explanations.

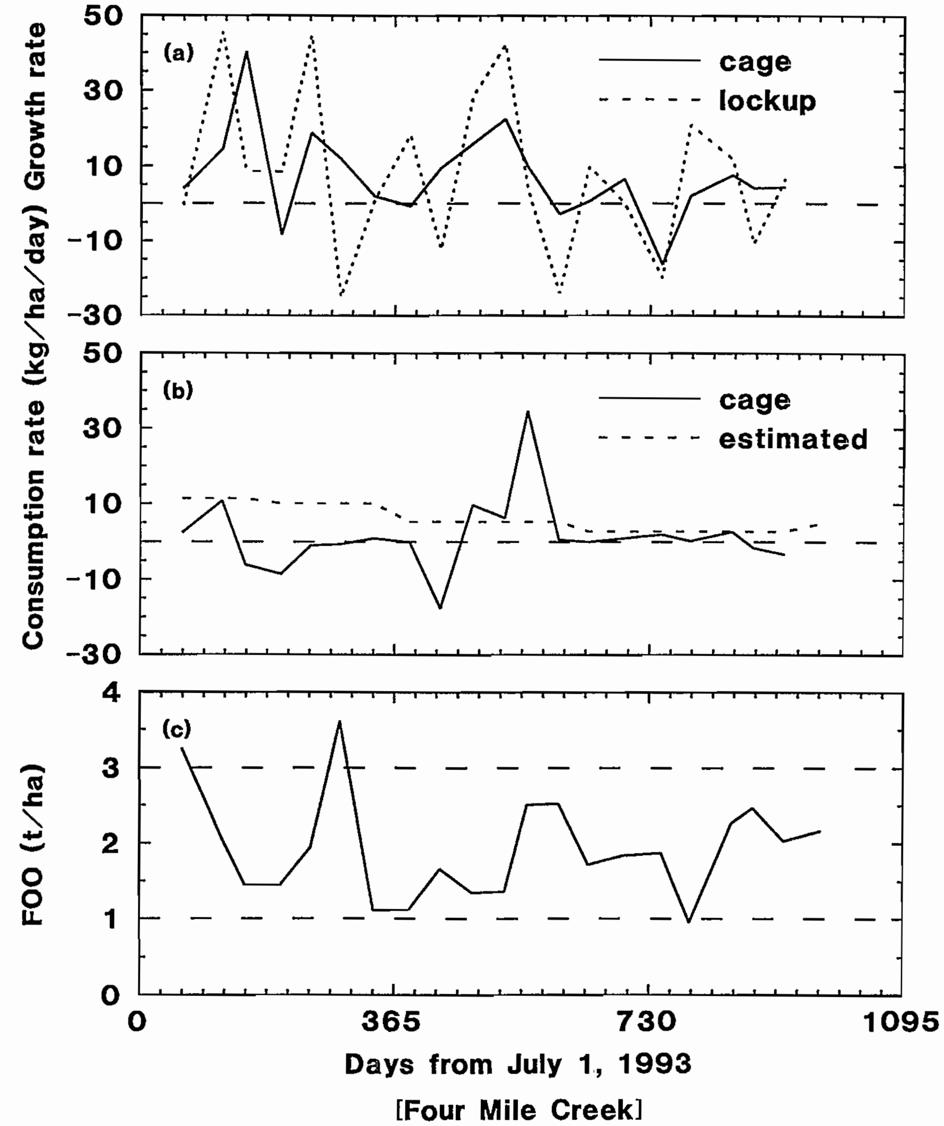

Figure 16: Pasture growth and consumption rates and forage on offer for a newly sown pasture at Four Mile Creek. Data derived from cages on plots or other plots that were locked up at times (a), from cages or estimated from tables (b) and from the plots (c). The dashed lines on (c) indicate the proposed management boundaries.

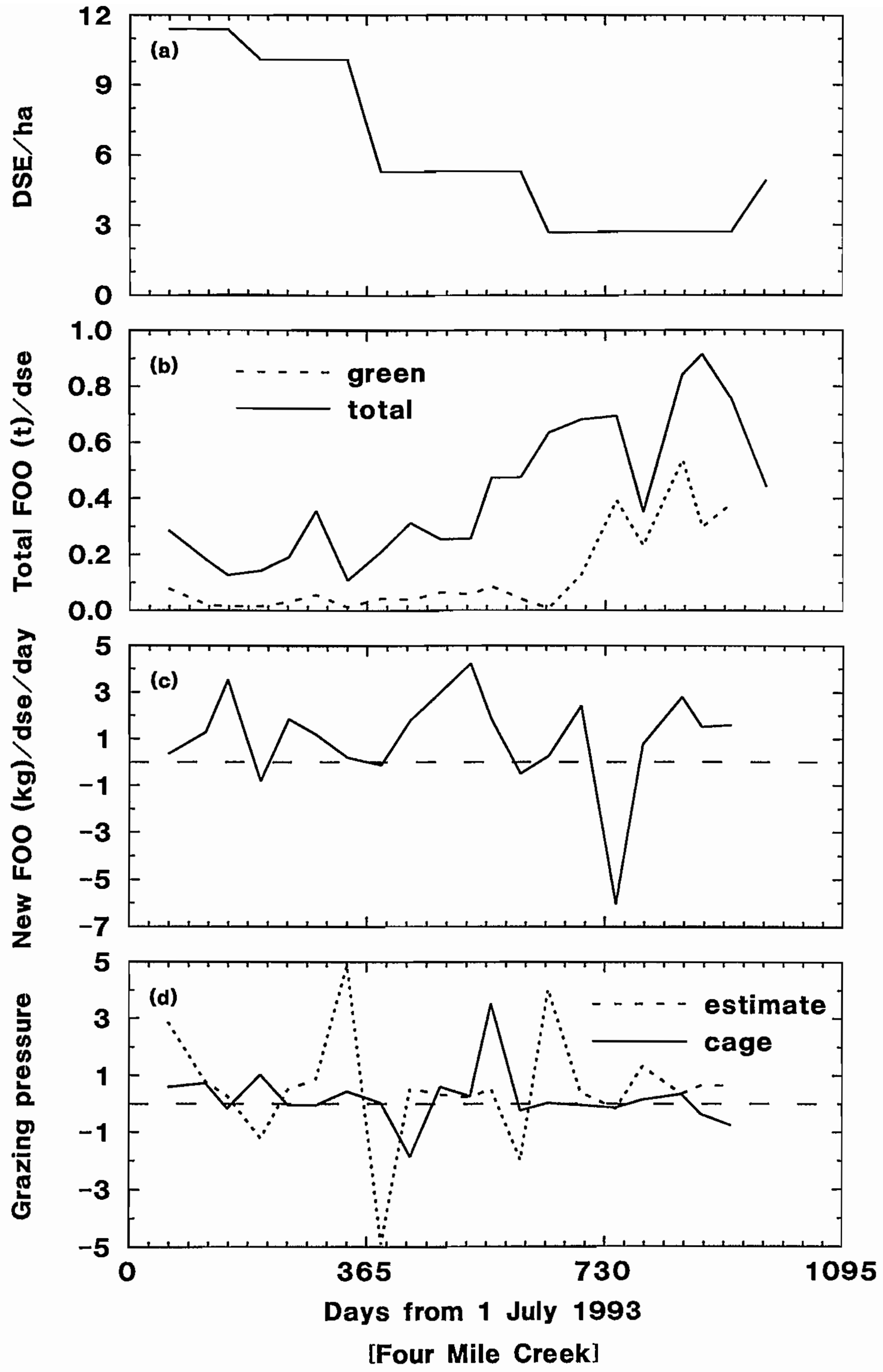

Figure 17: Stocking rates (a), total available forage per dse (b), new forage growth per dse (c) and estimated grazing pressure (d) for a newly sown cocksfoot pasture at Four Mile Creek. Grazing pressure was estimated using the two procedures for consumption rates discussed in the text.

One of the problems in estimating grazing pressure is the estimation of growth rates. Only two cages were used per plot in the TPSKP grazing experiments and the location of sample points was often restricted due to other needs for sampling within plots. Pasture growth rates, calculated from the cage data were compared with growth rates derived from other treatments that at times were locked up (Fig. 16a). These later estimates had yield data estimated at ten points within the plot and it was thought would be subject to less variation. The two data sets showed similar trends but with considerable variation between them. There was greater variation from the locked up plots. Higher growth rates from locked up plots are understandable at times, as they can accumulate higher leaf area indices (though care was taken to avoid data from plots that had considerably different levels of FOO), but the lower and more negative values, than from the cage data are more difficult to interpret. One possible cause may have been a more rapid use of the limited soil water causing a more rapid haying off than occurred under grazing. This possibility is suggested by the negative growth rates on locked up plots being recorded after a period of above average growth rates. From these data it suggests the information obtained from cages is suitable for the description of pasture growth rates.

Pasture consumption rates can be more difficult to estimate than growth rates as more assumptions are involved, especially that animals have grazed at the sample points at the same frequency and intensity as the average for the pasture as a whole. Estimates based on data from plots and the cages were compared with estimates derived from tables of animal requirements. This pasture was grazed by merino wethers and their requirements were approximately 1 kg DM/head/day. The estimates derived from tables declined during the experiment (Fig 16b) as stocking rates were reduced (Fig 17a). In contrast the estimates of consumption rates derived from cage and plot data were close to zero or negative, for the first year and then came closer to the table estimates in the later half of the experiment. Estimates of consumption rates below zero in a pasture grazed at 10 dse/ha do not make sense. They arose from the method of calculation when net pasture growth rates were negative and from variation in the measurements of FOO inside and outside the cages. This is a limitation in the methodology that then caused difficulties in estimating grazing pressure. The variation arising from use of the cage data and anomalous values does suggest it would be better to derive general estimates of animal consumption rates from knowledge of animal requirements. It may not be practical to have enough sample points within plots or paddocks.

During the three years stocking rates were progressively reduced due to continuing dry weather (Fig. 17a). This reduction in stocking rate lead to an increase in the total available FOO per dse (Fig. 17b) and also in new pasture growth per dse per day (Fig. 17c) derived from the pasture growth rate data (cages). Total available FOO per dse was very low on a green dry matter basis for the first two years reflecting the drought and then increased similarly to that for total dry matter. Grazing pressure estimates (equation i) calculated using the consumption estimates from cage and plot data, were often less than 1 or at times negative (Fig. 17d). The negative grazing pressure estimates arose from either negative estimates of net pasture growth or consumption rates. Grazing pressure estimates were also calculated using the estimates of consumption from tables, but these still showed considerable variation and at times were negative. The variability in this data could be reduced by amalgamating adjacent points, particularly when one observation was considerably above the trend and the other considerably below, on the grounds that this probably reflected the random grazing patterns of the stock i.e. all plots were not grazed at the same rates at the same times and only balanced out over time. Data could also be amalgamated over seasons to describe general effects. The interpretation of negative consumption rates and grazing pressure is difficult. It is unlikely that this occurs for biological reasons, but rather from the limited sample numbers possible in grazing experiments.

The estimation of grazing pressure as the ratio of pasture consumption to pasture growth rates proved to be difficult for the simple data set from the Four Mile Creek cocksfoot pasture. This index would be better applied to periods of active growth and not to drier periods when net pasture growth rates were low (and hence difficult to accurately estimate) or negative. To define the overall grazing pressure through the year under fluctuating climatic conditions, the better index may be the total available FOO per dse. Stocking rates alone have too many limitations to be used without any consideration of pasture biomass. Pasture biomass could be expressed on a total or green basis.

The derivation of net pasture consumption rates from cage data has several limitations. The low number of samples possible in an experiment and difficulties in estimating actual consumption rates suggest it is not practical to use this data in this way. Cage data did though, provide reasonable estimates of the trends in net pasture growth rates over time, especially when data from treatments that were not significantly different, could be combined. Net pasture growth is the balance between generation of new tissues and death of the old. The negative pasture growth rates often encountered indicate that tissue death rates exceeded the production of new leaves and stems over that period. Animals would have consumed the new tissue and this may have been adequate to sustain them through a subsequent period of tissue loss. The procedures considered here do not enable any evaluation of such effects.

The exploration of grazing pressure indices for the Four Mile Creek data did not find any one index that successfully explained why cocksfoot persisted at that site. The better explanation was still that derived from use of the *envelope* which suggested that persistence of the cocksfoot was due to maintaining the pasture biomass above the minimum FOO boundary of 1 tDM/ha. The data showing that the total available FOO per dse increased over time raises the possibility that reducing the pressure on the pasture may have been as important as keeping FOO above the minimum boundary. This would have reduced the frequency that individual plants were grazed. Future studies in SGSKP should consider this possibility.

