SHORT-TERM EFFECTS OF MIXED GRAZING BY CATTLE AND SHEEP IN HIGHLAND SOURVELD

by

Mark Benedict Hardy

A thesis submitted in partial fulfilment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in the
Department of Grassland Science
Faculty of Agriculture
University of Natal
Pietermaritzburg

1994

ABSTRACT

Data derived from a long-term grazing trial were used to determine short-term effects of mixed grazing by cattle and sheep in Highland Sourveld.

Five cattle to sheep ratio treatments (*viz.* 1:0, 3:1, 1:1, 1:3, 0:1) were applied, each at three stocking rates (*viz.* 0.5 (low), 0.71 (medium) and 1.0 (high) animal unit equivalents (AUE) ha^{-1}). Ratios were expressed in terms of AUE cattle:AUE sheep. Stocking rate and ratio treatments were balanced at the start of each grazing season. Fourteen-month old Hereford steers and 'two-tooth' Merino wethers were used as experimental animals.

The trial comprised two components, *viz.* an animal production component and a simulated component. The animal production component was conducted only in the medium stocking rate treatment where the effect cattle to sheep ratio on the performance of cattle and sheep was determined for each of four grazing seasons (*viz.* 1989/90, 1990/91, 1991/92, 1992/93). A four-paddock rotational grazing management system was applied. The low and high stocking rate treatments were implemented by simulating a four-paddock rotational grazing system and using a single paddock for each stocking rate/ratio combination. Grazing of the simulated treatments coincided with the grazing of a specific 'test' paddock in each ratio of the medium stocking rate treatment. These 'test' paddocks and the simulated treatment paddocks were monitored to determine the impact of mixed grazing by cattle and sheep on individual grass plants and the sward.

The whole of the experimental area was rested during the growing season prior to the start of the trial and all paddocks were burnt in the dormant season just before the start of the first grazing season. The trial therefore commenced with a with a uniform sward of immature herbage in all paddocks allocated to each group of animals. In the second and subsequent growing seasons only those paddocks which had been rested in the previous

season were burned prior to the onset of growth in early spring. Rainfall for the first three grazing seasons was similar to the long-term mean of 790mm whilst the last season was considered 'dry' with 554mm recorded during 1992/93.

In all grazing seasons, as the proportion of cattle in the species mix increased, sheep performance increased. A decline in sheep performance was recorded in each ratio treatment from the first to the third season. This decline was attributed to the increased maturity and thus lower quality of herbage on offer to the sheep, and the fact that only one paddock available to the animals in the second and third grazing seasons had been burned prior to the start of the season. Sheep performed best during the 'dry' season where herbage quality was maintained for longer into the grazing season than in previous seasons. In contrast, cattle performance was affected by the stocking rate (animals ha^{-1}) of cattle rather than the presence of sheep. As the quantity of herbage on offer per steer declined steer performance declined.

Animal performance data were also used to predict the effects of adding cattle to a sheep production enterprise and vice versa. The general trends were that the introduction of cattle into a low stocking rate, sheep-only production enterprise would allow for an increase in the stocking rate of sheep while maintaining the performance of the sheep. In this way the carrying capacity of a farm may be improved.

Stocking rate and ratio treatments varied from those established at the start of each grazing season due to the differential performance of the cattle and sheep in each treatment. As the proportion of cattle in the species mix increased, stocking rate increased and the ratio widened in favour of cattle. Stocking rate (AUE ha^{-1}), calculated *a posteriori* for each season, was the major influence on the severity of grazing on individual plants and within patches. As stocking rate of cattle and sheep at the various ratios increased, the extent and severity of grazing increased. At stocking rates in excess of 0.8AUE ha^{-1} however, sheep-only grazing resulted in a greater proportion of plants, per species and per area, being grazed more severely than was the case for an equivalent stocking rate (AUE ha^{-1}) of cattle. Furthermore, cattle and sheep had similar effects on patch size distribution when stocked at the same number of AUE ha^{-1}.

There were no measurable effects of stocking rate and ratio on proportional species composition and basal cover over a two year monitoring period. A technique for estimating basal cover in tufted grasslands was developed and is presented as an appendix to the thesis.

Data were also used to evaluate the use of AUE as an integral part of the grazing capacity concept. Results indicated that cattle and sheep cannot be equated in terms of AUE when referring to the grazing impact. It is suggested that the definition of grazing capacity should include the species of livestock and assume a grazing management system appropriate to the grazing habit of the animals concerned.

Results of the trial provide strong indications that, in the long-term, the current recommendations of grazing cattle together with sheep in order to prevent the degradation or loss of veld condition which occurs in sheep-only grazing systems, will not succeed. A four-paddock rotation grazing system does not appear to be an appropriate veld management system for sustainable sheep production in sour grassveld. An alternative approach to veld management is suggested in which the sheep are confined to only those areas of the farm which were burnt at the start of the grazing season. Ideally, sheep should not allocated to the same paddock for two consecutive grazing seasons.

DECLARATION

I hereby declare that this thesis and the associated research comprises my own original work, except for the assistance which is acknowledged or where due reference is made in the text. I also declare that the results contained in this thesis have not been previously submitted by me in respect of a degree at any University.

Mark Benedict Hardy

ACKNOWLEDGEMENTS

I express my sincere appreciation and thanks to the following persons and institutions:

The Cedara Agricultural Development Institute for current and continued support of the research program and permission to use the data for the purposes of this dissertation.

It is with a deep sense of gratitude that I wish to thank Professor Tainton, my supervisor and mentor, for his genuine interest and guidance, and for never being too busy to attend to queries or to get involved in stimulating discussion. It has been a privilege to have had the opportunity of working with a person with his insight. Prof. Tainton also provided post graduate students and funding which allowed for further component research to be conducted within the research program.

To Earle Buntting, Noel Gray and their staff at the Kokstad Research Station. Without their dedicated approach to ensuring that the trial ran smoothly, this thesis would not have been possible. To Donald Lyle and my other colleagues at the Kokstad, thank you for your support and encouragement through these long years.

To my colleagues at Cedara and staff and students in the Department of Grassland Science at Natal University, for encouragement, assistance and many useful discussions. You all helped to formulate ideas, and provided the company which ensured that some of the more strenuous field data collection procedures were easier to bear. A special thanks to Dr Peter Bartholomew, head of the Grassland Science Research Section at Cedara, for his continued support and encouragement.

To my colleagues at the Dohne and Nooitgedacht Agricultural Development Centres for the many discussions held over the years.

I'm sure that our combined efforts will lead to a better understanding of the requirements for sustained livestock production in areas of sour grassveld where sheep form an important component of the production enterprise.

To Felix Hobson and Dr Tim O'Connor (Dohne), Dennis Barnes (Nooitgedacht), Dr Margaret Friedel (Alice Springs) and other anonymous referees who have made valuable suggestions to draft proposals and publications associated with this research program.

To the many colleagues who worked 'behind the scenes'. Irene van Wyk for data capture and for preparation of Figures 2.1 and 7.1, the ladies of the Cedara typing pool for coping with some of my 'rough' drafts, and Cathy Stevens and Margie Whitwell of the datametrics section for analyses of some of the data sets. To Les Thurtell (feed lab - Cedara) and Dr HO de Waal (Animal Science - Glen Agricultural Development Institute) for crude protein and digestible organic matter analyses respectively.

Finally, and most importantly, a word of thanks and appreciation to my wife who has provided strong, patient and wholehearted support during my many years as a student.

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CHAPTER 1

INTRODUCTION

1.1 Background

The continued retrogression of veld in many areas of southern Africa is perceived to be a function of farm management practices. The high-elevation, sour-grassveld areas on the eastern seaboard of South Africa (hereafter referred to as sourveld), where sheep form an integral part of the livestock production system, are no exception. While the sourveld is considered to have the highest grazing capacity of any vegetation type in southern Africa (see Tainton 1981a), a major constraint to livestock production is that the sward becomes increasingly unpalatable and its nutritional value declines as it matures (Edwards 1981a; Hardy 1986). Cattle are well adapted to grazing low quality forage while sheep are less well adapted, requiring high quality, short, leafy grazing for satisfactory livemass gains (Barnes & Dempsey 1992). As the growing season progresses, growth rates decline and so the proportion of high quality short, leafy herbage in the sward decreases. Sheep then become increasingly selective in their grazing as they attempt to meet dietary requirements (Mentis 1981a).

Management practices commonly applied in sourveld grazed by sheep include 1) annual burning and 2) continuous grazing (as soon after the burn as possible) at stocking rates which maintain the sward in a short, palatable and nutritious state (Malherbe 1971; Danckwerts 1989a; Barnes & Dempsey 1992). Veld management is therefore aimed at providing sheep with immature, high quality herbage in an attempt to achieve maximum wool and mass gains and thus maximize financial returns. There is, however, a large amount of circumstantial evidence indicating that such management is responsible for the deterioration in veld condition in sheep producing sourveld areas (Rethman & Kotze 1986; Danckwerts 1989a; Barnes 1990). O'Reagain and Turner (1992), who present a comprehensive analysis of grazing trials which have been conducted throughout southern Africa, support this observation in concluding that sheep, which graze more selectively and more closely than cattle, have greater potential for causing veld degradation than do cattle.

To limit the negative effects of sheep on veld condition it is generally recommended that they should be grazed together with cattle at a ratio which favours cattle or, at worst, at a ratio of 1AU[1] cattle to 1AU sheep (Malherbe 1971; Mentis 1981a). These recommendations are based on the assumption that, provided the correct stocking rate is applied, the less-selective grazing habit of cattle should ensure that the sward will be maintained in a state suited to the requirements of sheep.

he effects of grazing cattle and sheep together (and varying stocking rates for each ratio) on animal performance and veld condition have received little attention in southern Africa, despite the fact that mixed-species grazing is a common practice in commercial and subsistence pastoral systems. Current recommendations on the appropriate cattle-to-sheep ratios to apply are based on research which was conducted at the Dohne and Athole Research stations during the 1950s and 1960s (Hildyard 1970; Malherbe 1971; Mentis 1981a; Danckwerts pers. comm.). Research involving treatments where cattle and sheep grazed together, but not specifically designed to test the effects of cattle-to-sheep ratios on veld condition and animal performance, has been conducted at Kokstad, Potchefstroom and in Griqualand West (Coetzee 1969, cited by Mentis 1981a; Hildyard 1970; Mostert, *et al.* 1971). The added effects of stocking rate on animal performance and veld condition were not discussed by these authors.

A further important concept regarding the implementation of veld management practices aimed at ensuring sustained livestock production from the grazing resource, is that of grazing

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[1]An animal unit (AU) is generally understood, in this context, to be a steer of approximately 450kg or 6 mature sheep (see Meissner, *et al.* 1983)

capacity. The grazing capacity of a particular vegetation type is defined in terms of the number of animal units which may be carried on a specified area on a sustainable basis (Edwards 1981b; Trollope, *et al.* 1990). Estimates of grazing capacity have been provided for all vegetation types in South Africa. A major assumption in the definition is that, as long as the AU equivalents of each class and species of animal allocated to an area of veld is known, and the appropriate number of AU equivalents are allocated to the area, veld condition and grazing capacity will be maintained, **irrespective of the class and/or species of animal**. This assumption has not been tested. However, despite the fact that there is a considerable body of theoretical and circumstantial evidence that different species of herbivore have different impacts on the resource, the use of AU equivalents, as an integral part of the grazing capacity concept, has gained wide acceptance.

It is important that the effects of grazing by cattle and sheep, alone and in combination, on veld condition and animal performance should be well understood before promoting grazing management strategies for sustained cattle and sheep production systems off sourveld.

1.2 Objectives

Research programmes designed to investigate the sustainability of livestock production from natural systems are, of necessity, long-term. In the present context, the term sustainability implies that the fodder production potential of the system is maintained whilst 'acceptable' livestock production (which depends on the objectives of the grazier) is realised. The broad, long-term objectives of the trial (from which the data used in this dissertation were derived) were, therefore, to investigate the effects of cattle to sheep ratio and stocking rate on:

1. the floristic composition, basal cover and herbage production potential of sourveld, and
2. the performance of cattle and of sheep, with the added

influence of between-year climatic variation.

The ultimate objective was to obtain an understanding of the effects of interactions between cattle-to-sheep ratio and stocking rate on the grazing impact on sourveld and on animal performance.

In the present study, short-term effects of mixed grazing by cattle and by sheep on Highland Sourveld are analysed and discussed. Specific goals of the study were to:

1) determine the effects of cattle-to-sheep ratio on animal performance (chapter 5),
2) characterise the impact of grazing by cattle and by sheep, stocked at varying ratios and stocking rates, as reflected by the forage demand (Chapter 6), the defoliation patterns on individual grass species (Chapter 7), and the extent and intensity of patch grazing (Chapter 8),
3) quantify the short-term effects of cattle-to-sheep ratio and stocking rate on grass species composition and basal cover (Chapter 9), and
4) evaluate the utility of the grazing capacity concept when applied to grazing systems which include both cattle and sheep (Chapters 6 to 10).

1.3 Approach

One of the main aims of applied agricultural research is to gain a sufficient depth of understanding of the structure and function of a particular system in order to provide managers the knowledge whereby they can operate effectively within the environmental and biological constraints of the system. Biological systems are complex and the complexity of the animal/plant/soil/climate environment provides a particular challenge to the grassland science discipline.

An absolute knowledge of how the system 'works' is practically unattainable. What is required is a top-down approach in which a broad understanding of how a particular system operates is obtained, and components which most sensitively influence the structure and function of the system are identified. Research efforts may then be directed toward obtaining greater understanding of the identified components.

The present study attempts to identify the main independent variables which vary sufficiently to significantly affect the sustainability of cattle and sheep production systems in Highland Sourveld. Relevant information and data were obtained through literature reviews and the establishment of a grazing trial. Since the grazing trial was conducted at a relatively remote out-station, detailed and intensive data collection procedures were kept to a minimum. Furthermore, financial and logistical constraints precluded replication of treatments. The trial was therefore designed such that data emanating from it were amenable to regression analyses. Nonparametric and multivariate procedures were also used when appropriate.

The results of these analyses served to identify the short-term, main effects influencing the impact of grazing by cattle and sheep, at a range of cattle-to-sheep ratios and stocking rates, on the forage production potential of sourveld, and on animal performance. The implications of the results are discussed in relation to the sustainability of cattle and sheep production systems in Highland Sourveld.

CHAPTER 2

CATTLE AND SHEEP PRODUCTION SYSTEMS IN SOURVELD

The purpose of this chapter is to provide an over-view of the distribution and extent of the high-elevation, sourveld regions of South Africa, its vegetation characteristics, and veld management practices currently applied for cattle and sheep production systems.

2.1 Definition, distribution and extent

Sourveld is defined as veld in which the forage plants become unacceptable and less nutritious on reaching maturity, thus allowing the veld to be utilized for only a portion of the year in the absence of licks (Trollope, *et al.* 1990).

High-elevation sourveld is located in the eastern seaboard areas of South Africa (Figure 2.1). It comprises the foothills and eastern slopes of the Drakensberg range stretching from Stutterheim in the south to the north-eastern Transvaal Highveld in the north. The vegetation may be described as a short, dense grassland with the grasses seldom reaching a height in excess of 0.5 meters (Edwards 1983). Altitude ranges from 1350m to 2150m above sea level. Mean annual rainfall varies between 700mm and 1200mm, with those areas which receive less than approximately 800mm per annum classified as dry sourveld.

The following Veld Types (Acocks 1988) are included: North-Eastern Mountain Sourveld (Veld Type 8); Highland Sourveld and Dohne Sourveld (Veld Type 44); Highland Sourveld to Cymbopogon Themeda Veld Transition (Veld Type 56); North-Eastern Sandy Highveld (Veld Type 57); Piet Retief Sourveld (Veld Type 63); and Natal Sour Sandveld (Veld Type 66).

2.2 Community dynamics

Fire has been a part of the environment since time immemorial and is the major driving force maintaining these areas as grassveld (Tainton & Mentis 1984). Where forest or scrub vegetation have developed these tend to be confined to areas where fires are absent, infrequent or burn with low intensity. If fire and, to an extent, grazing were excluded from the system, most of the grassveld would be replaced by scrub or forest vegetation.

As compared with other grassveld communities in the southern African region, sourveld is considered to be stable (Mentis & Huntley 1982). This is due to the dense grass cover, the inherently low erodibility of soils in sourveld areas, and the high and relatively reliable rainfall. Grazing was not likely to have been a major factor influencing plant dynamics in sourveld before the large scale introduction of livestock to the country. Wild ungulates may have been attracted to the green, leafy, high quality regrowth which accumulates after fire in early spring, but probably moved to sweeter grassveld or savanna areas as the herbage matured and became less palatable and nutritious during the summer. Under these conditions of frequent fire and low grazing pressure, sourveld would have comprised communities dominated by *Themeda triandra*. However, increased year-round grazing pressure due to the introduction of domestic livestock by both commercial and subsistence pastoralists, and to a certain extent, an increase in the frequency of fire, have resulted in changes in community composition and structure of the grassland. Typically, excessive and prolonged grazing leads to a loss of palatable species such as *T. triandra* and the establishment of pioneer, grazing tolerant, less-palatable species such as *Eragrostis curvula*, *E. plana*, *Sporobolus africanus* and *S. pyramidalis* (the 'mtshiki' species). Selective grazing tends to result in an increase in the abundance of 'wire grasses'[2], for example *Aristida junciformis*, *Elionurus muticus*, and

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[2]'Wire grasses' is a collective term for a complex of species with filiform, normally highly fibrous leaves of low acceptability and palatability.

Diheteropogon filifolius (Foran, *et al.* 1978).

Such changes in species composition and vegetation structure alter the grazing value of sourveld, usually resulting in reduced livestock production potential (Tainton *et al.* 1980; Hardy & Mentis 1986). In contrast to most sweetveld, once sourveld has degraded to a state in which unpalatable and grazing tolerant species are dominant, there is little chance of it recovering to its original state even once the cause has been removed. That is, sourveld has low resilience.

The most useful veld composition for animal production in sourveld is that intermediate between the scrub or forest community and a community dominated by unpalatable, pioneer grass species. Although the botanical composition of different sour grassveld types varies greatly, in most cases the dominance of *T. triandra* is considered to be an indication of high grazing value.

2.3 Adapted animal types

Typically, spring growth is highly palatable and provides high quality feed to cattle (Hardy & Mentis 1986) and sheep (Barnes & Dempsey 1992). However, palatability and quality decline rapidly as the plants develop and mature. Herbage which accumulates during the growing season has a low feed value in winter, particularly in areas of very high rainfall where the grass tends to mature early in the growing season. In such areas most classes of livestock lose mass during winter, even when supplied with a protein-rich supplement. By contrast, in the drier (sweetveld) regions, grazing stock may maintain mass or gain mass slowly on winter veld when an appropriate supplement is supplied.

Most classes of cattle are well able to produce on sourveld during spring and summer. Yearling beef animals will normally gain between 70 and 110 kg per animal over the period October/November to March/April, and beef cows which calve in spring will wean calves weighing between 180 and 240 kg in April/May. The cows will also maintain condition provided they are stocked at the appropriate stocking rate (van Niekerk 1988, Lyle pers. comm.). Although sheep are not well adapted to sourveld, they are farmed on a large scale on such veld. Sheep perform well only when they are provided with short, leafy grazing which is free of dead herbage.

2.4 Veld management

Management is aimed primarily at ensuring sustained production of animal products at minimum cost. This implies that veld must be managed in a way that ensures satisfactory animal performance, while maintaining or improving its grazing value. In sourveld this involves consideration of four aspects, namely,

(a) the controlled use of fire as a management tool,
(b) the type of animal involved, that is, whether utilization is with sheep or cattle, or both,
(c) the stocking rate, and
(d) the grazing management.

2.4.1 Fire as a management tool

As stated earlier, these grasslands are well adapted to fire. Controlled burning of sourveld during the dormant season or early spring is therefore an accepted management practice. Common objectives are the provision of herbage free of dead material, and the prevention or reduction of continued patch selective grazing. A further aim might be the prevention of loss of vigour of the desirable grasses as a result of excessive accumulation of dead herbage (Staples 1930; Cook 1939; Scott 1952; Edwards 1968; 1969; Scotcher & Clarke 1981; Everson *et al.* 1985).

Stocking too early after burning in spring has in the past been regarded as a major cause of veld degradation. A general recommendation therefore is that sourveld burnt in spring should not be grazed until it has grown to a 'mean height of 100- 150 mm'(e.g. Trollope 1984; Kohlmeyer 1987; Tainton 1987). However, while such management has been successfully applied in cattle production systems, sheep performance, particularly where sheep are grazed alone, has been poor. It seems that to ensure adequate sheep performance, the grass must be kept short (Anon. 1989; Barnes & Dempsey 1992). Accordingly, sheep producers tend to burn frequently, and to stock heavily after burning in late winter or early spring. In contrast, although there is evidence that cattle also perform best on veld free of old dead grass (Lyle pers. comm.), their performance does not appear to be unduly affected by the presence of old dead herbage.

2.4.2 Animal type

Selective intensive grazing of the preferred grasses in veld (which inevitably occurs in sheep grazing systems) may greatly reduce their vigour. If defoliation is frequent and severe, and is continued for a number of consecutive seasons, a high proportion of the selected grasses may die, leaving a vacuum which will normally be filled by less palatable grasses. Barnes & Dempsey (1992) reported that intensive defoliation by sheep at a level which supports good sheep performance resulted, after only one season of treatment, in a drastic reduction in the vigour of the most preferred grass species. Yields of these species in the season after intensive grazing were only about half of those of the same species in veld which had been rested in the previous season. The depressive effect of such grazing practice on the less palatable grasses was much smaller, while the production of the unpalatable grasses was actually enhanced.

No rigorous comparisons of the residual effects on vigour of grazing sourveld with either sheep or cattle have been made. However, observation and evidence from long term grazing trials with cattle indicates that, at stocking rates in keeping with the grazing capacity of veld, the vigour of the preferred grasses can be maintained with relatively simple grazing procedures involving, for example, a season-long rest once every four years (Kreuter, *et al.* 1984, van Niekerk et al. 1984). It is also general experience that veld stocked with cattle is usually less closely, and more evenly grazed, than that stocked with sheep at equivalent stocking rates.

2.4.2.1 Mixed stocking with cattle and sheep

An alternative to the 'burn/early graze' veld management system is to graze cattle together with sheep (Malherbe 1971). It was suggested that if cattle are grazed together with sheep, the cattle, by removing material which is rejected by sheep because it is too tall or too mature, will stimulate new regrowth from a large proportion of the plants which would otherwise be rejected by sheep. Research and experience have indicated that by stocking at a narrow cattle-to-sheep ratio the veld would be grazed more evenly, selective grazing by sheep would be reduced and sheep performance enhanced (Anon. undated; Malherbe 1971).

2.4.2.2 Stocking rate

The rate of stocking on sourveld, especially if it is markedly less than or greater than the grazing capacity, may have an important influence on both livestock performance and floristic composition. In the absence of burning, or with infrequent burning, light stocking results in an excessive accumulation of old dead herbage. This commonly leads to reduced animal performance, especially of sheep, and undesirable changes in floristic composition. For example, the desirable grass *T. triandra*, in particular, is not adapted to this situation and will decrease in abundance if such conditions develop. Likewise, grasses which are only moderately palatable to livestock, or which are unpalatable, such as *Alloteropsis semialata* and *Cymbopogon plurinodis*, may increase. At the other extreme, stocking at a rate which exceeds the grazing capacity of the veld (overstocking) will also result in reduced animal performance and undesirable changes in composition. The reduced animal performance is a consequence of nutritional stress concomitant with overuse of the preferred grasses. Sooner or later, depending on the specific veld type and the degree of overstocking, the palatable grasses will be replaced by less palatable or unpalatable grasses. These may vary in different circumstances. With moderate overstocking *Heteropogon contortus* might assume dominance. With severe or long continued overstocking, grasses such as *Eragrostis curvula, E. plana,* *Sporobolus africanus*, and *Aristida* spp. might increase.

Experience indicates that the essential requirement for optimum cattle performance, while avoiding the overuse of the preferred grasses, is to stock at a rate slightly below the critical level beyond which, in terms of the familiar Jones and Sandland (1974) model, individual animal performance declines with increasing stocking rate. Hence, optimum animal performance can be used as a criterion for the conservation of the grazing resource.

The situation with sheep is less clear. Current recommendations are that an AU of cattle may be substituted by an AU of sheep when calculating stocking rate to match the estimated grazing capacity. Such practice is, however, questioned (see Chapter 3).

2.4.3 Grazing management

As a result of wide spacial variation in factors such as elevation, aspect, soil type and depth, and slope, sourveld is characteristically heterogeneous. Such heterogeneity is often expressed in variations in floristic composition and growth pattern of the veld. This, in turn, affects the patterns of utilization by livestock, which commonly graze certain communities, and landscape positions, in preference to others. For example, livestock prefer grazing on northern aspects rather than on southern aspects. Accordingly, a cardinal principle in the utilization of veld for livestock production is the separation, by means of fences, of veld types which differ markedly in acceptability to livestock (Edwards 1972). On a farm scale, the degree or scale of separation is commonly limited by practicability, and only major differences can be taken into account. The number and the size of the paddocks available from such primary subdivision is usually insufficient for the application of sound veld management. Further subdivision is normally required as, for example, additional paddocks would be needed in an attempt to ensure even grazing pressure over the whole paddock, and for the application of practices such as controlled burning and periodic resting. Also, they are often a prerequisite for sound livestock management.

Grazing management recommendations are that sourveld should be grazed rotationally using a multi-paddock system in which each paddock is grazed intensively for a short period of about a week or less, and is then rested for four to six weeks. Where, for example, the veld is grazed by cattle alone, or at a narrow cattle-to-sheep ratio, it is not normally necessary to burn or rest the veld more frequently than once in four years. Several comparable areas of veld should then be made available per herd to allow for such grazing, burning and resting management (Venter & Drewes 1969; Booysen et al. 1974; Murray 1991).

The same recommendations are given for sheep production systems providing that the sheep are grazed together with cattle at a 1AU cattle to 1AU sheep ratio, or at a ratio which favours cattle. While grazing systems which comprise sheep-only are not advocated, such systems are widely practised with the apparently inevitable consequence of veld degradation.

It is apparent that most grazing management recommendations derive from research and experience relating to cattle production systems. Little research has been conducted on the effects of cattle-to-sheep ratio and stocking rate on veld condition and on animal performance in sourveld. Such research is required to provide a sound basis for the development of grazing management strategies for sustained cattle and sheep production systems off sourveld.

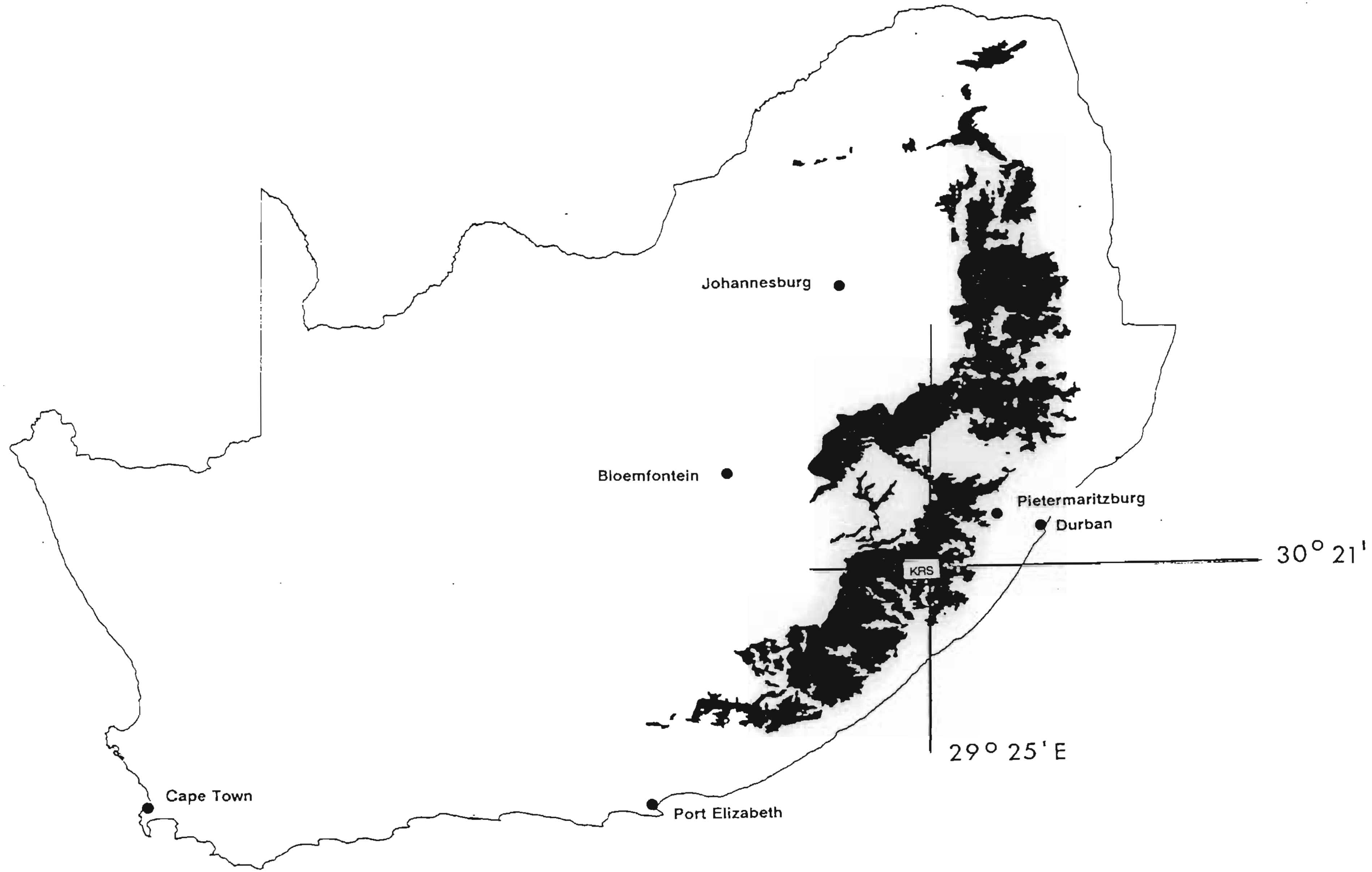

Figure 2.1 The distribution of high elevation sour grassveld in South Africa and the location of the Kokstad Agricultural Research Station (KRS)

CHAPTER 3

SOME CONCEPTS APPROPRIATE TO MIXED-SPECIES GRAZING

The purpose of this chapter is to provide a short review of research on mixed-species grazing considered to be relevant to the present study, and to discuss the concept of grazing capacity as it relates to cattle and sheep production systems.

3.1 Mixed-species grazing

The practice of utilizing a common forage source by more than one species of herbivore is referred to as 'mixed- or multi-species grazing' (Baker & Jones 1985; Lambert & Guerin 1989). Mixed-species grazing systems may be based on one species following another through the grazing area or the various species grazing the area simultaneously. Species of grazing animals differ in their grazing patterns and habits. These differences may be complimentary and that mixed-species grazing may result in increased out-put per unit area (Nolan & Connolly 1977). One of the objectives of such practices is therefore to ensure the most efficient utilization of the forage resource and thus to maximize livestock production (Lambert & Guerin 1989). Achievement of this aim is determined principally by selection of the appropriate animal enterprise and by the quality and quantity of feed ingested by grazing animals. Animals of the same species have more similar requirements than animals of different species, so inter-specific competition is less intense than intra-specific competition. Thus, substitution of a proportion of the individuals of one species by individuals of another species could result in increased outputs (of animal products) i.e. complementary effects occur. It is important to identify the complementary elements in mixed-species grazing and to use them in developing production systems superior to single-species grazing (Nolan & Connolly 1977; Lambert & Guerin 1989). The complementary effects would be expected to be greatest where grazing efficiency of either one or all of the animals species is low, the sward is botanically complex, and topographical variation is large (Lambert & Guerin 1989).

Another important objective for practising mixed-species grazing is to compensate for the selective grazing habit of certain species of herbivore (e.g. sheep) in species-rich swards. Where sheep graze alone extreme area- and species-selective grazing occurs (Mentis 1981a). On the preferred areas of the landscape or in areas occupied by the preferred species, denudation often results. At best, selective grazing leads to gradual change in species composition in favour of the unpalatable species. By introducing cattle into the system the sward may be kept in a state more suited to sheep, thus reducing the need for sheep to graze selectively (Mostert, *et al.* 1971). This is supported by several authors who suggest that the proportion of sheep to cattle should not exceed 50% (where 6 mature sheep = 1 steer of 450 kg) as a safeguard against the detrimental effects of sheep on veld condition (Malherbe 1971; Mostert, *et al.* 1971; Heady 1975).

3.1.1 Animal production: single- versus mixed-species grazing

Animal production data derive mainly from trials conducted on cultivated or improved pastures. Few grazing trials have considered the production potential of natural pastures. However, many of the principles obtained from cultivated pasture regarding single- and mixed-species grazing could be applied to animal production systems from veld (Nolan & Connolly 1977; Baker & Jones 1985; Lambert & Guerin 1989). In most grazing trials involving mixed-species grazing, output per unit area has been higher than in single-species grazing. The advantage of mixed cattle/sheep grazing has, for example, been attributed mainly to improved sheep performance with no effect on cattle performance (Bedell 1968; Bennett, *et al.* 1970; Conway, *et al.* 1972; Hamilton 1975; Boswell & Cranshaw 1978). Nolan and Connolly (1976; 1989) and Nolan (1980) have, however, reported that both cattle and sheep showed improved levels of production when grazing together compared to single-species grazing on improved pasture whilst

Merril (1975) reported a similar result in a scrub/forb/grass rangeland. Ebersohn (1966) and Reynolds, *et al.* (1971), who worked in the eastern Cape Thorn Veld and on improved pastures respectively, reported that mixed-species grazing had no advantage over single-species grazing.

Various studies have attempted to explain the animal performance responses to mixed- versus single-species grazing in terms of one of, or combination of, a number of the following factors.

3.1.1.1 Grazing habit and diet selection

Bedell (1968; 1973) and Dudzinski and Arnold (1973) found differences in the botanical composition of the diets of cattle and wethers under mixed-species grazing. On average the diets of cattle contain more grass (70%) than those of sheep (50%) where grazing occurs in a grass/forb community (van Dyne, *et al.* 1980). Sheep diets were also reported to contain more green material than those of cattle (Wilson 1976) and contain consistently higher crude protein and digestible dry matter when compared to cattle (van Dyne & Heady 1965a; Bedell 1971; Lyle, *et al.* 1970). Increased sheep production could therefore be linked to a higher quality diet selected by sheep. Peart (1962, cited by Nolan & Connolly 1977) suggested that cattle complement sheep by grazing the coarser material, thus providing a more nutritious diet for the sheep.

It is interesting to note that, on improved pastures, several authors have attributed improved production per unit area to the improved utilization by sheep of herbage avoided by cattle (Snell 1935; van Keuren & Parker 1967 - both cited by Nolan & Connolly 1977; Ronnel, *et al.* 1980). These authors state that sheep would consume the rank herbage which developed around dung pats. They observed that the cattle would eat the shorter grass in preference to herbage near their dung pats. In addition, sheep were observed to consume broadleaved forbs which cows refused, thus indicating the advantage of adding sheep to cattle to ensure more efficient utilization of the herbage on offer to livestock

(Nolan & Connolly 1989).

The grazing habits of livestock are perhaps the most important considerations when examining the relationships between livestock production and mixed-species grazing. Smaller animals have a lower digestive efficiency than larger animals due to their smaller gut capacity (Demment 1982) and the shorter retention time of forages in their rumen (Prigge, *et al.* 1984). They are therefore forced to select a higher quality of forage than larger animals. However, because their absolute food requirements are lower (Moen 1973) they can spend more time per unit nutrient being ingested (Bell 1970). Small animals also have a greater physical ability to be selective due to their smaller mouth dimensions. Sheep therefore tend to exhibit a greater degree of selective grazing than cattle (Mentis 1981a).

3.1.1.2 Stocking rate

Stocking rate is widely accepted as the major factor influencing livestock production from improved pastures and veld (Edwards 1981c; van Niekerk, *et al.* 1984; Turner 1988). Few mixed-species grazing trials have considered the added influence of stocking rate on animal performance (Nolan & Connolly 1977). There are indications that at a high stocking rate sheep are better able than steers to supply their dietary requirements. This is supported by Bennett, *et al.* (1970) and Hamilton and Bath (1970) who observed that sheep performed relatively better than steers during periods of reduced herbage availability.

3.1.1.3 Effects of cattle to sheep ratios

Nolan and Connolly (1977) and Lambert and Guerin (1989) have reviewed the literature on the influence of cattle to sheep ratios on animal production in mixed-species grazing experiments. A summary of various aspects of these reviews is presented below.

Bedell (1973), working in a grass/clover pasture, reported a lower animal production per unit area with an increased proportion of sheep in the system. This result was attributed to the reduced clover fraction in the sward as a consequence of sheep grazing. Ebersohn (1966) reported no effects of mixed-species grazing over a range of ratios and stocking rates from grazing trials conducted in sweet grassveld. He suggested that this may have been due to the relatively low range in stocking rates applied in the experiment.

The results of several experiments on both improved pasture and veld have, however, shown that the growth rate of sheep increases as the proportion of sheep in species mix decreases (van Keuren & Parker 1967; Hamilton & Bath 1970; Malherbe 1971; Nolan & Connolly 1976).

3.1.2 The influence of mixed-species grazing on sward composition and herbage production

Bedell (1973) found that the effects of sheep preference for clover were cumulative and reduced the clover fraction with time but stated that this could have been due to the low stocking rates applied. Mixed-species grazing has been used to advantage e.g. in systems with a high proportion of cattle relative to sheep the cattle may be used to encourage white clover growth, resulting in increased nitrogen fixation (Lambert & Guerin 1989).

In southern Africa Ebersohn (1966) and Malherbe (1971), who worked in the sweet- and sourveld respectively, have reported that mixed-species grazing (using cattle and sheep) at a range of ratios had no effect on veld composition. However, Malherbe (1971) applied a single stocking rate for all ratio treatments and Ebersohn (1966) applied extremely light stocking rates which may, in part, explain their results. The lack of change in botanical composition is surprising as a number of veld grazing experiments with cattle have indicated that stocking rate has a significant influence on species composition (e.g. Tainton, *et al.* 1978; Hardy & Hurt 1989; Morris, *et al.* 1992). The fact that Malherbe (1971) applied a range of cattle to sheep ratios implies that the stocking rate of sheep would have varied. One would have expected the variation in sheep numbers to have influenced botanical composition, particularly due to the selective grazing habit of sheep. Evidence that extensive grazing systems with sheep and cattle influence botanical composition of the sward is provided by Rethman and Kotze (1986), Barnes (1990), Martens, *et al.* (1990) and Hurt, *et al.* (1993).

Although there is a considerable amount of circumstantial evidence that sheep grazing systems are largely responsible for the deterioration in veld condition, few studies have been initiated to quantify the influence of sheep grazing on the vegetation. In any event, such deterioration is likely to be a function of numerous factors. These factors include:

1. whether sheep are grazed alone or together with cattle,
2. the stocking rates applied,
3. the grazing management system (e.g. continuous or rotational grazing, number of camps per group of animals, seasonal use of the veld and time of grazing after burning),
4. the inherent productivity and stability of the resource (both plant and soil),
5. the frequency of burning, and
6. various combinations of the above.

3.2 Grazing capacity

Danckwerts (1981) provides a detailed review and analysis of methods of determining grazing capacity, with particular reference to livestock production systems of the Ciskei. More recently, a series of papers, which provide detailed analyses of the grazing capacity concept and its application in the African context, have been presented in Behnke, *et al.* (1993). The intention here is not to repeat these reviews but rather to highlight a number of issues relating to the use of the grazing capacity concept in South Africa and the implications of such use in mixed-species livestock production systems.

3.2.1 Defining grazing capacity

There is considerable confusion in the international literature regarding the terms grazing capacity and carrying capacity

(Bartels, *et al.* 1993). In South Africa an attempt has been made to limit the confusion.

Grazing capacity is defined as the "productivity of the grazeable portion of a homogeneous unit of vegetation expressed as the area of land required to maintain a single animal unit over an extended number of years without deterioration of the vegetation or soil" and is expressed in terms of hectares per animal unit (ha AU^{-1}) or its reciprocal AU ha^{-1} (Trollope, *et al.* 1990).

Carrying capacity is defined as the " potential of an area to support livestock through grazing and/or browsing and/or fodder production over an extended number of years without deterioration of the overall ecosystem" and is expressed in terms of hectares per animal unit (ha AU^{-1}) or its reciprocal AU ha^{-1} (Trollope, *et al.* 1990).