Initial and subsequent composition

In using guidelines for pasture management there are some advantages if measurements taken in one season can help predict the likely composition of the pasture at some point in the future. These early measurements can then assist management decisions. The general relationships between successive measurements of pasture composition were then explored using data from the newly sown cocksfoot pasture at Four Mile Creek. Data was used from the main grazing experiment and from the supplementary studies done to investigate the impact of variation in pasture composition on subsequent pasture performance.

The ratio of legume to perennial grass content was used to broadly define the composition of the pasture. Measurements taken at one time were then compared with measurements 6, 12 and 26 weeks later. These results (not presented) showed that there was a reasonable correlation across a range of treatments for the first six weeks which was gradually reversed over the next six months. This reasonable initial relationship does mean that management decisions based on current estimates of pasture composition should be relevant for the near future.

The relationship between measurements taken 26 weeks apart was an inverse i.e. those plots with the highest initial legume : perennial grass ratio had the lowest six months later and *vice versa.* This may have arisen from the alternating high and low legume years as discussed earlier. If this is though, an aspect of pasture ecology it will warrant further investigation as it has considerable implications for maintaining quality pastures.

There were differences between initial measurements taken in autumn compared with spring and later composition of the pasture (Fig. 18). In both cases there was a reasonable agreement between the initial and six weeks later measurements, but subsequently the legume : perennial grass ratio increased relative to initial autumn measurements and decreased relative to the initial spring measurements. The increase in legume : perennial grass ratio after autumn does suggest that if the pasture has a low legume content it is more likely to increase than decrease over future months. In contrast a low legume content in spring is unlikely to increase and consideration may need to be given to practices that enhance legumes in the following autumn. The mechanisms behind these relationships need further exploration and similar relationships for other pasture ecosystems need to be considered to establish how general they are. If general relationships can be established for different pasture types this would then enable longer-term planning of pasture management strategies.

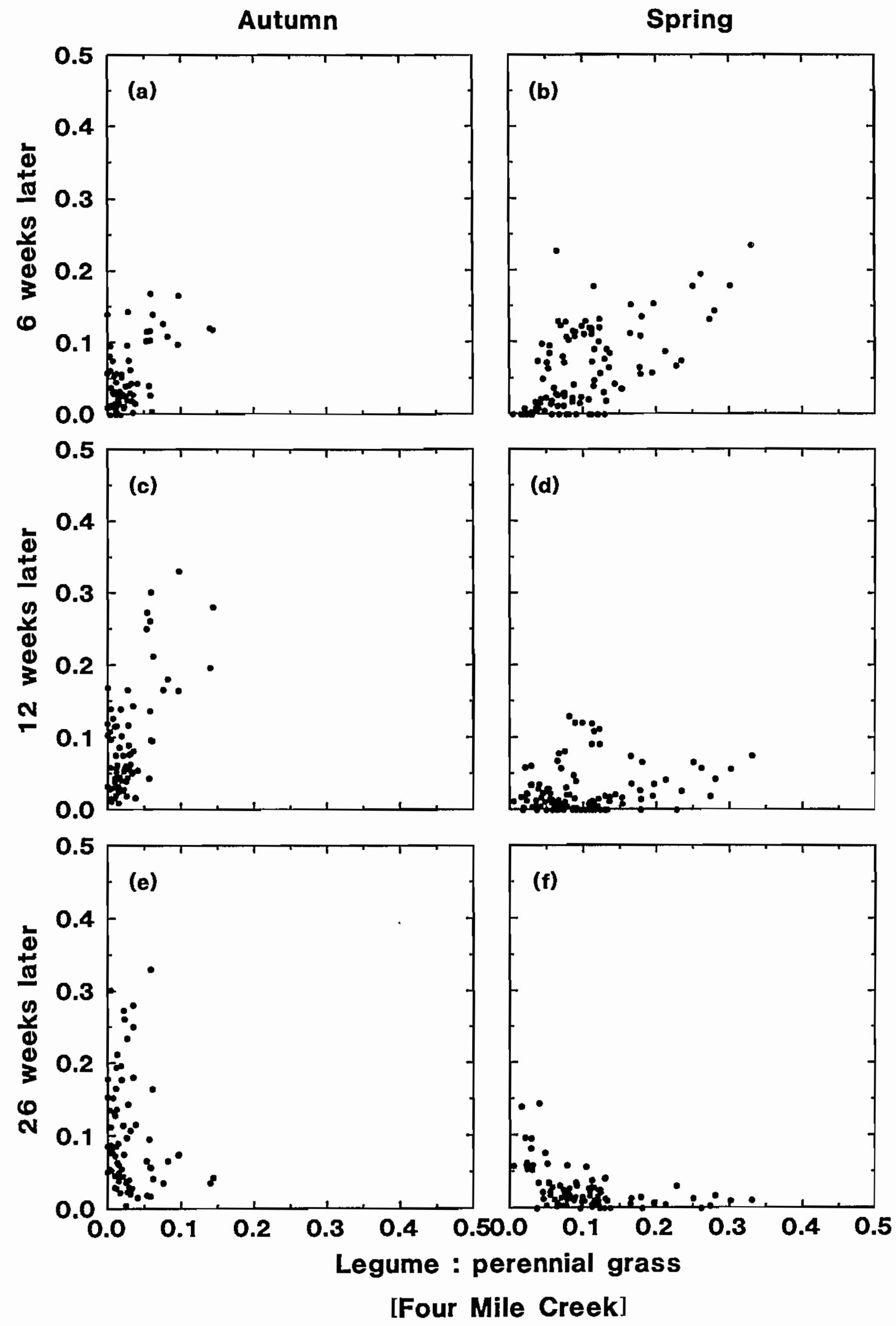

Figure 18: Legume : perennial grass ratios in autumn or spring in relation to the ratios six, twelve or twenty six weeks later. Data from a newly sown cocksfoot pasture at Cargo. Measurements from twelve treatments plus supplementary experiments designed to vary the legume : grass ratios.

DISCUSSION

The four sites considered in this chapter have shown some similarities in behaviour that have enabled some common guidelines for management within a *pasture management envelope* to be developed. Initial estimates were made for a productive phalaris dominant pasture and then modified for three other quite different pasture ecosystems.

The initial proposals of key species limits of 15-60% were supported with data from the other three pasture types. The limits for forage-on-offer (FOO) were varied from 1.5-3.5 t DM/ha for the phalaris pasture to 1-3 t DM/ha for the other less vigorous pastures. Perennial grasses were maintained or increased when FOO was kept above the lower boundary. Legumes were decreased in some cases when the upper FOO boundary was exceeded, but there is some flexibility about that limit and it did not appear to be as critical as the lower boundary. In a similar context the upper boundary for perennial grasses could be viewed as flexible as perennial grass contents of 70% were sometimes associated with reasonable legume contents. This occurred when pastures were well established and presumably the nitrogen supply and cycling were adequate to maintain productivity. This higher perennial grass content could be sustained if the annual grass content was low and hence 'resource space' was available for legume recruitment. This key issue of minimising less desirable species such as annual grasses needs to be a central part of optimising pasture composition.

The boundaries proposed here need to be evaluated against other data sets, especially those where the pasture did behave somewhat differently to the ones discussed here. The phalaris experiments at Tamworth (within TPSKP) faced a severe drought and under continuous grazing the phalaris largely died out (Fig. 19a) in a fourteen year old pasture. The better treatment at that site was a spring and autumn rest (Fig 19b). Under continuous grazing the percent phalaris and FOO were below 60% and 1.5 tDM/ha respectively during the early part of the experiment when dry conditions were severe. In contrast phalaris was above 60% and FOO within the boundaries of 1.5 to 3.5 tDM/ha in the spring / autumn rest treatment. Subsequently the phalaris declined on this treatment, though remaining within the 15 to 60% boundaries. This provides confirmation for the proposed boundaries and also raises the interesting question as to whether the persistence of phalaris can be achieved by simply managing FOO within boundaries, arguably keeping it above 1.5 tDM/ha, or if it requires specific rests in spring and autumn. These issues need to be tested within SGSKP.

The boundaries proposed here are broader than were often suggested in the past. These broad boundaries enable the goals of managing pastures for productivity and persistence to be realised while giving flexibility to land managers. The results presented show that it can be difficult to keep a pasture within even these broad boundaries. Some of the tactics tested produced better results than others, but they would need further development to achieve more consistent results and provide reliable recommendations. The use of narrower definitions could pose considerable problems for producers, such that if they rarely meet the conditions proposed they could consider the task as being too difficult. Management to boundaries is though, a clearly superior tactic compared with management to fixed points and some notion of an 'ideal' pasture. Management to one set of boundary conditions was also easier than to two. This reinforces the view that lists of 'benchmarks' for producers could impose unreal expectations on management. A priority needs to be placed on the more important components. These studies suggest there could be more flexibility in the FOO boundaries than may have been expected and management to maintain FOO within limits was not a particular problem for some of the pasture studied as this is largely done by manipulating stocking rates and grazing pressure. Emphasis could then be placed upon managing the composition of key species over FOO boundaries. Management of species composition mostly involved tactical practices.

The analyses presented have predominantly used the data on percent composition. It is readily acknowledged that actual yield of individual species is important. By maintaining an adequate FOO and a reasonable percent of desirable species this implies that the yield of those species is adequate. The values suggested here have been considered in relation to the species yields to assess if there was any major conflicts. This assessment did not change the suggestions made.

The *envelope* is defined in terms of green FOO, but in these analyses total FOO was used in most circumstances. This was done because the percent green was often > 70% and similar across treatments, estimates of percent green for individual harvests are difficult to make and most users are likely to be more familiar with estimating total FOO. Use of green FOO would probably improve the relationships developed, but the extent of that improvement may only be marginal for pastures during the season of active growth - the period given most emphasis in deriving these boundaries.

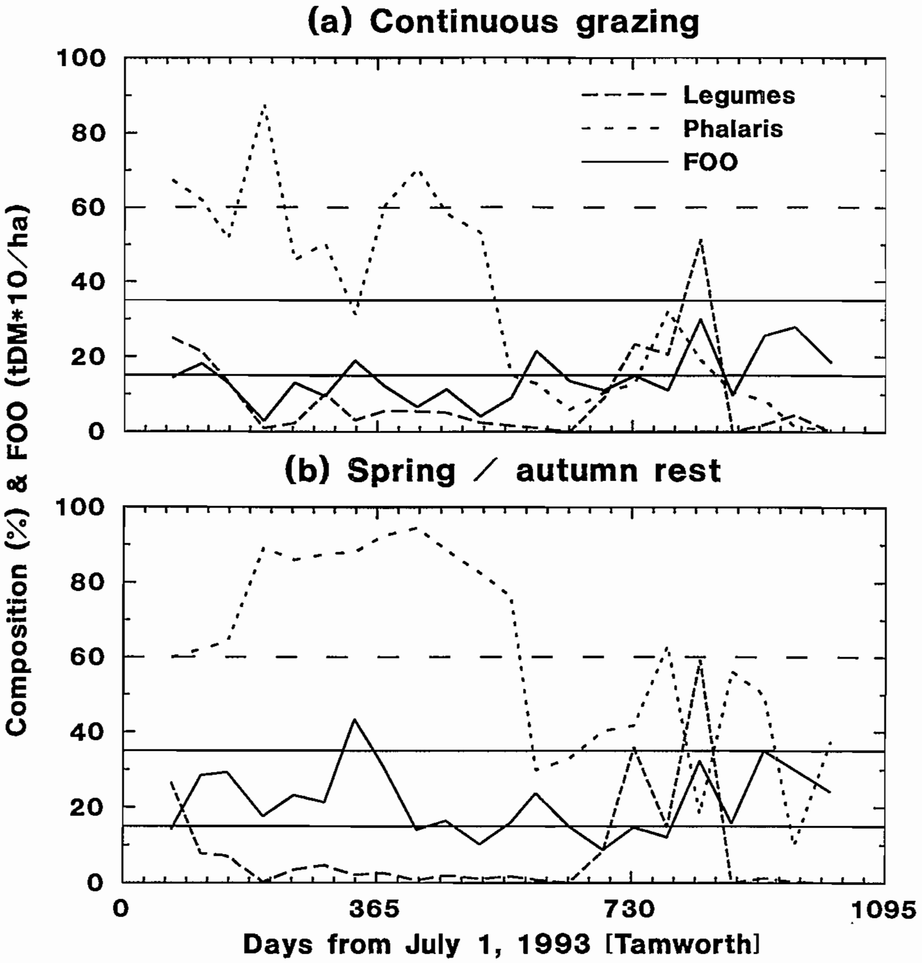

Figure 19: Trends in perennial grass, legumes and forage on offer in a fourteen year old phalaris pasture at Tamworth under continuous grazing or spring and autumn rests. Horizontal lines indicate the proposed management boundaries derived from a phalaris pasture at Orange.