A major source of confusion between the meaning of the two terms is that much of the theory relating to the calculation/ determination of grazing capacity (as defined above) derives from ecological texts which invariably use the term carrying capacity (*e.g.* Caughley 1979). When dealing with livestock production systems where the natural vegetation is the sole source of forage however, the two terms have the same interpretation.

Grazing capacity is expressed in most definitions in terms of the number of animal units which may be carried on an area on a sustainable basis (Stoddart 1952; Booysen 1967; Caughley 1979; FAO 1988; Trollope, *et al.* 1990). Mentis (1977), Caughley (1979) and Behnke & Scoones (1993) point out that sustainable livestock production must be seen in the context of the objectives of the livestock production enterprise. In much of Africa the objective tends to be one of maximising the number of animals carried on the veld (see Behnke, *et al.* 1993), and relates to the so-called ecological carrying capacity (Caughley 1979). Most definitions of grazing capacity, however, reflect the objectives of commercial livestock enterprises (*e.g.* Samson 1923; Dasmann 1945;

Booysen 1967; Heady 1975; Trollope, *et al.* 1990), the so-called economic carrying capacity (Caughley 1979). Discussion for the remainder of this section relates to the latter definition.

The grazing capacity concept is based on succession theory (Behnke & Scoones 1993). One of the main assumptions is that there is some vegetation state, either the climax or some form of sub-climax, which is considered 'optimal' for commercial livestock production. Veld management systems therefore strive to balance grazing pressure with the forage production potential of the desirable state of the vegetation. This balance has been referred to as the "potential grazing capacity" (*e.g.* Tainton, *et al.* 1980). Also incorporated in the concept is the principle of preventing deterioration of vegetation or soil. The intention here is not to debate the use of succession theory in the grazing capacity concept. Such debate is presented by Behnke, *et al.* (1993). It should suffice to say that where variation in rainfall is relatively low and rainfall is high (> 500mm per annum), grazing capacity and successional theory tend to be viable, compatible concepts (Coppock 1993). In South Africa, philosophy related to grazing capacity developed from research and knowledge of livestock production systems in humid grasslands (Booysen 1967; Edwards 1981c; Tainton 1981a). It is not surprising, therefore, that its use has gained wide acceptance, not least with Government Departments who have the responsibility for promoting wise-use of natural resources. To this end, grazing capacities (ha AU^{-1}) have been determined for all vegetation types in the country.

3.2.2 The calculation/determination of grazing capacity

There have been two main approaches to the determination of grazing capacity. The first approach involves establishing the herbage production potential of an area and calculating the potential dry matter intake of the different species and classes of herbivore. Herbage production is usually expressed as a function of rainfall and soils. A 'proper-use' factor is then applied which is based on minimising the negative effects of grazing on the potential productivity of plants, estimating the proportion of herbage which could be considered forage, and determining the dry matter requirements of the resident animals (Coe, *et al.* 1976; le Roux 1979; Botkin, *et al.* 1981; Behnke & Scoones 1993). Allied to this approach is the approach which applies local knowledge and experience of the livestock production systems of an area. Livestock production records are used (*e.g.* long-terms stocking rates) together with estimates of the condition of the veld (*e.g.* species composition, basal cover, soil status, and plant vigour). These data are then used to provide an estimate of grazing capacity (Stoddart 1952; Tainton, *et al.* 1980).

The second approach can best be applied to data derived from formal grazing trials. Animal production data, together with measurements of the impacts of the various grazing treatments on the vegetation, are then used in the estimation of grazing capacity.

Whatever the approach used, grazing capacity is expressed in terms of ha AU^{-1} or its reciprocal.

3.2.3 The animal unit (AU)

A common factor among all methods for defining grazing capacity is the animal unit (AU). This is not surprising due to mixed-species use of veld in agricultural and, in particular, game production systems. The AU provides a point of reference against which animals of different species, and classes within a species, may be equated. Various definitions for the AU have been proposed. These relate to 1) the expected dry matter intake of an animal according to its livemass (*e.g.* Vallentine 1965; Society for Range Management 1974; Carl Bro International 1982; Scarnecchia & Kothman 1982; de Leeuw & Tothill 1993), 2) the energy requirements of an animal based on its metabolic mass (*e.g.* Brody 1945; ARC 1965; Mentis & Duke 1977; Mentis 1978; Edwards 1981c; Mentis 1981a), and 3) the energy requirements of an animal of a specified mass and a specified level of performance (Meissner, *et al.* 1983; Trollope, *et al.* 1990). Turner (1988) provides detailed discussion on the utility of the above definitions for an AU in establishing the grazing capacity for any area. It should be noted here that central to these definitions is that the amount of herbage consumed by herbivores is equated across animal types. This has generally been taken to imply an equivalent impact on the sward. For the purposes of the present discussion, however, the following issue is emphasised.

A major, largely untested, assumption associated with the definition of an AU and its use in defining grazing capacity is that, irrespective of the livestock species or species-mix using the veld, and assuming that appropriate veld management systems are applied, veld condition will be maintained provided that the grazing capacity is not exceeded. This statement may seem to be an over-simplification of the implications of the grazing capacity concept. However, in presenting their definitions of AU and grazing capacity, few authors have emphasised the differences in feeding habits between different species of herbivore and the different potential effects of these different feeding habits on veld condition. One exception is Mentis (1980) who stresses that, for example, " 1AU of cattle cannot safely be replaced by 1AU of Impala" when comparing the potential grazing impact of cattle versus Impala. Small herbivores such as the Impala (or sheep) are anatomically and physiologically adapted to graze more selectively and closely than cattle (Heinemann 1970; Mentis 1980) and therefore have greater potential to degrade the vegetation than do cattle. Danckwerts (1981) and Turner (1988), in their reviews on grazing capacity and AU, also allude to the problem by quoting Mentis (1980). Mentis (1980) states that the AU "permits direct comparison of mixed herbivore populations at different times and places only on an energy consumption basis". This is the same premise upon which Meissner, *et al.* (1983) present their definition of an AU equivalent.

In the final analysis, the grazing capacity of a specified area of vegetation is defined in terms of AU ha^{-1} (or its reciprocal) without regard to the species or class of herbivore/s. This definition is entrenched in the basic philosophy which underpins veld management recommendations in South Africa (see Tainton 1981a) and is applied by the various Government Departments responsible for promoting wise-use and maintenance of the natural resources of the country (*e.g.* Anon. 1985; du Toit, *et al.* 1991). It is suggested here that the current grazing capacity estimates for the sourveld regions in South Africa probably derive from observation, experience and limited experimentation on the management requirements for **cattle production systems** and that the simple substitution of an AU of cattle by an AU of sheep will not result in the same grazing impact on the sward as would have occurred had the substitution not been made. For sheep production systems, therefore, the grazing capacity estimates are probably misleading and, if applied, are likely to promote, rather than prevent, further degradation of the grazing resource.

SECTION 2

EXPERIMENTAL PROCEDURE AND TRIAL DESIGN

CHAPTER 4

EXPERIMENTAL PROCEDURE

The purpose of this chapter is to describe the experimental area, the treatments applied, experimental design and veld management system applied.

4.1 Experimental area

The trial was located at the Kokstad Agricultural Research Station (30°31'S, 29°25'E; altitude 1341m) which is situated in the drier phase of the Highland Sourveld of Natal (Acocks 1988). The mean annual rainfall is 790 mm and rain falls mainly from October to March (Figure 4.1). Winters are cold with regular frosts (mean minimum of 2.1°C) while the growing season is warm (mean maximum of 24.5°C). The veld is typical of sourveld (as described in Chapter 2).

4.2 Ratio and stocking rate treatments

Ratio and stocking rate treatments were based on animal units (AU's) and calculated according to the formula presented by Edwards (1981b). The animal unit equivalent (AUE) of each animal, of mass m, allocated to a treatment was calculated as $m^{0.75}/450^{0.75}$. Stocking rate and ratio treatments were balanced at the start of each grazing season.

Five cattle to sheep ratio treatments were applied, each at three stocking rates. The range of ratio treatments applied were chosen to include the 1AUE cattle:1AUE sheep ratio which is currently recommended for sheep production systems in sourveld, and to ensure an even spread of ratios for each of the three stocking rates. Cattle-only and sheep-only treatments were included according to the recommendations of Connolly and Nolan (1976). Accordingly, the cattle to sheep ratios (AUE cattle:AUE sheep) applied for each stocking rate were 1:0, 3:1, 1:1, 1:3 and 0:1.

Stocking rate treatments were set at 0.5 AUE ha^{-1} (low), 0.71 AUE ha^{-1} (medium) and 1.0 AUE ha^{-1} (high). The range of stocking rate treatments applied was based on two criteria. First, that they should include the currently recommended stocking rate for the area, and second, that they should be wide enough to provide data on the potential impact of grazing on veld condition within a relatively short time-frame (8 to 12 years). Stocking rate recommendations for the drier phase of the Highland Sourveld range between 0.5 and 0.7 AUE ha^{-1}. A stocking rate of 1.0 AUE ha^{-1} is considered to be excessive for this vegetation type and to result in a rapid decline in veld condition.

Fifteen combinations of stocking rate (3) and ratio (5) treatments were therefore implemented in the trial.

4.3 Trial design

The trial comprised two components, viz. an animal production and a simulated component. Both components were designed to monitor the effects of stocking rate and cattle to sheep ratio on the sward and on the quality of intake selected by cattle and by sheep. The effect of cattle to sheep ratio on animal performance was also monitored in the animal production component. Two areas of veld which were similar in species composition, aspect and slope (referred to hereafter as S5 and N2) were used in the trial.

4.3.1 Animal performance component

Animal performance data were derived from the S5 area for each of the five ratio treatments, all of which were stocked at the 0.71 AUE ha^{-1} stocking rate. Five 14-month old Hereford steers and 10 'two-tooth' (18-month old) Merino wethers were used to monitor animal performance in each ratio treatment. Additional cattle and sheep of similar class were allocated to each treatment, as required, to balance the ratio and stocking rate treatments.

4.3.1.1 Veld management

The various veld management systems applied in sourveld have been discussed in Chapters 1 and 2. An 'ideal' management strategy for maximising sheep performance would be to burn off, while the grasses are dormant, dead herbage carried over from the previous growing season and to stock the veld as soon as possible after the burn. In terms of the current investigation, however, such a management strategy would result in variable burning frequencies both between and within treatments. The start of each grazing season would also vary between treatments. Treatment effects would be confounded with fire frequency and time of stocking. In addition, the 'ideal' management strategy would be governed by the ability of the individual managing the trial, who would have to decide on when to burn and to stock each treatment. It was considered unlikely that there would be any consistency in such decisions over the projected time-frame of the trial. To limit the potential confounding effects of variable management between and within treatments, it was decided that the veld management practices currently recommended for the area should be applied.

The whole of the experimental area was rested during the growing season prior to the start of the trial and all paddocks were burned while the plants were still dormant in August 1989. The trial therefore commenced with a uniform sward of immature herbage in all paddocks allocated to each group of animals. Each treatment was then managed as a four-paddock rotational grazing system, in which one of the four paddocks was rested for the whole growing season. In the second and subsequent growing seasons only those paddocks which had been rested in the previous season were burned prior to the onset of growth in early spring. Of the three paddocks available to the animals in any season subsequent to the first, therefore, only one provided a uniform sward of new season's growth free of dead herbage.

A 42-day grazing cycle was applied (with a 14 day period of stay and a 28 day period of absence for each paddock). All treatments were stocked at the same time in the spring once sufficient grass had accumulated to ensure positive mass gains for cattle. Grazing commenced before the end of October each year.

By the end of the second grazing season (June 1991) large quantities of herbage had accumulated in a number of paddocks designated for a full season's rest in the following grazing season. Aerial tillering was apparent in many tufts of the desirable species *Themeda triandra*, an indication that the plants were becoming moribund and losing vigour. An additional growing season without defoliation would have resulted in further loss of vigour in these plants rather than have provided them the opportunity to regain vigour (Tainton 1974, 1981b). It was therefore considered necessary to remove all herbage from these paddocks prior to the season's rest. To prevent the potential confounding effects of burning some paddocks and not the others prior to resting, burning management was extended to include the burning of all paddocks designated for a full season's rest prior to the onset of spring growth in the rest year.

4.3.2 Simulation component

The 0.5 and 1.0 AUE ha^{-1} stocking rate treatments for each cattle-to-sheep ratio treatment were implemented (in the **N2** area) by **simulating** the four-paddock rotational grazing system described in 4.3.1.1. A single paddock was used for each of the ten stocking rate/ratio treatments. Treatment animals would enter their respective paddocks for a period of stay of 2 weeks, after which they were removed to an area of veld adjacent to the experimental site for four weeks before being replaced in their treatments for a further two-week period of stay. Five such six-week grazing cycles were completed each grazing season. Two 14-month old Hereford steers and a minimum of 3 'two-tooth' (18-month old) Merino wethers were allocated to each treatment at the start of each grazing season.

Grazing, resting and burning management in each simulated treatment at the N2 site corresponded to the management received by a selected paddock in each ratio treatment at the S5 site. In the first grazing season (1989/90) the selected paddocks in S5, referred to as 'test' paddocks, were grazed first in the grazing cycle. In the second and third seasons the 'test' paddocks were grazed second and third in the grazing cycle respectively. The 'test' paddocks in S5 and the simulated paddocks in N2 were rested for a full season in the fourth year of the trial. Treatment animals entered and were removed from the 'test' paddocks (in S5) and the simulated treatment paddocks at N2 on the same dates through each season. This was done in an attempt to ensure similar climatic conditions and sward growth pattern between treatments (during periods of stay in, and periods of absence from, the 'test' paddocks) thus limiting non-treatment influences on the grazing impact and selection patterns.

4.3.3 Summary

In summary, the five 'test' paddocks located at the S5 area and the ten paddocks of the simulated component of the trial (the N2 area) were monitored to determine the effects of the stocking rate and ratio treatments on the sward, and on the quality of intake selected by cattle and by sheep. The four paddocks allocated to each of the five ratio treatments at the S5 area were used to examine the influence of ratio on the performance of cattle and of sheep. Details of the number of animals allocated to each treatment each grazing season are presented in Table 4.1[3]. Maps of each of the experimental areas are presented in Appendix Figures 4.1 & 4.2.

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[3]Inspection of the data presented in Table 4.1 illustrates the logistical (both practical and financial) problems associated with replicating the trial. Had the trial been replicated only once, an additional 187 sheep and 39 head of cattle, and double the amount of area with similar slope, aspect and species composition would have been required. Added to this would be the additional fencing and watering facilities and the man power required to manage a trial of this magnitude and the additional technical inputs required to monitor grazing impact and animal performance in both replicates.

It is stressed that all veld management actions applied to the 'test' paddocks in the S5 area were applied equally to the simulated component (the N2 area) of the trial. In the second and third grazing seasons the simulated treatments were grazed second and third in the grazing cycle respectively. Grazing in the simulated component of the trial therefore commenced two to four weeks after grazing had commenced in the animal production component (S5) in the second and third grazing seasons respectively.

The grazing and burning history of each paddock in the animal performance and the simulated components of the trial are presented in Table 4.2.

4.4 Animal husbandry

The same class of animal was used each season. Experimental animals were obtained from the Kokstad Research Station's resident breeding herds and flocks. All animals used in the trial were therefore adapted to local climatic conditions and the herbage production characteristics of the veld. Both the cattle and the sheep had grazed on veld for the whole of the previous grazing season.

An important consideration in using locally bred animals was the presence of the poisonous plant *Senecio retrorsis*, or ragwort, in the experimental area. The *Senecio* genus is listed as one of the most poisonous plant groups in South Africa (Steyn 1949). Ingestion of *S. retrorsis* has been responsible for high stock losses due to its alkaloid content. Acute cases of poisoning have frequently been recorded, especially where stock are unaccustomed to the plant and encounter it for the first time (Hildyard 1967). The plant appears to be most toxic to stock during its flush of growth in spring. Death may occur within 24 hours of ingesting the plant.

Experience indicates that animals bred in *Senecio* infested areas 'learn' to avoid taking the plant. Experience also indicates that the *Senecio* plant will be avoided by stock provided there is sufficient grass available to them. In the present trial, therefore, besides using locally bred animals, two additional precautionary measures were taken in an attempt to avoid Senecio poisoning of the experimental animals. First, since *Senecio* is one of the first plants to start growing after winter, animals were allocated to their treatments only when sufficient grass had accumulated after the onset of spring growth. Second, the animals were dosed with 'activated charcoal' before being stocked in their treatments and every four days for the first two weeks of grazing. The 'activated charcoal' apparently binds the alkaloids while in the rumen, thus rendering them harmless to the animal.

Each experimental group of animals was subjected to the same feeding regime prior to entering the trial. The steers (14 months old at the start of each grazing season) were weaned in May/June of the previous grazing season, having been on veld with their dams for the whole of that grazing season. The wethers (18 months old at the start of each grazing season) were on the veld for the whole of the previous grazing season. During the winter months, prior to being allocated to their treatments, experimental steers were fed to gain approximately 200 to 300 g d^{-1} and the wethers to gain approximately 50 g d^{-1}.

A dicalcium-phosphate 'summer' lick was available to all animals from the start of the grazing season to the end of February. A 'winter' lick was supplied from the beginning of March each season. The winter lick comprised 15% urea, 30% salt, 30% maize meal, 10% dicalcium phosphate and 15% feed lime. A creep system was used to ensure that sheep had free access to the winter lick. The licks were fed *ad lib*. Treatment animals were also dosed, inoculated and dipped as prescribed by the local veterinarian.

Table 4.1 Cattle to sheep ratio (C:S - expressed in terms of animal unit equivalents (AUE)) and stocking rate (SR in AUE/ha) treatments applied at the start of each grazing season. The number of animals, paddocks and the total area (ha) allocated to the animal production (S5) and simulated (N2) components of the trial are also given.

C:S	SR	Cattle*	Sheep[1]	Paddocks	Total area
Animal production component - S5					
1:0	0.71	5	0	4	3.8524
3:1	0.71	8	11	4	8.3831
1:1	0.71	5	20	4	7.6632
1:3	0.71	5	52	4	13.3560
0:1	0.71	0	10	4	2.0884
Simulated component - N2					
1:0	0.50	2	0	1	0.5400
3:1	0.50	2	3	1	0.8100
1:1	0.50	2	8	1	1.0800
1:3	0.50	2	25	1	2.1600
0:1	0.50	0	6	1	0.4000
1:0	1.00	2	0	1	0.2900
3:1	1.00	2	3	1	0.3600
1:1	1.00	2	8	1	0.5400
1:3	1.00	2	25	1	1.0800
0:1	1.00	0	6	1	0.2000

* 200 kg yearling Hereford steers were used

[1] 40 kg "two tooth" Merino wethers were used

Table 4.2 The burning sequence (BURN) and position of each paddock in the grazing cycle (CYCLE) in the animal performance (S5) and simulated (N2) components of the trial for each of four grazing seasons

GRAZING SEASON		S5 PADDOCK A	B	C	D	N2 ALL PADDOCKS
1989/90	BURN	yes	yes	yes	yes	yes
	CYCLE	1st	2nd	3nd	rest	1st
1990/91	BURN	no	no	no	yes	no
	CYCLE	2nd	3rd	rest	1st	2nd
1991/92	BURN	no	yes	yes	no	no
	CYCLE	3rd	rest	1st	2nd	3rd
1992/93	BURN	yes	yes	no	no	yes
	CYCLE	rest	1st	2nd	3rd	rest

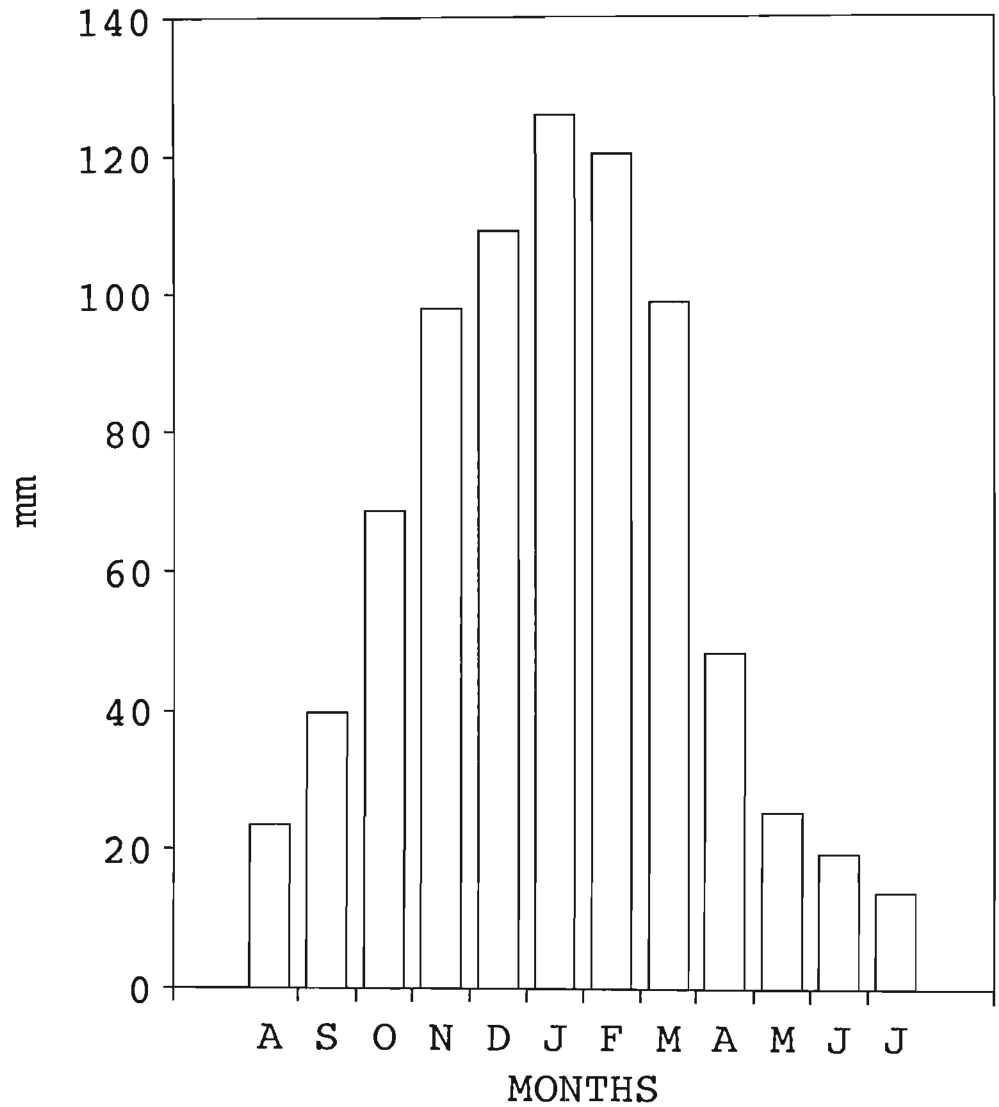

Figure 4.1 Mean monthly rainfall (mm) for the Kokstad Agricultural Research Station (62 year data record)

SECTION 3

ANIMAL PERFORMANCE AND CLIMATE DATA

CHAPTER 5

THE EFFECT OF CATTLE TO SHEEP RATIO ON ANIMAL PERFORMANCE

In this chapter the effect of cattle to sheep ratio on animal performance is examined. Animal performance is also discussed in relation to the quality of forage selected by the cattle and the sheep, and the herbage mass on offer to the animals through each grazing season. Data were obtained from the animal performance component of the trial.

5.1 Procedure

5.1.1 Climatic data

Daily rainfall and temperature (maximum and minimum) were recorded for the duration of the present study.

5.1.2 Seasonal patterns of herbage accumulation

Various methods for estimating herbage mass in veld and pastures have been suggested (e.g. Brown 1953). These include both destructive and non-destructive methods. A non-destructive method of estimating herbage mass was considered desirable for the present study. Destructive sampling techniques require that large numbers of quadrats should be cut for each treatment on each sampling occasion to ensure a high level of precision of the estimate of herbage mass. Such a sampling procedure would result in numerous short 'patches' in each treatment, each of which would contain regrowth of a higher quality than the surrounding herbage. Sheep, as has been discussed earlier, prefer short, high quality grass. It was considered highly likely therefore, that the sheep in each treatment would actively select for these sampled patches in preference to the surrounding herbage. Such a situation was undesirable since one of the main objectives of the trial was to examine the extent of patch and species selective grazing by various combinations of cattle and sheep in each treatment (see specific goal 2, Chapter 1).

However, a degree of destructive sampling is always necessary if quantitative data are required. It was therefore decided that the disc meter, which has been applied with satisfactory results in many studies (*e.g.* Bransby & Tainton 1977; Danckwerts & Trollope 1980; Bartholomew 1985; Trollope & Potgieter 1986; Turner 1988), should be used. Estimation of herbage mass using the disc pasture meter requires a two-stage procedure. The disc meter must first be calibrated for the conditions in which it is to be used. Calibration involves developing a regression of 'herbage mass under the disc' on disc height. Mean disc height of the sward is then estimated from a number of randomly placed disc readings in the area concerned. Substitution of mean disc height into the regression relationship provides an estimate of mean herbage mass 'under the disc'. This estimate is then converted to herbage mass per hectare.

5.1.2.1 Calibration of the disc meter

Requirements for calibrating the disc pasture meter have been discussed by several authors. Bransby & Tainton (1977) indicated that there was little point in taking more than 50 paired observations per calibration. Danckwerts & Trollope (1980) and Bartholomew (1985) applied a random sampling procedure in obtaining data for their calibrations. Danckwerts & Trollope (1980) go further to suggest a statistically acceptable method for removing data points before arriving at a finally acceptable calibration. Clarke (pers. comm.) has suggested, however, that a non-random procedure should be applied for the purposes of calibration. The operator should actively seek to include the full range of disc heights in the sward and ensure that, in particular, the end points of the calibration are adequately sampled. This procedure assumes that the relation between disc height and herbage mass is linear. A review of literature reveals that in all situations where the disc meter has been used to estimate herbage mass, linear regression functions have been applied (Bransby & Tainton 1977; Danckwerts & Trollope 1980; Bartholomew 1985; Hardy 1986; Trollope & Potgieter 1986; Turner 1988). There was no reason, therefore, to refute this assumption.

As destructive sampling had to be kept to a minimum, the number of points per calibration was reduced to 25. The approach suggested by Clarke (pers. comm.) was adopted to ensure that the full range of disc heights was included in each calibration curve.

Various studies (*e.g.* Bransby & Tainton 1977; Danckwerts & Trollope 1980; Bartholomew 1985; Hardy 1986) have discussed the need for providing calibrations for each of a number of situations which are likely to influence the slope of the regression function describing the dependence of herbage mass or disc height. Factors such as season, moisture content, species composition and grazing impact are likely to influence the regression function. In the present study three factors were considered to be important; a) season *i.e.* spring, summer or autumn, b) whether the sward was being grazed or rested, and c) within grazed paddocks, whether or not there was a carry over of herbage from one season to the next. Calibration data were obtained for each of these situations. Those data derived from the 1989/90 and 1990/91 grazing seasons were used for estimating the patterns of accumulation of herbage mass for all four grazing seasons of the present study.

5.1.2.2 Mean disc height

Fifty randomly placed disc meter readings were taken in all paddocks (grazed and ungrazed) of each ratio treatment every two weeks to obtain estimates of mean disc height for use in the calibration. Readings were taken the day before animals were moved to a new paddock.

5.1.3 Quality of selected forage

Cattle and sheep, fistulated at the oesophagus, were used to obtain samples from which the quality of forage selected by the animals in each treatment could be estimated. The fistulated animals were available for only the 1989/90 grazing season thus restricting the data to this period of the trial. As all paddocks had been burnt prior to the start of the 1989/90 grazing season, the quality of selected forage would therefore be expected to be at least as high, if not higher, than in the subsequent seasons where there was a carry-over of residual herbage in two of the paddock allocated to each group of animals. Further support for the assumption that diet quality was likely to be higher in the first year of the trial than in the others is derived from Mes (1958) & Tainton *et al.* (1977) who reported that the quality of early season regrowth (as estimated from crude protein content) was higher from veld burnt before the onset of growth than from veld which had not been burnt.

Oesophageal fistula extrusa samples were obtained, as far as practically feasible, during each period of stay in each paddock of each ratio treatment. In an attempt to obtain an estimation of the mean quality of forage selected during each period of stay, samples were collected two days after the animals entered a paddock and again two days before they left the paddock.

On each sampling occasion one sample of extrusa was obtained from each species of animal allocated to each treatment. Danckwerts (1989b) and Hardy & Mentis (1986) reported that there were no significant differences in the quality of diet selected by different animals (of the same class and species) grazing on the same pasture when sampled at the same time of day.

The fistulated animals were maintained as a separate group in paddocks adjacent to the grazing trial. These paddocks had a similar species composition to those used in the trial and were also managed as a four-camp rotation grazing system. There were sufficient fistulated animals to allocate only one to each treatment on each sampling occasion. Samples were obtained before 10h00. The fistulated animals were 'kraaled' at 05h00 on each sampling day and forage was withheld from them until they were used for sampling.

Sample extrusa were dried in a forced-air-draught oven at 60°C for 48 hours. The dried samples were milled through a 1 mm sieve. Samples were analysed for per cent *in vitro* digestible organic matter (%IVDOM), applying the technique described by Tilly & Terry (1963) as modified by Engels and van der Merwe (1967). The %IVDOM data were then converted to *in vivo* per cent digestible organic matter (%DOM) values, separately for cattle and for sheep, using the regression approach developed by Engels *et al.* (1981). The conversion of %IVDOM to %DOM involves the incorporation of a series of standards of known *in vivo* digestibility (determined for cattle and for sheep) in each batch of %IVDOM determinations. The series of standards includes the range of digestibilities of forages from low (approximately 35% DOM) to high (approximately 80% DOM). A regression equation is developed which relates the %IVDOM of the standards to their known *in vivo* values. These regressions are developed separately for the *in vivo* values of the standards for cattle and the sheep. The %IVDOM values of the samples are then used in the regression to derive their %DOM values.

The percentage nitrogen content of each sample was also determined using the standard Kjeldahl method (AOAC 1980). Crude protein per cent (%CP) was calculated by multiplying percentage N of the sample by 6.25 (Barnes 1973).

5.1.4 Animal performance

All ratio treatments were stocked at the same stocking rate (in terms of animal unit equivalents per ha - AUE ha^{-1}) at the start of each grazing season. Stocking rate treatments used in this trial were designed to establish the long-term impacts of grazing on the sward and were therefore calculated on the total area allocated to each treatment *i.e.* over all four paddocks. However, in any one grazing season three of the four paddocks were grazed whilst the fourth was rested. Animal performance is influenced by the actual stocking rate applied for a specific period of time (e.g. Mott 1960; Petersen & Lucas 1960; Riewe 1961; Cowlishaw 1969; Conway 1974; Jones & Sandland 1974;

Connolly 1976; Petersen, *et al.* 1965; Conniffe, *et al.* 1970). The actual stocking rates applied in each treatment were therefore re-calculated according to the area of the three paddocks available to experimental animals in each grazing season. On this basis, the adjusted stocking rates applied to each ratio treatment in the S5 area at the start of each season were, therefore, approximately 1 AUE ha^{-1} instead of 0.7 AUE ha^{-1} (see Chapter 4 for more detail on treatments). For beef production systems in the dry phase of Highland sourveld such a stocking rate would be expected to restrict mass gains of the cattle compared to the potential mass gains expected at lower stocking rates (Kreuter, *et al.* 1984).

All animals were weighed every two weeks. Water and fodder were withheld for 16 hours prior to weighing the cattle. For practical reasons the sheep were weighed without water and fodder being withheld. In addition, the sheep were shorn at the start of each grazing season and again when they were removed from the trial for winter feeding. The fleeces were weighed.

5.2 Results

5.2.1 Climatic data

Total rainfall for each of the four grazing seasons and mean seasonal rainfall (61 year data record) are presented in Figure 5.1).

Monthly rainfall recorded for each of the four grazing seasons, and the mean monthly (61 year data record) rainfall are presented in Figure 5.2. The mean monthly maximum and minimum temperatures recorded for the duration of the trial are given in Figure 5.3. A season is defined here as the period 1 August to 31 July.

In three of the four grazing seasons, rainfall was greater than 90% of the long-term mean seasonal rainfall. During the final season (1992/93), however, only 70% of the long-term mean seasonal rainfall was received (Figure 5.1). A rainfall of less than 553 mm (i.e. < 70% of the long-term mean seasonal rainfall) has been recorded in five of the past 61 seasons. The 1992/93 season thus provides data for what could be described as a 'drought' season. The previous three seasons would be regarded as having had 'average' seasonal rainfall.

Of more interest, however, are the rainfall distribution patterns within each season (Fig 5.2). Data points in each Figure represent the total rainfall recorded for a particular month.

During the 1989/90 season the long-term mean monthly rainfall was exceeded in November, December and March while lower than expected rainfall was recorded at the start of the growing season (August and September) and in the mid-season (January and February) (Fig 5.2a). Early-season rains for 1990/91 were lower than the long-term mean while December and January received more than the long-term mean rainfall for those months. Rainfall for all other months of the year was lower than expected (Fig 5.2b). During October, November and December of the 1991/92 season, rainfall was well above the long-term mean for these months, while rainfall for the remainder of the season was similar to the long-term mean (Fig 5.2c). The mean long-term monthly rainfall was exceeded in only two months of the 1992/93 season i.e. August and November (Fig 5.2d).

Thus not only were there differences in total rainfall between seasons but there were also large differences between seasons in seasonal rainfall distribution. The latter (seasonal rainfall distribution patterns) are more likely to have influenced the patterns of herbage accumulation and therefore animal production patterns, through each season, than the former (total rainfall).

Monthly mean maximum and minimum temperatures were less variable than the monthly rainfall data. Similar patterns were followed for each season, with monthly mean maximum temperatures varying more from the long-term means than the monthly mean minimum temperatures (Fig 5.3). Monthly mean maximum temperatures recorded during the 1989/90 season were generally lower than the long-term mean. The monthly mean maximum temperatures were generally higher than the long-term mean during the latter part of each of the 1990/91, 1991/92 and 1992/93 seasons. Monthly mean max temperatures for the 1992/93 season were also higher than the long-term values during the early part of the season (Fig 5.3a).

Greater variation in monthly mean minimum temperatures was recorded for the early part of each season than in the latter part of the season (Fig 5.3b). The early part of the 1989/90 and 1990/91 seasons tended to have lower monthly mean minimum temperatures than the long-term mean whilst in the 1991/92 and 1992/93 seasons the monthly mean minimum temperatures for the early part of these seasons was generally higher than the long-term mean.

5.2.2 Seasonal patterns of herbage accumulation

The disc meter was calibrated on four separate occasions during the 1989/90 grazing season. Twenty five calibration pairs (disc height and herbage mass 'under-the-disc') were recorded across all ratio treatments for 1) the rest paddocks, 2) paddocks grazed first in the grazing cycle, 3) paddocks grazed second in the grazing cycle and 4) paddocks grazed third in the grazing cycle, on each sampling occasion. The linear regression equations developed from these data are presented in Table 5.1.

The disc meter was also calibrated during the 1990/91 season. The main aim here was to obtain a calibration for paddocks in which herbage from one grazing season was carried to the next i.e. for the paddocks which were grazed second and third in the grazing cycle. The linear regression equations developed for the 1990/91 grazing season are presented in Table 5.2.

Inspection of regression coefficient b, for the disc height variable determined for the 1990/91 season (Table 5.1), reveals that, in general, the coefficient increases with time within a grazing season. This implies that the bulk density (herbage mass per volume : the volume in this case being disc height multiplied by the surface area of the disc) of the sward increases as the growing season progresses. Such a process is to be expected for a tufted grassland from which all herbage had been removed, by burning, prior to the onset of growth in spring. Bulk density would be lower in the early part of the season particularly while the inter-tuft spaces remain free of herbage. A certain degree of lateral tillering occurs in many of the grass species found in the area. Bulk density would be expected to increase with increased lateral tillering. In addition, most of the tufted grasses in the study area have an upright growth habit and as the plants grow out through the season, a degree of lodging often occurs, thus increasing bulk density.

There is, however, a relatively low absolute difference between any two regression coefficients for disc height within a particular set of paddocks. Referring, for example, to regression coefficients for disc height of the rest paddocks (Table 5.1), there is a maximum difference of 107 kgDM ha^{-1} per centimetre of disc height. As will be seen later in this section, estimated herbage mass was in excess of 1 000 kgDM ha^{-1} for most paddocks in all seasons and often in excess of 2 000 kgDM ha^{-1}. The difference of 107 kgDM ha^{-1} was therefore, at most, generally less than 10% of estimated herbage mass.

However, practical application of the regression equations for estimating herbage mass from the mean disc height data derived from fortnightly disc meter readings for each paddock posed a number of problems.

First, there was no objective basis on which the decision regarding when in the season to stop using a particular equation and to start using the next, could be made. Second, there was similarly no objective basis for deciding on which of the regression equations would be most suited for use in grazing seasons during which the disc meter was not calibrated (viz. the 1991/92 and 1992/93 grazing seasons).

Because of the practical problems of applying the individual regression functions and the fact that differences in slope within each of the situations for which the disc meter was calibrated were considered insignificant for the present study, general regression functions were developed. All paired disc meter height and herbage mass 'under-the-disc' data collected in the study, were pooled for each of three situations. Regression functions were developed from these pooled data for 1) paddocks being rested for the whole season, 2) paddocks being grazed after they burnt at the start of the grazing season, and 3) paddocks being grazed but which had not been burnt at the start of the grazing season. The third general calibration was considered necessary as further inspection of Table 5.2 revealed that in three of the four regression equations developed for the paddock which carried residual herbage into the 1990/91 season, the regression coefficients for disc height were greater than those obtained for all other situations. The regressions developed for each of situations 1) to 3) are presented in Table 5.3. Correlation coefficients for all these calibrations were highly significant ($P < 0.001$). A comparison of the regression coefficients for disc height for the 'general' calibrations presented in Table 5.3 and the individual calibrations presented in Tables 5.1 and 5.2, indicates that the values of the coefficients of the 'general' calibrations are intermediate between the high and low values for the coefficients of the individual calibrations. This suggests that when applying the 'general' equation, herbage mass will be over-estimated in the early grazing season and under-estimated in the latter part of each grazing season.

The 'general' regression equations presented in Table 5.3 were used to establish seasonal patterns of herbage accumulation for each paddock in each treatment and for each of the four grazing seasons. Day 0 was taken as 30 September each year. Mean disc heights were calculated from the disc meter readings taken fortnightly in each paddock of each treatment. The results are presented in Appendix Fig. 5.1. This procedure resulted in a confusion of lines, making it difficult to detect differences in the patterns of herbage accumulation 1) between paddocks within treatments and 2) between treatments within a particular paddock in the grazing cycle (Appendix Figure 5.1). In the present context, discussion focuses on patterns of herbage accumulation within and between treatments for each of the four grazing seasons. Lack of replication precludes rigorous statistical analyses of the data. Furthermore, non-treatment related variation in the disc data, such as excessive moisture on the herbage at the time of taking fortnightly disc meter readings, could have added to the 'noise' and lack of pattern detected in the data sets (Appendix Figure 5.1). Analyses were therefore restricted to main effects.

In an attempt to highlight the main effects the following procedure was adopted. First, each grazing season was divided into three consecutive 60 day periods. Second, estimated mean daily herbage mass recorded for each of the 60 day periods was calculated for each paddock. The trapezoidal rule (Dixon 1974) was applied to calculate the area under the curve for each 60 day period. Each area was then divided by the number of days in the period concerned. Third, the mean daily herbage mass calculated for each period was treated to statistical analyses to determine differences in patterns of herbage on offer between treatments. The effects of ratio on mean daily herbage on offer within a specified paddock of the grazing cycle for a specific 60 day period was examined using the interaction as an error term (Levine, pers. comm.). Similarly, the within-ratio treatment effects on mean daily herbage availability due to position in the grazing cycle was also examined. These analyses suggested that there were no significant differences ($P > 0.05$) in the mean daily herbage mass on offer between ratio treatments within position in the grazing cycle and period within a grazing season (Figure 5.4). Inspection of Fig 5.4 reveals similar trends in herbage on offer for all ratio treatments. However, the 0:1 (sheep-only) ratio treatments tended to have a larger mean daily herbage mass on offer than the other treatments for all paddocks and all grazing seasons.