The boundary conditions proposed here are set to alert managers to when they should actively intervene in the management of their pastures. The range is broad, especially in key species limits but this should not deter managers from intervening within narrower limits if considered appropriate. Most importantly it enables managers to begin to think objectively about what is in their pastures.

The boundary conditions are useful for describing the impact of a treatment. They allow us to more objectively determine when a treatment has produced a desirable pasture. The development of a pasture can be followed over time as well as the impact of treatments designed to vary that development.

The form of presentation used in Figure 2 not only allows an appraisal of how well the pasture within each treatment met some desirable criteria, but also shows when those treatments were not ideal and suggests ways of improvement. For example; the spring short treatment did not always remain within the *envelope*, but this was partly due to the excess pasture growth that occurred in some autumns. Extra grazing pressure to utilise some of that excess growth could have brought the pasture back within desirable limits. Extra autumn grazing is not part of that treatment, but would be an obvious recommendation in commercial situations.

Judgements at this early stage are preliminary. The definition of boundaries will develop more rapidly now that a protocol has been established. This report demonstrates how it is possible to make some judgements from limited data. However, we need more then one season's data to be able to assess whether the suggested boundaries are appropriate. The proposed perennial native grass *pasture management envelope* will be useful in evaluating the effects of treatments on pasture composition at this and other sites and will be refined as more data becomes available. The drought has removed the effects of a relatively low stocking rate at this site but with a 'break in the drought' we will need to ensure that the stocking rate will be adequate to allow treatments to vary pasture composition. As noted previously the phalaris based experiment was conservatively stocked, which allowed phalaris to dominate. The native pasture site runs the risk of been dominated by the *Vulpia* if it is not carefully managed. Results do though suggest that the perennial native grasses maintained at the upper PME boundary may keep *Vulpia* at bay.

The reductions in FOO overall in the early stages of many of the TPSKP sites was a result of a grazing pressures above one but the dry conditions have resulted in a reduction in sheep numbers. Effectively this has meant that there has been a deliberate attempt to maintain GP at around one. The native grass site has retained sheep numbers and this has assisted in giving an opportunity to observe treatment effects within a conservative stocking policy. As more data comes to hand closer consideration can be given to combining data to attempt to reduce the effects of the variation between cages within treatments.

Managers require a ready reckoner to alert them to any unfavourable trends in pastures and the *pasture management envelope* (PME) helps provide that. To define the boundary conditions within which pastures should be managed we have considered several components i.e. species content and forage-on-offer (FOO). As noted previously, the boundary conditions for management of a pasture are not absolute because we are dealing with a continuous distribution for each component.

To evaluate pasture management practices and provide advice for producers an alternative model to the *pasture management envelope* is the *state and transition* model developed for rangelands (Westoby *et al*, 1989). This model is more concerned with defining the existence of more stable *states* in communities, why shifts in composition occur and the paths (transitions) between those different states. This model does not though, incorporate the production components of the *pasture management envelope*. The *state and transition* model has been adapted to higher rainfall native grass pasture ecosystems (Lodge and Whalley, 1989) but difficulties had been found when applying it to the pastures being studied in TPSKP. As part of this project an alternative model was developed whereby grazing management treatments on temperate pastures could be evaluated within a *state and transition* framework. This is discussed in the next chapter of the report under the *pasture species composition matrix*. The *pasture matrix* provides a simpler analysis of pasture changes and management and a broader picture than the *pasture management envelope* of the status and trends in pastures.

3. Pasture Species Composition Matrix

INTRODUCTION

The Temperate Pasture Sustainability Key Program (TPSKP) aims to improve the persistence and productivity of temperate perennial pasture ecosystems. One of the major problems with such pastures is that the species composition is frequently suboptimal for production and sustainability. This reflects the fact that the composition will change in response to management, environmental factors and the normal competitive influences among plants (see Moore, 1970 for examples). An objective of the grazing studies in TPSKP was to screen practices that could control the rate and direction of change to upgrade to, or maintain a pasture in, a desirable state. The *pasture management envelope* has been developed as a means to identify a desirable state, evaluate when treatments achieve that state and to provide advisory messages for producers.

Similar problems exist in rangelands. Management in those systems has often been based on the assumption that ecosystems tend towards a stable climax and it could be difficult to change the ecosystem to another condition. The assumed linear nature of trends has limited the application of these ideas, particularly in variable climates. In recent years it has been accepted that ecosystems can exist in a number of more, or less stable *states*. This led to the development of the *state and transition* model (Westoby *et al*, 1989) which defines the existence of more stable *states* in communities, and offers an explanation for shifts in composition and the paths (transitions) between those different states. It does not assume any one final climax state as normal. The *state and transition* model was primarily designed as a framework for interpreting research results and as a tool for technology transfer. This model does not incorporate the production components of the *pasture management envelope* i.e. it does not include assessment of the biomass required to sustain higher pasture growth rates and animal intake.

The *state and transition* model has been applied to higher rainfall native grass pasture ecosystems (Lodge and Whalley, 1989), but difficulties were found when applying it to the pastures being studied in TPSKP. It is often difficult to distinguish discrete states within temperate perennial pastures, typically continuous distributions are seen between the proportions of components such as perennial and annual grasses (Fig 20). An alternative model is needed that can incorporate these continuous distributions, overlayed with some judgements as to the state of a pasture and how management treatments can shift the pasture between generalised states.

As part of this project an alternative model was developed whereby grazing management treatments on temperate pastures could be evaluated within a *state and transition* framework. This model, referred to as the *pasture species composition matrix (or pasture states model),* provides a

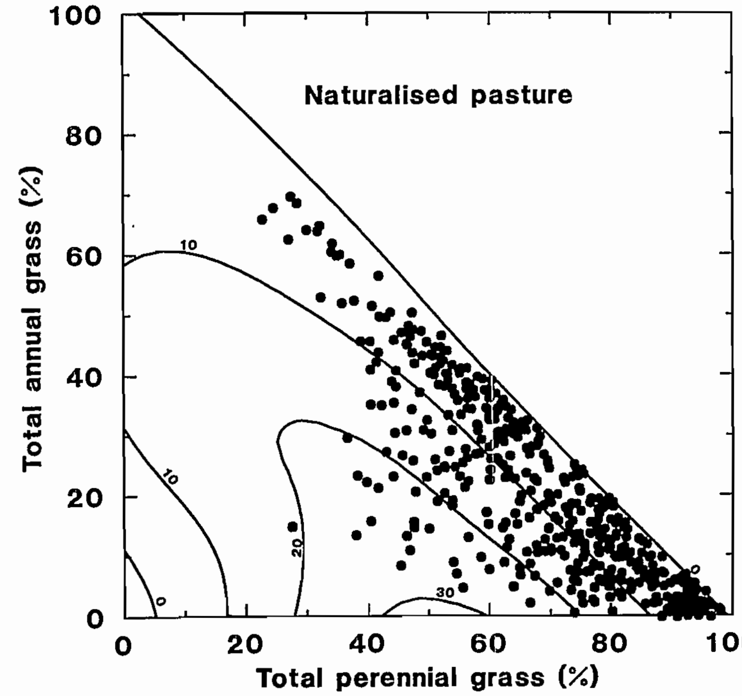

Figure 20: Continuous distributions between total annual and perennial grasses and legumes across a range of management treatments applied to a naturalised native grass pasture at Cargo.

simpler analysis of the relationship between management and changes in composition. This gives a broader picture than the *pasture management envelope* of the status and trends in pastures, as it encompasses all the main components in a pasture rather than only the key species.

Preliminary work on this model was presented at the review workshop for this project in late 1995. Further development of this model was then supported (Brown, 1995) as it was seen as a simpler way of introducing producers to the ideas of manipulating states within their pastures than the *pasture management envelope*, as well as solving one of the problems with the *state and transition* model i.e. the difficulty of overlaying objective research results on the framework of the model. When applying *state and transition* models to data, the definition of states and the mechanisms for transitions are usually deduced from observations and argument rather than directly from the results.

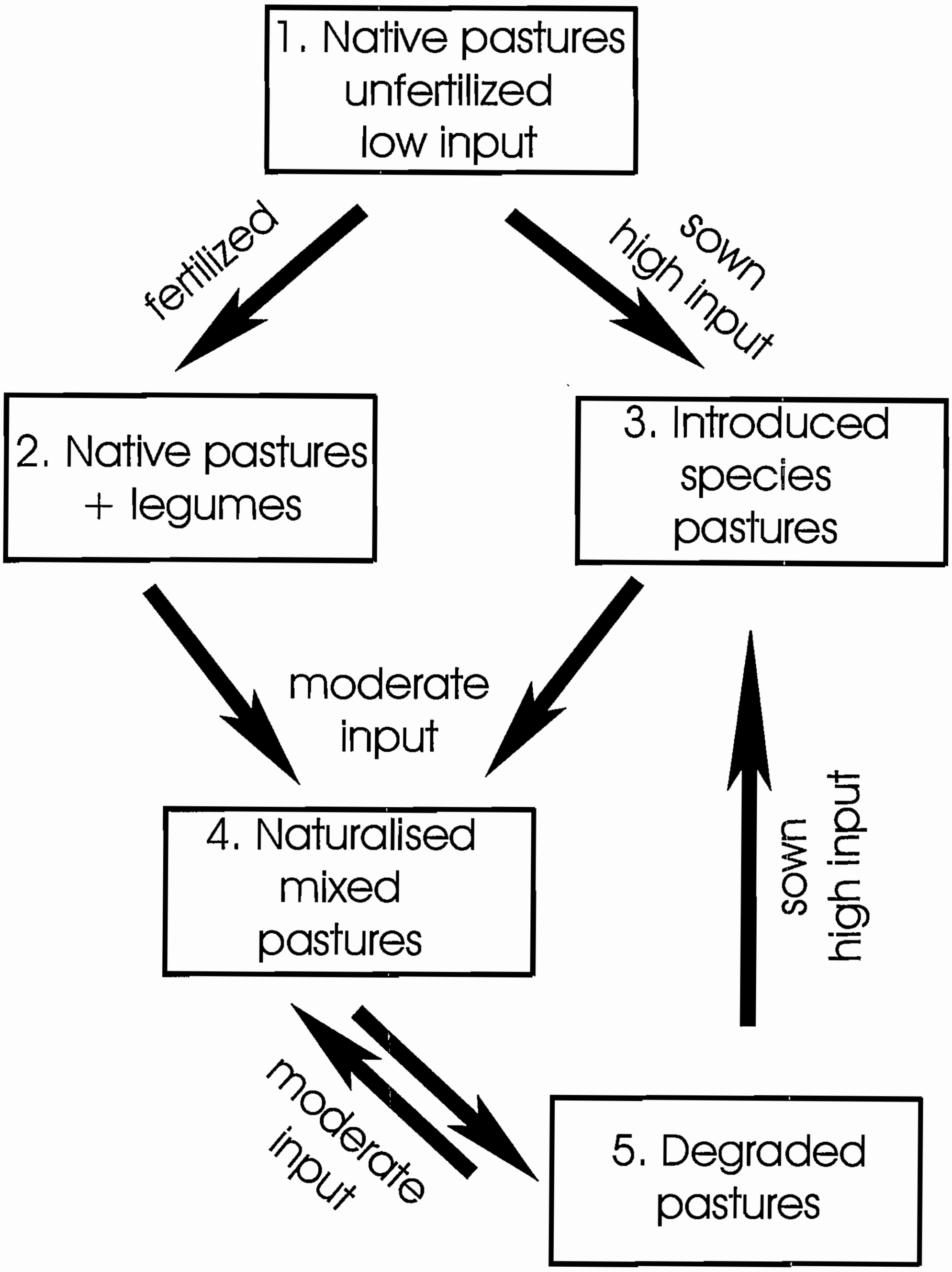

Figure 21:General pattern of change in pasture ecosystems on the NSW Tablelands.

Model concepts

Pastures in the higher rainfall zone of south-eastern Australia have changed considerably since European settlement. The general pattern of change (Fig. 21) can be considered as the general state and transition model for these pastures, with a few of the factors that have influenced changes identified. Other examples are given in Moore (1970) and Kemp and Michalk (1994). Most of the pastures now on the tablelands of New South Wales, would be in category 4, of naturalised mixed pastures. The 'degraded' pastures are those that producers consider have deteriorated to the state where remedial action is needed in the near future.

The 'states' identified in Figure 21 reflect a classification of species in terms of native versus introduced species and some split among the introduced species in terms of utility. This does not necessarily reflect functionality in an ecosystem context. There is no clear evidence for instance, that native grasses behave differently to introduced grass species, or use completely different resources. An alternative view of these 'states' is to consider the species involved in terms of functional groups that would apply to all these 'states'. Across all these groups are perennial and annual grasses, legumes and other broadleaved species. Within a group such as perennial or annual grasses, most species would compete for similar resources. The group where more variation in resource requirements may apply is the broadleaved species.

As suggested, most of the grasses compete for similar resources, and as there is a primary interest in whether annual or perennial grasses are dominant in the pasture, the ratio of perennial to annual grasses can provide a useful separation into different pasture *states*. This is particularly relevant where the aim is to improve, or maintain, the proportion of perennial grasses in a pasture. This model should be applicable to most of the common pastures. There may be some difficulties in using it to classify pastures where, for example some of the grasses were useful and others were a problem e.g. phalaris and serrated tussock, vulpia and soft brome, or *Danthonia* and *Aristida* spp. In these cases, it would be preferable to plot the ratio of desirable : undesirable grasses.

Legumes compete for similar resources as other broadleaved species, though with more variation between species than would apply to the grasses. The ratio of legumes to broadleaved species effectively separates legume (desirable) dominant mixtures from weedy (less-desirable) pastures, within the aim of better pasture management for the non-grass components. Many of the other broadleaved species e.g. thistles are considered to be weeds.

These ratios could be expressed in a range of units, but in the context of agriculture and TPSKP in particular, a ratio based on proportions of the biomass is arguably the more useful. Such ratios, which can be readily used by producers and their advisors, are easily obtained from measurements such as Botanal (Tothill *et al*, 1992).

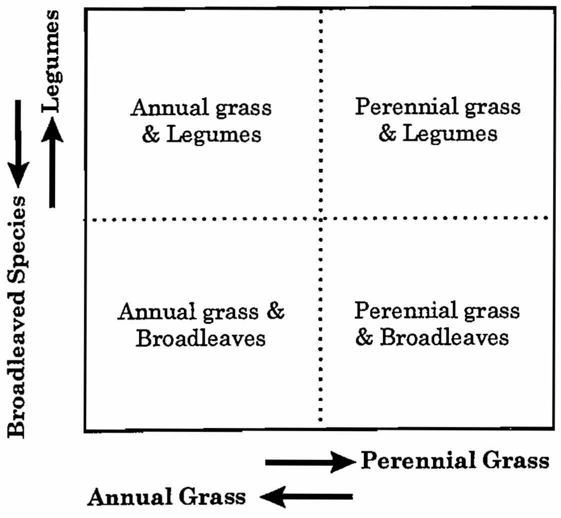

Figure 22: The Pasture Species Composition Matrix

Plotting the legume : broadleaf weeds ratio against that for perennial : annual grasses then defines four *states* within which most of the pastures commonly found would exist (Figure 22). These four *states* are those dominated by:

- annual grasses and broadleaf weeds
- annual grasses and legumes
- perennial grasses and broadleaf weeds
- perennial grasses and legumes

Within each ratio the relative proportions of species are considered, but between grasses and the other species they are not. This could be a difficulty where for example, the non-grass components were very low and not really a significant part of the pasture. Since this could result in some erroneous conclusions about management treatment effects, users would need to be aware of this when using this model. As with many generalised approaches some critical judgement is needed in interpretation. This same problem applies in the conventional *state and transition* models which often don't quantify the relative proportions of species. The model proposed here is likely to be most useful in mixed swards where more than one or two species are significant contributors to pasture production.

In plotting the ratios of functional groups logarithmic scales are used and the data constrained to a range of 0.1 to 10. This was done since the aim is to provide a general picture of trends and a ratio of 10:1 (or 1:10) was considered a clear indication of dominance. Going beyond those limits is not particularly useful.

RESULTS

To investigate the use of the *pasture matrix,* the data from three of the four pastures experiments considered in the chapter on the *pasture management envelope* were used. The cocksfoot dominant pasture at Four Mile Creek was not used as few other species were present in that pasture and treatment effects have so far been negligible. Preliminary analyses with the *matrix* suggested that it was most useful where each functional species group is present. The *matrix* analyses the effects of treatments and complements the results presented in the previous chapter.

Phalaris pasture (Orange)

The continuously grazed phalaris treatment maintained the pasture in a state where the perennial grass and legumes were dominant components. The data in Figure 23 show the trend in compositional changes over seven years. The spring rest treatment was more extreme in leading to dominance of components, though as discussed in the previous chapter, this treatment which often had a low legume content was not the most desirable. Points did move along the upper axis indicating that annual grasses were able to persist within the pasture at times. In contrast, the spring short treatment quickly moved to the right hand axis indicating that the proportion of phalaris was considerably greater than annual grasses and the latter only came back into the pasture during the drought year of 1995. The spring short treatment retained phalaris dominance, but at times the legumes were displaced by other broadleaved species, particularly in 1994 and 1995.

Degraded cocksfoot pasture (Newbridge)

Under continuous grazing and without fertiliser the composition of the pasture at Newbridge was dominated by annual grasses with a variable legume / broadleaved species ratio (Fig. 24). With the addition of fertiliser and a reduction in stocking rate, the perennial grass content increased in 1995. Both summer rest treatments caused a shift towards more perennial grasses and more broadleaved species. In this case, the addition of fertiliser increased the size of change, but not the direction. The use of herbicide reduced annual grasses causing an initial shift towards more (apparent) perennial grass. The real increase in perennial grass content only occurred after 1994 when seed

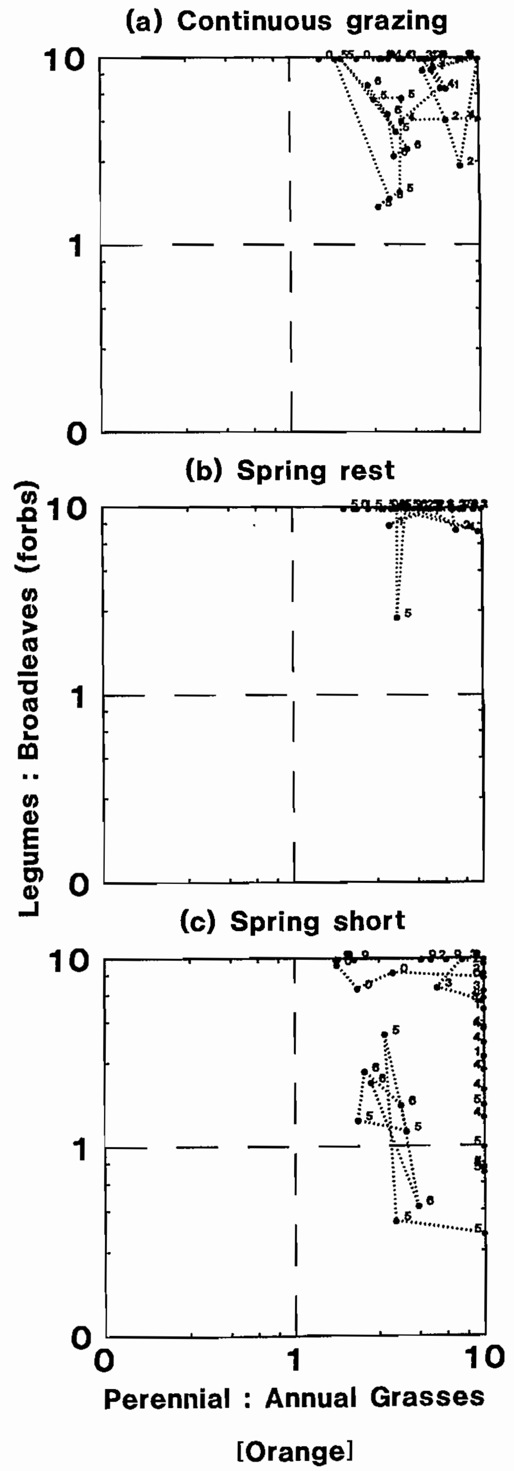

Figure 23: Changes in pasture composition over seven years for three treatments applied to a phalaris pasture at Orange. Numbers indicate the years 1988 to 1996.

was broadcast and a summer rest applied on this treatment. The herbicide treatment appeared to have a greater impact on the legume : broadleaves ratio than the summer rest treatment as there was not the same strong movement to the perennial grass / broadleaved *state* (lower right quadrant) and more points started to appear in the upper right quadrant after the treatment was modified. This backed the judgement that for this pasture, a combination of tactics would be necessary to improve botanical composition to a desirable state (Dowling *et al*, 1996).

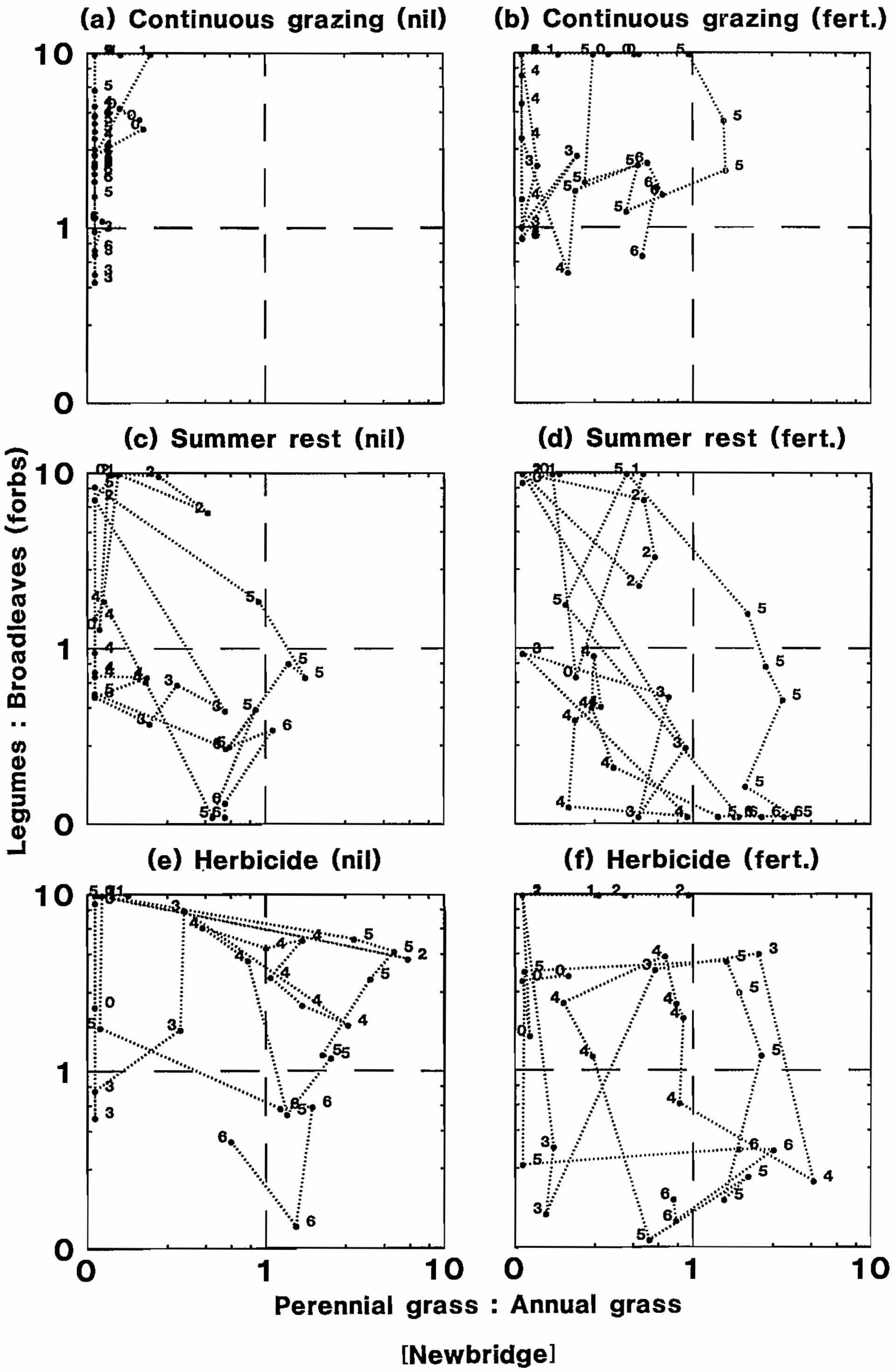

Figure 24: Changes in composition of a degraded cocksfoot pasture from 1990 (0) to 1996 (6) under three management treatments with nil or recommended fertiliser. Points are joined consecutively.