The within-ratio treatment patterns of herbage on offer are presented, for all grazing seasons, in Figure 5.5. Each point plotted in Figure 5.5 represents the mean daily herbage mass for a particular period of the grazing season and is plotted at the end of each period. [4]On average, and in all grazing seasons, paddocks grazed first in the grazing cycle had significantly lower ($P < 0.05$) herbage mass for the duration of the grazing season than paddocks grazed second and third in the grazing cycle. This is not surprising since residual herbage had been burnt before the start of the grazing season whilst the remaining two paddocks contained herbage carried over from the previous season, except for the 1989/90 season.

For paddocks grazed first in the grazing cycle the mean daily herbage mass on offer to the animals ranged from approximately 1 000 kg to 1 500 kgDM ha^{-1} for all treatments in the first three grazing seasons. In the 1992/93 grazing season (the season of low rainfall), however, mean daily herbage mass on offer to the animals in these paddocks ranged between 600 and 800 kgDM ha^{-1}. Paddocks grazed 2nd and 3rd in the grazing cycle showed similar trends in the pattern of herbage accumulation through the season (Fig 5.5 a to d). Whilst it was expected that the paddocks grazed 3rd in the cycle would have accumulated more herbage than paddocks grazed 2nd in the grazing cycle, there was no consistent pattern in this regard. It is important to note, however, that with the exception of the first grazing season (1989/90), there was a tendency for more herbage to accumulate in the 2nd and 3rd

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[4]It must be realized that, due to the lack of replication, it was not possible to determine the significance of differences in herbage on offer, due to position in the grazing cycle, within each ratio treatment. The level of significance presented here relates to estimates of herbage mass, for a particular period in the grazing season, analysed over all ratio treatments.

grazed paddocks of the 0:1 (sheep-only) treatments than in the other ratio treatments (Figure 5.5 b to d).

Mean daily herbage mass on offer to the animals in the 2nd and 3rd paddocks of the grazing cycle was similar for all treatments, excluding the 0:1 (sheep-only) treatment, in the 1989/90, 1990/91 and 1992/93 seasons. In these grazing seasons mean daily herbage mass on offer ranged between 1 000 and 1 800 kgDM ha^{-1}. During the 1991/92 grazing season, however, mean daily herbage mass on offer ranged between 1 400 and 2 200 kgDM ha^{-1}. The above average early season rainfall recorded in the 1991/92 season (see Figure 5.2 c) may have been responsible for these higher herbage production figures.

5.2.3 Quality of selected forage

The main objective for collecting herbage quality data for the present discussion was to determine patterns in the quality of forage selected by cattle and by sheep through the first grazing season.

A knowledge of the quality of diet selected by animals together with the estimates of herbage mass on offer should assist in understanding observed animal performance patterns. Problems encountered with the fistulated animals subsequent to the first grazing season precluded the collection of samples in the remaining grazing seasons.

The primary requirement in ruminant nutrition is for dietary energy (t' Mannetjie 1984). However, there is a minimum protein requirement for the microbial breakdown of ingested forage in the rumen. This has been estimated at between 6 and 8,5% CP. If dietary protein is below this level then intake will be reduced (t' Mannetjie 1984).

5.2.3.1 Digestible organic matter of selected forage

There is a strong (essentially linear) correlation between the metabolizable energy concentration (ME_c in MJ $kgDM^{-1}$) of tropical forages and the digestibility of organic matter (%DOM) of these forages (e.g. Moir 1961; Armstrong 1964; Butterworth 1964; Minson and Milford 1966; Corbett 1978).

The %DOM of forage selected by the cattle and the sheep therefore provides an estimate of the seasonal patterns of metabolizable energy selected by animals in each treatment. Per cent DOM values in excess of 50 are adequate with respect of ensuring positive animal performance depending, of course, on the amount of forage ingested by the animal and the protein content of the forage.

The %DOM of forage selected by cattle and by sheep through the first grazing season (1989/90) are presented in Figures 5.6 and 5.7 respectively. The X axis represents time (t) with t = 0 set at 30/09/89. The last day in September was chosen to represent the onset of growth each season. Sampling dates reflect the potential age of the herbage from the start of each growing season.

Age or maturity of herbage is the most important factor influencing the nutritive value of grasses. Per cent DOM and crude protein (%CP) content of plants both decrease with age while lignin increases (Raymond 1969; Ulyatt 1973; Bransby 1981; Mentis 1982; Hardy & Mentis 1986; de Waal 1990).

In almost all cases the %DOM of forage selected by cattle and by sheep exceeded 50% throughout the season. Furthermore, there was a general trend of declining quality as the season progressed. The %DOM at the start of the season was high (65 to 70%). This is not surprising as all paddocks available to the animals had been burnt prior to the start of the grazing season, thus ensuring a flush of high quality new season's growth. As the season progressed, however, the increasing maturity of plants would have resulted in a consistent decline in %DOM of forage on offer to the animals.

In the latter part of the season, at approximately 160 days since the assumed onset of spring growth (30/09/89), there was a general increase in the %DOM of selected forage over all ratio treatments for both cattle and sheep. Thereafter the %DOM of selected forage again declined (Figures 5.6 and 5.7).

This increase in quality was most likely a function of a flush of new growth at that time, but in the absence of quantitative data it is impossible to corroborate this statement. However, inspection of the rainfall pattern for the 1989/90 grazing season (Figure 5.2a) indicates that good rains fell in March 1990, approximately two weeks prior to the start of the period of increased %DOM. It is probable that the increased %DOM of forage was a function of new growth which, in turn, was a function of increased soil moisture availability.

5.2.3.2 Crude protein (%CP) content of selected forage

Trends in the %CP content of sample extrusa through the 1989/90 grazing season were similar to the trends detected in % DOM. As expected there was a general decline in %CP content of selected forages from the start to the end of the grazing season (Figures 5.8 and 5.9). Crude protein content was approximately 11% at the start of the sampling period, fell rapidly to approximately 7% at 60 to 80 days and then declined to approximately 5% after 227 days from the assumed start of growth (30/09/89). As observed in the %DOM data, there appeared to be a slight increase in %CP content of sample extrusa in the latter part of the grazing season (160 to 180 days), whereafter the %CP again declined (Figures 5.8 and 5.9).

5.2.3.3 General

The seasonal patterns in quality (%DOM and %CP) of forage selected by cattle and sheep in each of the ratio treatments are highlighted in Table 5.4. In developing Table 5.4 the season was divided into three consecutive 60 day periods. Mean daily %DOM and %CP of selected forage was calculated for each of these periods for each treatment and animal species using the procedure applied to determine seasonal patterns of herbage accumulation (section 5.2.2).

During the first 60 day period the mean daily %CP content of forage selected by cattle was in excess of the minimum range of %CP content required by the cattle i.e. intake should not have been limited by %CP content of the forage. It is surprising however, to note that the mean daily %CP content of forage selected by the sheep during this first 60 day period (except for the 3:1 ratio treatment) was within the minimum range of %CP below which intake could be limited. Clearly, for much of the grazing season both the sheep and the cattle were potentially in a situation of nutritional stress with respect to the availability of protein in the forage (Table 5.4). However, the low protein content of sourveld has been well documented and it is common practice, as was the case in the present study, to supply a protein-based supplement to the animals during the latter part of the grazing season (usually from late February).

The mean %DOM of selected forage at the start of the season ranged from 68% (cattle)/ 65% (sheep) to 58% (cattle)/ 54% (sheep) towards the end of the season (Table 5.4). Such levels of %DOM in the diet are sufficient to maintain positive animal performance provided that the quantity of dry matter intake is not limiting (NRC 1976; ARC 1980).

It must be remembered that these %DOM values are the estimated *in vivo* values for the sheep and the cattle. Sheep selected a forage which had lower %DOM than that selected by cattle (Table 5.4). This is a function of differences between sheep and cattle in the efficiency of use of ingested forage (Engels, *et al.* 1981). These data suggest that the sheep, despite their reported ability to select higher quality forage than cattle (see Chapter 3), were under greater nutritional stress than the cattle in the present trial.

5.2.4 Date of stocking

All treatments were stocked at the same time in any one season. Time of stocking, however, varied between years. Dates of stocking in each of the four seasons reported on here are presented in Table 5.5.

5.2.5 Animal performance

Animal performance data are presented in two ways. First, seasonal trends in mean cumulative livemass changes for the cattle and the sheep in each ratio treatment are presented in Figures 5.10 & 5.11 respectively. Polynomial functions were fitted to the cumulative mean mass gain per animal on time data. 'Best-fit' polynomials for the cattle data included both quadratic and quartic functions whilst quartic functions provided the 'best-fit' for the sheep data in all ratio treatments and seasons (Table 5.6). Plots of fitted and actual data for each species of animal, cattle to sheep ratio treatment and season (1989/90, 1990/91, 1991/92 and 1992/93) are presented in Appendix Figures 5.2 to 5.5.

Second, mean livemass gain per animal and per hectare for each ratio treatment and for each season is presented in Table 5.7. Also presented in Table 5.7 are the wool production data (kg ha^{-1}) for each treatment and season.

All livemass gain data were analyzed over the same time period. Deciding on an appropriate time period provided some difficulty. Comparisons of animal performance between treatments often requires that the animals are in a positive growth phase or, at least, maintaining mass (e.g. Bartholomew 1985 pp133). Since, after attaining maximum mass, animals tend to lose rather than maintain mass, between treatment comparisons are generally made over the time taken for the first group of animals to attain maximum mass. In the present study, however, the number of days taken to meet this requirement varied both between seasons and between species of livestock (Table 5.8).

In the 1991/92 grazing season, for example, between treatment comparisons of cattle performance would have been made over a 161 day period whilst, for the sheep, comparisons would have been made over a 49 day period (Table 5.8). Comparing treatments over such time frames was clearly unrealistic. In the practical farming situation, sourveld is grazed for at least 6 months in any one grazing season. Inspection of Table 5.8 reveals that, for most treatments, maximum mass was attained after approximately 6 months (182 days). This time period was therefore used in the analyses of animal performance data for both species of animal and for all seasons despite the fact that animals in certain treatments would have been in a negative growth phase. It must be noted that the livemass gain data for sheep included wool production over the grazing season.

Lack of treatment replication precludes rigorous statistical analyses for comparing differences in animal performance between treatments. Interpretation of the results thus rests on inspection of the trends in mean mass change of animals (Figures 5.10 & 5.11, and Table 5.7).

5.2.5.1 Cattle performance

Cattle performance was poorest in the cattle-only (1:0) ratio treatment in all four grazing seasons (Fig 5.10, Table 5.7). During the first 80 to 100 days of each season there was little difference, however, in mean cumulative mass gain per animal between any of the treatments. It is clear, however, that the performance of animals in the 1:0 ratio treatment started to decline, relative to the remaining treatments, after the first 80 to 100 days (i.e. from the end of January) in each season. Differences in animal performance between the remaining ratio treatments (3:1, 1:1 and 1:3) were small and inconsistent, except in the 1992/93 grazing season where animals in the 1:3 ratio treatment gained approximately 15% more mass than animals in the 3:1 and 1:1 ratio treatments (Figure 5.10 & Table 5.7).

Maximum mean cumulative mass gain per animal was achieved after 160 to 210 days in the grazing season, i.e. in April/May, depending on the treatment applied. At this time the quality of herbage being selected by the animals was poor, with %DOM and %CP at approximately 55% and 6% respectively (Figures 5.6 to 5.9). In all treatments and for all seasons the animals showed consistent mass losses within a week of having achieved maximum mass. Animals in the 1:0 treatment were the first to attain maximum mass in all grazing seasons with cattle in the 3:1 and 1:3 ratio treatments attaining maximum mass at the same time in the 1991/92 and 1992/92 grazing seasons respectively (Table 5.8).

Total live mass gain per hectare of the cattle in each treatment was calculated as the product of mean gain per animal and the stocking rate of cattle (animals ha^{-1}). As the stocking rate of cattle declined cattle mass gains per hectare declined in all four seasons, except at the 3:1 ratio in the 1992/93 grazing season (Table 5.7).

In the cattle-only (1:0) ratio treatment there were clear differences in total mass gain per hectare between seasons (Table 5.7). Mass gains of cattle per hectare for the first two grazing seasons were 30 to 40 per cent greater than for the third and fourth grazing season. For the remaining ratio treatments there was little difference in cattle livemass gain per hectare between the first, second and fourth season. In the third (1991/92) season, however, livemass gain per hectare of the cattle was 15 to 25 per cent lower (depending on the ratio treatment) than the mean livemass gains per hectare recorded for the other three seasons (Table 5.7).

For the purposes of the above discussion it was considered important to ensure that comparisons were made over the same period of time each season. It must be pointed out, however, that for any livestock production system in sourveld, the longer animals can be kept on the veld through summer, autumn and into winter, the lower are the over-wintering costs. In the present context the number of days taken to achieve maximum mass provides a direct comparison of the effects of ratio treatment on the length of the grazing season (Table 5.8). While some mass losses are normally accepted towards the end of a grazing season, in animal production systems in sourveld, inspection of Appendix Figures 5.2 to 5.5 indicates that such losses may be quite large. Maintaining the animals on the veld for too long into the winter may therefore have a large negative influence on the viability of the production enterprise.

Cattle in the 1:3 treatment continued to gain mass for between one to six weeks longer than the other ratio treatments (Table 5.8). The magnitude of the differences depended on the ratio treatment with which the 1:3 was being compared and the grazing season concerned (Table 5.8).

In general, as stocking rate of cattle (animals ha^{-1}) increased so the number of days to maximum mass decreased.

5.2.5.2 Sheep performance

During the first approximately 50 days of each season there was a rapid increase in mass per animal for all ratio treatments and for all seasons (Figure 5.11). Thereafter, individual mass changes were strongly influenced by the stocking ratio treatment applied. The general trend, which was maintained for all four seasons, was one of a decline in mass gain per animal as the ratio increasingly favoured sheep, with poorest performance when sheep grazed alone (Fig 5.11, Table 5.7). Mean cumulative livemass gain of sheep in the 3:1 ratio treatment was consistently higher than the mean cumulative livemass gains in any of the other treatments except in the 1991/92 grazing season when the sheep in the 1:3 ratio showed similar performance to the sheep in the 3:1 ratio treatment (Table 5.7).

Considering the seasonal effects on animal performance within ratio treatments, mass gain per animal declined in all ratio treatments for the first three grazing seasons. In the fourth grazing season, however, individual animal mass gains far exceeded mass gains of the previous three seasons for all ratio treatments (Figure 5.11, Table 5.7).

Maximum mean cumulative livemass gain per animal was attained after 49 to 189 days in the grazing season, depending on the ratio treatment applied and the grazing season concerned (Table 5.8). Animals in the sheep-only (0:1) ratio treatment were always first to attain maximum mass. In the first, second and third grazing seasons, maximum mass was attained by animals in the 0:1 ratio treatment between 84 to 133 days before sheep in the 3:1 ratio treatment reached their maximum mass, but there was little difference in the fourth season.

Total livemass gain of the sheep per hectare for each treatment was calculated as the product of mean gain per animal and the stocking rate of sheep (animals ha^{-1}). As the stocking rate of sheep declined, sheep mass gains per hectare declined in all four seasons (Table 5.7). There were large differences in sheep livemass gain per hectare between seasons for all ratio treatments, with the first and particularly the last grazing seasons providing the highest gains (Table 5.7).

Wool production data are presented as the mean mass of wool produced per animal and per hectare (Table 5.7). No data were available for the 1:1 ratio treatment in the 1991/92 grazing season. The data presented in Table 5.7 reflect approximately 200 days of wool growth per animal. Stocking ratio does not appear to have had any consistent effect on the mean wool mass per animal. It is obvious therefore that as the proportion of sheep in the ratio treatments increased, so wool production per hectare increased (Table 5.7).

5.2.5.3 Discussion

As mentioned previously, animal performance is primarily a function of the quality and quantity of dry matter ingested. The herbage mass and quality data reported on in this chapter were collected with the intention of providing some explanation for observed differences in animal performance between treatments and between seasons. Inspection of Table 5.4 indicates that differences between treatments in the quality of forage selected by cattle and by sheep during the 1989/90 grazing season were small and show similar trends through the grazing season. These quality data do not therefore provide an explanation for the observed seasonal differences in animal performance between ratio treatments. They do, however, indicate that the forage selected by the cattle and the sheep during the first season (1989/90) had sufficiently high %DOM to ensure mass gain of animals for most of the season. In addition, the fact that a protein-based supplement was available to the animals from late February each season supports the statement that quality of intake *per se* should not have had a major influence on mass gain of the experimental animals. However, the quantity of forage, of a sufficiently high quality, ingested by the animals was likely to have been the major factor limiting animal performance.

The poor performance of the sheep in the sheep only (0:1) treatment may partially be explained from inspection of Figures 5.5a - d. In all grazing seasons, except the first (1989/90), there was more herbage on offer to the animals in the 0:1 treatment throughout the season than in any other ratio treatment. The known preference of sheep for short green and leafy herbage may have resulted in the sheep restricting their feeding to individual plants or areas which had previously been grazed short, and ignoring the remaining taller, more mature herbage on offer. This explanation, however, does not hold for the situation in 1992/93 when the sheep exhibited excellent performance relative to their performance in previous seasons, despite having high levels of herbage on offer in paddocks grazed 2nd and 3rd in the grazing cycle throughout the 1992/93 grazing season.

While it was not possible to quantify animal performance due to the quantity of herbage on offer and quality of ingested forage, the animal performance data themselves may be used directly to investigate the effects of interactions between cattle and sheep on their respective performances.

5.2.6 Towards a general model for predicting the performance of cattle and sheep in mixed-species grazing systems

The animal performance component of this trial was not designed to provide a rigorous analysis of the effects of cattle to sheep ratio on cattle and sheep production systems in Highland Sourveld. However, the following analytical approach provides a framework for establishing the interactive effects of ratio and stocking rate on the performance of cattle and of sheep in mix-species grazing systems. Analysis of animal performance data, derived from the animal performance component of the trial, follows the procedures described by Connolly and Nolan (1976), Connolly (1987) and Nolan and Connolly (1989). It must be noted here that these analyses were based on the number of cattle and sheep allocated to each treatment (animals ha^{-1}).

5.2.6.1 Procedure

5.2.6.1.1 Average daily gain (ADG)

Statistical treatment was based on multiple regression. Consider a mixed-species grazing system (C, S) with C cattle and S sheep per unit area. Let W_1 and W_2 be the live-weight gains per head of cattle and per sheep respectively, and let

$W_1 = f_1 (C,S)$ and

$$W_2 = f_2 (C,S) \qquad \text{.......... 5.1}$$

where f_1 and f_2 are functions relating individual live-weight gain to the stocking rates of C and S. A linear relation may result viz

$W_1 = a_{10} + b_{11} C + c_{12} S$ and

$$W_2 = a_{20} + b_{21} C + c_{22} S \qquad \text{.......... 5.2}$$

where b_{11} and c_{22} are intraspecific coefficients measuring the effects of a species stocking rate on its performance, c_{12} and b_{21} are interspecific coefficients measuring the effects of a species stocking rate on its companion species, and a_{10} and a_{20} are coefficients describing the intercepts. More complex equations (eg. involving quadratic and cross-product terms in C and S) may be required to model the responses properly.

These equations were developed for the current data set and were used to describe and compare the ADG of the cattle and the sheep in the C-S plane. A useful way of displaying such information is in the form of isoclines. An isocline joins all points at which the value of the variable concerned is a constant. In the present context, for example, the C = 200 isocline joins all points in the C-S plane at which the ADG of cattle is 200 g animal^{-1} d^{-1}.

5.2.6.1.2 Relative resource total

The relative resource total (RRT) was proposed by Connolly (1987) "to measure whether species capture more or less resources under mixed- than under single-species grazing" (Nolan & Connolly 1989). In a mixed-species grazing situation, the RRT is the area required to carry, under single-species grazing, the same number of each animal type at the same level of ADG as produced in a unit area of mixed-species grazing. An RRT of >1 implies that more than a unit area is required under single-species grazing to produce, for the same number of animals, the same ADG as in the mixed-species grazing situation. This suggests that mixed animal populations are capturing either more or different resources, or using them more efficiently than single-species populations. A value of <1 suggests interference (competition) between species in use of the resource.

The models (equation 5.2) predicting ADG for cattle and sheep as functions of the C and S were applied in developing the RRT index. The RRT may be used as a measure of the carrying capacity of a farm under a mixed- and a single-species grazing system.

5.2.6.1.3 Substitution rates (R_1 and R_2)

Substitution rates index the influence that the animal types have on each other and can be quantified as R_1 and R_2 using the models predicting ADG of the cattle and the sheep (Connolly 1987). For example $R_1 = 3$ means that, from the viewpoint of the first animal type, increasing its stocking rate by 3 units would produce the same effect on it as increasing that of the other animal type by 1 unit. Alternatively, replacement of the first animal type by the second animal type at a rate of 3:1 would leave the performance of the remaining members of the first animal type unchanged.

5.2.6.2 Results

5.2.6.2.1 Average daily gain (ADG)

Average daily gains of the cattle and the sheep (Table 5.9) were calculated for each ratio treatment and each season from the data presented in Table 5.7. Linear models of the form presented in equation 5.2 were fitted to the data for each season. Alternative models were not considered due to the low number of data points (4) available for each analysis. The results are presented in Table 5.10. Only one of the regression functions provided a significant ($P < 0.05$) fit for the regression of ADG on C and S viz. the 1990/91 sheep data. However it is stressed that the procedures adopted here are presented to illustrate an approach for analysing data from mixed-species grazing experiments. 'General' multiple linear regression models based on the pooled data from the first three grazing seasons, were also developed for the cattle and the sheep respectively. Regression coefficients for each of the models are presented in Table 5.10. The marked difference in animal performance recorded during the fourth ('dry') season precluded the use of these data in a 'general' model. The 1992/93 data were therefore applied in developing a 'dry-season' model for predicting the performance (ADG) of the cattle and the sheep as functions of C and S.

Isoclines of predicted ADG for the cattle and the sheep are presented in Figures 5.12 and 5.13 for the 'general' and 'dry-season' models respectively. Predicted performance of cattle in a cattle-only and sheep in the sheep-only grazing systems indicates that as stocking rate increases so ADG decreases

(Figures 5.12 and 5.13).

Referring to the 'general' model (Fig 5.12) at a stocking rate of 1 head of cattle ha^{-1} in a cattle-only grazing system, an ADG of 600g is predicted. However, as sheep are introduced into the system, while maintaining a cattle stocking rate of 1 animal ha^{-1}, cattle performance declines.

Similarly, for a specific stocking rate of cattle, as the stocking rate of sheep increases so individual sheep performance declines (Fig 5.12). However, for any particular stocking rate of sheep, the addition of cattle to the system will improve the performance of the sheep (Figure 5.12). The 'general' model therefore substantiates the idea that the presence of cattle in the system will enhance sheep production. The converse does not occur.

In the dry season (1992/93) a somewhat different picture relating to the performance of the sheep emerges (Figure 5.13). The pattern of response by cattle in the C-S plane is similar to that shown in Figure 5.12 i.e. cattle performance declines with increasing stocking rate of both cattle and sheep. In contrast to the 'general' model, however, as the stocking rate of cattle increases for a given stocking rate of sheep, so the performance of the sheep declines. Such a response is unexpected in the light of general experience of sheep performance in sour grassveld and from the previous three seasons animal performance data. The observed responses illustrate the fact that sheep are better suited to grazing in drier regions, or in drier seasons, where plants do not generally grow rapidly to maturity, thus maintaining their palatability and nutritional value for longer into the season. It appears that during this 'dry-season', the cattle and sheep were in direct competition for the available forage. Increases in the stocking rate of cattle and/or of sheep resulted in decrease in the performance of both the cattle and the sheep (Figure 5.13).

The models may also be used to illustrate various **mixed-species** grazing effects on animal performance relative to animal performance in **single-species** grazing systems. The effect of mixed-species grazing on animal performance is expressed in terms of the number of cattle and the number of sheep per unit area.

A 'low' and a 'high' stocking rate were selected for each of the cattle- and the sheep-only grazing systems. The 'low' and 'high' stocking rates selected for cattle-only systems were 1 and 2 animals per hectare respectively, whilst those selected for the sheep were 4 and 8 animals per hectare respectively. For each of these stocking rates, mixed-species stocking rates were selected, where the species were in the proportions 0.25:0.75, 0.5:0.5 and 0.75:0.25 of the cattle- and sheep-only stocking rates. At a particular stocking rate, and for the 0.25:0.75 stocking ratio, therefore, the cattle component comprised 25% of cattle-only stocking rate whilst the sheep component comprised 75% of the sheep-only stocking rate. Predicted ADG of cattle and sheep grazing in a single- or a mixed-species grazing system are presented in Figure 5.14. The species mix is expressed as the proportion of cattle relative to the cattle-only stocking rate. Average daily gains shown for the 'high' cattle and 'high' sheep stocking rates simulate the stocking rate treatments applied in the current trial.

The predicted performance of sheep at the 'low' (4 animals ha^{-1}) and 'high' (8 animals ha^{-1}) stocking rates are compared to the predicted performance of the cattle at the 'low' (1 animals ha^{-1}) and 'high' (2 animals ha^{-1}) stocking rates respectively. For example, a value of 0.25 on the x-axis implies that, at the low stocking rate, there are 0.25 (0.25x1) cattle ha^{-1} and 3 (0.75x4) sheep ha^{-1} (Figure 5.14). As the proportion of cattle in the mix increases so ADGs of the sheep increase. At the 'high' stocking rate, sheep show a more rapid increase in ADG with an increase in the proportion of cattle than the sheep at a 'low' stocking rate. Average daily gain of the cattle increased with decreasing proportion of cattle (and thus increasing proportion of sheep) for both stocking rate comparisons.

The patterns exhibited in Figure 5.14 are strongly influenced by the choice of the single-species stocking rates used in the comparisons. To illustrate this point, sheep-only at the 'low' stocking rate (4 animal ha^{-1}) was compared to cattle-only at the 'high' stocking rate (2 animals ha^{-1}) and their respective mixed-species stocking rates. Similarly, sheep-only at the 'high' stocking rate (8 animals ha^{-1}) was compared to cattle-only at the 'low' stocking rate (1 animal ha^{-1}). The results are presented in Figure 5.15. In this instance, a value of 0.25 on the x-axis implies that, for the 'low' stocking rate sheep and 'high' stocking rate cattle comparison, there would be 3 sheep and 0.5 cattle per hectare.

In contrast to the results shown in Figure 5.14, sheep stocked at the 'low' stocking rate together with cattle at the 'high' stocking rate show better performance for all combination of species mix than sheep stocked at the 'high' stocking rate together with cattle at the 'low' stocking rate (Fig 5.15). Furthermore, there was a major change in the pattern of cattle performance for the cattle stocked at the 'low' stocking rate together with sheep at the 'high' stocking rate. Average daily gains of the cattle decreased as the proportions of cattle decreased and the proportions of sheep in the mix increased (Figure 5.15).

The regression models developed for the 1992/93 'dry-season' were applied in the same way to investigate the interactions between stocking rate of cattle and stocking rate of sheep on cattle and sheep performance (Figure 5.16). While the performance of the sheep was far greater than the mean performance of sheep from the previous grazing seasons, the patterns were similar when comparing species mixes, comprising 'low' stocking rates of cattle with 'low' stocking rates of sheep, or 'high' stocking rates of cattle with 'high' stocking rates of sheep. However, when sheep were stocked at the 'low' stocking rate together with cattle at the 'high' stocking rate, sheep ADG declined as the proportion of cattle in the species mix increased (Figure 5.16).

5.2.6.2.2 Substitution rates and RRT

Substitution rates R_1 and R_2 were calculated for the cattle and sheep components respectively from the linear functions developed for the 'general' and the 'dry-season' models. For linear equations R_1 and R_2 are constant and independent of the stocking rates of cattle and sheep in the mix. For cattle, simple division of the constant associated with stocking rate of sheep (c_{12}) by the constant associated with cattle stocking rate (b_{11}) (Table 5.10) provides the value for R_1. A similar calculation provides the value for R_2.

Values for R_1 for the 'general' and 'dry-season' models were 0.21 and 0.17 respectively. This implies that, for the 'general' model a substitution of 0.21 units of cattle by 1 unit of sheep did not change the performance of the remaining cattle. Similar R_1 values for both models suggest that seasonal differences in sheep performance had little influence on the performance of cattle.

Values for R_2 for the 'general' and 'dry-season' models were (-2.0) and 3.7 respectively. In the case of the 'general' model 2.0 units of sheep must be added to the mix for every 1 unit of cattle which is added, to ensure that the performance of the remaining sheep is maintained. Alternatively, decreasing the sheep stocking rate by 2.0 units will have the same effect on the performance of the remaining sheep as adding 1 unit of cattle to the species-mix. The 'dry-season' value for R_2 is considerably different from the R_2 value for the 'general' model. In this case a substitution of 1 unit of cattle for 3.7 units of sheep will result in no change in the performance of the sheep.

Relative resource totals (RRT) were calculated for each of the three mixed-species treatments applied in the current trial. Mean cattle and sheep stocking rates were calculated for the first three season's data and substituted into their respective 'general' models. Stocking rates applied in the fourth season were used in the 'dry-season' model. The maximum and minimum RRT values calculated from the 'general' model were 2.67 and 1.29 respectively while those for the 'dry-season' model (calculation not shown) were 1.12 and 1.07 respectively. A summary of these calculations is presented, for the 'general' models, in Table 5.11.

5.2.7 Discussion and conclusions

The objective of the work reported in this chapter was to obtain an understanding of interactions between cattle and sheep as they influence animal performance. Animal performance has been widely shown to be a function of the stocking rate of the animals concerned (e.g. Mott 1960; Petersen & Lucas 1960; Riewe 1961; Cowlishaw 1969; Conway 1974; Jones & Sandland 1974; Connolly 1976; Petersen, *et al.* 1965; Conniffe, *et al.* 1970). The effect of stocking rate is of course, indirect. Stocking rate influences the demand for available fodder. This demand affects the structure and growth pattern of the sward, and the quantity and quality of herbage on offer throughout the season.

The effect that grazing has on the sward is, in turn, a function of whether grazing is by cattle or by sheep, as their differing foraging strategies will have different impacts on the sward. In addition, sward characteristics are affected by 1) management decisions, such as when the veld is burnt and whether a single- or multi-paddock grazing system is applied, and 2) climatic variation, particularly rainfall.

Ultimately, animal performance is affected by the quality and quantity of forage ingested (which are influenced by the quality and quantity of herbage on offer) and the efficiency of use of ingesta by the animal (Bransby 1981; Evans 1982; Meissner, *et al.* 1983). While the quantity and quality data could not be used quantatively in explaining animal performance patterns, trends of herbage mass on offer through each season and the quality of forage selected through the first (1989/90) grazing season, seasonal rainfall distribution and burning and grazing management could be used to infer the effects of these variables on observed animal performance.

Late winter/early spring burning will reduce herbage mass accumulation of veld through the following spring and summer when compared to non-burnt veld (Tainton, *et al.* 1977; Tainton 1981c). The quality of herbage on offer to animals on veld which is burnt at the start of the growing season is also higher than the quality of non-burnt veld. This is largely because the new season's growth is not contaminated by low-quality residual herbage carried over from previous seasons (Barnes 1992). Furthermore, the new growth is also reported to have higher nitrogen and mineral content than unburnt veld in spring and early summer (Mes 1958; Tainton, *et al.* 1977). In the current trial,therefore, while the quantity of herbage on offer to the animals from burnt paddocks was low relative to the unburnt paddocks, the quality on offer would have been higher. The slower growth rate would also imply higher quality for longer in the season.

Grazing of veld which was burnt in spring is likely to reduce the rate of regrowth even further. The degree to which the growth rate is reduced would depend on grazing intensity, the timing of first grazing relative to when growth commenced and rainfall (seasonal distribution and amount). Theoretically, the grazing intensity applied to each ratio treatment should have been equal, each treatment having been stocked at the same number of AUE ha^{-1} at the start of the season. However, as will be seen in the next chapter the demand for dry matter, as reflected from the animal performance data, differed between treatments, with the lowest demand from the 0:1 (sheep-only) treatment. As grazing intensity is reduced there is increased opportunity for plants to grow out and mature, with a concomitant decrease in the quality of herbage on offer.

Delayed stocking of the veld after a burn has a similar effect. The older (more mature) the regrowth the lower is its quality. Consider the grazing system applied in the present trial, and the first grazing season (i.e. when all paddocks available to each group of animals were burnt at the start of the growing season). The paddock grazed first in the grazing cycle would have been stocked two and four weeks before the paddocks second and third in the grazing cycle respectively. The expected effect here would be to reduce the regrowth potential of the paddock grazed first in the cycle relative to the paddocks grazed second and third. Inspection of Figure 5.5 confirms this expectation.

The seasonal rainfall patterns (distribution and amount of rainfall) would also be expected to have a major effect on regrowth pattern of the veld. All other factors being equal early-season rainfall equivalent to or in excess of the long-term mean would be expected to provide the plants adequate moisture to achieve their regrowth potential, whereas rainfall below the expected long-term mean would imply that moisture may be limiting to regrowth. For example, when stocking the veld soon after spring growth had commenced (at a stocking rate which ensures a high grazing intensity) in seasons of low rainfall, the veld is likely to be kept short throughout the season. Thus a low quantity but high quality of herbage would be on offer. In contrast, in seasons of high early-season rainfall and delayed stocking of the veld, a high quantity of lower quality herbage on offer would be expected.

5.2.7.1 Mean cumulative live-mass gains per animal

Cattle

Following from these arguments it appears that cattle performance would have been influenced more by the quantity than the quality of herbage on offer in the first (1989/90) and second (1990/91) grazing seasons. Herbage mass accumulation in the first grazing season would have been restricted due to the burning of all three paddocks on offer to the animals in each treatment. In the following season herbage mass on offer to the animals through the season in the paddock grazed first in the cycle (the newly burnt paddock) was similar to the herbage mass which was on offer to the animals in the paddock grazed first during the first season (cf Fig 5.5a and 5.5b). Herbage mass on offer in paddocks grazed second and third in the cycle, however, was generally greater than the herbage mass in paddocks with the same position in the grazing cycle during the first season (cf Fig 5.5a and 5.5b). Such increased herbage availability during the second season may be part of the reason for the general improvement in cattle performance in the second year when compared to the first. There was also a large variation in the amount and distribution of monthly rainfall between the first and second season (Figures 5.2a and 5.2b). However, since paddocks grazed first in the cycle (which were stocked at the same stocking rate and at much the same time in the grazing season (Table 5.5)) showed similar patterns of herbage accumulation throughout each season, variation in rainfall distributions *per se* appears not to have differentially affected the accumulation of herbage mass in the first and second grazing seasons.

In the third grazing season, however, whilst the quantity of herbage on offer was greater than in any of the other seasons, lower livemass gains were realized. Inspection of Figure 5.5c reveals that paddocks grazed first in the cycle had approximately 50% more herbage mass on offer to the animals during the first period of the season, compared to the same period in the first and second seasons (Figures 5.5a and 5.5b). This suggests that herbage mass accumulation had been rapid in the early season despite the fact that the treatments had been stocked at much the same time of year and at the same stocking rates as in the previous two seasons (Table 5.5). Here, the rapid early-season herbage mass accumulation was probably a function of the rainfall distribution. Rainfall for October, November and December of the 1991/92 season was well above the long-term mean rainfall for those months (Figure 5.2c). Paddocks grazed second and third in the grazing cycle also had high levels of herbage mass on offer for most of the 1991/92 season (Fig 5.5c). Such rapid accumulation of herbage at the start of the season suggests that plants would have matured early in the season, thus presenting lower quality herbage to the animals. The low animal performance would then reflect a low quality of ingested forage and/or a restriction of intake due to the low availability of high quality forage. Cattle performance in the third grazing season seems, therefore, to be more a function of the quality of herbage on offer than the quantity on offer.

Monthly rainfall for the 1992/93 season was below the long-term mean for every month of the growing season except for November (Fig 5.2d). Herbage mass accumulation reflected rainfall patterns (Fig 5.5d), particularly in the paddock grazed first in the grazing cycle. The general pattern of cattle livemass gain (Fig 5.10d, Table 5.7) was similar to that which occurred in the first and second grazing seasons.

As mentioned earlier, the demand for forage by the sheep was low relative to the forage demand of the cattle (see Chapter 6). As the proportion of sheep in the species mix increased, therefore, more herbage became available for the remaining cattle than where the cattle had not been replaced by sheep. With a greater availability of dry matter on offer per animal, individual livemass gains of the cattle would be expected to improve. This trend was evident in all four grazing seasons. Animal performance in the cattle-only (1:0) treatment (i.e. the treatment with the lowest availability of herbage per animal) was lower than for the remaining treatments in all grazing seasons. As the availability of herbage per animal increased so cattle performance increased (Table 5.7). This trend was not consistent for all seasons except between the 1:0 and remaining ratio treatments. In the 1992/93 (dry) season, it is clear that the treatment with the highest availability of herbage per animal showed the highest animal performance. It must be remembered that herbage mass accumulation had been severely restricted due to the dry conditions experienced during the 1992/93 grazing season.

Sheep

Sheep performance appears to have been influenced more by the quality than the quantity of herbage on offer to the animals. The same trends occurred in each season i.e. a decrease in livemass gain per sheep as the proportion of sheep in the species mix increased. In the first season all paddocks available to the sheep in each treatment had new-season's growth, all having been burnt at the start of the season. In the second and third grazing seasons only one paddock in each treatment had been burnt. The remaining two paddocks carried over dead herbage from the previous season. Such carry-over of old herbage would be expected to depress animal performance, and particularly sheep performance (as was observed in the second and third seasons). The same trend in sheep performance was expected during the fourth season. However, as was stated earlier, livemass gains per hectare during the fourth season were far higher than during any of the previous grazing seasons. The main differences between the fourth and the first three grazing seasons were a) the lower rainfall recorded for the 1992/93 season (Figure 5.1 a&b) and b) the fact that treatments were stocked approximately two weeks earlier in the 1992/93 grazing season than in the previous grazing seasons (Table 5.5). Analysis of the growth pattern of veld in paddocks rested for the duration of the 1992/93 season indicates that herbage mass accumulation was significantly lower ($P < 0.01$) in these rest paddocks than in the paddocks rested for the duration of each of the previous grazing seasons (Figure 5.17). Such slow growth implies a slow rate of maturity of the herbage and therefore a higher quality available to the animals during the 1992/93 grazing season compared with previous grazing seasons. The continued positive live mass gains of the sheep in all ratio treatments throughout the 1992/93 season support this statement (Fig 5.11d).

Low rainfall and slow growth rates, together with the fact that sheep prefer to graze short grass and that they are better adapted to drier climates, are likely to have been the main causes of the observed differences in sheep performance between the 1992/93 and previous grazing seasons. It must also be noted that as herbage mass per head of cattle increased so sheep performance decreased. Increased quantity of herbage on offer per hectare therefore appears to have had a negative effect on sheep performance.

Mean cumulative mass gains of the sheep were considerably better when the sheep grazed together with cattle than when they grazed alone. Where sheep were stocked in low proportion to cattle (e.g. at the 3:1 ratio treatment), the stocking rate of sheep was low relative to the sheep-only treatment while the stocking rate of cattle was high. The sheep would therefore have had greater opportunity to select forage preferred by them. Added to this is that, at the relatively high stocking rate of cattle (3:1 ratio), more herbage would have been grazed ha^{-1} by the cattle than at lower cattle stocking rates. This implies that there would have been an increasing amount of high quality short regrowth available per sheep as stocking rate of cattle increased. Thus, at the 3:1 ratio, not only would the sheep have had a greater opportunity for selection, but there would have been a greater quantity of high quality herbage on offer to them relative to the other ratio treatments.

5.2.7.2 Modelling animal performance

From the 'general' model, a predicted increase in ADG occurred for both the cattle and the sheep as their proportions in the ratio declined when compared on the basis of low sheep-only vs low cattle-only and high sheep-only vs high cattle-only stocking rates (Fig 5.14). As stocking rate (animals ha^{-1}) increased at a particular cattle to sheep ratio, so predicted ADG of both cattle and sheep declined. Predicted sheep ADG to maximum mass at a 'low' stocking rate when grazed together with cattle at a 'low' stocking rate increased by 17% through 33% to 50% as the sheep proportion in the species mix decreased from 0.75 through 0.50 to 0.25 of the sheep-only stocking rate (Figure 5.14).

Similarly, in the high stocking rate comparisons, sheep ADG increased by 55% through 110% to 265% as the sheep proportion decreased. Cattle ADG improved by 2% through 4% to 6% as cattle proportion declined from 0.75 through 0.50 to 0.25 of the cattle-only, 'low' stocking rate treatment (Figure 5.14).