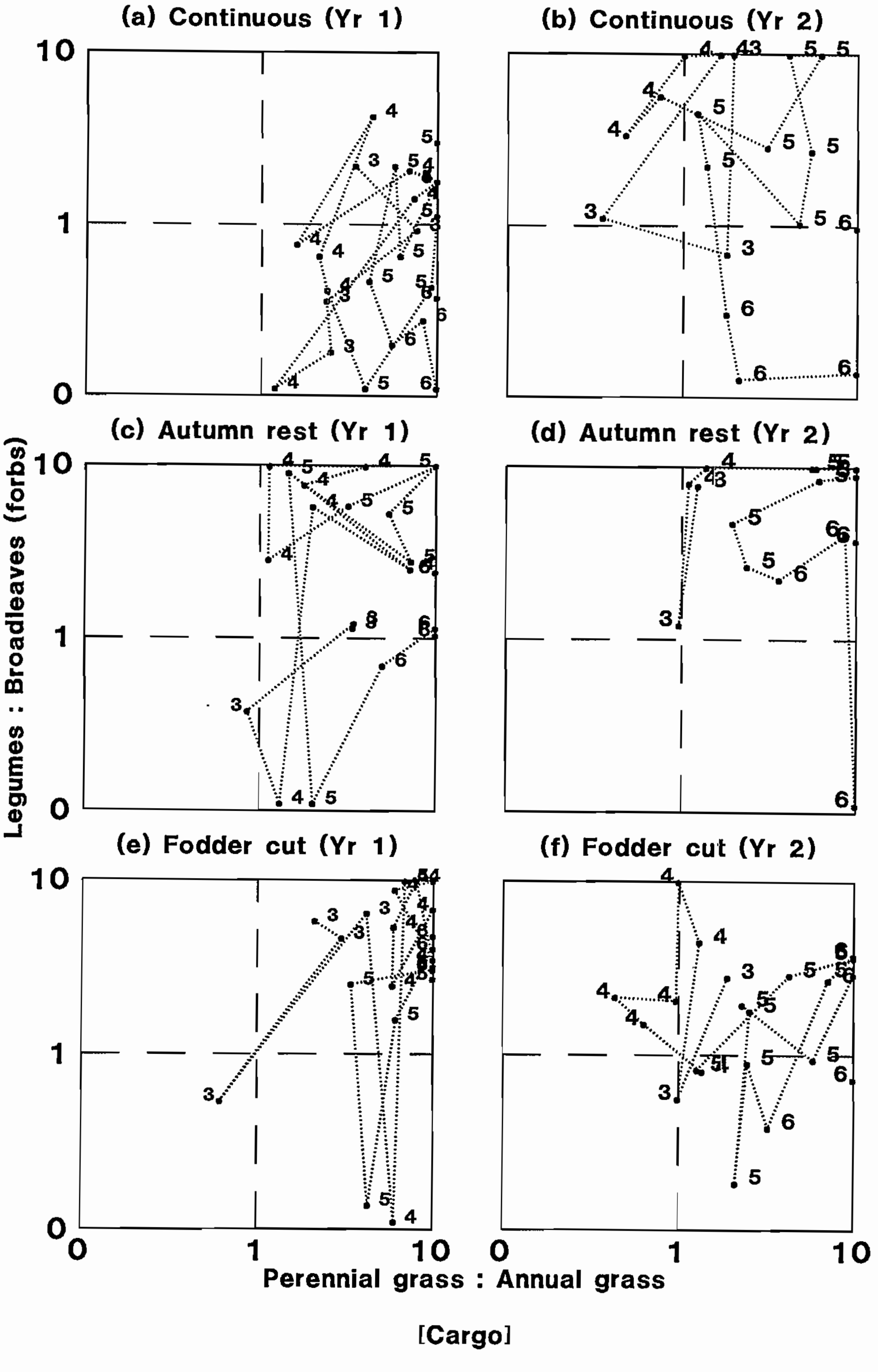

Figure 25: Compositional changes from 1993 to 1996 in a naturalised native grass pasture at Cargo. Data for three management treatments started in two years.

Native grass pasture (Cargo)

The native grass pasture at Cargo had a greater proportion of perennial than annual grasses, but fewer legumes than broadleaved species (Fig. 25). The variation across the site is reflected in the differences between the two continuously grazed control treatments with the second year of start plots having a higher legume content. Legume growth at this site was generally poor, except in 1995. The better treatments in that year were the autumn rest and fodder cut, both of which show more points clustering in the upper right quadrant than the mean of the two controls. The better legume growth in 1995 was not necessarily reflected in a higher legume :

broadleaves ratio in that year as the broadleaved species also benefited to some extent from these seasonal conditions.

The inclusion of all the data in these figures, including that from before the application of the treatments, masks the overall impact of a treatment. Inclusion of all data illustrates how changes in composition occurred, but in the case of sites such as the native grass pasture at Cargo and the second year of start treatments, this means that much of the data shown was before the treatment started. In the evaluation of treatment effects it may be appropriate to only consider the periods from just prior and subsequent to the application of a treatment.

Impact of compositional changes on forage production

The framework of the *pasture matrix* can be used to assess other aspects of pasture performance as well as changes in composition. The impact of different species on pasture production can sometimes be difficult to assess. Such information is useful in establishing if the shifts in composition are likely to have any detrimental effects on pasture and animal production.

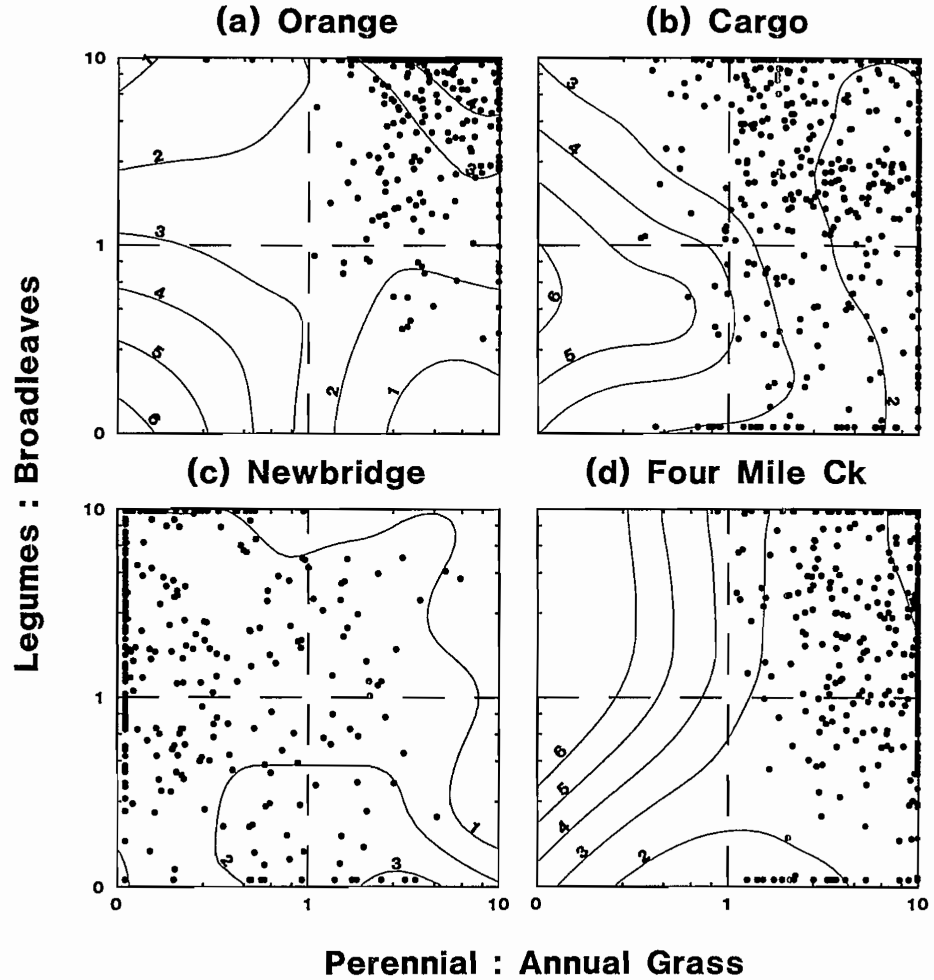

Figure 26: Relationship between composition and forage on offer (contours) for four grazing management experiments. Data from all management treatments in each experiment.

The data from all treatments was used for the four grazing management experiments discussed in this report. These were overlayed with the mean forage-on-offer for each measurement, shown as contours on Figure 26. In the phalaris pasture (Fig. 26a) most data points were concentrated in the top right quadrant and mean FOO values varied from 2-4 t DM/ha as legumes and perennial grasses increased. This largely arose from treatments, including the spring rest, which resulted in rank growth of phalaris and high yields in spring. The upper FOO boundary suggested for the *pasture management envelope* was 3.5 t DM/ha and these data show that when the pasture was in the top right corner of the *matrix,* this limit was being exceeded. Treatments that shifted the pasture to that position e.g. the spring rest (Fig. 23b) were outside desirable limits. The contours shown in the left side of the figure were not derived from data and are an artifact of the process for fitting them.

Forage yields in the degraded cocksfoot pasture at Newbridge generally increased towards the bottom right quadrant (Fig. 26c). There were few points in the top right quadrant. These trends reflected the increasing perennial grass content under the summer rest treatments (Fig. 24) and showed the benefits of this shift in composition on pasture production. The upper FOO limit suggested for this pasture was not generally exceeded.

In the cocksfoot dominated pasture at Four Mile Creek (Fig. 26d), forage yields averaged 2-3 t DM/ha for most measurements. There was a tendency for forage yields to decline as the ratio of legumes : broadleaves declined, but the effect was small. This pasture remained within the suggested forage boundaries (see previous chapter), arguably due to the conservative stocking policy at this site. It was considered that this was an important reason for the persistence of cocksfoot at this site.

Forage yields in the native grass pasture at Cargo (Fig. 26b) varied from 1-3 t DM/ha for most measurements. FOO was less as perennial grasses became more dominant, but varied little with changes in the legume : broadleaves ratio. The decline in yield with increasing proportion of perennial grass was attributed to the measurements from dry seasons. These were often over summer when the main species present were perennial grasses, but FOO was low due to dry weather. In general, the relationship between FOO and composition for this native grass pasture was in line with the FOO boundaries proposed earlier.

DISCUSSION

The *pasture matrix* provides a broad overview of the *state* of a pasture in terms of the major functional groups that are normally within that pasture. The only judgement required about the desirability of the pasture is whether or not the composition is generally satisfactory for production and sustainability. The *matrix* allows the direct evaluation of research results within a *state and transition* model context and then a simplification of those results for advisory messages.

These results show some of the benefits and limitations of using the *pasture matrix.* The phalaris pasture at Orange was largely maintained within a desirable *state* by contrasting treatments. This supports the view that phalaris pastures are amenable to a range of management tactics. To fully use this approach it is important to consider additional criteria. For example; the spring rest treatment (Fig. 23b) was dominated by phalaris and the absolute legume content was low. This suggests that when treatments result in a tight cluster of points along one axis the pasture may not have the most desirable composition. The spring short treatment resulted in more variation in composition and showed how other broadleaved species could displace legumes in some years. This treatment was considered to be the best tactic tested and hence it does indicate that some movement within the *matrix* is useful as it shows the pasture is being maintained in a dynamic state and the dominance of some components is being limited. The cost of limiting that dominance is that weed species can exploit some of the resource space created.

The *matrix* provides a useful description of the pattern of change over time as was clearly evident from the data for the degraded cocksfoot pasture at Newbridge (Fig. 24). The progressive increase in perennial grass content over the years was apparent in the summer rest treatment. These patterns can then be readily summarised for extension messages.

The *matrix* is based on ratios among four functional species groups. These groups all need to be present in the pasture to obtain meaningful results from the formulation used here. Variations on the basic *matrix* are possible and would be appropriate in some circumstances. For example; if annual grasses were a minor component and the perennial grasses comprised both desirable and less-desirable types the ratio of these two perennial grass groups would be more useful. The *matrix* is designed to explore the interactions between components and would not apply if the pasture was dominated by one, or two desirable components - this was almost the case with the spring rest treatment on the phalaris pasture at Orange (Fig. 23) and for Four Mile Creek.

The use of ratios between functional groups can have applications in other contexts for the evaluation of pasture systems. The legume : grass ratio can provide a general description of the 'balance' among two of the major groups in a pasture and how that changes with time. Ultimately this may have implications for sustainability indicators.

The analysis of the relationship between FOO and species composition, using the *pasture matrix* highlighted the need to critically examine the trends in composition over time and the implications for pasture production. The phalaris pasture often moved to the top right corner of the *matrix*, but that resulted in high forage yields beyond the FOO boundaries suggested for a desirable pasture. In this case data spread through the top right quadrant of the *matrix* would seem to indicate a better pasture

The *pasture management envelope* is a more specific tool than the *matrix*. It requires more knowledge about the pasture system and a more detailed specification of a desirable pasture. Both the *matrix* and the *envelope* can apply to temperate perennial pasture ecosystems. The *matrix* is probably more effectively used to describe the general status of a pasture and to indicate the management treatments that would be required to shift that pasture into a more desirable state. Once the pasture has a reasonable proportion of desirable species, the *envelope* can be used to focus the aims of management and make adjustments for the enterprises being run e.g. wool versus beef cattle. These ideas are shown in Figure (27).

The *pasture matrix* could be further developed. Each quadrant of the *matrix* has a set of attributes for livestock production, sustainability, viability etc. This framework could then be used to identify better bet options for producers and focus their management. As animal production can be influenced by the composition of a pasture it should be possible to provide some general guidelines to producers on the type of animal product most suited to different parts of the *matrix* and the likely market prices for those products, similar to the price grids for livestock that are based on size and meat quality. Once they have decided what they wish to do more specific benchmarks and, or the *pasture management envelope* can then be used. Producers could work with advisors to define the attributes of the different pasture *states* within the *matrix*. They would then be more involved in defining their problems and developing solutions.

The present model for the *matrix* only considers four *states*. It would be feasible to extend the number of *states* to several more in order to specifically identify boundaries for pasture management. The number of *states* to define would depend upon needs and the sophistication of the user. For example the boundaries between *states* could include those that define the *pasture management envelope* and then the two models would merge. This ability to start with a simple *matrix* and then increase the complexity as needs arise will be worthwhile considering in any future developments for technology transfer.

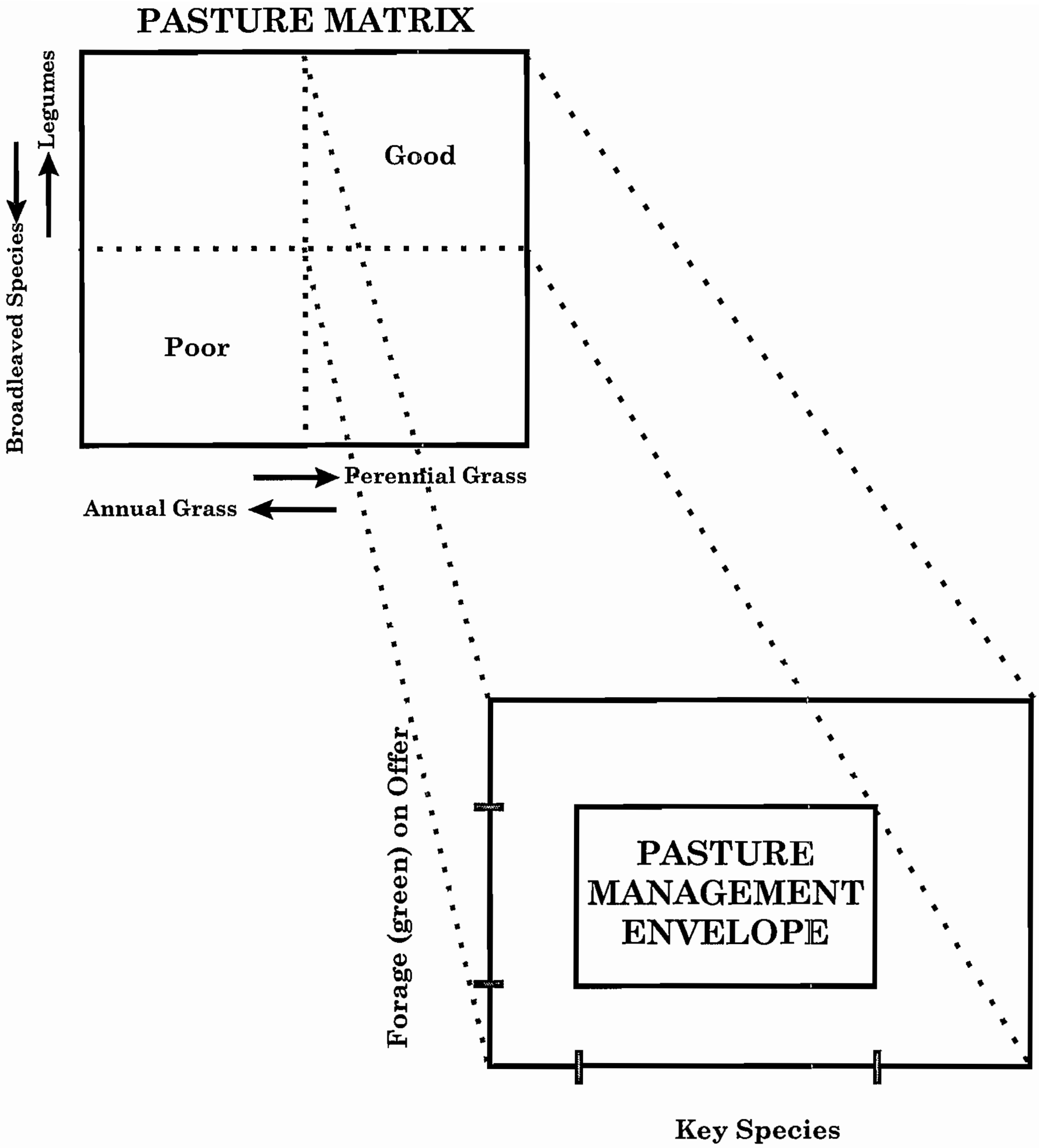

Figure 27:Relationship between the *Pasture Species Composition Matrix* and the *Pasture Management Envelope*.

4. Data Analysis of Grazing Management Experiments

INTRODUCTION

The main grazing experiments within TPSKP aimed to screen a range of treatments from which better management practices can be derived and which can also be used to better understand pasture ecosystems. Within those experiments measurements were frequently taken of biomass and composition, of the available forage and of pasture growth in cages. Prior to these studies there were no ideal statistical procedures for analysis of such data. It was also considered that the impact of treatments may need to be evaluated more by trends, than absolute values as the experiments were only going to run for three years. The short-term nature of these studies was further aggravated by drought at many sites.

This part of the *envelope* project aimed to establish the procedures for statistical data analyses, in cooperation with Biometricians, so that suitable advice could be given to those managing grazing experiments within TPSKP. Data obtained in a previous IWS / WRDC project was used to establish those procedures, rather than waiting until sufficient information was obtained from within TPSKP. Further improvements were then developed as the TPSKP data became available. Alternative procedures were evaluated on the basis of biological as well as statistical significance. This project was established early in the life of TPSKP, but then subsequently a separate project was developed for biometrical support. This chapter only outlines some of the procedures developed for the main data sets on yield and composition. The analysis of supporting data on e.g. seedling recruitment was done using individual analyses of variance of treatment effects. More details are provided in reports prepared by Ms H Nicol and Mr T Klein.

PROCEDURES DEVELOPED FOR ANALYSIS OF GRAZING MANAGEMENT EXPERIMENTS

Initial procedures

To establish significant differences between treatments various alternative methods of analysis are possible. These methods include: analysis of proportions or absolute values; of individual harvests, or groups; and of rates and direction of change between sample points. Analysis can proceed on each component of the pasture, on groups e.g. all the perennial grasses, or on secondary variables that consider all species in the pasture, such as principal components. Use of initial covariates may also help to adjust for variation in initial starting conditions. It was realised that it would be unlikely that there was one best procedure and that some would be more useful than others.

The extent and mass of data collected by site managers in the Key Program required special consideration during analyses. This was because statistical programs are not routine and hence not available 'off the shelf'. The size of the data bases alone, presented logistical problems. However with standardised data collection, entry and file naming by all researchers and support from the appointed Research Officer, these problems were overcome.

Once the data had been processed and organised within the BOTANAL procedures, four layers of analyses were initially considered. These initial procedures were based on using available univariate analyses while other new and more complex procedures were being developed.

Analysis of components from individual harvests.

Simplicity of analyses was possible in the initial analysis of individual harvests because of the extensive efforts made in the design and layout of experiments, derived from the use of principal components. The allocation of treatments to plots resulted in a simple error structure and hence simple analysis of variance for each harvest. The main difficulty was the variable number of treatments being measured at each harvest over the first two years. This meant that different programs were required for each harvest, or data sets were created where those treatments which were not currently being sampled, were included as missing values. Sample GENSTAT programs (developed with Ms H Nicol) were distributed to assist collaborators in setting up appropriate analyses for the management experiments. This assisted in ensuring standard analyses but was not intended to replace requirements for individual sites nor interpretations by each site manager.

Although the thrust of the Key Program was on the effects of grazing management on pasture composition (i.e. percent change in individual species) analyses were on both percent composition and estimated yield of individual components. Final judgements on the importance of effects needed to consider both parameters. Both the data sets from sampling standing biomass and the cage (growth rates) data need to be analysed in this way. Large changes in composition may only reflect small changes in biomass and *vice versa* depending upon season. Sampling of the cage data should coincide, in most instances, with the other harvests. Where cages were sampled between the 'normal' six week harvests, analyses could be done on the cage harvests and on the data accumulated so that it applies to the same period as the 'normal' harvest sampling.

It became obvious at an early stage (and based on previous experience with these type of designs) that simple contrasts between each of the treatments and the control are the important first step to take, to avoid becoming overwhelmed by the mass of data collected. Graphs need to be prepared from an early stage to show the patterns of compositional change for each treatment. Again this needs to be done on both percentage and yield data. Associated standard errors can be plotted on the graph. Routines were established where data from individual harvests were entered into a computer and analysed within a week or so of sampling.

An important consideration when doing some of these analyses is when to include data from treatments during any periods of exclosure. This can be a problem, for example, with spring data where yields from the spring rest treatment can be way in excess of other treatments. This can distort the analysis unless precautions are taken and, or transformations used to scale the data better. Excluding such data at times can be justified on the grounds that you know it is significantly different from the control during the period of treatment, but really only want to study any after-effects of the treatment.

Early consideration was given to the use of spatial analysis for these data sets. The design allowed for such procedures. Spatial analysis enables plot data to be adjusted for any underlying trends in fertility, or other factors. After some exploratory analysis it was decided that spatial analysis was suitable for total yields, but not for individual components. Spatial analysis can only be done on one factor at a time. When applied to individual components it was found that the total of all components would no longer equal 100%, or the actual or adjusted yields. In addition, the use of spatial analysis for components was not considered appropriate on theoretical grounds, as across a site the distribution of individual species is not necessarily in response to any underlying trends in the same way as total yield is influenced. The restriction of spatial analysis to total yield data was also applied in the analyses considered below.

Change in individual components between harvests.

Data analyses for each harvest give an indication of the most important treatment effects, but often there may not be any significant difference in absolute values, between a treatment and the control at the start, or end of a period of change. However treatments could be changing relative to the control without large differences in absolute values. Hence in the second layer of analyses, the rate and direction (slope) of change between harvests can be analysed i.e. the difference in percent composition and yield of a component between consecutive harvests. This procedure was aimed at detecting when and where significant changes start and finish. Ultimately it is important to identify these changes, when planning treatment combinations to form more complete grazing management systems.

This procedure was useful to confirm the duration of treatment effects, especially the times when differences between a treatment and the control started and stopped. However often the changes detected with this procedure were also detected using the initial analyses of differences in components at individual harvests discussed above. While this procedure was considered useful it was not considered essential for analyses and was reserved for resolving some individual cases.

Grouping of harvests over time.