These results appear to confirm the idea that the cattle may be used to 'condition' the veld (i.e. with cattle grazing there is likely to be an increased amount of regrowth generated from plants where relatively mature herbage is removed by the cattle), thus suggesting greater efficiency in use of the resource.

5.2.7.2.1 Livemass gains per hectare

For the first three seasons the general trend was a decrease in total livemass gain per hectare as the proportion of sheep in the species-mix increased (Table 5.7). In the first and third years total livemass gains per hectare were similar for the 1:0 and 3:1 ratio treatments. (Note: sheep livemass gains per hectare include wool growth). In the fourth (1992/93) grazing season, however, grazing sheep together with cattle increased total livemass gain per hectare over the livemass gains recorded in the 1:0 (cattle-only) and 0:1 (sheep-only) ratio treatments (Table 5.7). These data clearly illustrate the enhanced performance of the sheep in a 'dry', relative to a 'normal' growing season. One of the main questions which needs be asked when discussing total livemass gains per hectare in mixed- versus single-species grazing systems is: does mixed-species grazing provide a higher output per unit area than single-species grazing? Due to a lack of variation in stocking rates for each of the ratio treatments the current data set has limited value in providing a comprehensive answer to this question. Discussion, therefore, relates only to the stocking rates which were applied in this investigation.

Relative resource totals (RRTs) provide background for the answers to this question (see Table 5.11). From the 'general' equation, when cattle and sheep were stocked in the proportion of

3.8 units of sheep to 1 unit of cattle (at the stocking rates applied in the present trial) the RRT indicates that, to achieve the same levels of ADG for each species of animal, 2.67 times the area required to maintain the performance of the cattle and the sheep in the mix-species grazing system, would be required for the same number of cattle and sheep when stocked in separate single-species grazing systems. Similarly, when cattle and sheep were stocked in the proportion 11.8 units of sheep to 1 unit of cattle, 1.29 times the area would be required in single-species grazing systems to achieve the same ADG per species. Reference to the calculations presented in Table 5.11 reveals that the increased area required is mainly a function of predicted sheep performance in the single-species grazing situation.

In the 'dry' 1992/93 season, RRTs ranged between 1.07 and 1.12 indicating that there was an approximate 7 to 12% increase in output per unit area with mixed-species grazing than single-species grazing.

Despite the predicted advantage of applying a mixed-species grazing system on ADG of the sheep in particular, it is clear that, for the first three 'normal' rainfall grazing seasons, the increased ADGs of the sheep did not compensate for the loss of livemass gains of the cattle which the sheep replaced (Table 5.7). This is one of the reasons why such replacement studies should be conducted at a range of stocking rates as the answers could be different at different stocking rates (see predictions of changes in sheep and cattle ADG when stocking rates are altered in Figure 5.15).

Table 5.1 Coefficients (a and b), correlation coefficients (r), and degrees of freedom (DF), for the linear regression y = a + bx, where y is estimated herbage mass (kgDM ha^{-1}) and x is mean disc height (cm), for each of four sampling dates in the 1989/90 grazing season. Separate regressions were developed for paddocks grazed 1st, 2nd and 3rd in the grazing cycle and for the rest paddocks

DATE	a	b	r	DF
REST PADDOCKS				
23/11/89	5.4	195.6	0.87	23
08/01/90	−124.0	213.0	0.87	23
23/03/90	−282.8	302.1	0.84	23
26/04/90	−124.6	297.2	0.82	23
PADDOCKS GRAZED 1ST IN THE GRAZING CYCLE				
23/11/89	−11.4	172.7	0.81	23
08/01/90	−102.9	207.6	0.94	23
23/03/90	−125.8	289.4	0.81	23
26/04/90	−23.5	291.8	0.83	23
PADDOCKS GRAZED 2ND IN THE GRAZING CYCLE				
23/11/89	21.1	175.7	0.75	23
08/01/90	−95.7	199.8	0.89	23
23/03/90	−60.8	266.6	0.83	23
26/04/90	−81.3	246.1	0.81	23
PADDOCKS GRAZED 3RD IN THE GRAZING CYCLE				
23/11/89	−65.6	191.9	0.91	23
08/01/90	−188.3	238.9	0.89	23
23/03/90	94.5	261.1	0.85	23
26/04/90	−233.5	315.3	0.88	23

Table 5.2 Coefficients (a and b), correlation coefficients (r), and degrees of freedom (DF), for the linear regression $y = a + bx$, where y is estimated herbage mass (kgDM ha^{-1}) and x is mean disc height (cm), developed for paddocks grazed 1st, 2nd and 3rd in the grazing cycle in the 1990/91 grazing season.

REST PADDOCKS				
DATE	a	b	r	DF
14/11/90	5.4	195.6	0.87	23
PADDOCKS GRAZED 1ST IN THE GRAZING CYCLE				
DATE	a	b	r	DF
14/11/90	-77.6	204.6	0.71	23
19/02/91	-13.8	237.1	0.72	23
PADDOCKS GRAZED 2ND IN THE GRAZING CYCLE				
DATE	a	b	r	DF
14/11/90	-271.4	323.7	0.87	23
19/02/91	-657.7	354.4	0.80	23
PADDOCKS GRAZED 3RD IN THE GRAZING CYCLE				
DATE	a	b	r	DF
14/11/90	-605.3	371.9	0.84	23
19/02/91	334.53	202.2	0.77	23

Table 5.3 Coefficients (a and b), correlation coefficients (r), and degrees of freedom (DF), for the linear regression y = a + bx, where y is estimated herbage mass (kgDM ha^{-1}) and x is mean disc height (cm), developed for each of three situations viz. 1) rested paddocks, 2) grazed paddocks which were burnt at the start of the season, and 2) grazed paddocks which were burnt at the start of the previous season. Calibration data derived from the 1989/90 and 1990/91 were pooled for each of the three situations.

REST PADDOCKS			
a	b	r	DF
−253.9	285.8	0.84	123
PADDOCKS BURNT AT THE START OF THE SEASON			
a	b	r	DF
−121.5	249.7	0.81	348
PADDOCKS BURNT AT THE START OF THE PREVIOUS SEASON			
a	b	r	DF
−155.8	282.8	0.80	98

Table 5.4 Mean daily digestible organic matter (%DOM) and crude protein (%CP) values of forage selected by cattle and by sheep in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for each for three consecutive 60 day periods through the 1989/90 grazing season

%DOM			
	60 DAY PERIODS		
RATIO	1ST	2ND	3RD
CATTLE			
1:0	66.9	59.5	58.8
3:1	67.0	59.8	58.9
1:1	67.9	60.4	58.6
1:3	65.2	59.9	58.3
SHEEP			
3:1	64.8	56.3	54.7
1:1	63.0	56.8	53.8
1:3	63.8	56.7	55.0
0:1	61.9	57.9	53.8

%CP			
	60 DAY PERIODS		
RATIO	1ST	2ND	3RD
CATTLE			
1:0	8.5	6.7	6.6
3:1	9.4	6.6	6.6
1:1	8.5	6.9	6.7
1:3	8.3	6.4	6.9
SHEEP			
3:1	9.2	7.7	6.4
1:1	7.8	7.3	6.4
1:3	7.9	7.0	6.4
0:1	7.6	7.6	6.4

Table 5.5 Dates of stocking at the start of each grazing season

GRAZING SEASON	DATE OF STOCKING
1989/90	29/10/89
1990/91	25/10/90
1991/92	30/10/91
1992/93	13/10/92

Table 5.6a

Coefficients of determination (R^2) for the dependence of mean cumulative livemass change of the cattle, on time, for each of 4 polynomial functions (linear-LIN; quadratic-QUAD; CUBIC; quartic-QUART). R^2 are presented for each cattle to sheep ratio (RATIO) treatment for each grazing season (1989/90, 1990/91, 1991/92 & 1992/93). NOTE: all functions provided significant fits ($P < 0.001$)

		1989/90		
RATIO	LIN	QUAD	CUBIC	QUART
1:0	74.4	96.6	96.8	96.7
3:1	76.8	95.5	95.9	95.6
1:1	82.0	97.5	97.4	97.3
1:3	84.1	97.6	97.6	97.5
		1990/91		
RATIO	LIN	QUAD	CUBIC	QUART
1:0	75.2	93.4	98.7	98.6
3:1	80.0	95.0	99.0	99.6
1:1	81.9	95.0	99.0	99.6
1:3	81.9	94.1	98.7	99.1
		1991/92		
RATIO	LIN	QUAD	CUBIC	QUART
1:0	67.5	96.6	96.3	96.0
3:1	70.0	99.0	99.0	98.9
1:1	72.4	97.4	97.4	97.1
1:3	85.0	96.1	95.9	95.6
		1992/93		
RATIO	LIN	QUAD	CUBIC	QUART
1:0	84.8	95.0	97.4	98.3
3:1	90.7	94.5	97.4	98.1
1:1	93.1	97.0	98.4	99.2
1:3	96.1	97.1	97.9	98.7

Table 5.6b

Coefficients of determination (R^2) for the dependence of mean cumulative livemass change of the sheep, on time, for each of 4 polynomial functions (linear-LIN; quadratic-QUAD; CUBIC; quartic-QUART). R^2 are presented for each cattle to sheep ratio (RATIO) treatment for each grazing season (1989/90, 1990/91, 1991/92 & 1992/93). NOTE: all functions provided significant fits ($P < 0.001$) except where otherwise indicated

RATIO	LIN	QUAD	CUBIC	QUART
1989/90				
1:0	6.4^{ns}	82.5	86.8	89.9
3:1	55.4	81.9	81.0	91.0
1:1	57.6	89.2	89.7	93.5
1:3	76.7	96.4	96.2	97.5
1990/91				
1:0	15.8^{ns}	79.8	78.4	82.4
3:1	–	45.9	49.2	58.5
1:1	–	60.1	61.9	70.8
1:3	29.9^{*}	74.5	74.9	76.4
1991/92				
1:0	7.7^{ns}	33.7^{*}	32.9^{ns}	72.9
3:1	–	31.2^{*}	25.5^{ns}	76.0
1:1	11.7^{ns}	25.2^{ns}	19.4^{ns}	44.2^{*}
1:3	30.8^{*}	51.0	47.0^{*}	72.0
1992/93				
1:0	72.5	93.3	93.3	95.7
3:1	84.8	95.0	94.8	98.3
1:1	75.2	93.2	92.6	96.1
1:3	85.8	96.1	95.9	97.9

ns = $P > 0.05$
* = $P < 0.05$
– = residual variance exceeds variance of the y variate

Table 5.7 Mean cumulative livemass gain (for 182 days - see text) per animal and per hectare, for each cattle to sheep ratio treatment (RATIO - AU CATTLE:AU SHEEP 1:0, 3:1, 1:1, 1:3 & 0:1) and each season (YEAR). Also presented are the wool production data (kg animal^{-1} and kg ha^{-1}). Livemass gain per hectare was calculated from the stocking rate (SR - animals ha^{-1}) of cattle and of sheep in each RATIO treatment

				LIVEMASS GAIN PER						
		SR		ANIMAL		HECTARE			WOOL	
YEAR	RATIO	CATTLE	SHEEP	CATTLE	SHEEP	CATTLE	SHEEP	TOTAL	ANIMAL^{-1}	HA^{-1})
1989/90	1:0	1.74	–	73.9	–	128.6	–	128.6	–	–
	3:1	1.29	1.62	85.0	11.7	109.7	19.0	128.7	4.4	7.2
	1:1	0.87	2.78	88.7	7.0	77.2	19.5	96.7	4.0	11.2
	1:3	0.50	5.00	81.5	6.5	40.8	32.5	73.3	3.8	19.0
	0:1	–	6.20	–	6.2	–	38.4	38.4	4.1	25.3
1990/91	1:0	1.76	–	79.1	–	139.2	–	139.2	–	–
	3:1	1.13	1.61	91.6	6.5	103.5	10.5	114.0	2.8	4.5
	1:1	0.86	3.60	91.8	5.0	78.9	18.0	96.9	3.3	11.9
	1:3	0.39	5.22	94.9	4.0	37.0	20.9	57.9	3.3	17.2
	0:1	–	6.30	–	2.3	–	14.5	14.5	2.6	16.4
1991/92	1:0	1.74	–	56.2	–	97.8	–	97.8	–	–
	3:1	1.26	1.57	70.2	5.5	88.5	8.6	97.1	3.2	5.0
	1:1	0.88	3.51	69.4	4.5	61.1	15.8	76.9	*no data	–
	1:3	0.40	5.03	72.1	5.5	28.8	27.7	56.5	3.0	15.0
	0:1	–	6.45	–	1.6	–	10.3	10.3	2.9	18.7
1992/93	1:0	1.68	–	60.8	–	102.1	–	102.1	–	–
	3:1	1.25	1.56	81.8	17.1	102.3	26.7	129.0	3.4	5.3
	1:1	0.88	3.51	81.4	12.1	71.6	42.5	114.1	3.3	11.6
	1:3	0.40	5.02	93.8	15.5	37.5	77.8	115.3	3.4	17.1
	0:1	–	6.60	–	12.9	–	85.1	85.1	3.2	21.1

* no data due to theft of sheep at the end of the grazing season

Table 5.8 Days taken to achieve maximum mass per animal for the cattle (C) and the sheep (S) in each cattle to sheep ratio treatment (RATIO) for each grazing season

	GRAZING SEASON							
	1989/90		1990/91		1991/92		1992/93	
RATIO	C	S	C	S	C	S	C	S
1:0	189	–	175	–	161	–	189	–
3:1	196	189	182	168	161	182	196	189
1:1	203	182	182	161	168	182	189	189
1:3	210	182	189	161	203	175	203	189
0:1	–	105	–	70	–	49	–	182

Table 5.9 Average daily gain (ADG in g animal^{-1} d^{-1}) of cattle and sheep in each ratio treatment for each grazing season. Stocking rates of cattle and of sheep (animals ha^{-1}) in each treatment are also presented

YEAR	RATIO	STOCKING RATE		ADG	
		CATTLE	SHEEP	CATTLE	SHEEP
1989/90	1:0	1.74	–	406	–
	3:1	1.29	1.62	467	64
	1:1	0.87	2.78	487	38
	1:3	0.50	5.00	448	36
	0:1	–	6.20	–	34
1990/91	1:0	1.76	–	435	–
	3:1	1.13	1.61	503	36
	1:1	0.86	3.68	504	27
	1:3	0.39	5.22	521	22
	0:1	–	6.30	–	13
1991/92	1:0	1.74	–	309	–
	3:1	1.26	1.57	386	31
	1:1	0.88	3.51	381	25
	1:3	0.40	5.03	396	30
	0:1	–	6.45	–	9
1992/93	1:0	1.68	–	334	–
	3:1	1.25	1.56	449	94
	1:1	0.88	3.51	447	66
	1:3	0.40	5.02	515	85
	0:1	–	6.60	–	71

Table 5.10 Coefficients for the regression of average daily gain (ADG) on stocking rate (SR in animals ha^{-1}) of cattle and of sheep, for both the cattle and the sheep, for each grazing season and the first three grazing seasons combined to form a 'general' regression model. The coefficients of determination (R^2) are also presented

VARIABLE COEFFICIENT	1989/90	1990/91	1991/92	1992/93	'GENERAL'
ADG - CATTLE					
Constant a_{10}	957	725	772	1045	884
Cattle b_{11}	-310	-162	-252	-411	-282
Sheep c_{12}	-70	-26	-51	-70	-58
R^2	39.3	86.9	34.0	74.6	20.4
ADG - SHEEP					
Constant a_{20}	11	31	-5	404	40
Cattle b_{21}	32	8	25	-185	6
Sheep c_{22}	3	-3	3	-50	-3
R^2	8.1	99.7*	-	73.3	29.7

\- = residual variance exceeds variance of the y variate
* = $P < 0.05$

Table 5.11 Outline of the calculation for deriving Relative resource totals (RRT) from the 'general' equations predicting average daily gain (ADG) of cattle and of sheep as a function of the stocking rate (SR in animals ha^{-1}) of the cattle and the sheep

'General' regression equations (from Table 5.10)

ADG (cattle) = 884 − 282*(SR cattle) − 58*(SR sheep)
ADG (sheep) = 40 + 6*(SR cattle) − 3*(SR sheep)

Mean stocking rate of the cattle and the sheep over the first three grazing seasons for the three mixed-species ratio treatments, the ratio (in terms of animals ha^{-1}) of sheep to cattle (RATIO), predicted ADG of cattle and of sheep when stocked at the same SR in a single-species grazing situation, and the RRT for cattle and sheep individually and combined (total)

SR			ADG		RRT		
CATTLE	SHEEP	RATIO	CATTLE	SHEEP	CATTLE	SHEEP	TOTAL
1.23	1.6	1.3	444.3	42.6	.79	*(−.97)	−
0.87	3.3	3.8	447.3	35.3	.60	2.11	2.67
0.43	5.1	11.9	466.9	24.7	.29	1.00	1.29

The 3.8 ratio is used as an example to calculate to RRT separately for the cattle and for the sheep:

For cattle: 884 − 282*0.87cattle ha^{-1} = 447.3
solving for this equation, 0.60ha would be required for 0.87 head of cattle (of the class used in this study) and they would be expected to gain 447.3g d^{-1}

For sheep: 40 − 3*3.3sheep ha^{-1} = 35.3
solving for this equation, 2.11ha would be required for 3.3 sheep (of the class used in this study) and they would be expected to gain 35.3g d^{-1}

* = sheep will not achieve an ADG of 42.6g d^{-1} (over the same time period) if they graze on their own irrespective of the area allocated to them

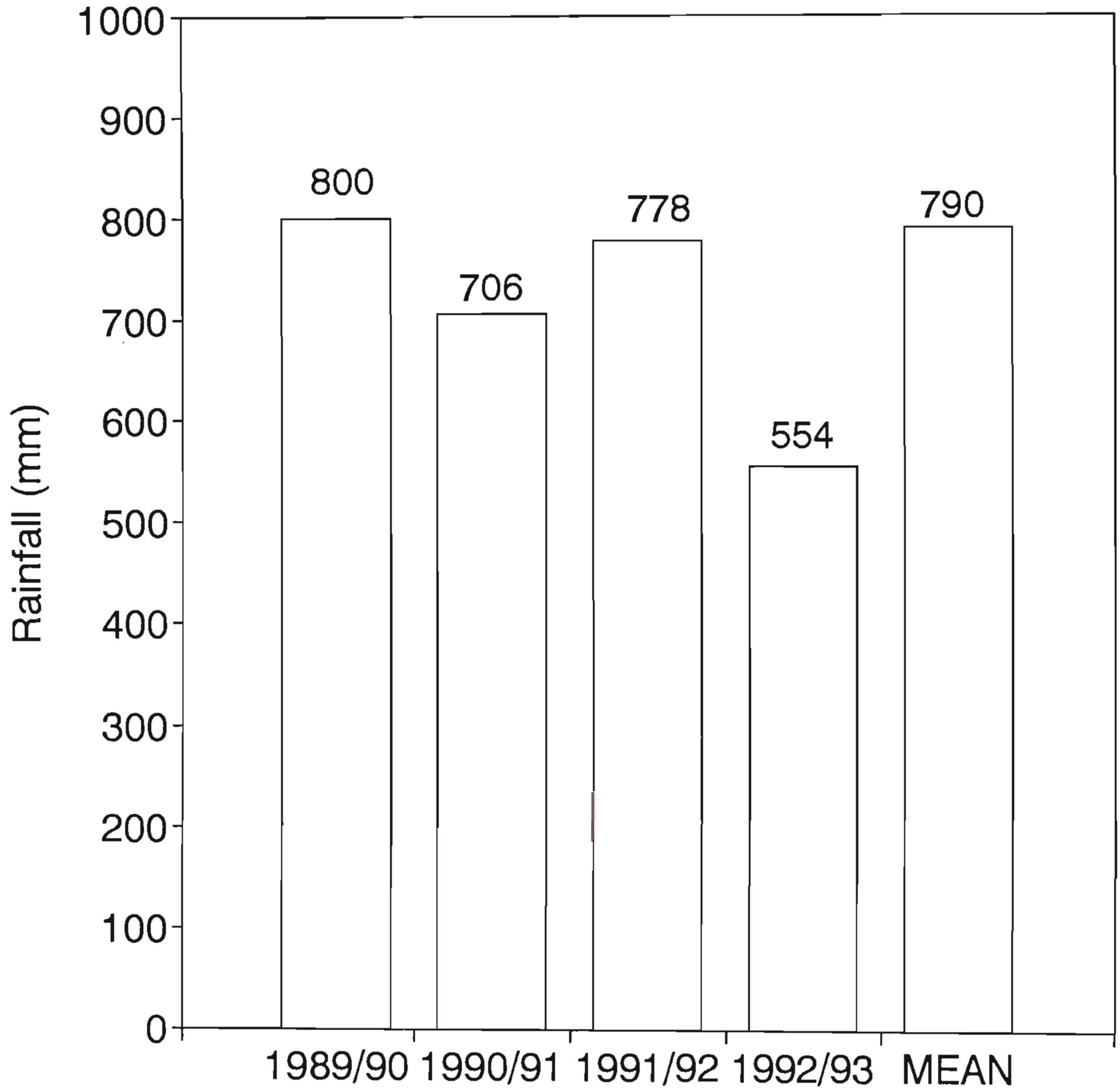

Figure 5.1 Total rainfall (mm) for each of the four grazing seasons (1989/90, 1990/91, 1991/92 & 1992/93) and the mean annual rainfall (mm - MEAN) from a 61 year rainfall record

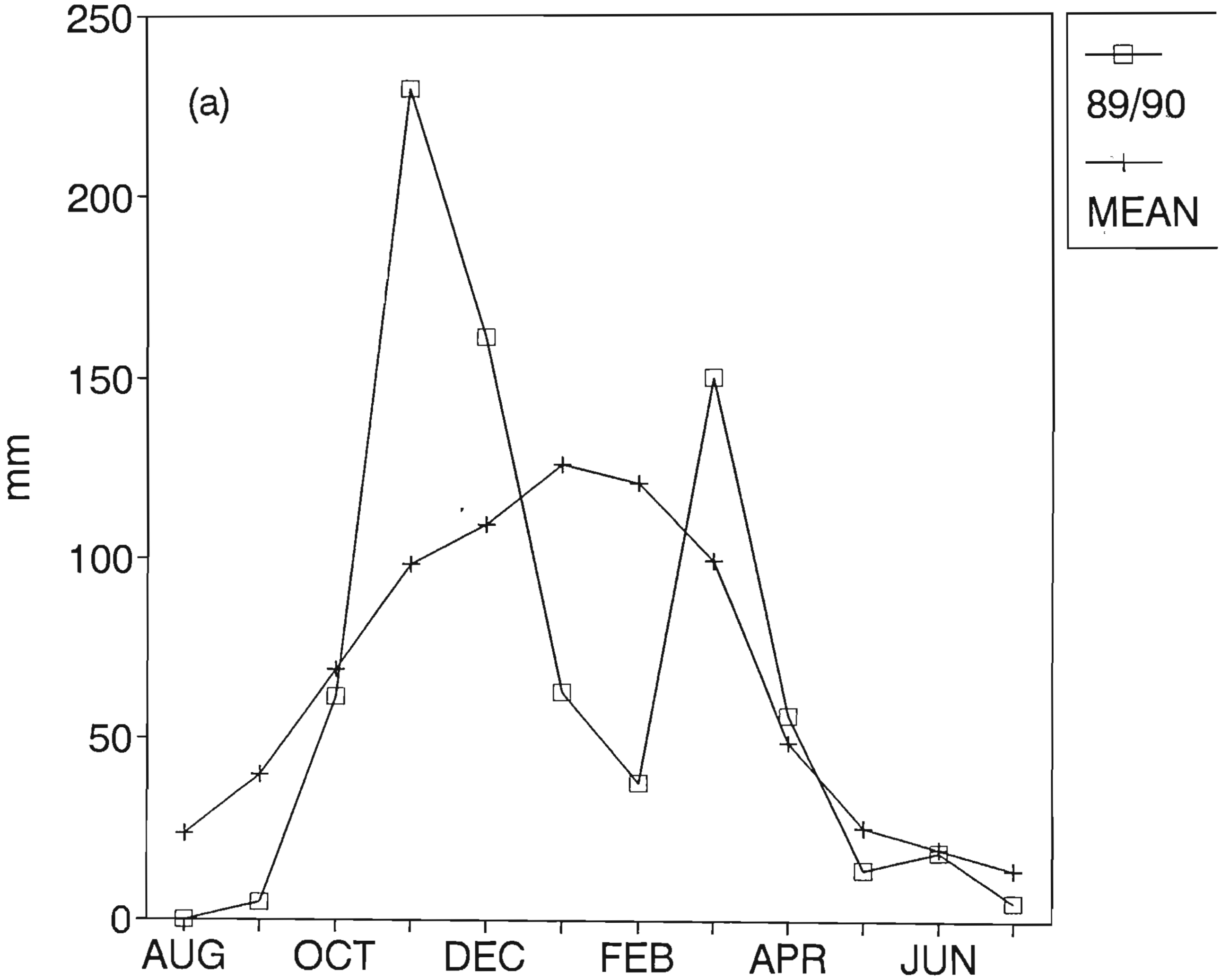

Figure 5.2 Monthly rainfall (mm) recorded for each grazing season viz. (a) 1989/90, (b) 1990/91, (c) 1991/92, & (d) 1992/93, and the mean monthly rainfall (mm) from a 61 year rainfall record

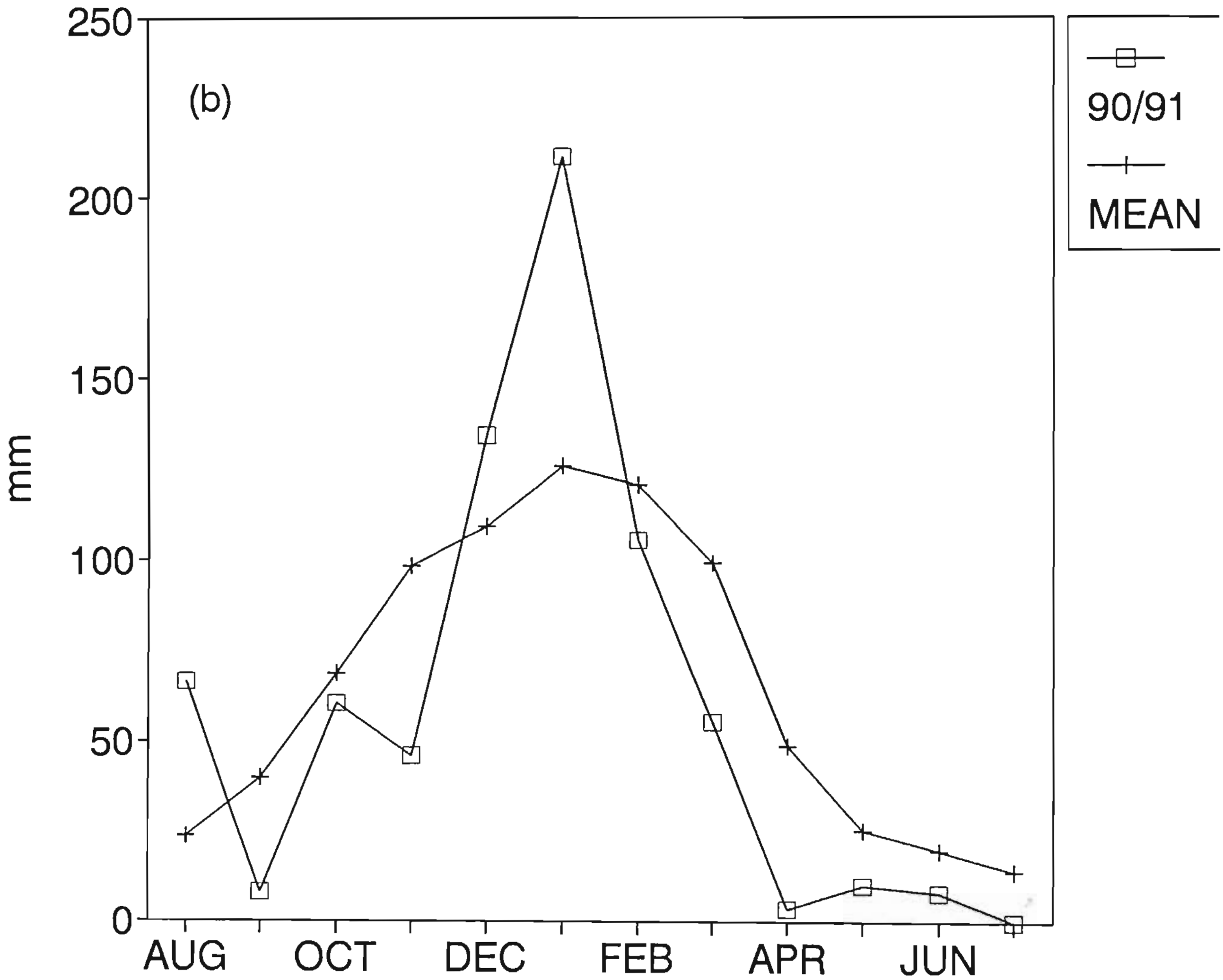

Figure 5.2 cont.

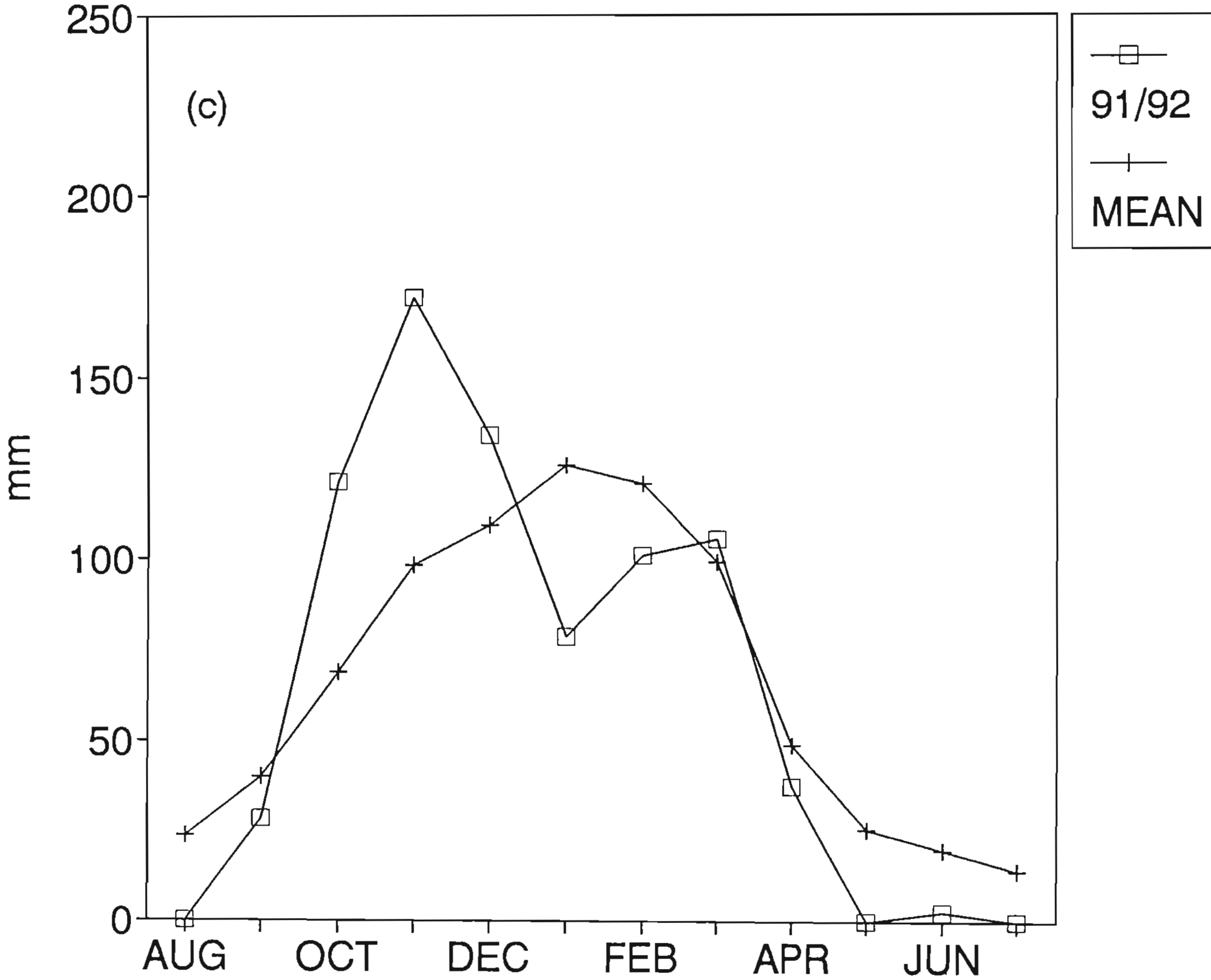

Figure 5.2 cont.

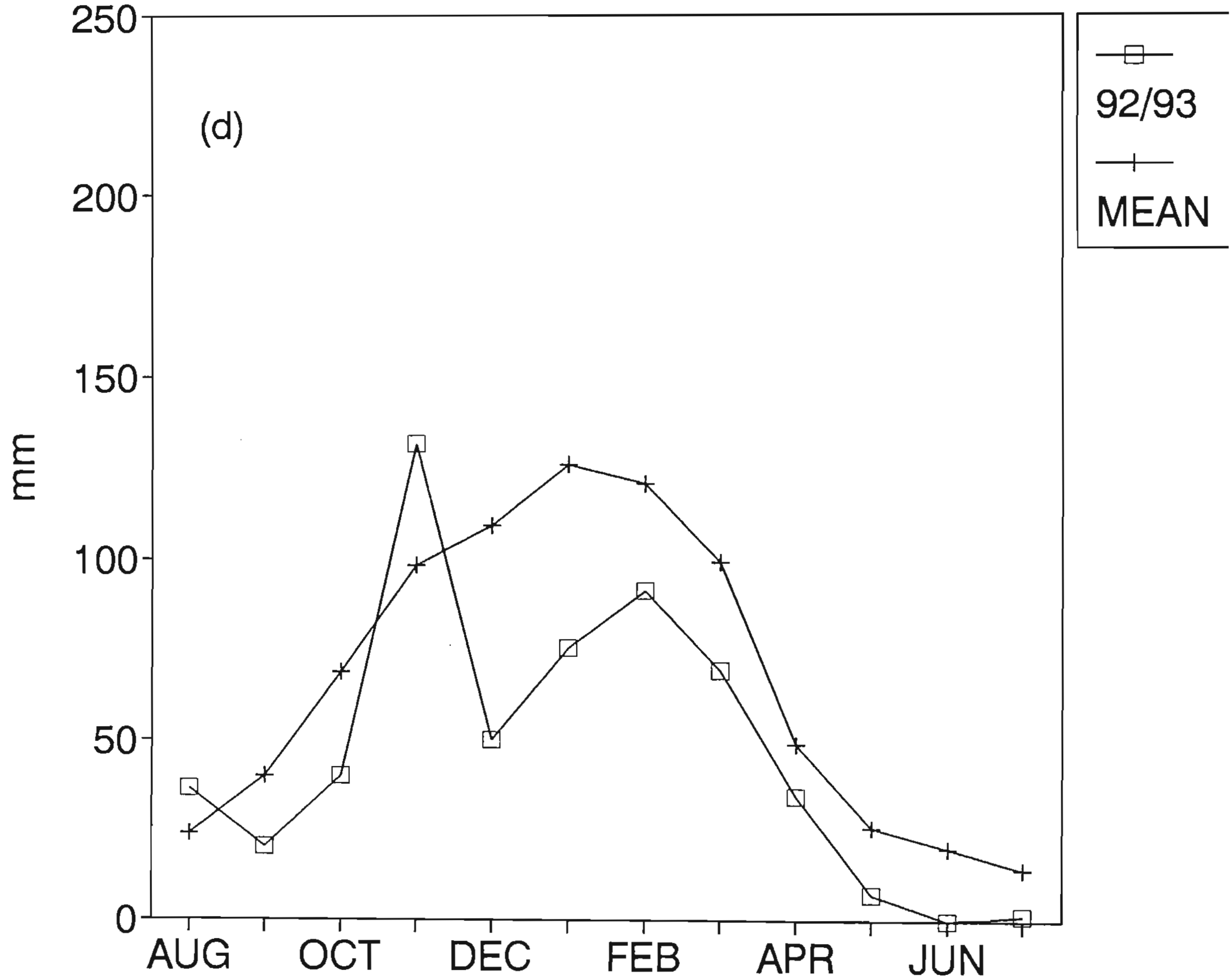

Figure 5.2 cont.

(a)

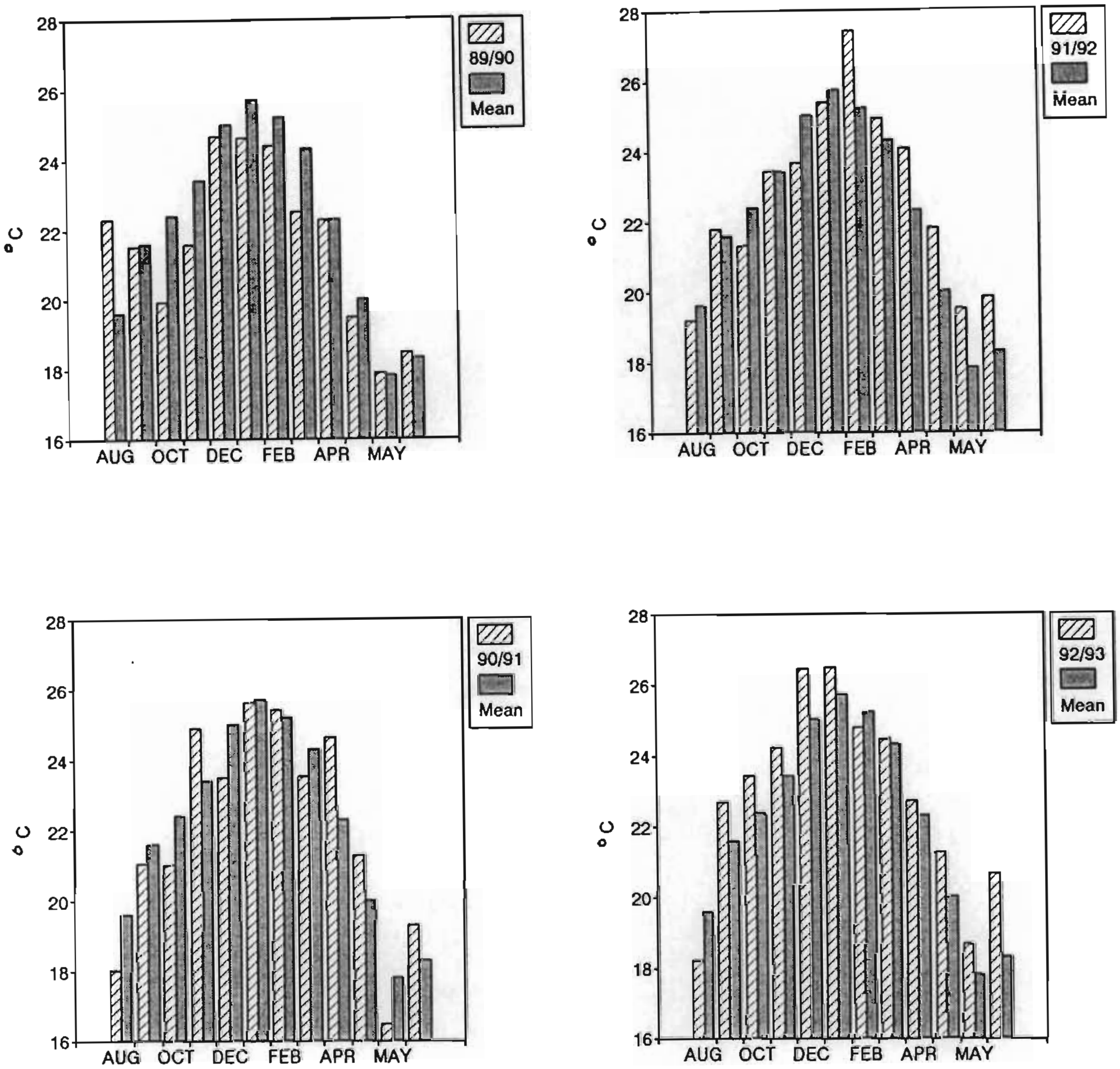

Figure 5.3 Mean monthly maximum (a) and minimum (b) temperatures °C recorded for each grazing season. The long-term mean maximum and minimum temperatures are also shown in (a) and (b) respectively

(b)

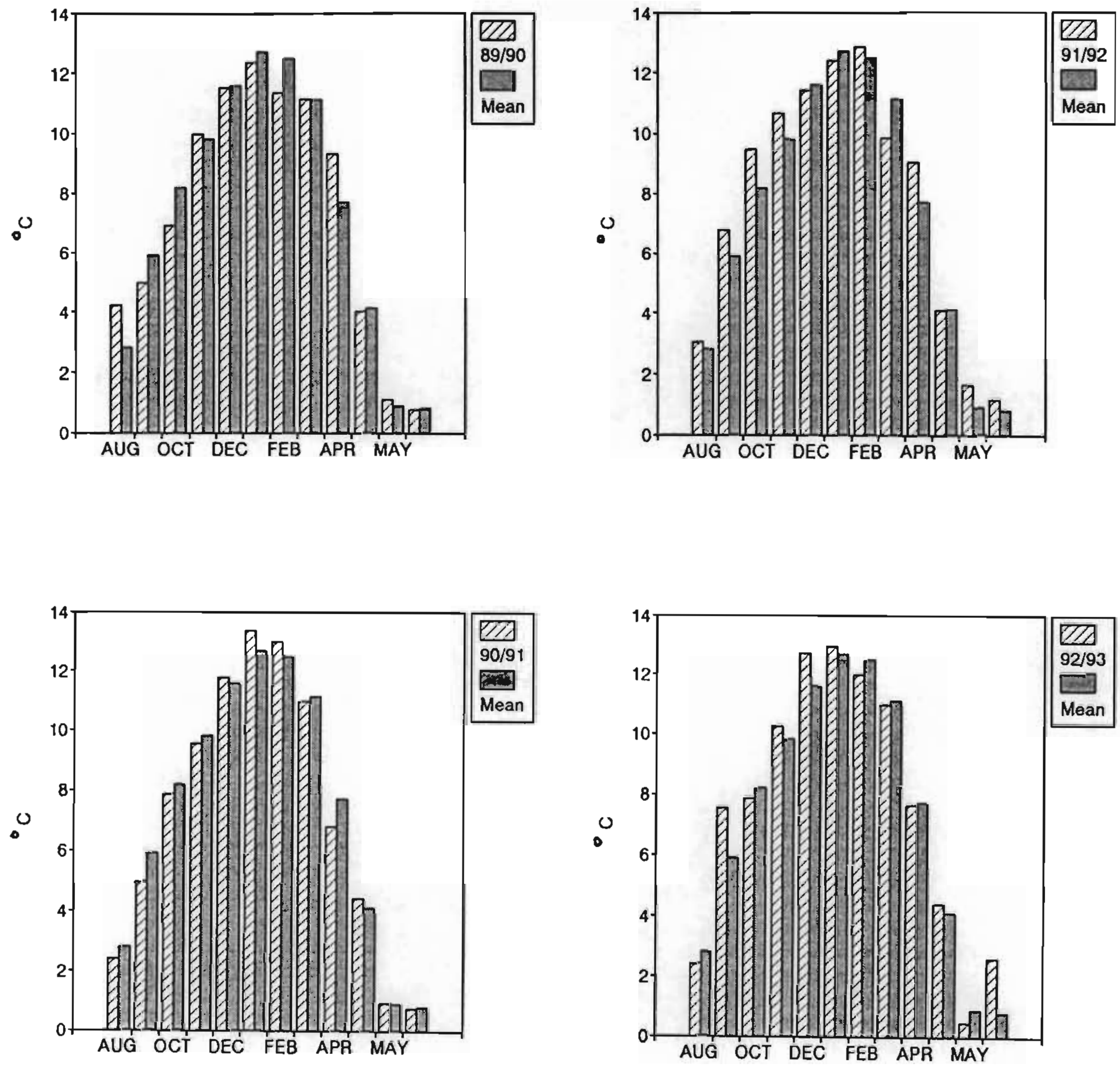

Figure 5.3 cont.