The third stage of data analysis investigated was to integrate the effects of treatments over time to determine mean or cumulative effects over more than one harvest. This can be a useful way to obtain appropriate error terms for comparison of the patterns in treatment effects over time i.e. the overall effect of a treatment on species often visually apparent from graphs. We can integrate data within a season, or a year, or groups of seasons for analysis. This approach allows detection of common events across time and identifies environmental effects (eg. effect of wet Vs dry periods).

Simple plotting of data points (as outlined under 1 above) will allow a visual appreciation of effects of different treatments on individual species and clarify appropriate groupings of data *in hindsight*. Initial groupings of data were done on a seasonal basis to check trends, but that was not always the most appropriate as treatment effects often extended for more than one season. Grouping data within years was not ideal either as this did not always reflect longer period effects, eg. in a phalaris pasture at Orange over several years, there were several phases within which the data could be grouped: these periods were; initial establishment and white clover dominance; dry seasons and subterranean clover dominance; wet summers, mature pasture and return of white clover dominance; a further drought where subterranean clover returned; and then another shift to white clover dominance. The response to treatments varied with each phase.

The integration of data over time needed to be done using the absolute yield information (for each species) and not the percentages. Once the cumulative yields (e.g. for growth rate data from cages), or average yields (e.g. for measurements of standing biomass), over time were obtained, the values could be converted back to percentages for analysis, or presentation. Percentages averaged over time did not necessarily give the correct figures.

This procedure was only used to a limited extent as it required a consideration of all the data from an experiment to decide upon how harvests should be grouped. This was then an individual decision for each site. Other procedures often provided as useful an analysis.

Combined analyses over time.

The fourth level of analysis considered was appropriate once all harvests were completed and was to supplement the analyses done at levels 1 and 2. A combined analysis would use all the data to provide general error terms for treatment comparisons at each harvest and between harvests. The simple way to analyse this was as a straight forward ANOVA of harvest * treatments. Such a procedure can improve some of the error estimates. Some trial analyses are recommended to establish the scale of gains. Caution is needed as average error estimates from a combined analysis, at periods of low yield could be larger than obtained from analysing individual harvests, while the reverse applies at periods of high yield. Sorting out treatment effects under low yield conditions can then be a problem. A combined analysis was difficult to set up, especially for the first two years as the number of active treatments varied (an alternative strategy was to include the data for the non-sampled treatments as missing values as mentioned earlier, thereby allowing the same structure for analysis at all harvests, but this was not an ideal solution).

Problems arose when considering these combined analyses due to the factorial nature of the main grazing experiments and the structure of the design. Treatments started progressively over two years and the year of start difference was not a constant effect for all treatments, which limited the value of any factorial analysis of means. Instead it was realised it would be better not to consider the treatments in terms of season of start, but simply as twice as many treatments i.e. instead of having 12*2 treatments there are in effect 24 and the value of having an interaction term was lost. There seemed little merit in trying to extract an overall comparison of years effect. It was likely that there may not be any significant interactions between year and treatments, when in fact there could be significant differences between seasons for some treatments. Secondary analyses looking for such effects need to be routinely done rather than being dependent upon looking first for significant primary interactions and this can be achieved with other procedures.

These considerations of the design and it's implications led to a small revision of the protocols. Originally it was decided to only implement one year of start for the winter treatments i.e. winter deferred and the autumn / winter mob stocking. This was done as winter is the more reliable period of rainfall at most sites and hence should be the more consistent season from year to year, and the short duration of TPSKP could preclude more than one years data from the second winter year of start treatments. However, the original balance of treatments assumed that a second year of start would occur in all cases. It was then decided to include the second year of start for all treatments and to extend TPSKP until October 1996 in order to provide at least one full years data for each treatment.. This meant that the only treatment with four replicates was the control, all others had two.

Combined analyses of individual components over all harvests using univariate procedures were not used in the end, due to the complications discussed and because by that stage alternatives had been developed that provided more comprehensive analyses of all components.

Analysis of original experiments from Orange

The first experiments using the open communal grazing design were done at Orange under an earlier IWS / WRDC project (DAN 28). These experiments were used to develop statistical procedures and to evaluate aspects of the experiment design.

The design involved lockups from grazing at intervals during the year and it was of interest to know how long it took after opening plots to grazing, before animals were grazing those plots at the same rate as the control. This was done using the data from plots and cages to estimate pasture growth and consumption rates and grazing pressure (as discussed in an earlier chapter), and also from examining the scale of changes in biomass on treatments Vs the control, or in the surrounding field between consecutive harvests (this was a less precise measure as growth rates could vary in relation to differences in green leaf area between treatments, but had the advantage of more available data with less variation). These analyses indicated that the net changes on most treatments were similar to the control within six weeks of any plots being opened to grazing. The main exception was the spring lockup which often took twelve weeks before usage rates were the same as the control.

In this analysis it was considered that differences in total available biomass between treatments were not important. What was important was the rate of consumption of biomass. If this was similar between treatments it indicated that the actual stocking rates on each treatment were also similar, supporting an assumption in the design. Such comparisons need to be done over a reasonable time interval as the conservative stocking rates used meant that animals could be somewhat selective and graze at random across a paddock. Six weeks appeared to be the minimum time to allow so that animals would have had enough chance to graze all parts of a paddock.

Consideration was also given to how long these experiments needed to run in order to detect useful effects. The main emphasis in the experiments was on changes in biomass of species, rather than on recruitment of new plants. The results showed that biomass effects were often visible within a season or year, but could take a few years to accumulate to a significant level. This was evident in the data for cocksfoot at the Newbridge site, discussed in earlier chapters. These considerations reinforced the view though, that the more useful data from the grazing experiments would be on trends rather than absolute changes, given the short-term nature of these studies.

Repeated measures and spline analysis of components over time

The evaluation of differences in individual components over time, between treatments, was an important part of the statistical analyses. The initial procedures considered above used standard analysis of variance techniques to provide information for this purpose. Improved analyses would involve a combined analysis over harvests of the trends in components. This is usually described as some form of repeated measures analysis.

Repeated measures techniques assess longer term trends over time and seek to adjust for the fact that observations at one time are often influenced by prior events. Such an analysis requires an exploration of appropriate models to fit the pattern of change in components over time. Considerable difficulties were encountered using the techniques available at the start of this project. The patterns of change for each component from each treatment, varied considerably and often without any regularity. It was difficult to select a suitable statistical model with enough flexibility to enable cross treatment comparisons. These problems prompted the Biometricians (Ms H Nicol and Drs Cullis and Gilmour) to develop procedures based on splines.

Splines involves the use of polynomial functions that link all data points in a continuous fashion. They are usually constrained to pass through (at nodes) all data points, or the means. The routines developed enabled fitted functions to describe changes in individual components over time, adjusted for underlying trends and then statistical comparisons to be made between components for different treatments. The *t* test used to compare a component between treatments, provides an estimate of statistical significance over the whole of the data set. This is a limitation in the current methodology as individual treatments may only have short-term effects (and designed as such) and some treatments did not start until over halfway through the experiments so that they were similar to the control for a long time. The *t* test is also largely influenced by the largest change over the period under test (compared to the control) and does not analyse smaller period effects. The latter effects require analyses of subsets of data. Despite these limitations the use of splines for the analysis of individual components is the better technique currently available and has considerable potential for development. All data from the grazing sites in TPSKP is being put through this procedure. As with other analyses all data should be first plotted to detect trends and when considering the outputs from the analysis.

Multivariate analyses of treatment effects

The analyses of individual species provides some evidence on significant differences between treatments, but not on significant treatment differences as a whole. A dilemma can arise if one species is significantly different between treatments but others are not. It is then uncertain if a Type II error has occurred. Establishing general differences in components between treatments using univariate analyses can become complex. Multivariate procedures are considered the better way to solve this problem.

Multivariate analyses have not been used much in grazing studies and the better techniques have not been resolved. Such techniques are very common in ecological studies, though usually only applied to individual data sets and not to changes over time. Initial analyses using principal components suggested it may be possible to detect how the grouping of treatments change over time. This method was then evaluated.

The procedure developed with principal components analyses was to do a canonical variate analysis on functional groups for harvests over time. Routines are available in GENSTAT. The functional species groups used were the same as discussed in the *pasture species composition matrix* i.e. perennial and annual grasses, legumes and other broadleaf species. These groups were used rather than individual species for the same reasons as those outlined in the chapter in the *matrix* and to insure that data was available for each harvest analysed. Multivariate routines do not work well, or enable valid comparisons over time if there are missing values.

The first two canonical variates usually explained in excess of 60% of the total variation and often up to 90%. There were few occasions where the third variate made important contributions to the analysis and hence most analyses used a plot of the first two variates. Tests can be applied to the distance between points on a plot of canonical variates to establish if treatments differ significantly. A biplot procedure was used (Gabriel, 1971) to identify the major functional species group influencing the canonical variates. This procedure was then applied to all the data from the grazing experiments.

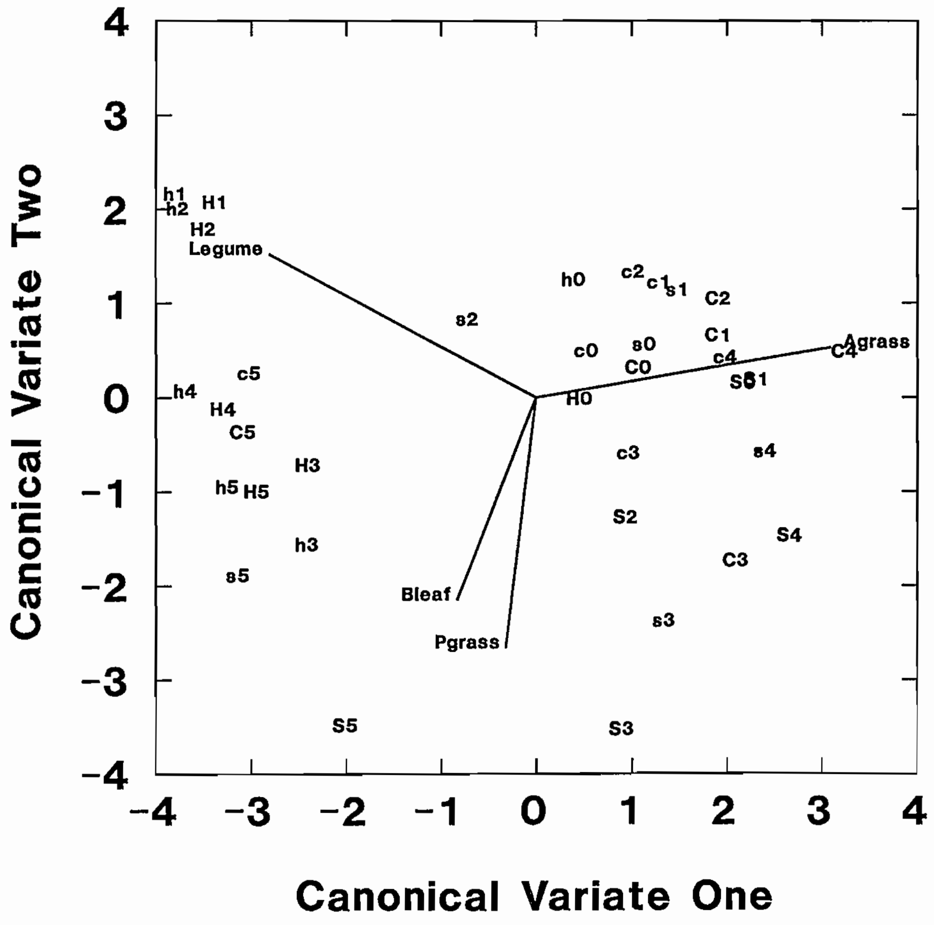

Figure 28: Biplot of the first two canonical variates from analysis of harvests in early spring from a degraded cocksfoot pasture at Newbridge. Treatments are the continuously grazed control (c), summer rest (s) and herbicide (h). Lower case denotes nil fertiliser, upper case recommended fertiliser and the numeral the last digit of the years 1990-95. Plots overlayed with major coordinates for each of the four functional species groups.

The results of a principal components analysis for the harvests taken in early spring each year for the cocksfoot pasture at Newbridge are shown in Figure 28. The control treatments were largely dominated by annual grasses, while legumes were more important in the herbicide treatments in early years. In later years after cocksfoot seed was broadcast and summer rests imposed the herbicide treatments then shifted down to where perennial grasses and other broadleaf species were more important components. Summer rest treatments were initially dominated by annual grasses and moved to where perennial grasses were more important. This analysis does enable a valid separation of treatments and encapsulates the major effects better than any of the univariate procedures.