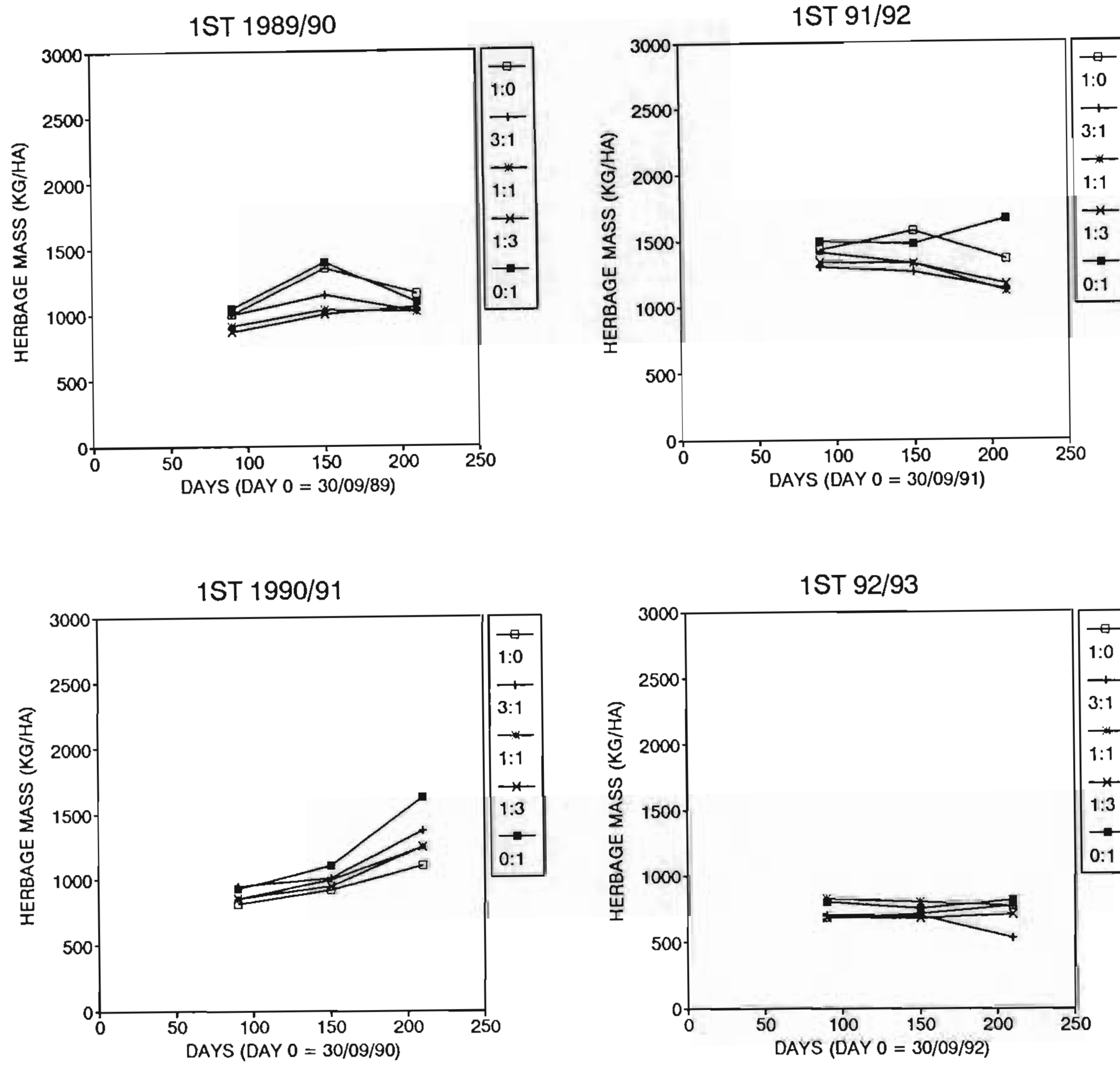

Figure 5.4 Mean herbage mass on offer (kgDM ha^{-1}) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for each of three consecutive 60 day periods within a grazing season. Data are presented for all four seasons (1989/90, 1990/91, 1991/92 & 1992/93) and for each paddock in the grazing cycle (i.e. grazed 1st, 2nd or 3rd). Each point is plotted at the end of each 60 day period

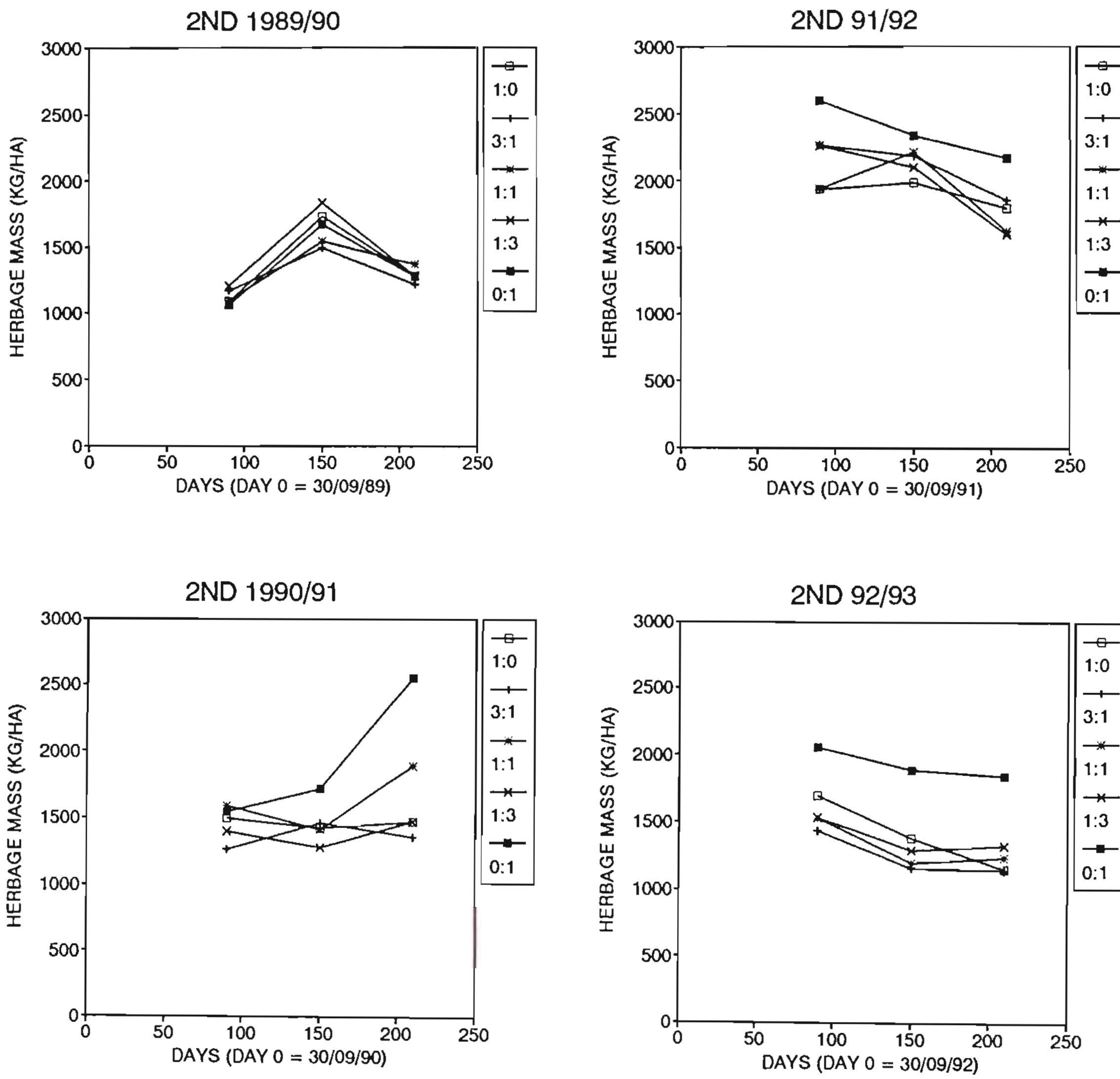

Figure 5.4 cont.

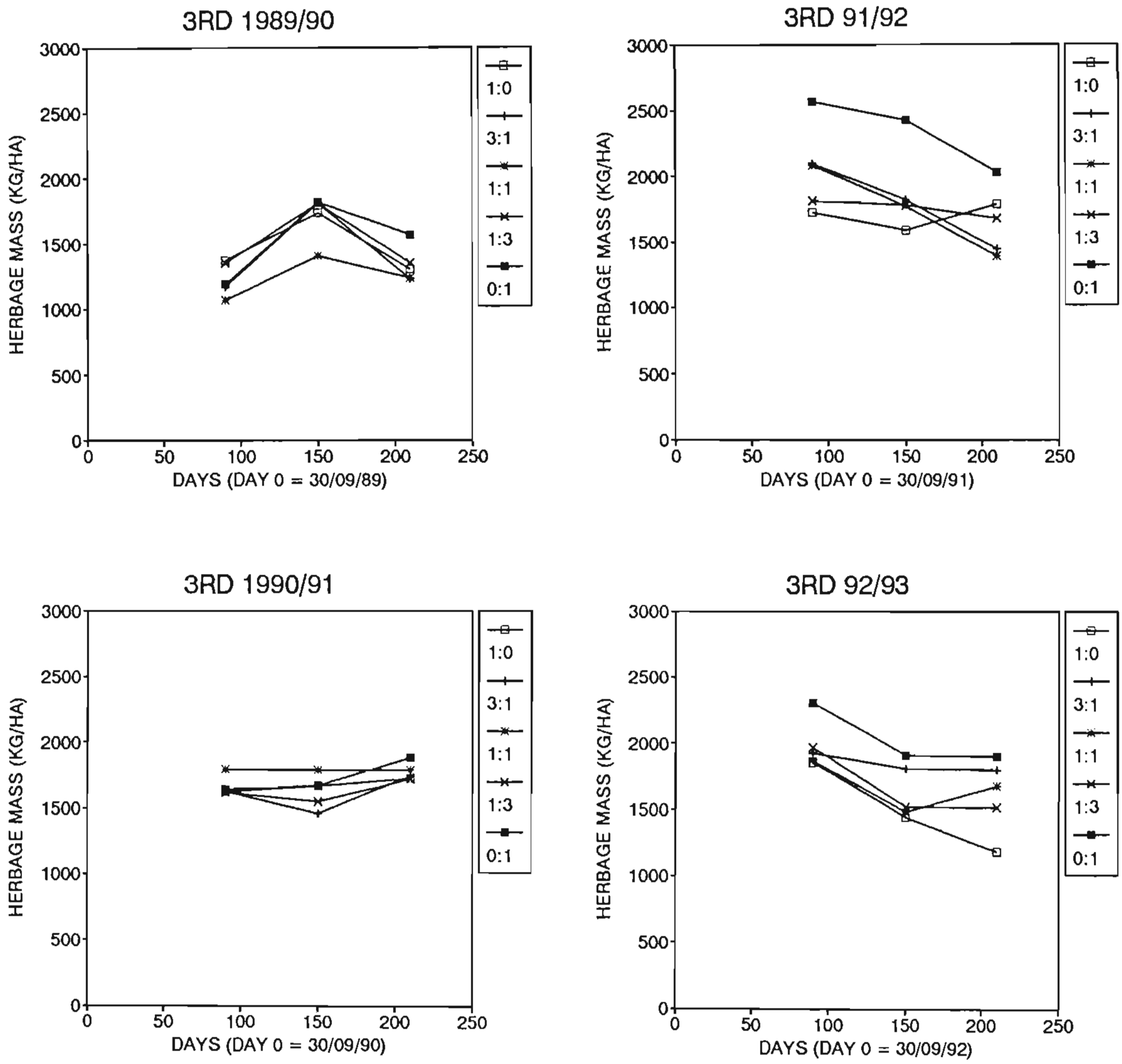

Figure 5.4 cont.

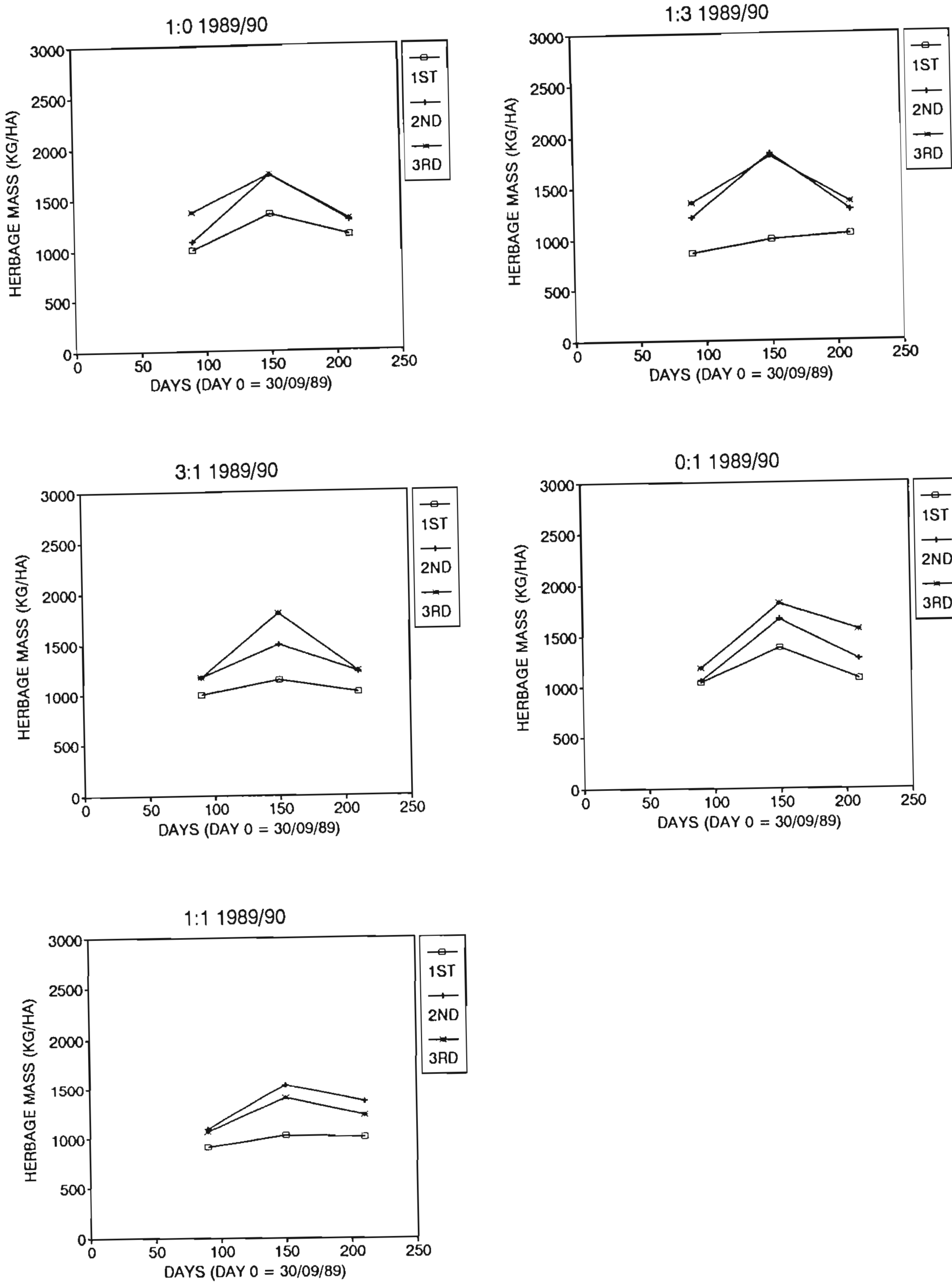

Figure 5.5a Mean herbage mass on offer (kgDM ha^{-1}) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for each of three consecutive 60 day periods within a grazing season. Data are presented for the 1989/90 grazing season and for each paddock in the grazing cycle (i.e. grazed 1st, 2nd or 3rd). Each point is plotted at the end of each 60 day period

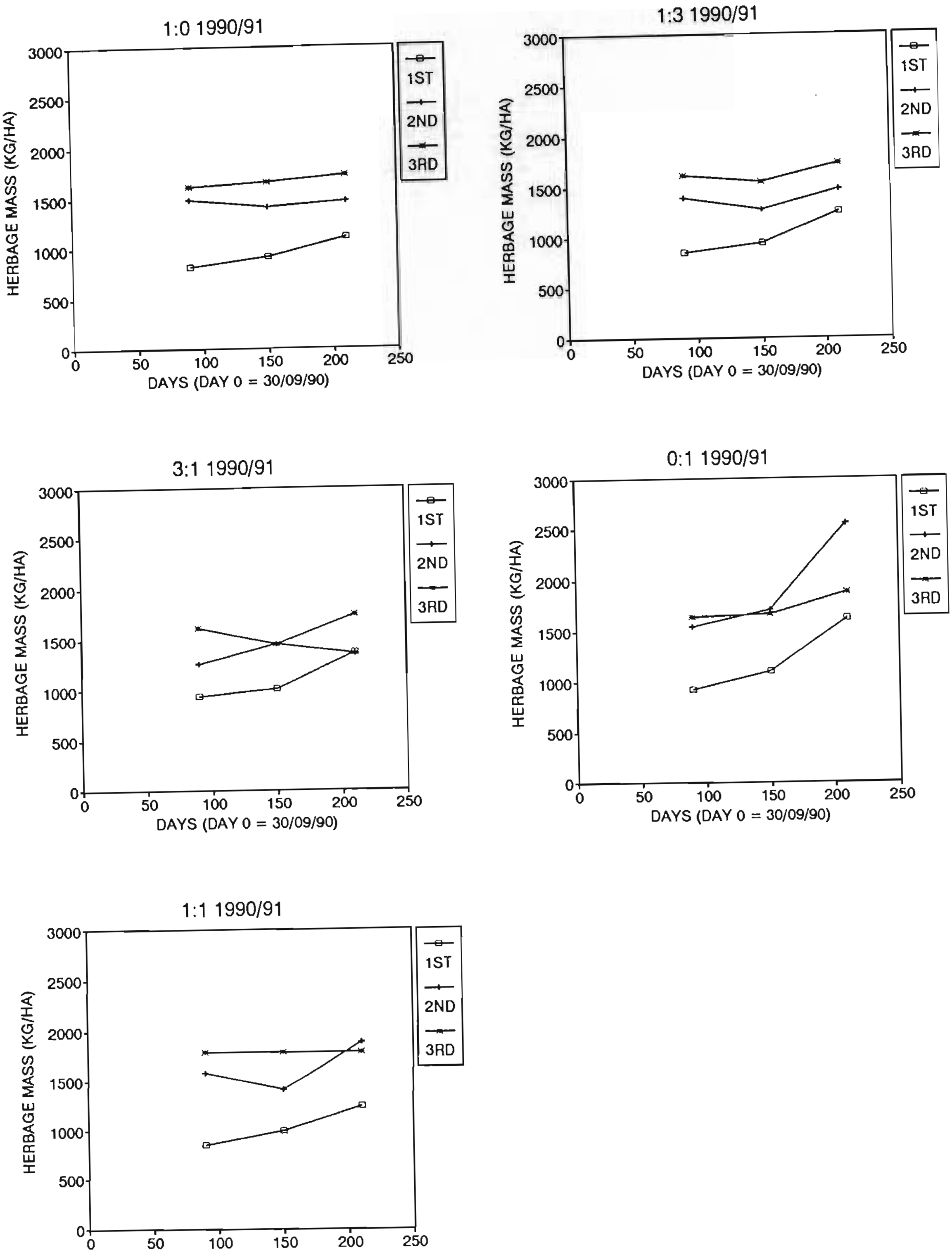

Figure 5.5b Mean herbage mass on offer (kgDM ha^{-1}) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for each of three consecutive 60 day periods within a grazing season. Data are presented for the 1990/91 grazing season and for each paddock in the grazing cycle (i.e. grazed 1st, 2nd or 3rd). Each point is plotted at the end of each 60 day period

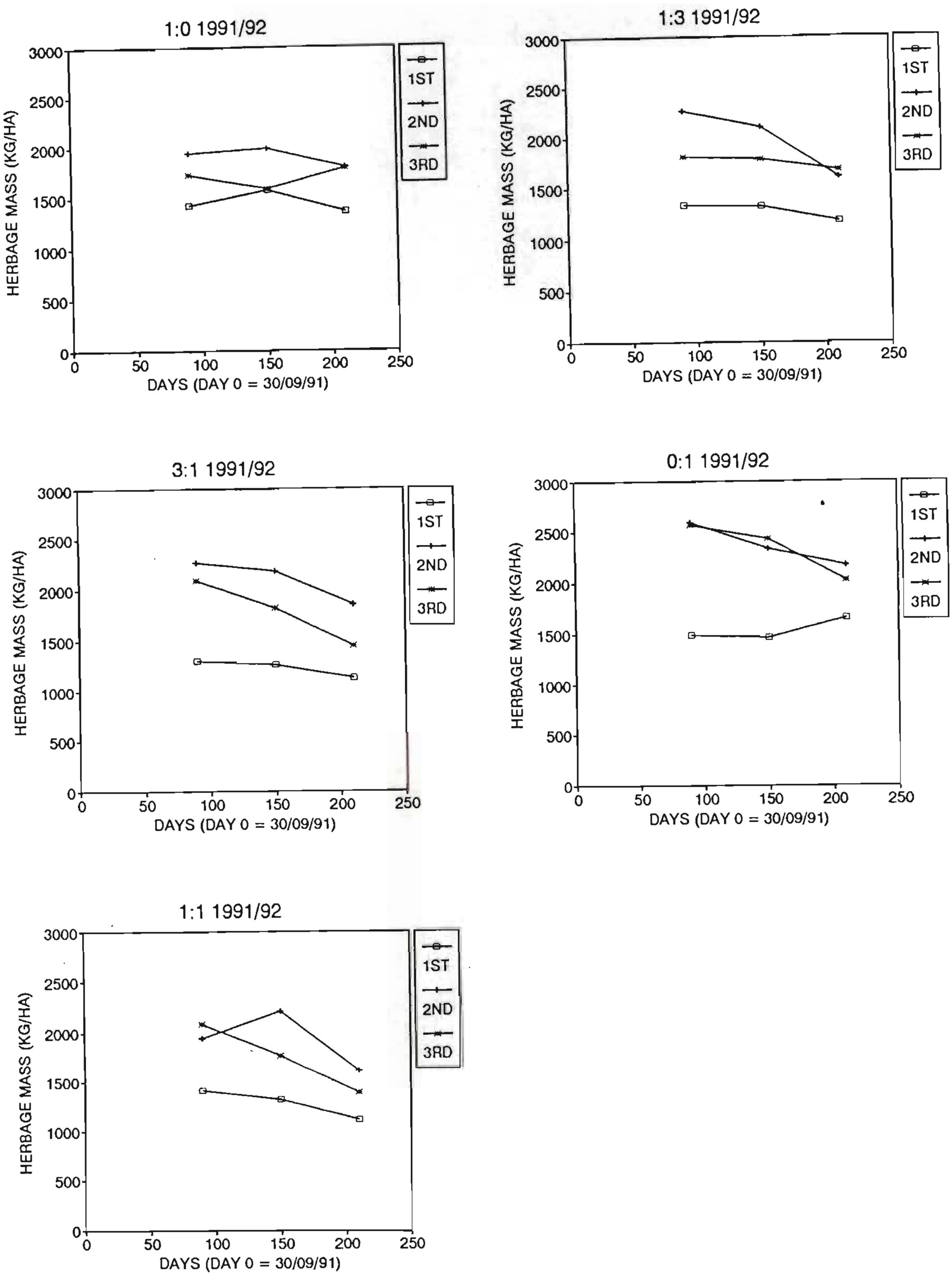

Figure 5.5c Mean herbage mass on offer (kgDM ha^{-1}) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for each of three consecutive 60 day periods within a grazing season. Data are presented for the 1991/92 grazing season and for each paddock in the grazing cycle (i.e. grazed 1st, 2nd or 3rd). Each point is plotted at the end of each 60 day period

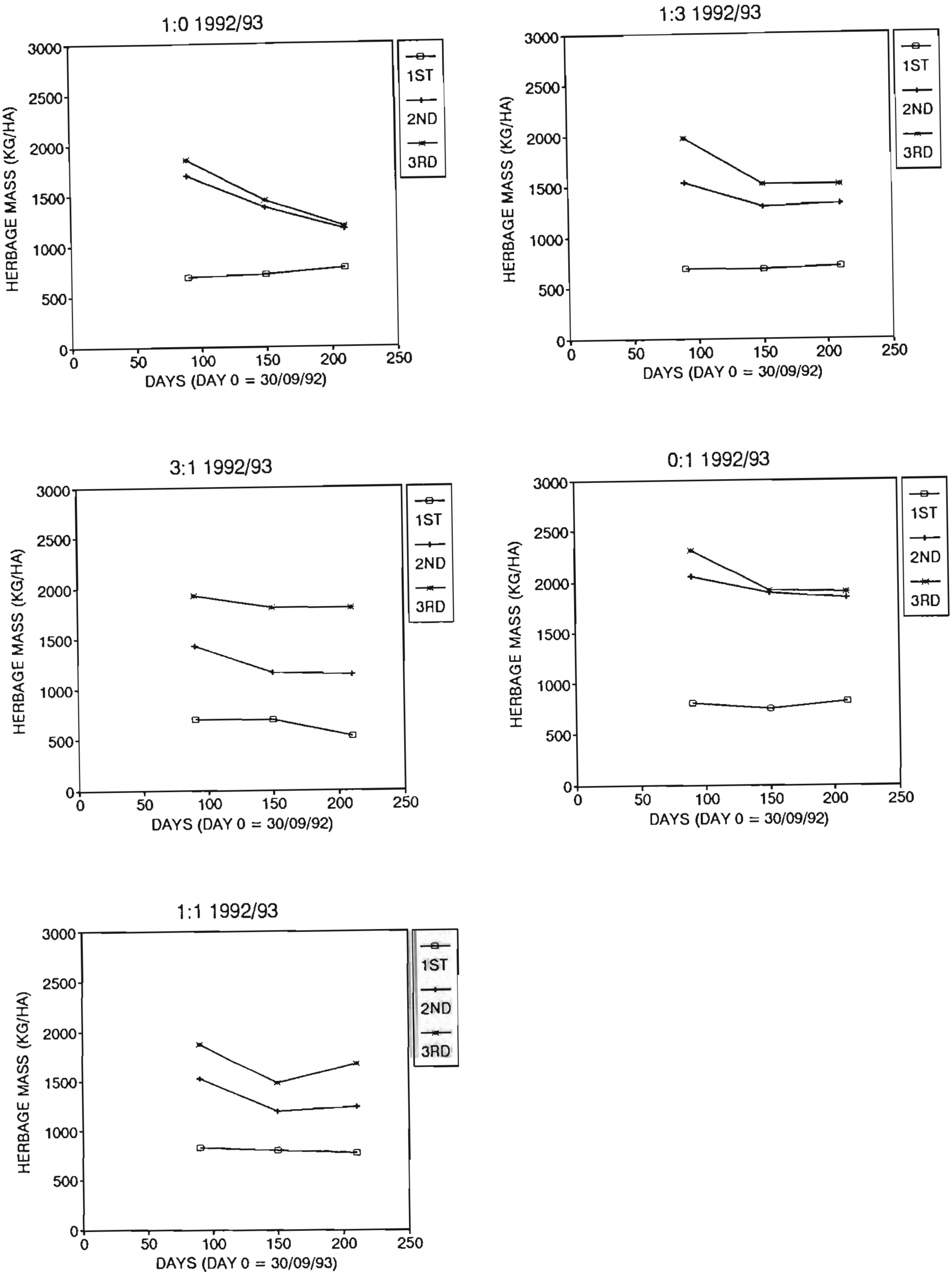

Figure 5.5d Mean herbage mass on offer (kgDM ha^{-1}) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for each of three consecutive 60 day periods within a grazing season. Data are presented for the 1992/93 grazing season and for each paddock in the grazing cycle (i.e. grazed 1st, 2nd or 3rd). Each point is plotted at the end of each 60 day period

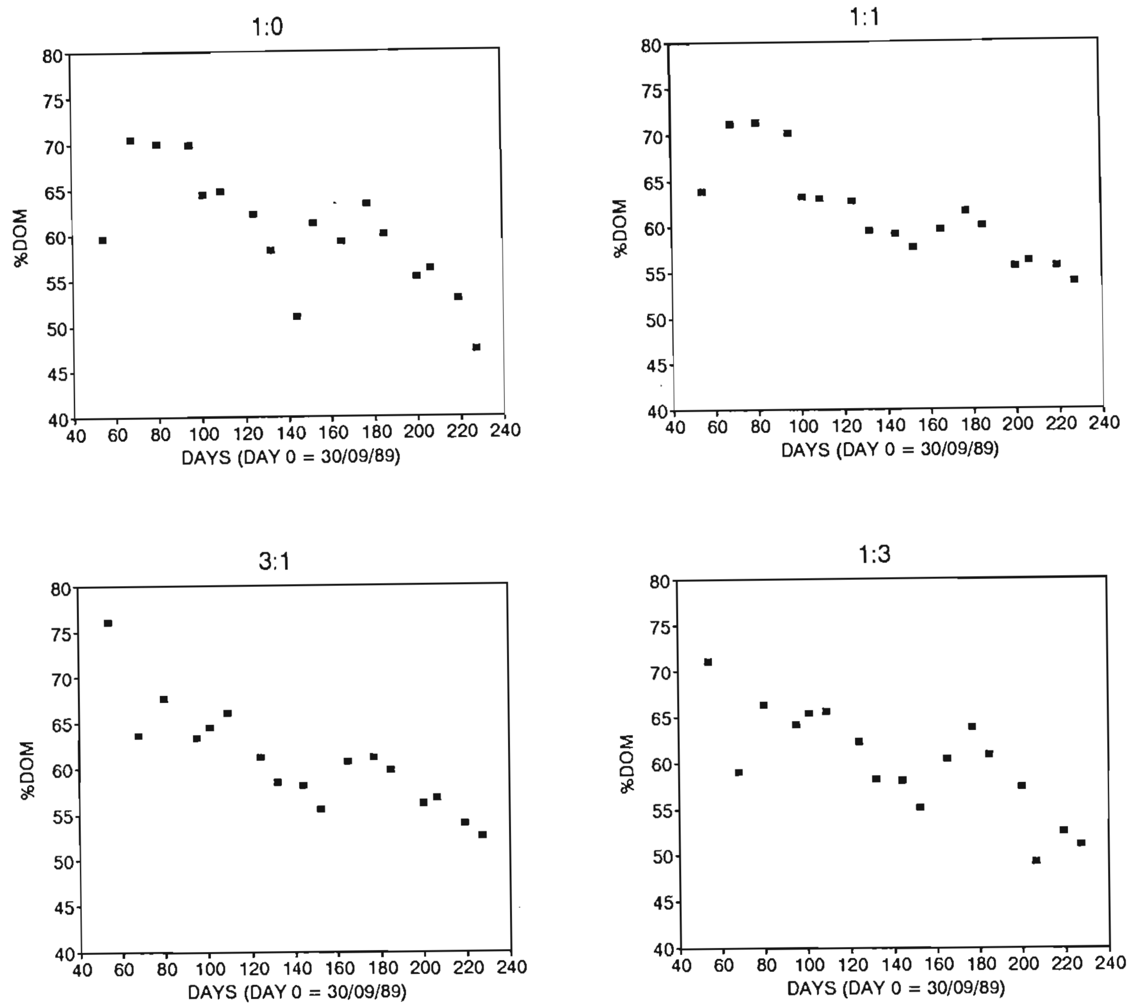

Figure 5.6 Digestible organic matter (%DOM) of forage selected by cattle in each cattle to sheep ratio treatment (1:0, 3:1, 1:1 & 1:3) through the 1989/90 grazing season. Data derive from the animal production component (medium stocking rate treatment) of the trial

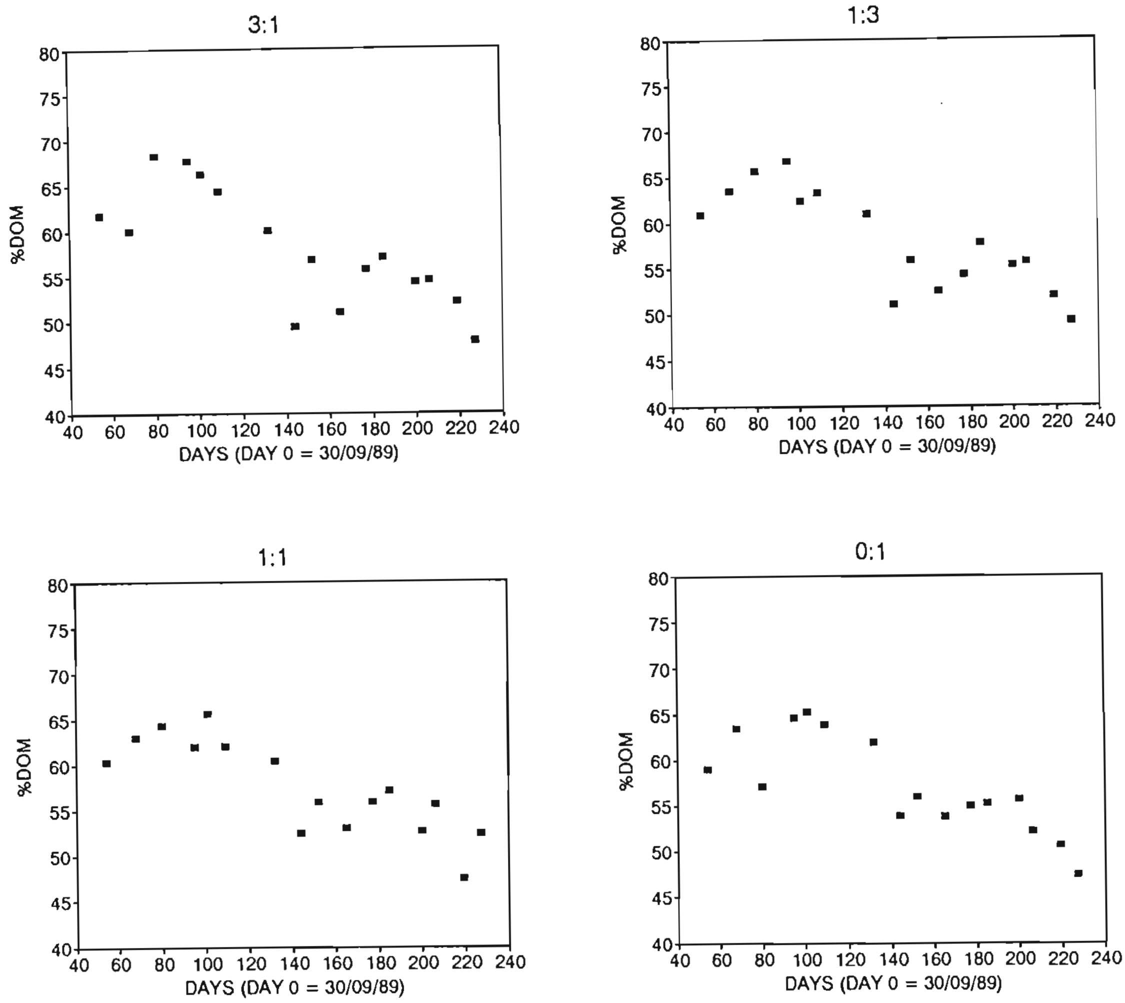

Figure 5.7 Digestible organic matter (%DOM) of forage selected by sheep in each cattle to sheep ratio treatment (3:1, 1:1, 1:3 & 0:1) through the 1989/90 grazing season. Data derive from the animal production component (medium stocking rate treatment) of the trial