Caution is needed when interpreting the results of principal components analyses. The signs of variates have no biological meaning and this is also true of the direction that treatments shift i.e. a positive change in a component can be a negative change in a canonical variate. Shifts in treatments can also be substantially influenced by minor components. In some cases in the phalaris dominant pasture at Orange, it was noted that treatments were being distinguished on a change in the broadleaf component from 5-10% whereas shifts in the perennial grass content from 60-75% had almost no effect. Treatments were the broadleaved species content only varied significantly from 5-10% could be considered to have no agricultural relevance, other things being equal.

DISCUSSION

The procedures outlined here have enabled the successful statistical analysis of the grazing management experiments. In practice the initial analysis of individual components for each harvest is valuable when done routinely soon after measurements are taken. This enables an early appreciation of the results as well as checks for errors and provides summaries of treatment effects for data plots. The other initial procedures outlined can be used to further resolve effects and details of changes on components.

Resolution of general treatment effects was best achieved with principal components analysis and biplots. This enabled a rapid appreciation of main effects and when they occurred. Trends over time were deduced and the influence of major species functional groups detected. These procedures should be developed further as more could probably be done with the 'inter-group distance' between treatments and how it varies over time and in developing more sensitive tests to identify when the distance between treatments is significant. This could be an additional application of the splining procedure. This is the first time such techniques have been applied to the analysis of grazing experiments over time. Other multivariate procedures need to be explored in SGSKP as they could offer enhanced analyses of trends. The better procedures to use have not yet been established as this will require some consideration of the underlying theories.

The new techniques for fitting and analysing splines, to individual components has provided the best procedure to date for such data. It is superior to older techniques for repeated measures or the analysis of individual components for individual harvests, even when harvests are combined for analysis, and also provides a general description of trends in the data after removing the 'noise'. This technique has not been fully developed as only simple tests of significance are available and these only provide a test for the whole data set. An ability to test differences on part of data sets would be more relevant to grazing studies.

The statistical procedures outlined here provide tests of significance for differences between treatments as a whole and of pasture components between treatments. When significant differences are found they need to be evaluated in a broader context to judge their agricultural relevance and then translated into messages for producers. Principal components analyses provide a good summary of treatment effects on composition, but information is limited on which components are the more important and no biomass information is included. The *pasture management envelope* and *pasture species composition matrix*, as discussed in this report, are designed as tools for that purpose. No applications of statistical tests to the *envelope* or the *matrix* have yet been done. This should be a fruitful area and should be explored in future studies in SGSKP. Principal components analyses could offer an alternative procedure for development of the *matrix*.

5. Discussion and Recommendations

The results from the Temperate Pasture Sustainability Key Program and it's successor the Sustainable Grazing Systems Key Program, need to be presented to producers in ways they can readily understand. The *pasture management envelope* and the *pasture species composition matrix* both aim to provide ways of presenting that information to producers. Both techniques enable the evaluation of pasture management practices in a framework that can specify the agricultural relevance of the results and then the simplification of those results for communication to producers. The general influence of summer rest treatments on a degraded cocksfoot pasture is shown in Figure 29.

The message shown in Figure 29 identifies that that treatment is not perfect and additional tactics need to be employed to shift the pasture into the most desirable state. The same message is applied to the *envelope* (Figure 30) along with one derived from the phalaris grazing experiment. In both cases a pasture assessment is required to establish if the pasture under consideration is in the zone of the *matrix* or *envelope* where the message applies. Additional data sets need to be analysed in this way to find those applying to other zones of the *matrix* or *envelope* and the consequences of different management tactics. In general on the *envelope* grazing tactics are used to shift species composition and stocking rates FOO. Defining the interaction can be the more important issue.

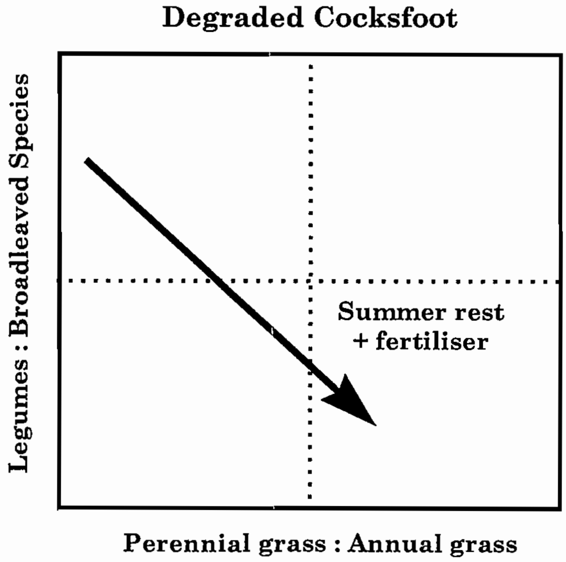

Figure 29: General effect of summer rest on a degraded cocksfoot pasture at Newbridge. Derived from Fig. 24d.

The results presented here show how treatments can be more effectively evaluated within these frameworks than simply doing an analysis of variance. An additional step of applying statistical analyses to the *envelope* or *matrix*, has not been explored. Both techniques provide a means of exploring changes that occur within a pasture over time and help our understanding of how components interact while enabling rules for pasture management to be developed.

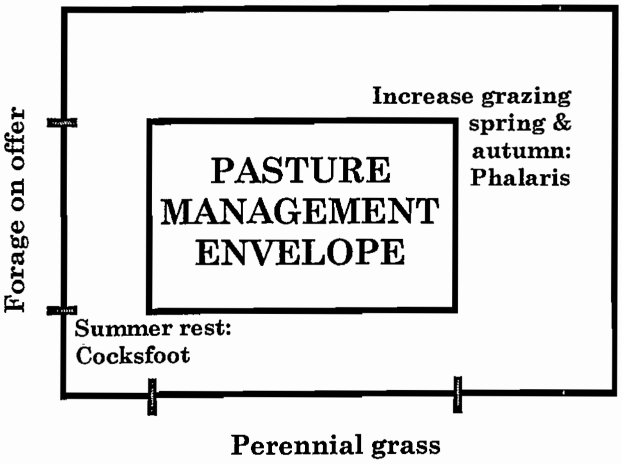

Figure 30: Advisory messages derived from grazing management experiments on cocksfoot and phalaris applied to the *pasture management envelope.*

Benchmarking has become a useful practice in many industries, including agriculture. Benchmarks have been developed for pasture and animal management and these do provide guidance for producers. This report provides benchmarks for management of different pasture types, based on Australian data, that have not been available previously. The *envelope* and the *matrix* however, go beyond the approaches previously used in that they look at the interaction between different benchmarks and allow some analysis of which benchmarks are the more important. For example, in a phalaris pasture where annual grasses are a minor component, the lower species and FOO boundaries are arguably more important than the upper ones. In addition, tactics to manipulate species composition should be emphasised (but not exclusively so) over those to manipulate FOO. In this case there is some complementarity between techniques to limit FOO and phalaris dominance, and increase legumes. The *envelope* can then be a useful research tool which does need to be used when evaluating results. The incorporation of FOO and composition in the *envelope* provides an image of the interaction between key parameters.

The two procedures explored in this report are complementary. The *matrix* encompasses the major functional species groups that are in mixed pastures and provides a useful picture of major shifts within the pasture and how they are influenced by treatments. The *envelope* is more appropriate where the key species are significant components in the pasture and where the aim is to manage the pasture for optimal production and persistence. The *envelope* requires more information on the appropriate boundary conditions for key components and a better understanding of pasture and animal performance to be used effectively. Surprisingly, when the *envelope* was presented to some advisory staff early in this project, they considered it to be complex. In retrospect, that was understandable given the limited use of benchmarks in pasture management at that stage. This deficiency is being overcome with the Prograze program (Allan, 1994). Where knowledge is limited and more precise management is not required, the *envelope* can be used as a concept to guide pasture management.

Once the *pasture management envelope* is defined a hierarchy of decisions can be envisaged. The *pasture management envelope* aids initial judgements as to whether or not, a pasture is being managed appropriately for production, sustainability and animal performance. When the limits of the envelope are reached, action decisions are required. The treatments screened in TPSKP and to be developed in Phase II (SGS) of this Key Program will provide the information on how to maintain a pasture within the appropriate boundary conditions. The main role of this project was to define the boundaries where decisions are needed and not necessarily to decide on the better management treatments. That will depend upon a full analysis of results from the current and future grazing studies. Current studies will not finish until late 1996.

One way to ultimately use this information could be to construct 'decision trees' providing indicators of likely outcomes from different grazing practices - both good and bad. The aim of such support systems would be to provide better advice to producers on ways to manage their pastures on a paddock basis. This advice would emphasise the role of plants in pastures.

Once fully developed the outcomes from this project are expected to have a substantial impact on meat and livestock industries. The methodology presented puts the results from the TPSKP grazing experiments in an agricultural context, rather than simply describing significant differences between treatments. The methodology also enables a consideration of how treatments could be modified to improve practices.

RECOMMENDATIONS

☞ The development of sustainable grazing systems needs to be done within a framework that enables an evaluation of research results and a vehicle for their presentation to producers and their advisers in simple, readily implemented ways. This work needs to continue within SGSKP and should proceed in consultation with producer groups.

☞ This report has been prepared before TPSKP has concluded and before most of the analyses of data from experiments in the Key Program have been completed. Most site managers have not yet had the opportunity to explore their data and to find the best way of interpreting and presenting that information. This process will therefore need to continue during SGSKP.

☞ The procedures developed in this report should be applied to all the data from the experiments in TPSKP and future experiments in SGSKP. The other pasture ecosystems studied in TPSKP need to be evaluated against the boundary conditions proposed. The ability of treatments to satisfy these boundary conditions should then be explored and where treatments lie outside boundaries possible modifications to those treatments should be considered (where appropriate) in designing improved management practices to test in SGSKP and for recommendation to producers.

☞ Where suitable boundary conditions for management of pasture ecosystems cannot be decided from experiments to date, the experiments in SGSKP may provide suitable information. If that is not possible then consideration should be given to establishing suitable studies within SGSKP to obtain that data. This could include additional treatments or separate experiments.

☞ The results presented in this report suggest that the left and bottom boundaries of the *envelope* are the more critical for management. This needs to be tested in further work.

☞ *Envelope* boundaries need to be evaluated in relation to livestock production. In this project boundaries for animal performance were only deduced from the literature.

☞ Within TPSKP data analysis has proceeded at a faster rate than has often occurred in similar projects. This was largely attributed, to having a Research Officer employed for that task who could assist site managers and liaise with the biometricians. The Research Officer worked closely on the *envelope* project which further helped him to evaluate information for site managers. In SGSKP, a similar position should be funded so that data analysis and interpretation can be centrally coordinated and done as efficiently as practical. The appointment of an experienced person would also help in the design of new experiments.

☞ Data analysis procedures for grazing experiments have advanced considerably during TPSKP. The latest splining techniques have only been developed to a useful stage during 1996. Further development of statistical procedures will be needed in SGSKP. For example, it is expected that the application of splining techniques to the multivariate analyses over time will help resolve significant treatment differences more effectively.

☞ The application of statistical procedures to the *envelope* and *matrix* has not yet been done, but there is the prospect of being able to resolve treatment effects statistically within that framework. Such investigations and further refinements should be an integral part of SGSKP.

☞ The work done on the *envelope* and on the *matrix* has focused mainly on changes in species and pasture biomass. Nothing has been done to link these components with other aspects of sustainable grazing systems. Future work should explore how the boundaries for pasture management interact with sustainability indicators. For example, the legume content that is appropriate to regulate nitrogen fluxes and the minimum biomass to minimise erosion.

☞ The short-term nature of TPSKP and adverse seasons have limited opportunities to understand recruitment processes in many of the pasture ecosystems being studied. Long-term persistence of desirable species will depend upon managing recruitment of new plants and assessment of optimal plant sizes. Little is known of how the boundary conditions for pasture management would influence recruitment, basal cover and plant size and these demographic parameters should be investigated in future work. Such work should also consider issues of 'site potential'.

☞ Future work in SGSKP should consider the role of the *matrix* and of the *envelope* as well as any other relevant procedures that may be developed. This would proceed first through evaluation and interpretation of research results within a suitable framework and then focus on how to effectively present that information to producers.

☞ Closer links should be developed with the Northern Australia Key Program on the development of these tools for technology transfer. Scientists within that program have used *state & transition* models to frame their studies and are developing additional tools to evaluate and present their results. There are a lot of common issues in both the northern and southern programs.

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