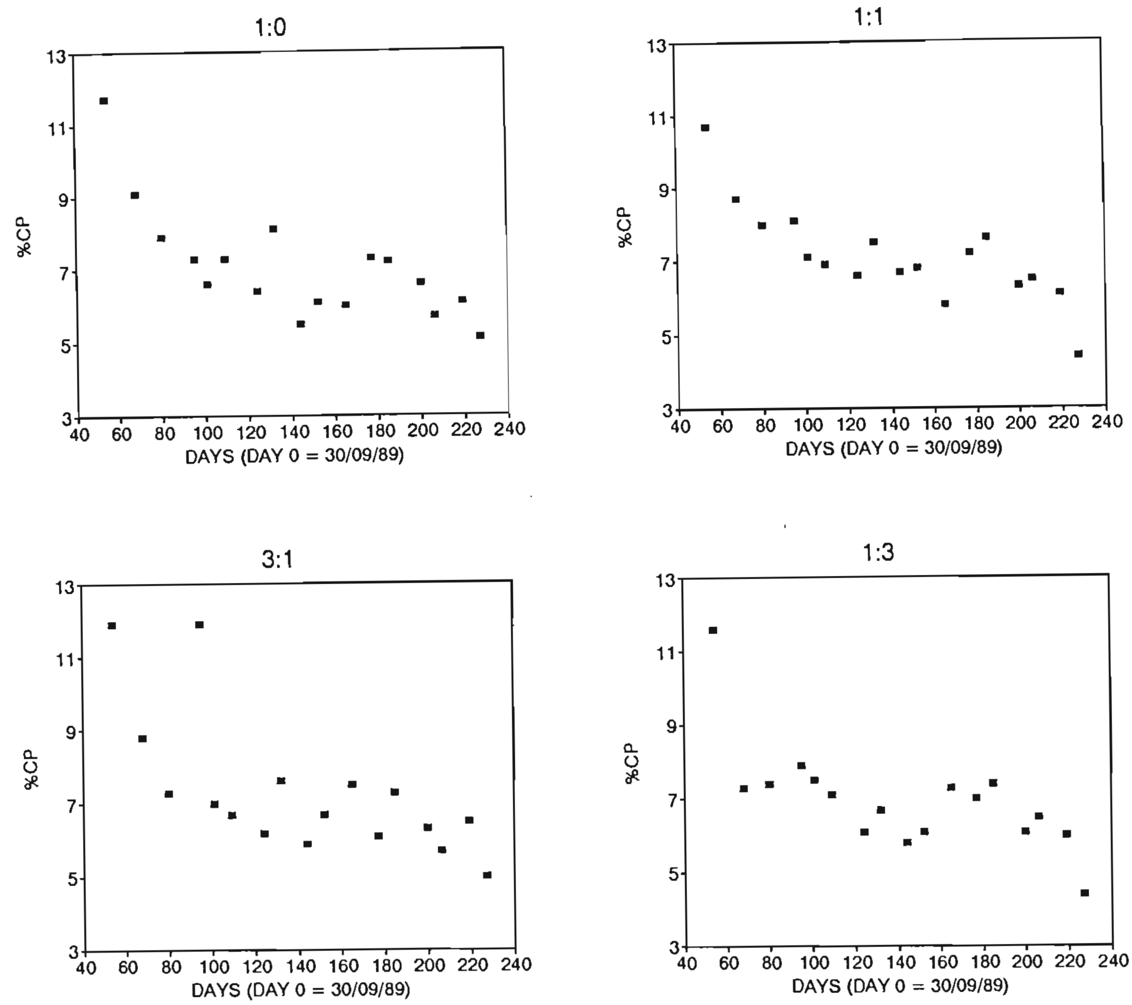

Figure 5.8 Crude protein percentage (%CP) of forage selected by cattle in each cattle to sheep ratio treatment (1:0, 3:1, 1:1 & 1:3) through the 1989/90 grazing season. Data derive from the animal production component (medium stocking rate treatment) of the trial

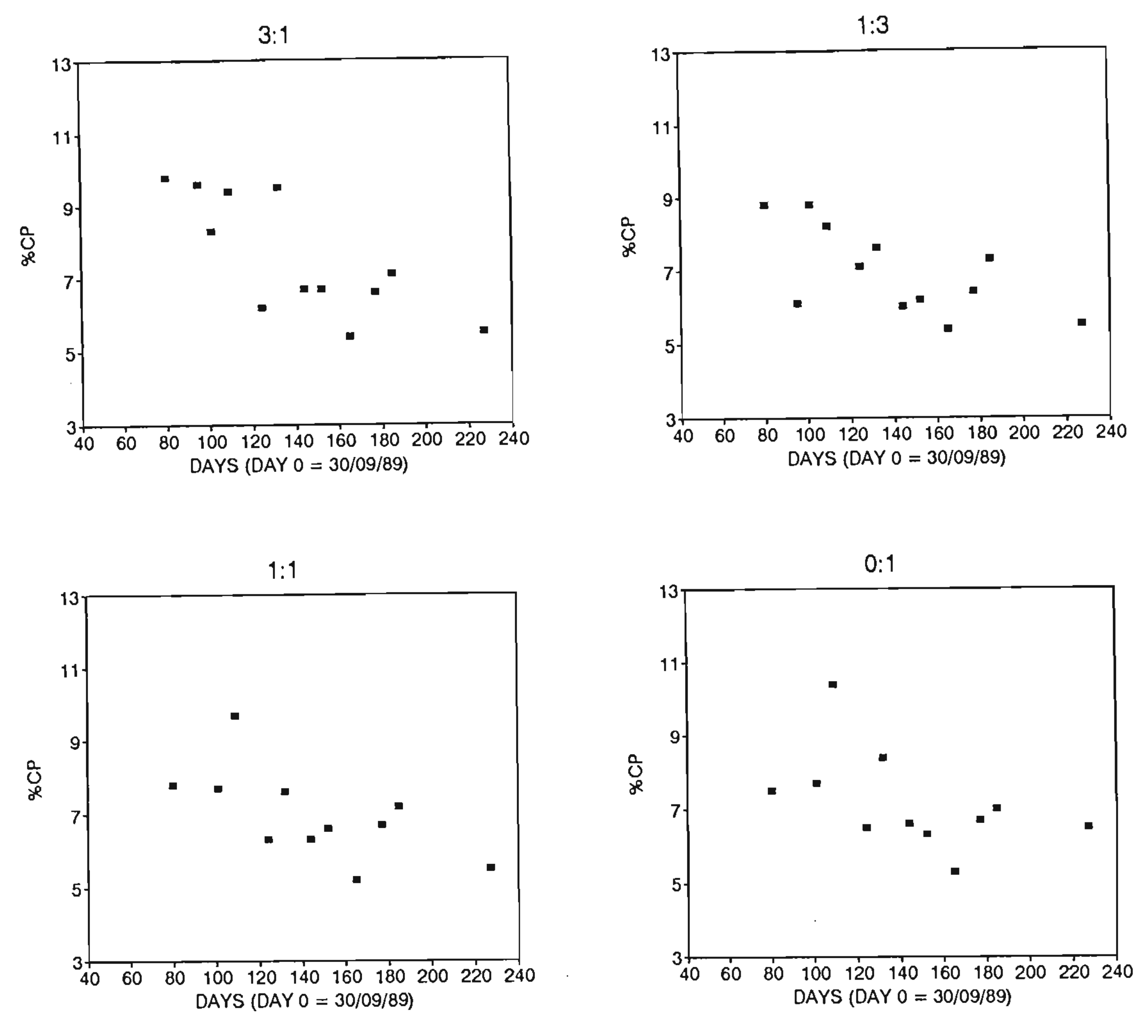

Figure 5.9 Crude protein percentage (%CP) of forage selected by sheep in each cattle to sheep ratio treatment (3:1, 1:1, 1:3 & 0:1) through the 1989/90 grazing season. Data derive from the animal production component (medium stocking rate treatment) of the trial

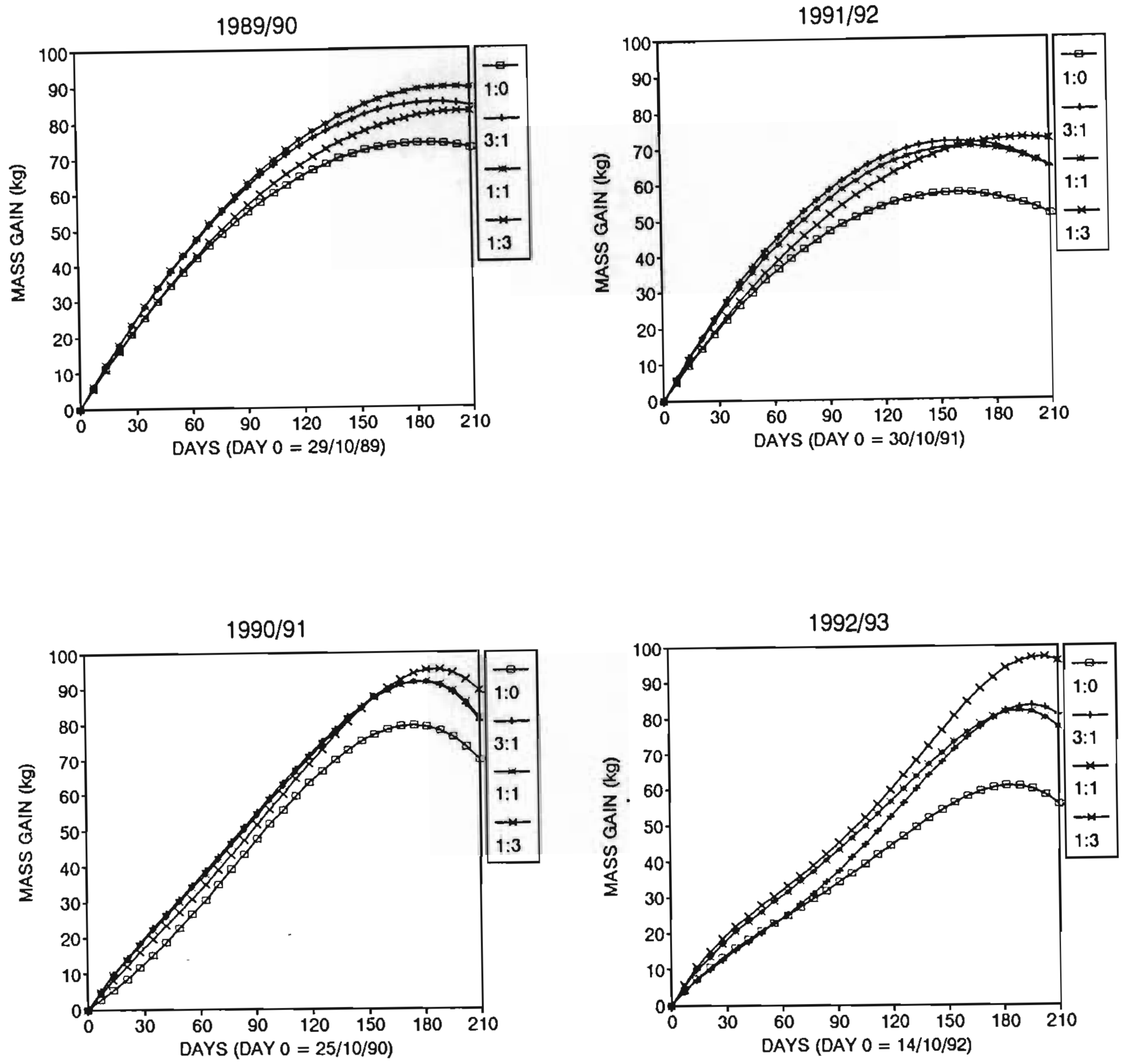

Figure 5.10 Mean cumulative mass gains (kg animal^{-1}) of cattle in each cattle to sheep ratio treatment (1:0, 3:1, 1:1 & 1:3) for each of four grazing seasons i) 1989/90, ii) 1990/91 ii) 1991/92 & iv) 1992/93

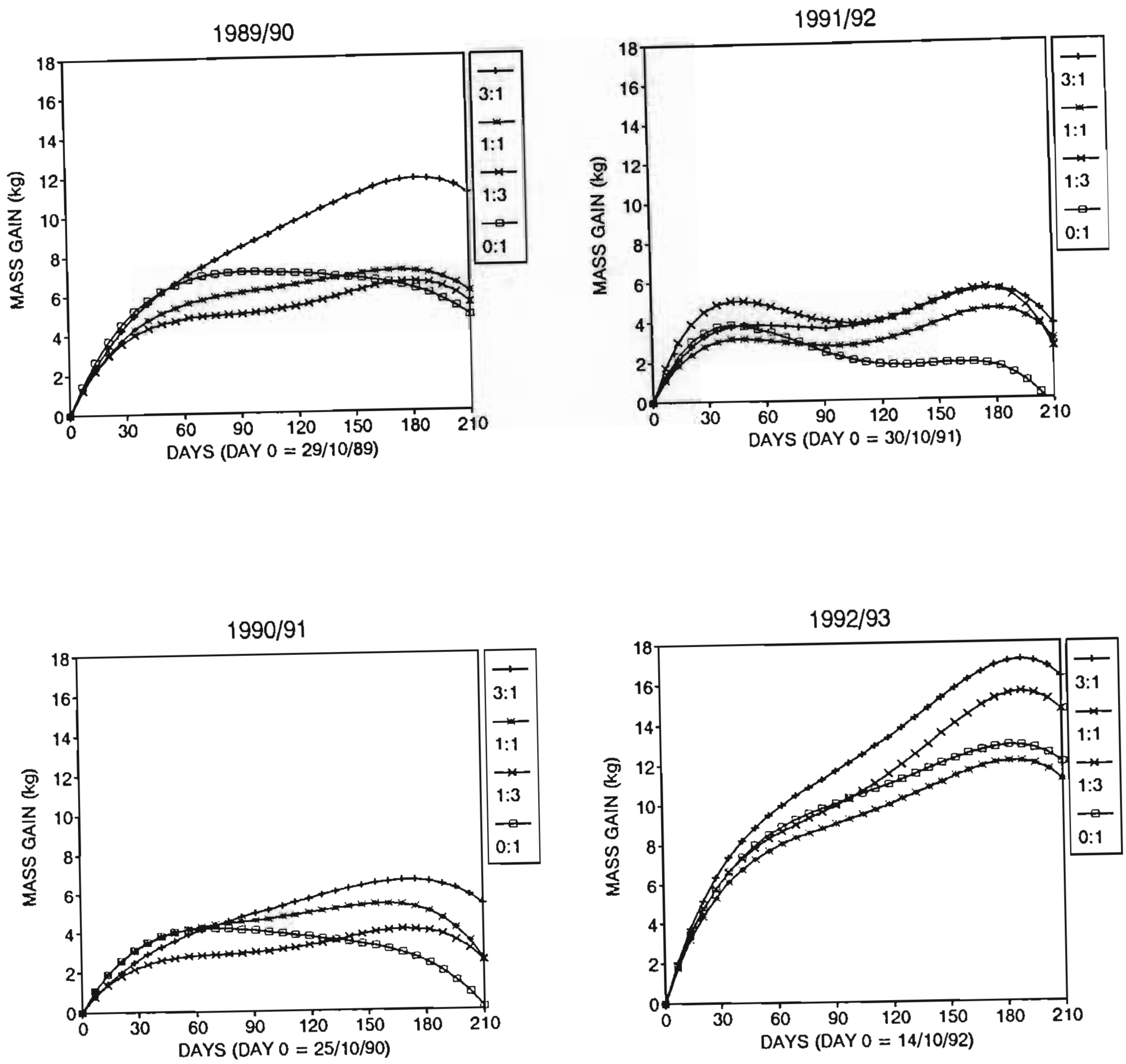

Figure 5.11 Mean cumulative mass gains (kg animal^{-1}) of sheep in each cattle to sheep ratio treatment (3:1, 1:1, 1:3 & 0:1) for each of four grazing seasons i) 1989/90, ii) 1990/91 ii) 1991/92 & iv) 1992/93

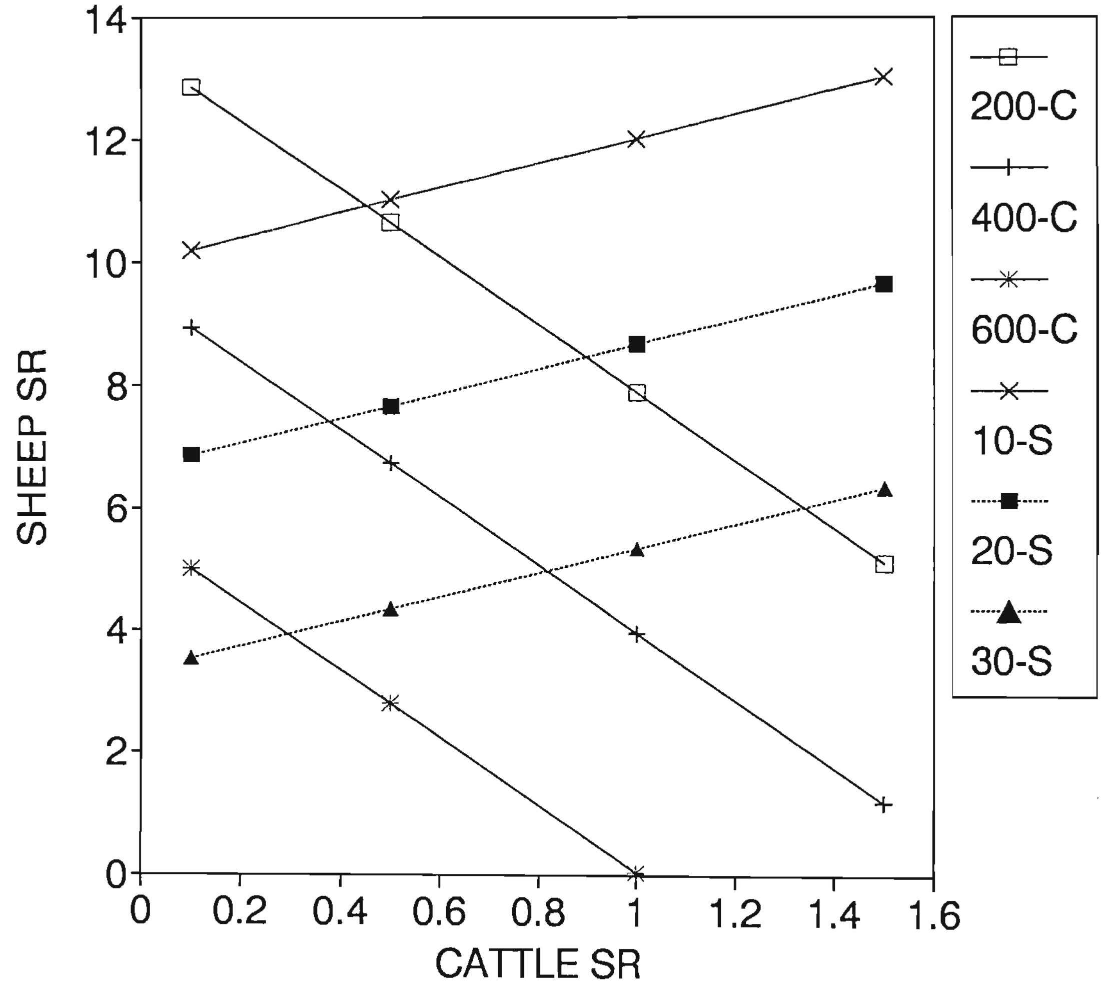

Figure 5.12 Isoclines for predicted average daily gains (ADG) of 200g, 400g and 600g for the cattle (C) and ADGs of 10g, 20g and 30g for the sheep (S) as functions of the stocking rate (SR in animals ha^{-1}) of cattle and sheep. Developed from the 'general' regression model - see text

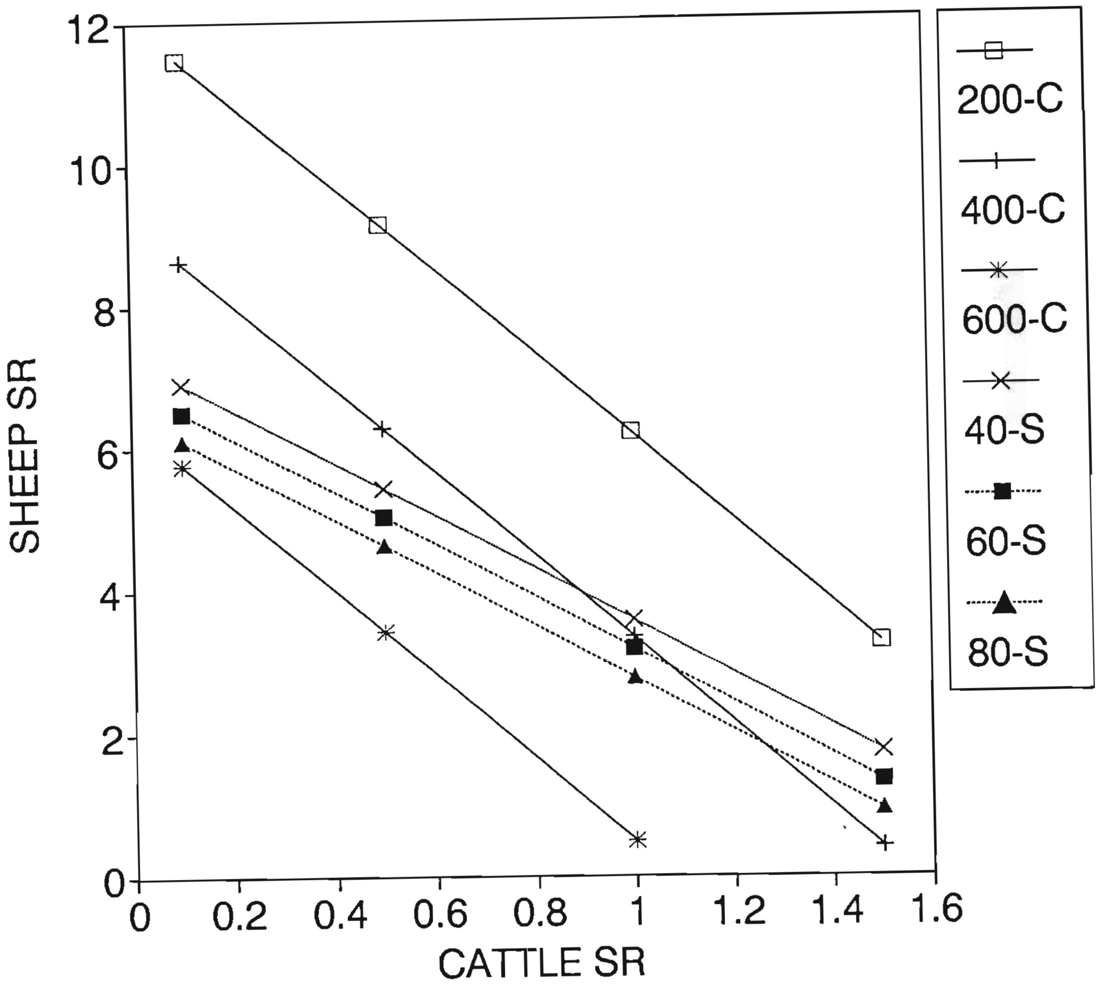

Figure 5.13 Isoclines for predicted average daily gains (ADG) of 200g, 400g and 600g for the cattle (C) and ADGs of 40g, 60g and 80g for the sheep (S) as functions of the stocking rate (SR in animals ha^{-1}) of cattle and sheep. Developed from the 'dry-season' regression model - see text

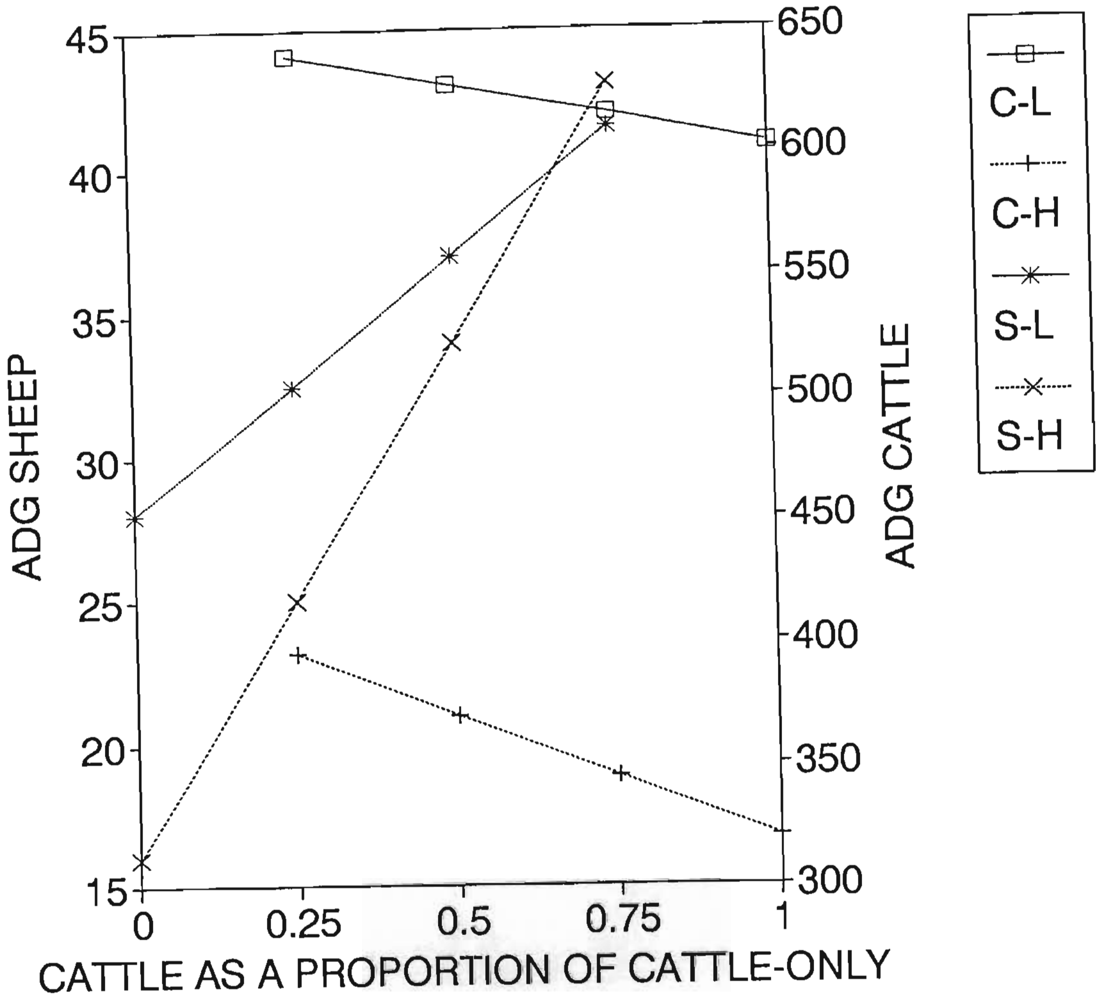

Figure 5.14 Predicted average daily gains (ADG in g animal^{-1} d^{-1}) for the cattle (C) and the sheep (S): i) with C at a high (C-H) stocking rate together with S at a high (S-H) stocking rate, and ii) with C at a low (C-L) stocking rate together with S at a low (S-L) stocking rate, as functions of the proportion of cattle relative to the cattle-only stocking rate. Refer to the text for the stocking rates and ratios used in the comparisons. The 'general' models were applied

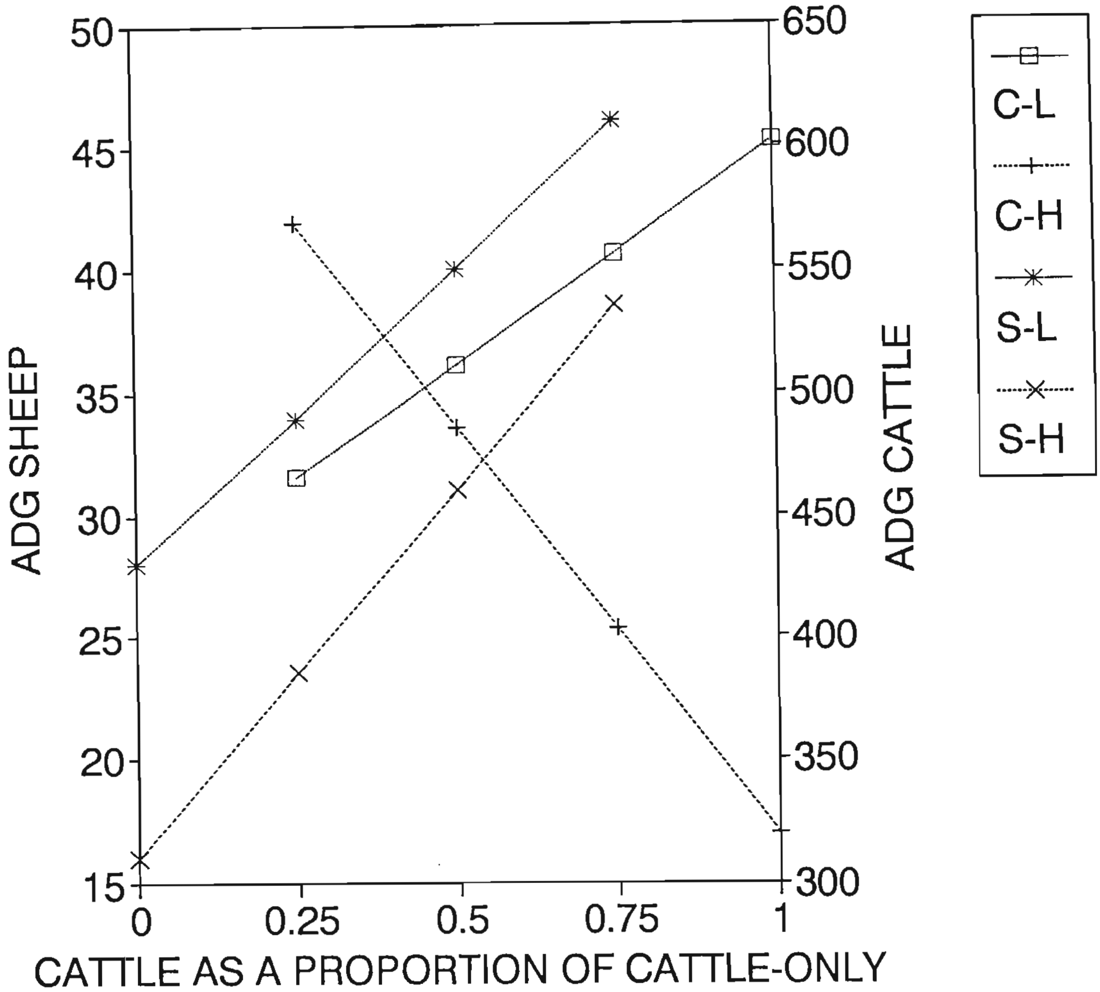

Figure 5.15 Predicted average daily gains (ADG in g animal^{-1} d^{-1}) for the cattle (C) and the sheep (S): i) with C at a high (C-H) stocking rate together with S at a low (S-L) stocking rate, and ii) with C at a low (C-L) stocking rate together with S at a high (S-H) stocking rate as functions of the proportion of cattle relative to the cattle-only stocking rate. Refer to the text for the stocking rates and ratios used in the comparisons. The 'general' models were applied

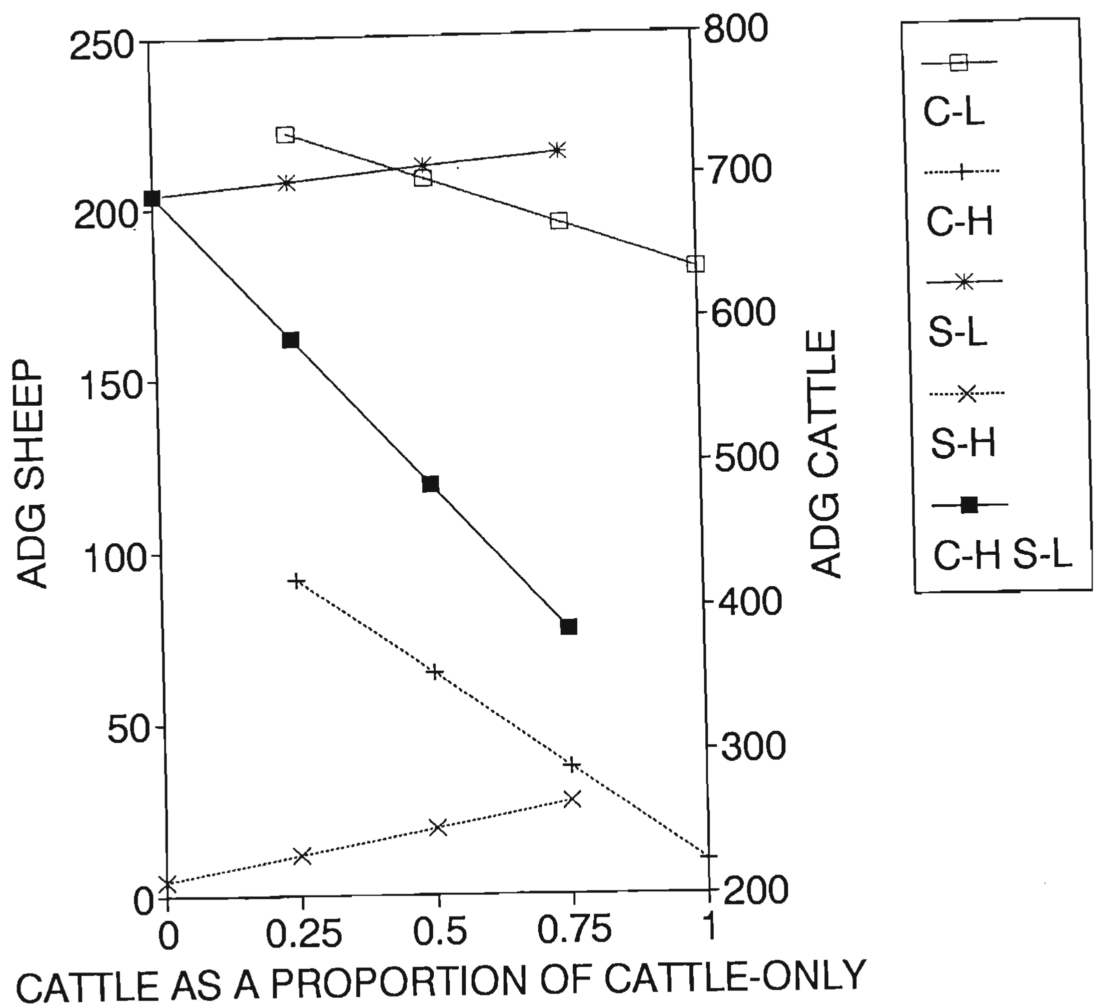

Figure 5.16 Predicted average daily gains (ADG in g animal^{-1} d^{-1}) for the cattle (C) and the sheep (S): i) with C at a high (C-H) stocking rate together with S at a high (S-H) stocking rate, ii) with C at a low (C-L) stocking rate together with S at a low (S-L) stocking rate, and iii) ADG of S with C-H and S-L, as functions of the proportion of cattle relative to the cattle-only stocking rate. Refer to the text for the stocking rates and ratios used in the comparisons. The 'dry-season' models were applied

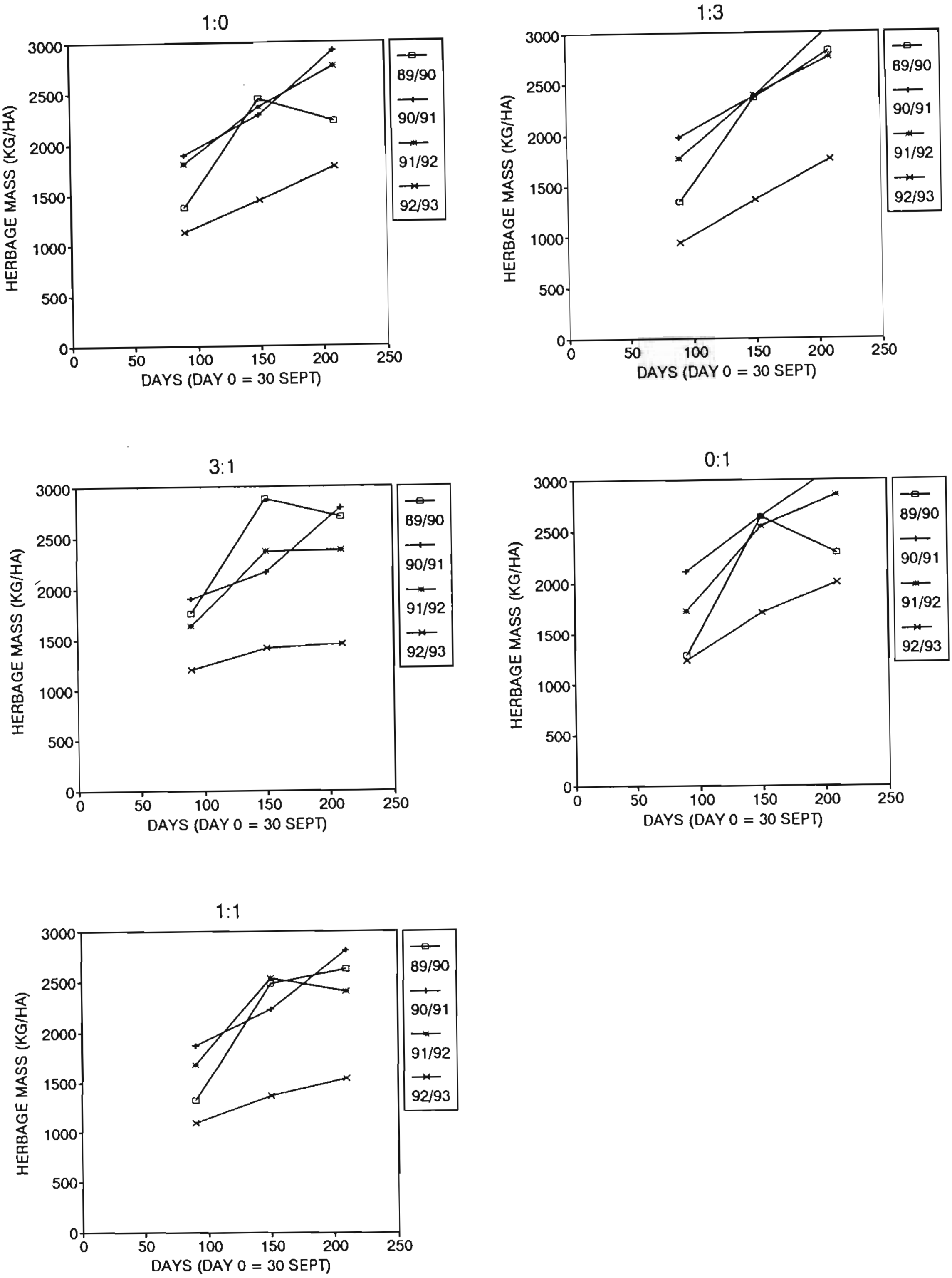

Figure 5.17 Mean herbage mass accumulation (kgDM ha^{-1}) for the rest paddocks of each ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for each of three consecutive 60 day periods within each of four grazing seasons (1998/90, 1990/91, 1991/92 & 1992/93)

SECTION 4

THE GRAZING IMPACT

QUANTIFYING THE GRAZING IMPACT IN TERMS OF ANIMAL UNIT EQUIVALENTS PER HECTARE

THE EFFECT OF CATTLE TO SHEEP RATIO AND STOCKING RATE ON DEFOLIATION PATTERNS OF THREE GRASS SPECIES

THE EFFECT OF CATTLE TO SHEEP RATIO AND STOCKING RATE ON THE EXTENT AND SEVERITY OF PATCH GRAZING

SHORT-TERM EFFECTS OF CATTLE TO SHEEP RATIO AND STOCKING RATE ON PROPORTIONAL SPECIES COMPOSITION AND BASAL COVER

CHAPTER 6

QUANTIFYING THE GRAZING IMPACT IN TERMS OF ANIMAL UNIT EQUIVALENTS PER HECTARE

The purpose of this chapter is to present a detailed analysis of the animal performance data with respect to the 'actual' stocking rate (expressed in terms of animal unit equivalents per hectare (AUE ha^{-1})) and cattle to sheep ratios (AUE cattle:AUE sheep) applied in each treatment. Calculation of AUE was based on the mass of the animal, its performance (average daily gain - ADG) and estimated quality of forage ingested.

6.1 Introduction

One of the main objectives of the trial was to characterize the impact of grazing at various stocking rates and cattle to sheep ratios as reflected by defoliation patterns on individual grass species and the extent and intensity of patch grazing. Stocking rate treatments were applied at the start of each grazing season in terms of AUE ha^{-1}. To balance a ratio treatment, one animal species (e.g. cattle) was replaced by an equivalent number of AUE of the other animal species (e.g. sheep). However, the cattle to sheep ratios and stocking rates set at the start of each grazing season did not persist throughout the season. A comparison of trends in the performance of sheep in the sheep-only (0:1) ratio treatment with trends in cattle performance in the cattle-only (1:0) ratio treatment (Figs 5.10 and 5.11) indicates that these two treatments would have had very different demands on the herbage on offer through each season. The differences in demand for herbage implies differences in grazing impact. It was therefore considered necessary to quantify the 'actual' stocking rates and cattle to sheep ratios applied through each season to allow for direct comparison between treatments on their impact on the sward.

Such detailed analyses also provides an opportunity to highlight the potential problems associated with the use of AUE as an integral part of the grazing capacity concept.

The specific objectives of the work reported in this chapter were therefore to:

1) quantify the 'actual' stocking rates and cattle-to-sheep ratios in terms of animal unit equivalents per hectare (AUE ha^{-1}), applied each season as determined, *a posteriori*, from the animal mass and performance data,
2) quantify the effects of cattle-to-sheep ratio on forage demand[5] at the medium stocking rate treatment,
3) determine the impact of grazing in each treatment, based on forage demand, and
4) discuss the implications of using the concept of AUE when estimating grazing capacity.

The reason for restricting objective 2) to the medium stocking rate treatment will be explained later in this chapter.

6.2 Calculating AUE ha^{-1}

Several methods for calculating AUE have been proposed. These include 1) the expected dry matter intake of an animal according to its livemass (*e.g.* Vallentine 1965; Society for Range Management 1974; Carl Bro International 1982; Scarnecchia & Kothman 1982; de Leeuw & Tothill 1993), 2) the energy requirements of an animal based on its metabolic mass (*e.g.* Brody 1945; ARC 1965; Mentis & Duke 1977; Mentis 1978; Edwards 1981b; Mentis 1981), and 3) the energy requirements of an animal of a specified mass and a specified level of performance (Meissner, *et al.* 1983; Trollope, *et al.* 1990). The approach presented by Meissner, *et al.* (1983) was adopted since it allows for direct comparisons between species and classes of animal, based on an estimate of the quantity of energy consumed. Calculations were based on the mass of the animal and its performance through each season.

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[5]In this context the term "forage demand" refers to estimates of apparent intake by the animals.

The consumption of energy is considered the most "basic and mutually descriptive quantity in animal production" (Meissner, *et al.* 1983). One of the main advantages of energy intake is its close relationship to animal mass and ADG. The two most commonly used measures of energy are metabolizable energy and nett energy. Metabolizable energy (ME) is the utilizable energy fraction i.e. gross energy minus energy lost (e.g. in urine, heat, faeces). Nett energy (NE) is ME minus the heat increment during digestion. Feeds are generally described in terms of ME and not NE because the efficiency of use of ME by the animal for production varies according to the quality of the feed and the level of production of the animal (Anon 1975; ARC 1980; Meissner, *et al.* 1983). In veld, a measure of the ME consumed represents the amount of energy removed from the sward by the animal. Metabolizable energy consumed therefore provides one measure of the impact of grazing on the veld and was therefore used in calculating the 'actual' stocking rate and ratio treatments applied in the current trial.

An AUE has been defined earlier as "the equivalent of a head of cattle with a mass of 450 kg which gains 500 g d^{-1} in mass on a grass pasture with a mean digestible energy (DE) of 55%" (Meissner, *et al* 1983). Seventy five MJME d^{-1} are required to maintain the defined AUE (on a fodder source which has 55% DE). However, the efficiency of use of a feed will vary with the quality of the feed. Therefore, as the % DE of the fodder source increases or decreases through the season so the amount of energy (MJME d^{-1}) required to support the standard AUE varies.

6.2.1 Calculation of daily energy intake per hectare

In the procedures presented by Meissner, *et al.* (1983) the energy requirements of an animal of particular mass (kg) and average daily gain (ADG in g) are calculated in terms of NE (MJ d^{-1}). Net energy requirements are then converted to ME requirements. Since the relationship between ME and NE requirements are influenced by the nature of the production, the level of production and the ME concentration of the feed (MJME $kgDM^{-1}$), ME requirement must be calculated for each situation (Meissner *et al* 1983).

Conversion of NE to ME involves partitioning energy requirements for maintenance and for growth which, together, provide the "relative level of production" (Meissner *et al* 1983). However, as the relative level of production varies, so the efficiency of use of a feed varies. An efficiency coefficient is therefore determined to account for the variation in efficiency of use of a forage with a particular ME concentration at a particular relative level of production. The amount of energy consumed per hectare is simply calculated as the sum of energy consumed by the animals grazing on that hectare.

Requirements for calculating stocking rates for each treatment in terms of AUE were, therefore, 1) the mass and ADG of each animal, 2) the ME concentration of forage selected by each animal species, and 3) the number of each species of animal allocated per hectare. Animal performance data, estimates of the energy concentrations of ingested forage, and the number of each species of animal per hectare were obtained from both the simulated and the animal production components of the trial i.e. for all stocking rate and ratio treatments. In the animal production component all calculations were related to the 'test' paddocks; these 'test' paddocks having had the same management as the paddocks of the simulated grazing treatments.

6.2.2 Animal performance data

Polynomial functions were fitted to the animal mass data recorded for each treatment for the first three seasons of the trial. Animal performance data from the fourth season could not be considered as the 'test' paddocks in the animal production component and the paddocks of the simulated component of the trial were rested for the whole of the 1992/93 season.

At any time in the grazing season the mean cumulative mass and ADG of the cattle and sheep in each treatment were determined from the 'best-fit' polynomial functions derived for each animal species.

6.2.3 Energy concentration of the feed (MJME $kgDM^{-1}$)

Cattle and sheep, fistulated at the oesophagus, were used to obtain samples of forage selected by the animals in each treatment through the first (1989/90) grazing season. Samples were collected two days after animals entered and two days before they left the 'test' and simulated paddocks. Digestible organic matter (%DOM) content of each sample was determined (Engels *et al.* 1981). Regression functions were fitted to the %DOM on 'time-in-the-season' data for each treatment. Day zero in the growing season was assumed to be 30 September. Energy concentration (MJME $kgDM^{-1}$) of each sample was estimated from the mean (fitted) %DOM values. Several regressions equations relating ME concentration to %DOM are available (e.g. Moir 1961, Armstrong 1964, Butterworth 1964, Minson & Milford 1966, Corbett 1978), all producing similar results. The equation presented by Corbett (1978) has been applied to local forages, including sourveld, with some success (Hardy and Mentis 1986, Hardy *et al.* 1990), and was therefore used. The equation has the form:

$$ME = 0.83\ (0.193 * \%DOM - 0.661)\ MJ\ kgDM^{-1} \qquad ..... \qquad \textbf{6.1}$$

where ME and %DOM are defined as before.

The regression equations developed for each treatment in the 1989/90 season were also used to predict the %DOM selected by the animals through the second and third growing seasons. For any particular time in the grazing season, this procedure assumes no difference in the %DOM of herbage selected between seasons.

6.2.4 Number of animals per hectare

Each of the paddocks in the simulated component were managed as if they formed part of a four-paddock rotational grazing system, with one paddock of each treatment being rested for the whole grazing season (see Chapter 4). Calculations of the number of animals of each species allocated to each treatment were therefore based on the assumption that three equal size paddocks were available to the animals each season. The area of the paddock allocated to a stocking rate and ratio treatment was therefore multiplied by three to obtain the total 'simulated' area available to each group of animals. Areas thus calculated were divided into the number of each species of animal allocated to the area to determine the numbers of sheep and cattle per hectare for each treatment. The same procedure was followed for calculating animals per hectare for the 'test' paddocks of the 'S5' area.

6.2.5 Animal unit equivalents (AUE)

Animal unit equivalents were calculated at seven day intervals from the animal performance, quality and animals per hectare data for each treatment in each of the first three grazing seasons by applying the procedure described earlier in this chapter. Since animals remained in their treatments for a minimum of 210 days each grazing season (November to May inclusive), calculations of AUE ha^{-1} were based on this period for each season.

6.3 Grazing impact in terms of forage demand

This part of the study involved two components. First, the forage demand was estimated, *a posteriori*, for each treatment. Here, the output simply provides an index of grazing impact based on the amount of forage remove by the animals allocated to each grazing treatment during each grazing season. Second, since cattle-to-sheep ratio and stocking rate influence animal performance (Chapter 5), and animal performance is influenced mainly by the quality and quantity of intake, the effect of cattle-to-sheep ratio and stocking rate on forage demand may be determined. Determining these effects from the current trial, however, was possible for only the medium stocking rate treatment since, in this treatment, animal performance was directly related to the applied ratio treatments (all animals having been confined to their specific treatment area). In the simulated component of the trial, animal performance was also influenced by the fact that animals from all treatments grazed together, in a single group, during the periods of absence from their treatment (simulated) paddocks. The forage demand by these animals was therefore influenced by factors other than the 'planned' cattle-to-sheep ratio and stocking rate treatments. Animal performance could therefore not be directly related to these treatments.

6.3.1 Estimating the forage demand

Estimates of daily dry matter intake per animal (kgDM d^{-1}) form an integral part of the calculation of AUEs. Daily dry matter intake per animal was calculated from the equation (Meissner, *et al.* 1983):

$$\text{kgDM animal}^{-1}\ d^{-1} = (\text{NE requirement}/(\text{MJME kgDM}^{-1} \times \text{kmp}))$$

where

i) NE is the net energy requirement of the animal from its mass and ADG,

ii) MJME kgDM^{-1} is the metabolizable energy concentration of ingested feed, and

iii) kmp is a coefficient describing the efficiency with which the ME of a feed of a particular ME concentration is utilized for a particular relative level of production.

Estimates of forage demand per hectare per day (kgDM $ha^{-1}\ d^{-1}$) were determined as the sum of the estimated daily dry matter intake of each animal species allocated per hectare. The total seasonal demand for forage per hectare for each treatment was determined as the sum of the daily forage demand per hectare for a grazing season of 210 days.

6.3.2 The effect of cattle-to-sheep ratio on forage demand (at a single stocking rate)

The effect of cattle-to-sheep ratio on annual forage demand per hectare (kgDM $ha^{-1}\ a^{-1}$) by cattle and by sheep was determined by using the procedures described in section 5.2.6.1.1 of Chapter 5. Separate multiple linear regression functions were developed for predicting forage demand of cattle and of sheep as influenced by the stocking rate of cattle and of sheep. For the purposes of this exercise stocking rate was expressed as the number of each animal species per hectare in each treatment.

6.4 Results

6.4.1 Animal performance

Seasonal trends in mean cumulative livemass changes in each ratio treatment are presented in Figures 5.10 and 5.11 (for the medium stocking rate treatment), Figure 6.1 (for the low stocking rate treatment) and Figure 6.2 (for the high stocking rate treatment). Trends in the performance of the cattle and the sheep in the medium stocking rate treatment (the animal production component of the trial - the 'S5' area) have been compared and discussed in detail in Chapter 5.

As mentioned in section 6.3, the effect of stocking rate and ratio on animal performance could not be established for the simulated component of the trial (the low and high stocking rate treatments). While the experimental animals were not in their simulated treatments they grazed as a single group of cattle and sheep in a paddock adjacent to the trial area (see Chapter 4 for more detail of the experimental design). Thus, for four weeks of every grazing cycle during a grazing season all the animals were stocked at the same stocking rate (and ratio). It was only during the 2 weeks periods of stay in a treatment paddock that stocking rate and ratio would have influenced animal performance. However, animal performance data derived from the simulated component of the trial could be used to estimate the 'actual' stocking rates applied in each treatment in terms of AUE ha^{-1}. A major assumption associated with the use of these data to estimate AUE ha^{-1} was that ADG of the animals was maintained during each period of stay in their respective treatments. The mass and ADG of the animals were derived, for each period of stay, from the 'best fit' polynomial functions fitted to the animal mass data recorded in each treatment.

'Best-fit' polynomials for the cattle included both quadratic and quartic functions (Table 6.1). The sheep performance data were extremely variable, with animals in many of the low and high stocking rate treatments barely maintaining mass through the season. 'Best-fit' polynomials for the sheep also included quadratic and quartic functions. For a number of treatments, however, low order polynomials could not be fitted to the sheep performance data (Table 6.1). Inspection of the data for these latter treatments indicated that the animals were essentially at maintenance for much of the season. Accordingly, the initial mean mass of the animals was taken as the mass throughout the season and ADG = 0 (Figures 6.1 and 6.2).

6.4.2 Energy concentration of the feed (MJME $kgDM^{-1}$)

The %DOM of forage selected by cattle and by sheep in each of the ratio treatments during the 1989/90 grazing season is presented in Figures 5.6 and 5.7 (medium stocking rate), Figures 6.3 and 6.4 (low stocking rate) and Figures 6.5 and 6.6 (high stocking rate). Linear regression functions were fitted to the %DOM on time data for each treatment. In most cases linear functions provided the best fit. Where a higher order polynomial function accounted for a larger proportion of the variance in a data set, such a function resulted in distortion of prediction of %DOM of selected forage, particularly at the beginning of the grazing season. For example, a quartic function accounted for most of the variance in the data set for the low stocking rate 3:1 ratio treatment. The predicted intercept for the resultant equation i.e. the predicted %DOM at day 0 in the grazing season, was given as 43.3%. This value is obviously incorrect as the %DOM of the flush of new growth after burning in early spring would be expected to be in the range 60% to 75% DOM (Hardy & Mentis 1986; de Waal 1990; Barnes & Dempsey 1992). In all cases there was a significant linear relation ($P \leq 0.05$) between %DOM of selected forage and time in the growing season (Table 6.2). The ME concentration of selected forage was calculated for seven day intervals through each season by applying equation 6.1 to the predicted %DOM of forage at each time interval.

6.4.3 Number of animals per hectare

The number of animals per hectare of each animal species are presented in Table 6.3. In the medium stocking rate treatment between year variation in animals ha^{-1} within a species and ratio treatment were due to small differences in the size of paddocks allocated to each stocking rate treatment. Differences in the number of sheep ha^{-1} in the low and high stocking rate treatments between the 1989/90 and the two subsequent (1990/91 and 1991/92) grazing seasons were due to adjustments related to the initial mass of the sheep available for the trial in those seasons.

6.4.4 Animal unit equivalents

Seasonal trends in stocking rate in terms of AUE ha^{-1} of cattle and of sheep in each treatment are presented in Figures 6.7, 6.8 and 6.9 for the low, medium and high stocking rate treatments respectively. Data for the 1:0 (cattle only) and 0:1 (sheep only) treatments are placed in the same Figure to facilitate direct visual comparisons between these two treatments. The data presented in Figures 6.7, 6.8 and 6.9 are based only on positive mass change of each group of animals. The procedures presented in Meissner, *et al.* (1983) do not account for mass losses. In several cases therefore the number of AUE ha^{-1} could not be calculated for a large part of the season e.g. the 0:1 ratio treatment in Figure 6.7b(i).

Stocking rate (AUE ha^{-1}) of cattle declined through the grazing season for all treatments and all seasons (Figures 6.7, 6.8 & 6.9). A similar trend occurred with the sheep stocking rates. In the medium stocking rate treatment, however, increased mass gains of the sheep towards the end of the grazing season (Figure 5.11) halted the decline in AUE ha^{-1} of sheep and, in some cases, resulted in a small increase in AUE ha^{-1} at the end of the grazing season (Figure 6.8). The horizontal line presented for a portion of the grazing season in some of the sheep treatments (e.g. Figure 6.8c) is the assumed stocking rate (AUE ha^{-1}) while the animals were maintaining mass or were losing mass (see Appendix Figure 5.4b), as inferred from the 'best-fit' polynomial function.

The 'planned' and 'actual' (calculated) stocking rates (AUE ha^{-1}) applied at the start of each season for each animal species and for each treatment are presented in Table 6.4. 'Actual' stocking rates of cattle and of sheep in each treatment expressed as the mean AUE ha^{-1} of each animal species over the season, were based on a 210 day grazing season. In treatments where the animals had achieved maximum mass early in the grazing season it was assumed that their intake of energy, subsequent to their achieving maximum mass, was sufficient to maintain mass until day 210. This assumption results in a slight over-estimate of AUE ha^{-1} at the end of each season for most treatments. However, in the absence of a suitable method for determining the energy intake of livestock while animals are losing mass, the assumption would seem to be acceptable. The 'planned' and calculated mean stocking rate and ratio treatments applied in each season are presented in Table 6.5.

6.4.5 Grazing impact in terms of forage demand

The estimated seasonal forage demand for all treatments is presented in Table 6.6. Considering the amount of forage required to maintain the level of production recorded in the high stocking rate treatment (Table 6.6), it is probable that dry matter intake (particularly in those ratio treatments with a high proportion of cattle) would have been restricted. Reference to the total seasonal herbage mass accumulation in the rest paddocks of the animal production component of the trial (Appendix Figure 5.1) suggests that the maximum potential herbage mass accumulation in each of the three seasons ranged between approximately 3 000 & 3 500 kgDM ha^{-1}. The assumption that the animals in the high stocking rate maintained their level of performance during each period of stay in the simulated treatments may therefore have resulted in an over estimate of the forage demand in those treatments. It should suffice to point out that for high stocking rate treatments with a high proportion of cattle, a high proportion of the seasonal production of herbage would have been grazed by the animals. Despite the foregoing, there are a number of trends in the data set (Table 6.6) which are consistent with the treatments applied, with total forage demand increasing with increasing stocking rate. Furthermore, within a 'planned' stocking rate treatment there was a general increasing demand for forage with an increase in the proportion of cattle. This was a result of the relatively better performance of the cattle than the sheep in each treatment.

For the purposes of comparing the forage demand between treatments, the potential mean herbage mass accumulation for each of the three seasons was estimated as 3 200 kgDM ha^{-1} (see Appendix Figure 5.1). In the cattle-only treatments approximately 40%, 56% and 82% of the potential herbage production per hectare was removed from the low, medium and high stocking rate paddocks respectively. In contrast, in the sheep-only treatments approximately 27%, 40% and 59% of the potential herbage production per hectare was removed for the low, medium and high stocking rates respectively. It should also be noted that for most seasons and stocking rate treatments, similar amounts of herbage were used by the animals in the 3:1 and the 1:0 ratio treatments (Table 6.6). From the perspective of forage demand, cattle-only or treatments which have a high proportion of cattle in the species mix, would appear to have a greater impact on the sward than sheep-only grazing systems (or systems where sheep are in high proportion to cattle). What was not considered in this approach was the intensity of grazing on individual plants or on 'patches' as a function of stocking rate of sheep and cattle. These interactions are discussed in the following chapters.

The effect of cattle to sheep ratio on seasonal forage demand (kgDM ha^{-1} a^{-1}) by the cattle and the sheep in each ratio treatment of the animal production component of the trial are presented, together with the stocking rates (animals ha^{-1}) of the cattle and sheep, in Table 6.7. Linear models of the form presented in equation 5.2 (see Chapter 5) were fitted to the pooled data for all three grazing seasons. Separate regressions were developed for the cattle and the sheep. The results are presented in Table 6.8. It should be stressed at this stage that the models are suited only to this particular data set. The forage demand was related to specific cattle-only and sheep-only stocking rates. When replacing a proportion of the cattle stocking rate with sheep, the calculations were based on the cattle-only and sheep-only stocking rate treatments e.g. 25% of the cattle-only stocking rate was replaced by 25% of the sheep-only stocking rate. In comparing the effects of mixed species grazing on forage demand, therefore, similar cattle-only and sheep-only stocking rates were applied in the models i.e. for cattle-only the stocking rate was 1.75 animals ha^{-1} and for sheep-only the stocking rate was 6.3 animals ha^{-1}. For each of these stocking rates, mixed-species stocking rates were selected, where the species were in the proportions 0.25:0.75, 0.5:0.5 and 0.75:0.25 of the cattle- and sheep-only stocking rates. Predicted forage demand by sheep and cattle grazing in a single- or mixed-species grazing system are presented in Figure 6.10. The species mix is expressed as the proportion of cattle relative to the cattle-only stocking rate. A value of 0.25 on the x axis implies a stocking rate of 0.44 cattle ha^{-1} plus 4.7 sheep ha^{-1}.

It is clear that the sheep-only ratio treatment had a lower forage demand than the cattle-only treatment for all three grazing seasons (Table 6.7). The predicted total forage demand for each treatment was 1779, 1696, 1602, 1504 and 1287 kgDM ha^{-1} a^{-1}, reflecting the general observation of increasing forage demand with increasing proportion of cattle in the species mix. The sheep-only treatment removed approximately 28% less dry matter per hectare than the cattle-only treatment (see also Figure 6.10).

However, inspection of the mixed-species treatments (Table 6.7) indicates that, in all cases, the predicted forage demand was in excess of 85% of the predicted forage demand in the cattle-only treatment. Another indication that the cattle had a higher demand on forage than the sheep (where the proportions of cattle and sheep were related to the single-species stocking rate applied in the trial) is that rate of increase in forage demand by cattle as the proportion of cattle increased was higher than the rate of increase in forage demand by sheep as the proportion of sheep increased (Figure 6.10). For example as the proportion of cattle increased from 0.25 to 0.5, forage demand increased by approximately 420 kgDM ha^{-1} a^{-1}, whereas, as the proportion of sheep increased from 0.5 to 0.75, forage demand increased by only approximately 320 kgDM ha^{-1} a^{-1}.

6.5 Discussion

6.5.1 Animal unit equivalents per hectare (AUE ha^{-1})

The suspected large differences between the 'planned' and 'actual' stocking rates and cattle to sheep ratios (from inspection of the animal performance data) were confirmed (Table 6.5). Inspection of Figure 6.8 (medium stocking rate data) indicates that while the ratio treatments were stocked in the correct proportion at the start of each season (in terms of AUE ha^{-1}), these ratios were not maintained throughout the season. Within the 4-paddock rotational grazing management system applied in this trial, therefore, differences in the performance between the cattle and the sheep resulted in differences between the 'planned' and 'actual' treatments. In the simulated component of the trial, animal performance was strongly influenced by the fact that all the experimental animals grazed together in a single (large) paddock during each period of absence from their treatment paddocks. Here, differences between the 'planned' and 'actual' stocking rate and ratio treatments were even more marked than they were in the animal performance component of the trial.

While for practical purposes it would have been preferable to quantify the impacts of grazing on the sward as a function of the stocking rate of cattle and sheep in terms of the **number** of animals of each species per hectare, this was not possible for the reasons **presented** in the previous paragraph. Quantifying each treatment, *a posteriori*, in terms of the **AUE ha^{-1}** of cattle and of sheep provided a meaningful basis for determining the grazing impact in each treatment. The first objective, listed earlier, was therefore achieved, with the results being presented in Table 6.5.

Another point to be borne in mind, however, was that estimated ME concentration of intake in the second and third grazing seasons was based on equations developed from data collected during the first season. On average, the quality of herbage on offer to the animals during the second and third seasons was likely to have been lower than during the first season since 1) regrowth was derived from an unburnt sward and 2) there would have been carry-over of old, dead herbage from the previous grazing season (see Chapter 5 for discussion on these effects). Animals would either have had to select for higher quality forage or ingest a larger quantity of the lower quality forage to achieve the levels of performance recorded during these seasons. Selection for forage of a higher quality than the average quality of herbage on offer, and at a level equivalent to the first season, assumes that there was sufficient quantity of such quality herbage available to the animals. The lower performance of the sheep in the second and third grazing seasons relative to the first suggests that there was a limitation in quality (or in quantity of high quality herbage) during the second and third grazing seasons. The lower the quality of ingested forage the higher the quantity of intake must be to achieve the same level of performance on the two diets. A higher quantity of dry matter intake per hectare would suggest a higher AUE ha^{-1}. This being the case, it is probable that the number of AUE ha^{-1} was under-estimated for the second and third grazing seasons. However, re-analyses of the data, with an assumed lower quality of intake through the season, revealed only small differences in estimated AUE ha^{-1}. All treatments showed less than a 5% increase in AUE ha^{-1} when a lower quality of intake was assumed. The results presented in Table 6.5 were therefore not adjusted and were accepted, acknowledging the possible biases involved.

'Actual' stocking rates (AUE ha^{-1}) of each treatment at the start of each season were generally higher than 'planned' (cf the 'planned' and 'actual' total stocking rates (Table 6.4)). This result was due to the calculations being based on the 'actual' animal performance data recorded for each season. The 'planned' stocking rate treatments were based on the definition of an Animal Unit given by Edwards (1981b) (see section 4.2). In the present trial however, the cattle (with a mass of 200kg) gained in excess of 900g $animal^{-1}$ d^{-1} at the start of each season. It is not surprising, therefore, that the calculated stocking rates at the start of each grazing were higher than the 'planned' stocking rate treatments (Table 6.4).

The mean stocking rates calculated for each season also differed from the 'planned' stocking rate treatments (Table 6.5). As the proportion of cattle in the species-mix increased, stocking rate increased as a consequence of the differential performance of cattle and sheep throughout the trial.

In the medium stocking rate treatment (i.e. the animal production component of the trial) the proportions of cattle and of sheep (expressed as AUE ha^{-1}) allocated to each treatment at the start of the trial closely followed the 'planned' ratio treatments (Figure 6.8 and Table 6.4). The stocking rates applied at the start of each season, although they were higher than the 'planned' stocking rate treatments, were similar for all ratio treatments (Table 6.4). By contrast, there was considerable variation in both the 'actual' stocking rate and ratio treatments in the simulated component of the trial. For example, in the 1989/90 grazing season the stocking rates applied for the high stocking rate treatment varied from 1.73 AUE ha^{-1} to 1.17 AUE ha^{-1}. The large variations in the treatments within and between seasons, highlight the need to quantify the 'actual' treatments applied each season.

The decline in the AUE ha^{-1} for all treatments and in each season was not expected. Superficially, as animal mass increases the general expectation would be that the demand for forage and thus the grazing impact would increase. A commonly applied method for setting stocking rates for different classes and species of livestock is to convert the livemass of each animal to metabolic mass (e.g. Edwards 1981b). This method was applied in the present trial to calculate initial stocking rates for each treatment (see Chapter 4). The metabolic mass of an animal was calculated as $W^{0.75}$ where W is the livemass of the animal. It follows then, that as animals grow though the season their metabolic mass increases. Stocking rate would therefore be expected to increase (in terms of $W^{0.75}$) while animals are in a positive phase of growth.

The seasonal decline on stocking rate when expressed in terms of AUE ha^{-1} reflects the fact that, as animal mass increases, the NE requirements for maintenance of livemass increases at a slower rate than the NE requirements for growth decrease. Stocking rate is therefore influenced more by the level of animal performance than by the livemass of the animal. Animal performance data from the medium stocking rate treatment show that the ADG of, for example, the cattle, was a maximum at the start of the season, whereafter ADG declined through the season in almost all treatments. Where there was an increase in ADG during the season (e.g. Fig 5.10b) this increase was small relative to the general declining trend, and did not persist. Thus, the consistent general decline in ADG is reflected in the consistent general decline in AUE ha^{-1}.

The mean seasonal stocking rate and ratio treatments presented in Table 6.5 indicate that, per AUE stocked at the start of the season, cattle will maintain a higher level of performance than sheep when grazing a sour grassveld. This statement is best illustrated from the medium stocking rate treatment data where the mean seasonal cattle to sheep ratio treatments actually applied were 4:1, 1.5:1 and 1:2 rather than the 'planned' 3:1, 1:1 and 1:3 respectively.

6.5.2 The effect of cattle to sheep ratio on forage demand

The observation that the total seasonal forage demand in the mixed-species treatments was, from the predicted values, no more than 275 kgDM ha^{-1} less than in the (single-species) cattle-only treatments is of interest. In Chapter 5 it was reported that no consistent differences in herbage mass on offer between the 1:0, 3:1, 1:1 and 1:3 treatments was observed while herbage mass on offer in the 0:1 (sheep-only) treatment was generally greater than the other treatments (Figures 5.4). It was also suggested in Chapter 5 that estimates of herbage mass using the disc meter and the general calibration curves may have been too crude for use in explaining animal performance. The present estimates of forage demand suggest that the disc meter data provided acceptable estimates of herbage mass on offer to the animals in each treatment.

6.5.3 Animal unit equivalents and the concept of grazing capacity

Potential problems associated with the use of AUE in the concept of grazing capacity have been outlined in section 3.2 of Chapter 3. In the present context the medium stocking rate data were applied to highlight the use of AUE in setting stocking rates in line with grazing capacity recommendations. As stated in Chapter 3, the use of AUE in the definition of grazing capacity assumes a similar seasonal demand for forage by different species or classes of animal when they are stocked at the same number of AUE ha^{-1}. This is clearly not the case when replacing a proportion of the cattle with an equivalent proportion of sheep (in terms of AUE ha^{-1}) at the start of a grazing season. While the proportions of AUE of cattle and sheep may have been as 'planned' at the start of each season, these did not persist through each season (Figures 6.8a, b and c). Theoretically the AUE ha^{-1} of cattle-only (1:0) and sheep-only (0:1) treatments should have coincided for the duration of each season. Similarly, at the 3:1 and 1:3 ratios the seasonal trends in AUE ha^{-1} of the cattle and sheep should have been parallel while those for the 1:1 ratio should have coincided. The only treatment to show these theoretical trends was the 3:1 ratio in the 1989/90 season and, to an extent, in the 1990/91 grazing season. The total seasonal forage demand data (Table 6.6) highlight the differences. Cattle on their own had a higher forage demand than sheep on their own despite being stocked at the same number of AUE ha^{-1} at the start of the season.

These data suggest that cattle and sheep are not comparable in terms of AUE ha^{-1} and that defining grazing capacity in terms of AUE ha^{-1} is incorrect! Not considered in this chapter, however, was the effect of cattle-to-sheep ratio and stocking rate on defoliation patterns of different species and areas in the sward. Such data are required to test whether a similar grazing impact on the sward occurs when the area is stocked at equivalent seasonal AUE ha^{-1} of cattle or sheep, or a mixture of cattle and sheep.

le 6.1 Coefficients of determination (R^2) of polynomial functions fitted to the animal mass on time data for each stocking rate (low, medium and high) and ratio treatment in each season.

		1989/90		1990/91		1991/92	
ocking te	Ratio	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep
w	1:0	[1]Quad 96.2***		Quad 96.8***		Quad 91.7***	
	3:1	Quad 95.3***	Quad 73.0***	Quad 97.1***	Quad 41.4*	Quad 83.8***	Quad 45.2*
	1:1	Quad 98.0***	Quad 94.9***	Quad 96.7***	[3]Lin –	Quad 82.4***	Quad 17.2^{ns}
	1:3	Quad 92.7***	Quad 86.5***	Quad 97.4***	Quad 28.1^{ns}	Quad 96.9***	Lin –
	0:1		Quad 88.8***		Quad 11.2^{ns}		Lin –
dium	1:0	Quad 96.6***		Quart 98.6***		Quad 96.6***	
	3:1	Quad 95.5***	[2]Quart 89.9***	Quart 99.6***	Quart 82.4***	Quad 99.0***	Quart 72.9***
	1:1	Quad 97.5***	Quart 91.0***	Quart 99.6***	Quart 58.5***	Quad 97.4***	Quart 76.0***
	1:3	Quad 97.6***	Quart 93.5***	Quart 99.1***	Quart 70.8***	Quad 96.1***	Quart 44.2*
	0:1		Quart 97.5***		Quart 76.4***		Quart 72.0***
gh	1:0	Quad 98.0***		Quad 96.6***		Quad 91.6***	
	3:1	Quad 98.8***	Quad 4.2^{ns}	Quad 95.1***	Quad –	Quad 83.7***	Lin –
	1:1	Quad 98.7***	Quad 95.3**	Quad 94.8***	Quad 33.6*	Quad 94.0***	Lin –
	1:3	Quad 97.6***	Quad 89.0***	Quad 97.4***	Quad 10.8^{ns}	Quad 82.4***	Lin –
	0:1		Quad 88.9***		Quad 5.5^{ns}		Quad 33.1^{ns}

[1] Quad = quadratic function [2] Quart = quartic function [3] Lin = linear function

*** = $P < 0.001$ ** = $P < 0.01$ * = $P < 0.05$ ^{ns} = $P > 0.05$

– = residual variance exceeds variance of the y variate

Table 6.2 Correlation coefficients (r) for the linear functions fitted to the %DOM of forage selected by cattle and by sheep in the low, medium and high stocking rate, for each ratio treatment, through the 1989/90 grazing season

		r	
		Cattle	Sheep
Low	1:0	0.89**	
	3:1	0.74*	0.96***
	1:1	0.75*	0.96***
	1:3	0.92***	0.97*
	0:1		0.90*
Medium	1:0	0.72***	
	3:1	0.84***	0.77***
	1:1	0.85***	0.82***
	1:3	0.77***	0.80***
	0:1		0.79***
High	1:0	0.93***	
	3:1	0.68*	0.91***
	1:1	0.87**	0.98***
	1:3	0.82**	0.88**
	0:1		0.94***

*** = $P < 0.001$ ** = $P < 0.01$ * = $P < 0.05$

Table 6.3 Stocking rate (animals ha^{-1}) of cattle and of sheep in each stocking rate (low, medium and high) and ratio (AU cattle:AU sheep) treatment for the 1989/90, 1990/91 and 1991/92 grazing seasons

		Stocking rate (animals ha^{-1})					
		1989/90		1990/91		1991/92	
Stocking rate	Ratio	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep
Low	1:0	1.23	–	1.23	–	1.23	–
	3:1	0.82	0.82	0.82	1.23	0.82	1.23
	1:1	0.62	1.85	0.62	2.47	0.62	2.47
	1:3	0.31	2.78	0.31	3.86	0.31	3.86
	0:1	–	4.17	–	5.00	–	5.00
Medium	1:0	1.74	–	1.76	–	1.74	–
	3:1	1.29	1.62	1.13	1.61	1.26	1.57
	1:1	0.87	2.78	0.86	3.60	0.88	3.51
	1:3	0.50	5.00	0.39	5.22	0.40	5.03
	0:1	–	6.20	–	6.30	–	6.45
High	1:0	2.30	–	2.30	–	2.30	–
	3:1	1.85	1.85	1.85	2.78	1.85	2.78
	1:1	1.23	4.32	1.23	4.94	1.23	4.94
	1:3	0.62	6.17	0.62	7.72	0.62	7.72
	0:1	–	8.33	–	10.00	–	10.00

le 6.4 The planned and actual stocking rates (SR in AUE ha^{-1}) applied at the START of each grazing season for each ratio treatment (AU cattle:AU sheep)

	Planned SR			Actual SR								
				1989/90			1990/91			1991/92		
Ratio	Cattle	Sheep	Total	Cattle	Sheep	Total	Cattle	Sheep	Total	Cattle	Sheep	Total
1:0	0.67	–	0.67	0.81	–	0.81	0.97	–	0.97	0.77	–	0.77
3:1	0.50	0.17	0.67	0.60	0.11	0.71	0.70	0.13	0.83	0.41	0.14	0.55
1:1	0.34	0.34	0.67	0.56	0.30	0.86	0.53	0.26	0.79	0.33	0.26	0.59
1:3	0.17	0.50	0.67	0.22	0.42	0.64	0.29	0.43	0.72	0.27	0.35	0.62
0:1		0.67	0.67	–	0.61	0.61	–	0.49	0.49	–	0.46	0.46
1:0	0.95	–	0.95	1.35	–	1.35	1.37	–	1.37	1.17	–	1.17
3:1	0.71	0.24	0.95	1.06	0.34	1.38	1.00	0.23	1.23	0.98	0.30	1.28
1:1	0.48	0.47	0.95	0.73	0.57	1.29	0.70	0.67	1.37	0.62	0.63	1.25
1:3	0.24	0.71	0.95	0.38	1.00	1.38	0.32	0.83	1.15	0.27	1.21	1.48
0:1	–	0.95	0.95	–	1.36	1.36	–	1.15	1.15	–	1.32	1.32
1:0	1.33	–	1.33	1.73	–	1.73	1.96	–	1.96	1.54	–	1.54
3:1	1.00	0.33	1.33	1.82	0.19	2.01	1.49	0.25	1.74	1.12	0.26	1.38
1:1	0.67	0.66	1.33	1.02	0.57	1.59	0.92	0.62	1.54	0.82	0.45	1.27
1:3	0.33	1.00	1.33	0.57	0.84	1.31	0.48	0.84	1.32	0.37	0.72	1.09
0:1	–	1.33	1.33	–	1.17	1.17	–	1.07	1.07	–	1.17	1.17

le 6.5 Stocking rate (SR in animal unit equivalents [AUE] per hectare) and ratio (AUE cattle:AUE sheep) treatments at the start of each season (PLANNED), the mean SR and ratio calculated from animal performance data for each of three grazing seasons (1989/90, 1990/91 & 1991/92), and the mean SR and ratio for each treatment over the three grazing seasons (MEAN)

PLANNED		1989/90		1990/91		1991/92		MEAN	
SR	RATIO	SR	RATIO	SR	RATIO	SR	RATIO	SR	RATIO
0.67	1:0	0.73	1:0	0.90	1:0	0.69	1:0	0.77	1:0
0.67	3:1	0.61	5.8:1	0.75	5.8:1	0.50	3.2:1	0.62	4.9:1
0.67	1:1	0.70	1.9:1	0.70	1.9:1	0.54	1.3:1	0.65	1.7:1
0.67	1:3	0.53	1:1.8	0.61	1:1.5	0.54	1:1.6	0.56	1:1.6
0.67	0:1	0.50	0:1	0.46	0:1	0.44	0:1	0.47	0:1
0.95	1:0	1.13	1:0	1.13	1:0	0.94	1:0	1.07	1:0
0.95	3:1	1.12	3.7:1	1.02	4.4:1	0.96	4.3:1	1.03	4.1:1
0.95	1:1	0.97	1.7:1	1.02	1.4:1	0.90	1.3:1	0.96	1.5:1
0.95	1:3	0.95	1:1.9	0.85	1:2.1	0.86	1:2.6	0.89	1:2.2
0.95	0:1	0.81	0:1	0.72	0:1	0.74	0:1	0.76	0:1
1.33	1:0	1.49	1:0	1.68	1:0	1.43	1:0	1.53	1:0
1.33	3:1	1.59	7.8:1	1.60	6:1	1.19	4:1	1.46	5.9:1
1.33	1:1	1.37	1.9:1	1.44	1.6:1	1.12	1.6:1	1.31	1.7:1
1.33	1:3	1.19	1:1.6	1.16	1:1.8	1.01	1:2.1	1.12	1:1.8
1.33	0:1	1.00	0:1	0.96	0:1	0.98	0:1	0.98	0:1

le 6.6 Estimated forage demand in each grazing season (FD in kgDM ha^{-1}) by the cattle and the sheep for each of the planned stocking rates (SR low, medium and high) and ratio (AUE cattle:AUE sheep) treatments

Planned		Fodder demand								
		1989/90			1990/91			1991/92		
SR	Ratio	Cattle	Sheep	Total	Cattle	Sheep	Total	Cattle	Sheep	Total
Low	1:0	1199	–	1199	1490	–	1490	1221	–	1221
Low	3:1	888	169	1057	1110	208	1319	701	238	939
Low	1:1	777	440	1217	795	454	1249	563	469	1032
Low	1:3	308	624	932	389	696	1085	354	665	1019
Low	0:1	–	904	904	–	856	856	–	864	864
edium	1:0	1860	–	1860	1858	–	1858	1566	–	1566
edium	3:1	1441	394	1835	1349	327	1676	1282	317	1604
edium	1:1	992	583	1575	954	746	1700	825	692	1517
edium	1:3	555	1008	1563	454	1008	1462	394	1079	1473
edium	0:1	–	1333	1333	–	1257	1257	–	1289	1289
High	1:0	2497	–	2497	2836	–	2836	2584	–	2584
High	3:1	2431	336	2767	2413	432	2845	1744	476	2220
High	1:1	1478	874	2352	1487	1028	2515	1221	836	2057
High	1:3	792	1299	2091	731	1361	2092	595	1337	1932
High	0:1	–	1891	1891	–	1838	1838	–	1979	1979

le 6.7 The forage demand (kgDM ha^{-1} a^{-1}) in each grazing season (year – 1989/90, 1990/91, 1991/92) by the cattle and sheep in each ratio (1:0, 3:1, 1:1, 1:3, 0:1) of the medium stocking rate treatment (S5 area) – the small variation in stocking rate between seasons was a function of the size of the paddocks allocated to the animals during a particular grazing season

Year	Ratio	Stocking rate (Animals ha^{-1})		Forage demand	
		Cattle	Sheep	Cattle	Sheep
1989/90	1:0	1.74	–	1860	–
	3:1	1.29	1.62	1441	394
	1:1	0.87	2.78	992	583
	1:3	0.50	5.00	552	1008
	0:1	–	6.20	–	1333
1990/91	1:0	1.76	–	1858	–
	3:1	1.13	1.61	1349	327
	1:1	0.86	3.60	954	746
	1:3	0.39	5.22	454	1008
	0:1	–	6.30	–	1257
1991/92	1:0	1.74	–	1566	–
	3:1	1.26	1.57	1282	317
	1:1	0.88	3.51	825	692
	1:3	0.40	5.03	394	1079
	0:1	–	6.45	–	1289

ble 6.8 Coefficients for the regression of forage demand (kg $animal^{-1}$ a^{-1}) of cattle and of sheep as a function of stocking rate (SR – animal ha^{-1}) of cattle and sheep

Forage demand	Constant	Cattle SR	Sheep SR	n	R^2
Cattle	1114	380	–158	12	96.1***
Sheep	184	–97	175	12	98.8***

*** = $P < 0.001$

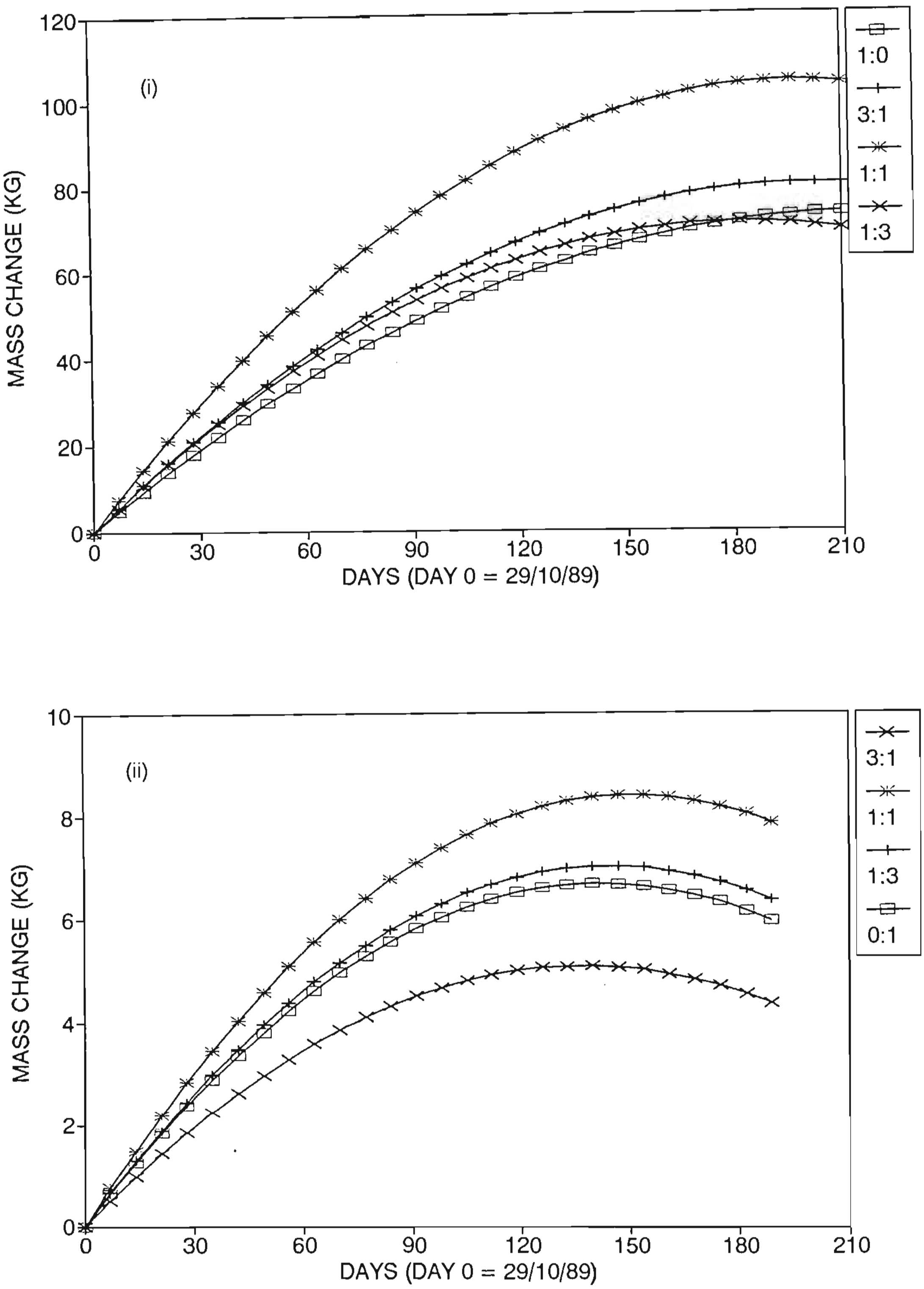
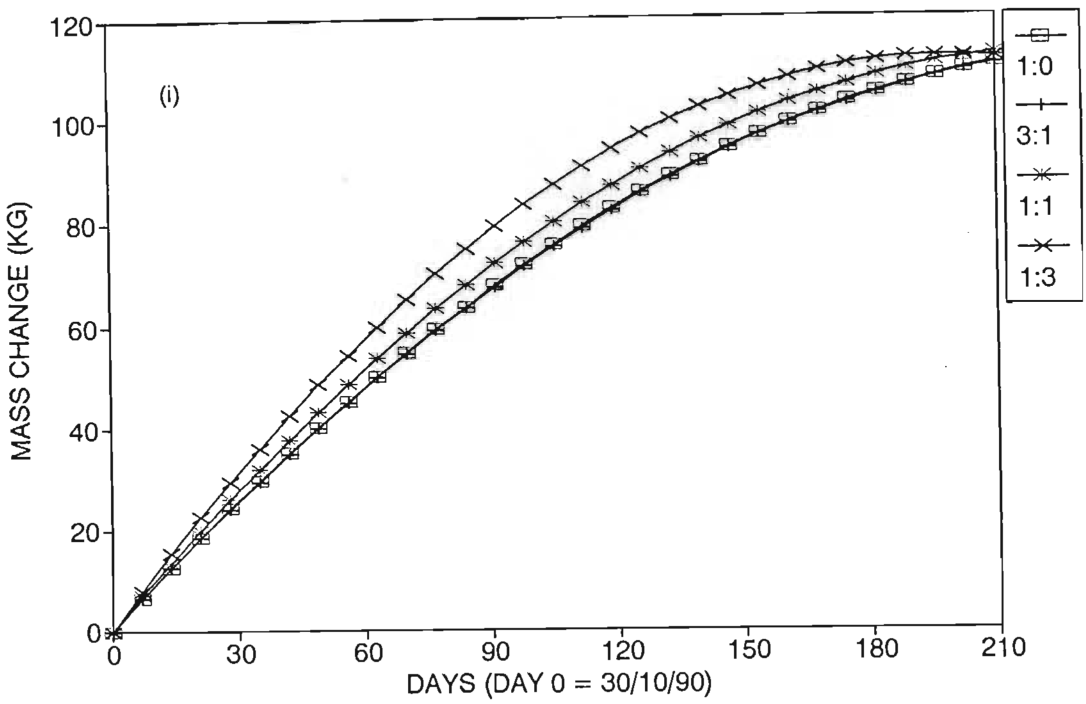


Figure 6.1a Mean cumulative mass change (kg animal^{-1}) of the cattle (i) and of the sheep (ii) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 and 0:1) for the low stocking rate treatment during the 1989/90 grazing season



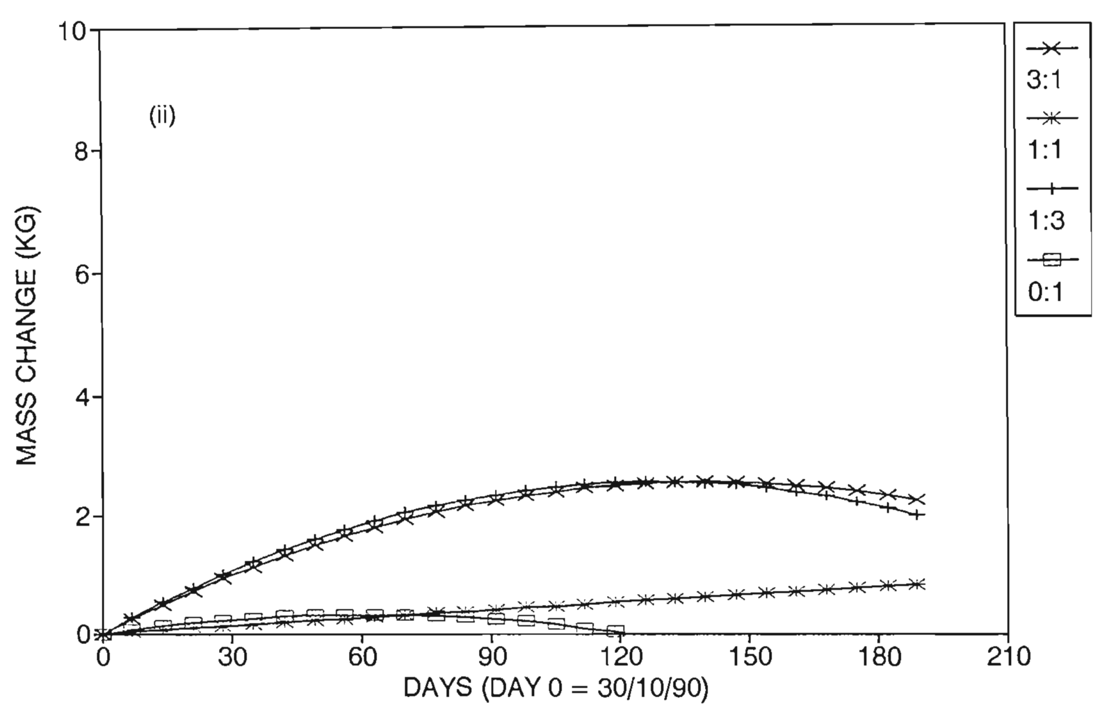


Figure 6.1b Mean cumulative mass change (kg animal^{-1}) of the cattle (i) and of the sheep (ii) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 and 0:1) for the low stocking rate treatment during the 1990/91 grazing season

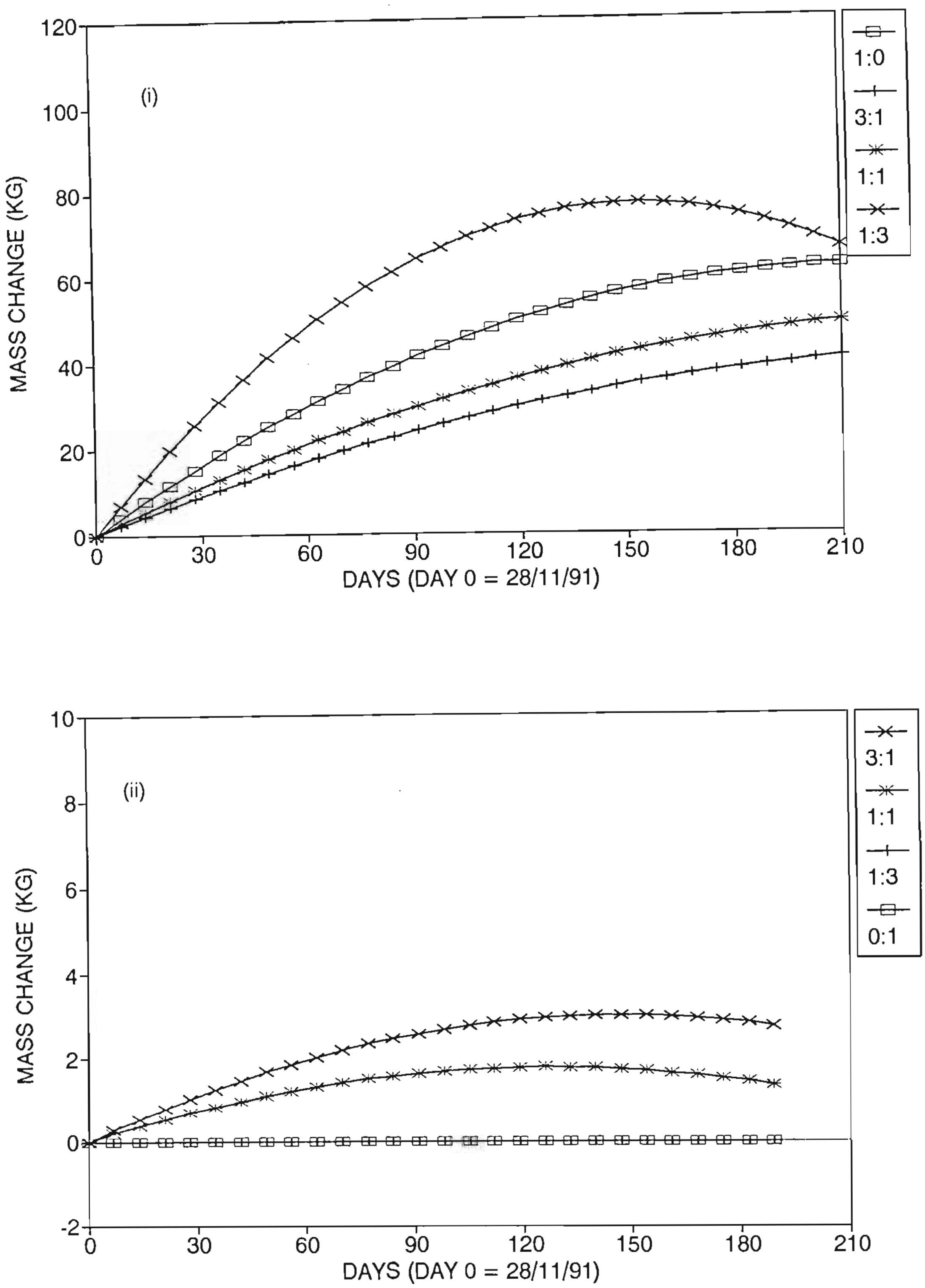


Figure 6.1c Mean cumulative mass change (kg animal^{-1}) of the cattle (i) and of the sheep (ii) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 and 0:1) for the low stocking rate treatment during the 1991/92 grazing season

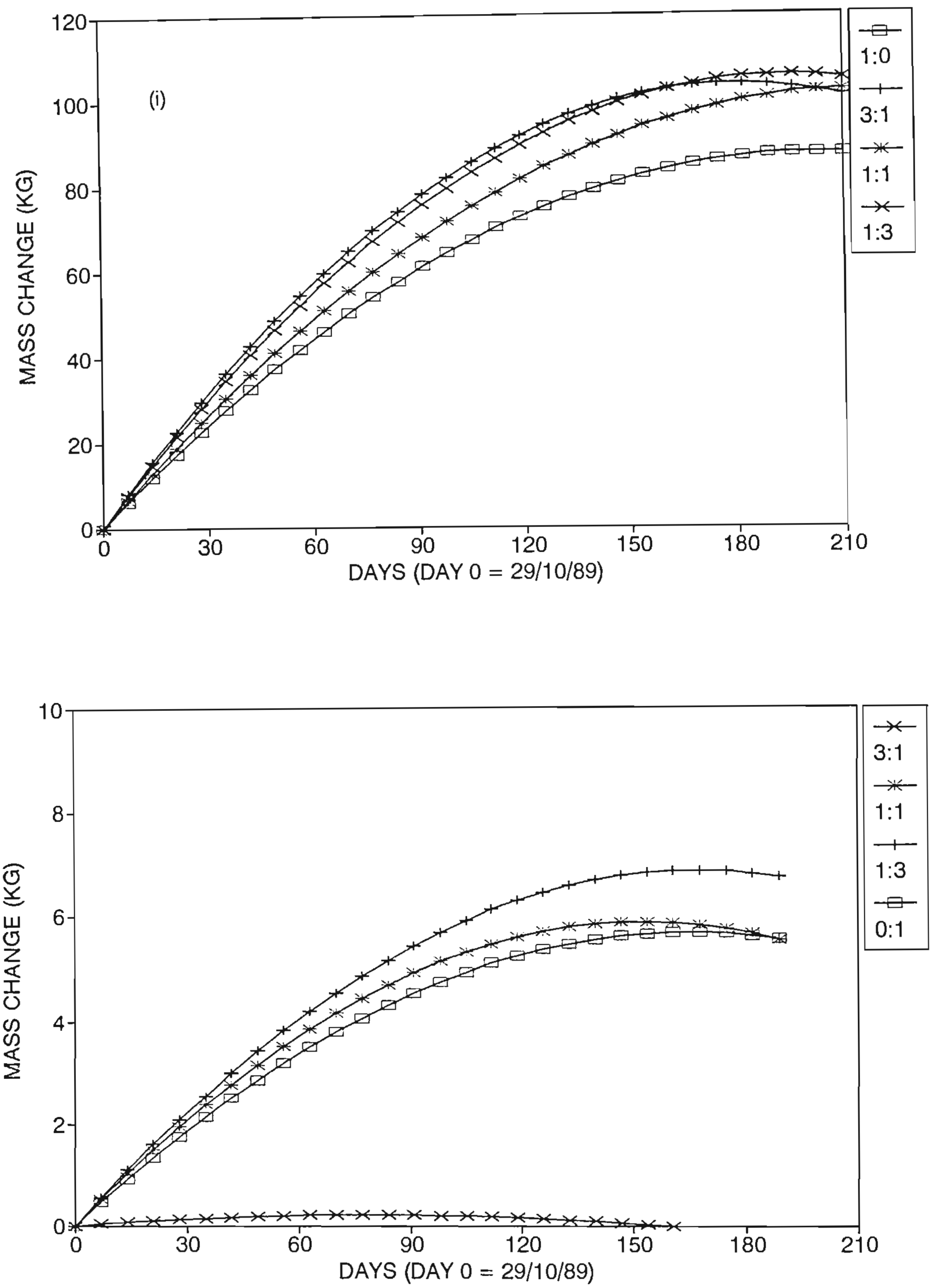


Figure 6.2a Mean cumulative mass change (kg animal^{-1}) of the cattle (i) and of the sheep (ii) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 and 0:1) for the high stocking rate treatment during the 1989/90 grazing season

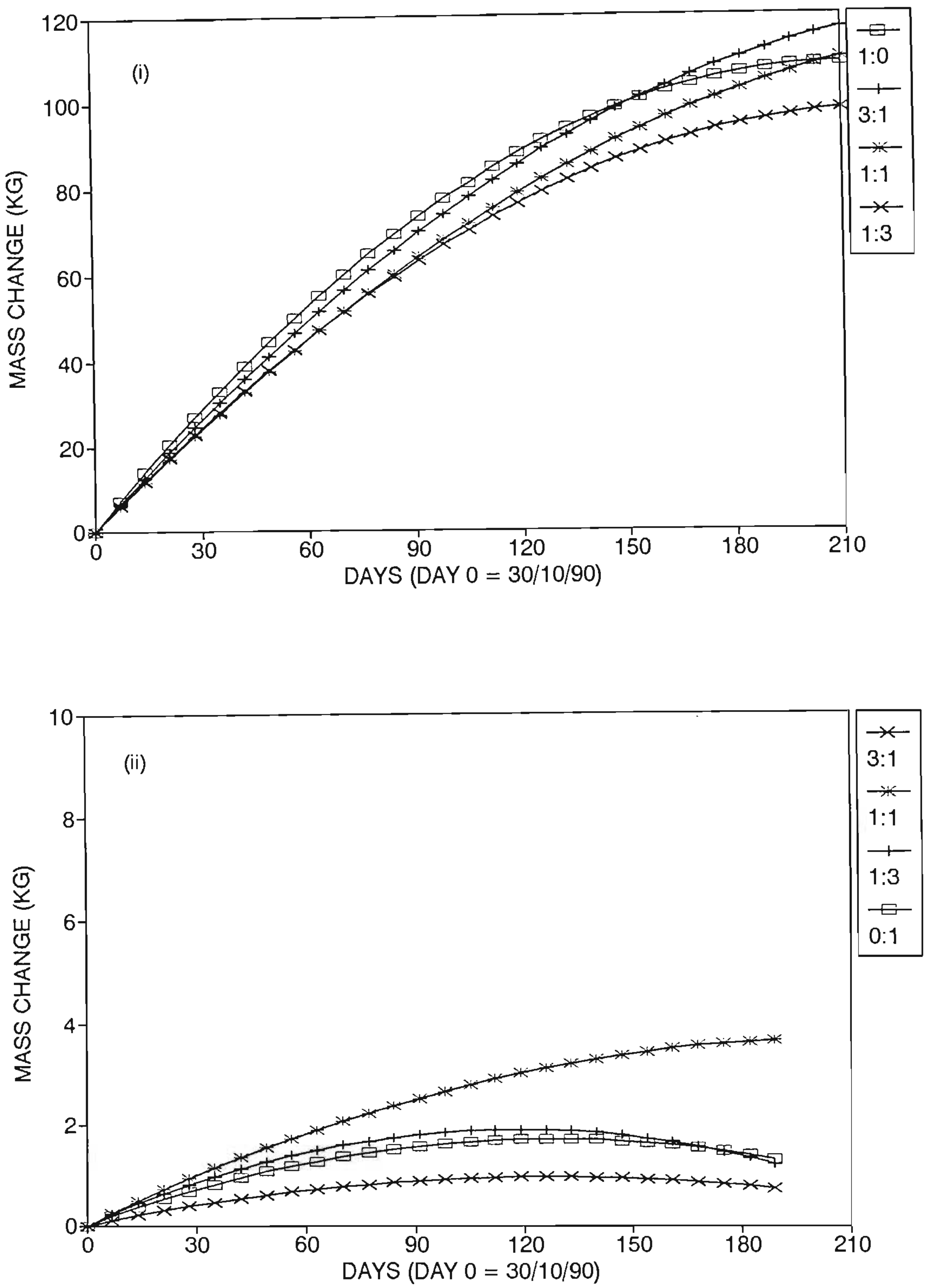


Figure 6.2b Mean cumulative mass change (kg animal^{-1}) of the cattle (i) and of the sheep (ii) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 and 0:1) for the high stocking rate treatment during the 1990/91 grazing season

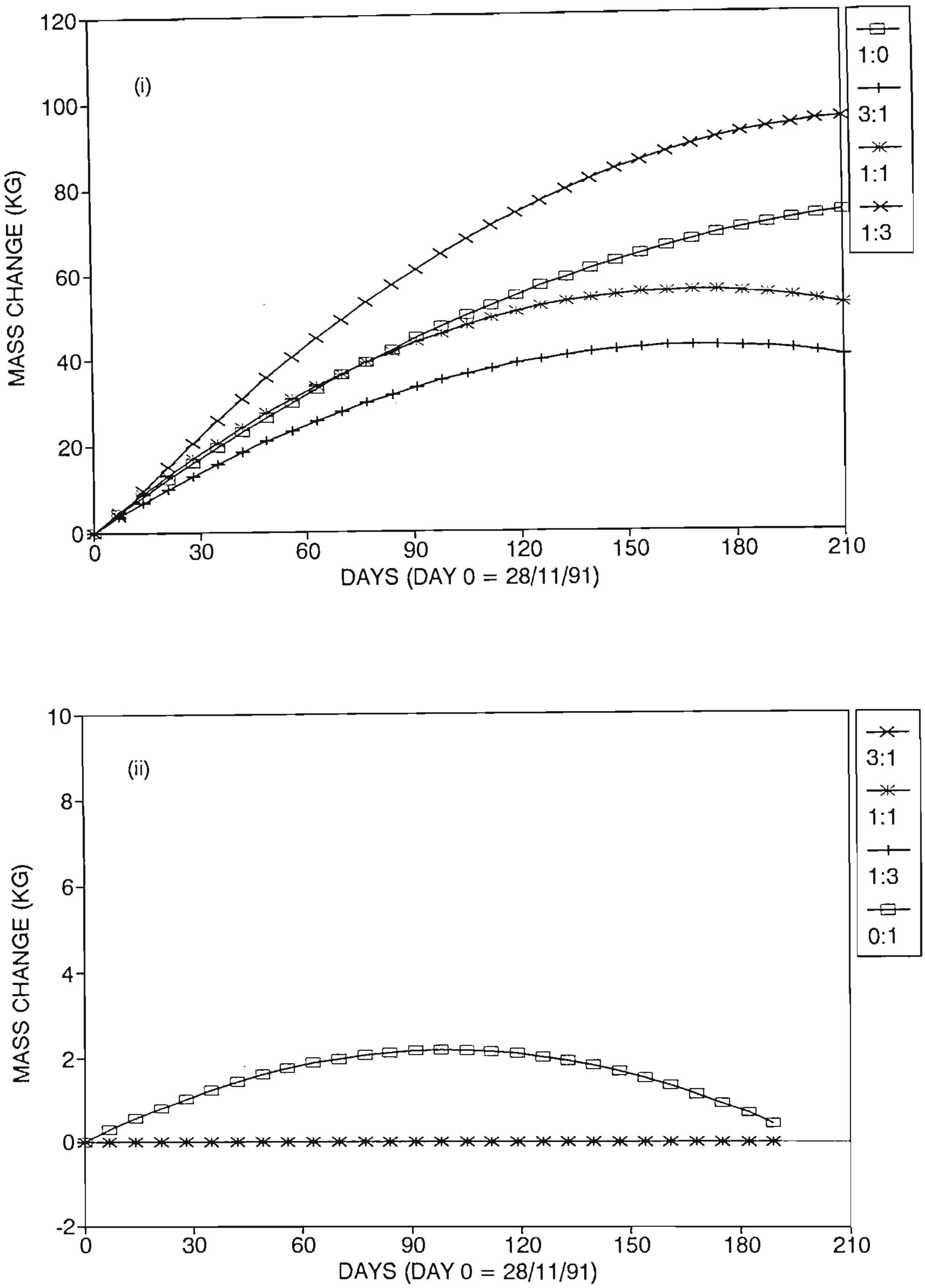


Figure 6.2c Mean cumulative mass change (kg animal^{-1}) of the cattle (i) and of the sheep (ii) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 and 0:1) for the high stocking rate treatment during the 1991/92 grazing season

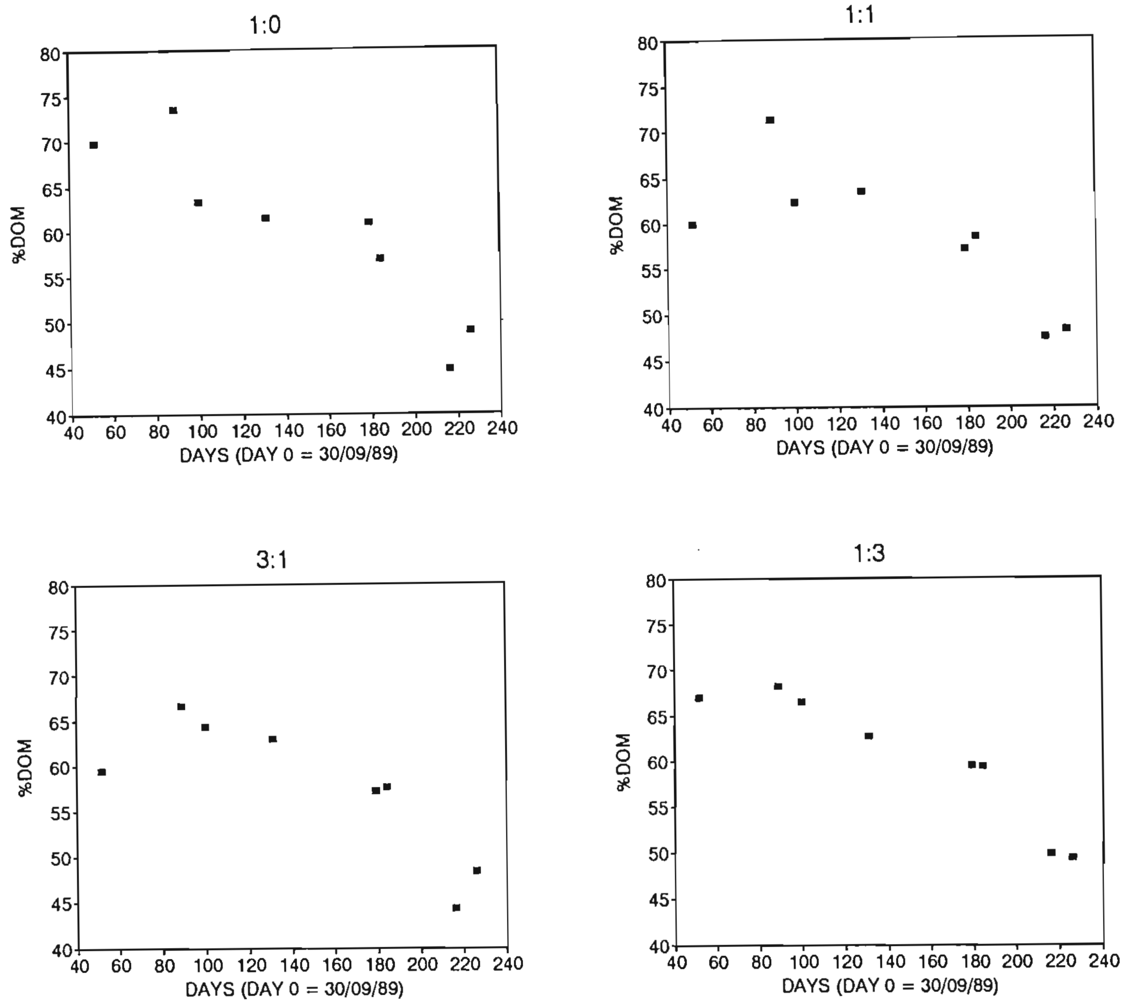


Figure 6.3 Digestible organic matter (%DOM) of forage selected by cattle in each cattle to sheep ratio treatment (1:0, 3:1, 1:1 & 1:3) through the 1989/90 grazing season for the low stocking rate treatment

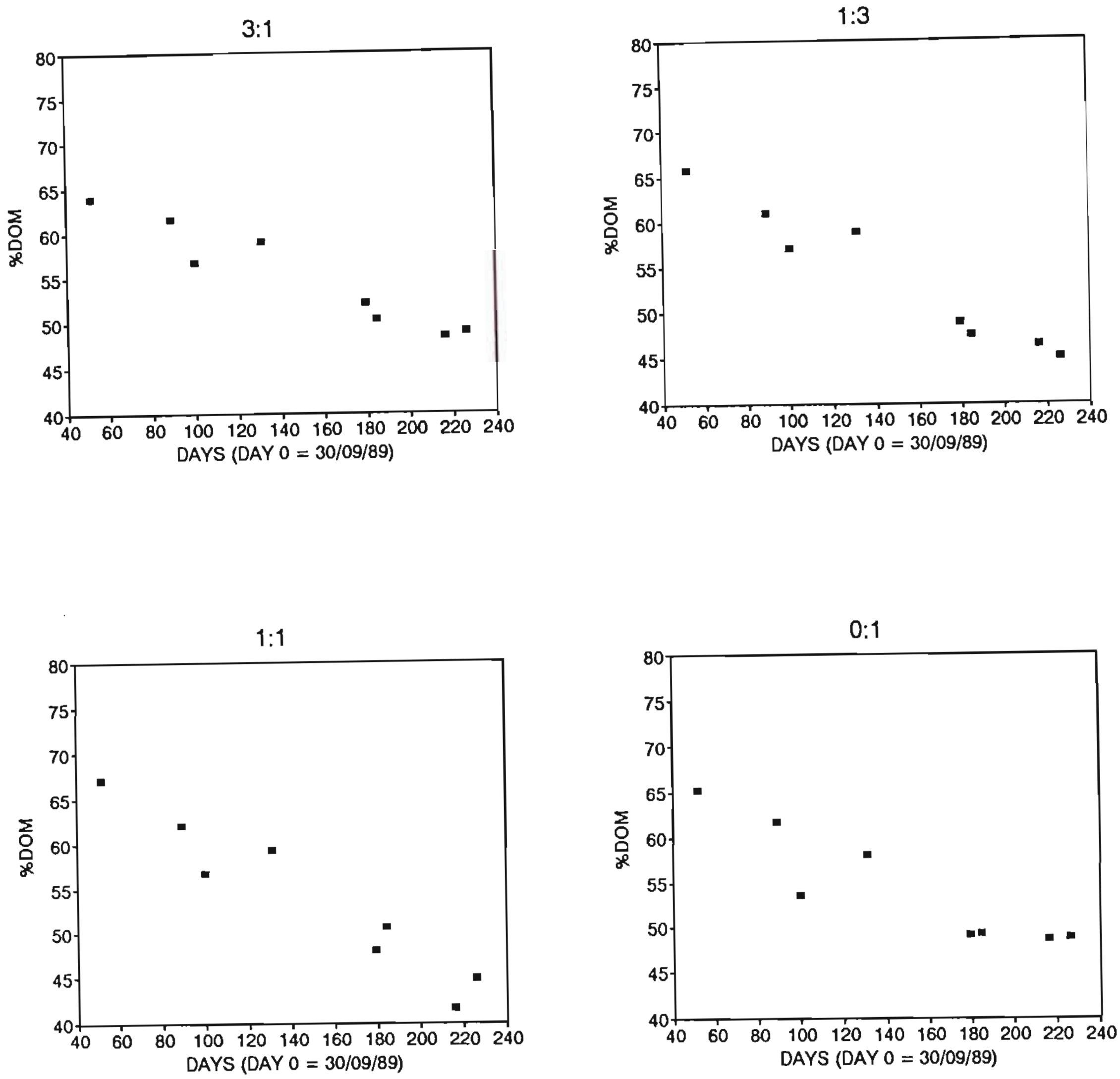


Figure 6.4 Digestible organic matter (%DOM) of forage selected by sheep in each cattle to sheep ratio treatment (3:1, 1:1, 1:3 & 0:1) through the 1989/90 grazing season for the low stocking rate treatment

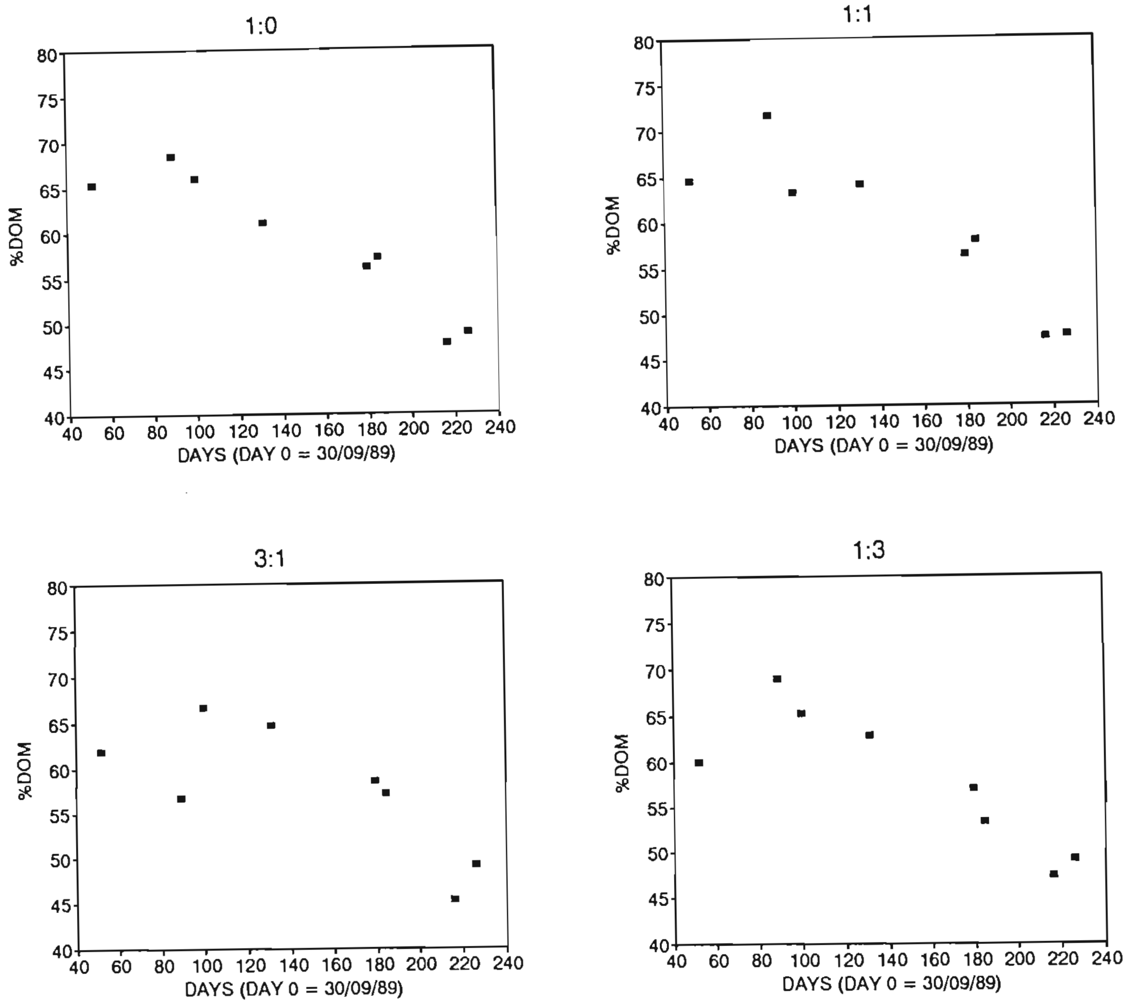


Figure 6.5 Digestible organic matter (%DOM) of forage selected by cattle in each cattle to sheep ratio treatment (1:0, 3:1, 1:1 & 1:3) through the 1989/90 grazing season for the high stocking rate treatment

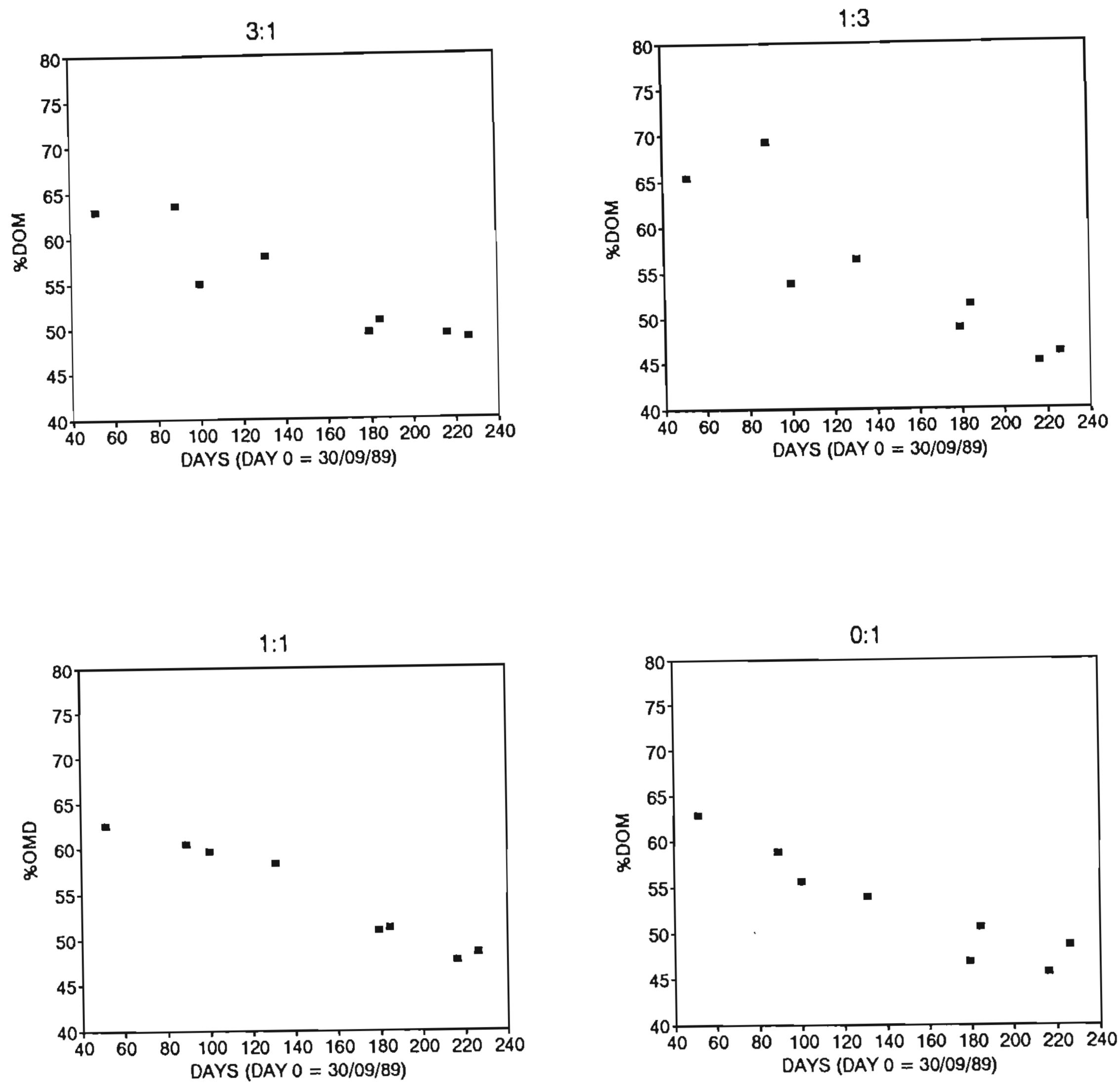


Figure 6.6 Digestible organic matter (%DOM) of forage selected by sheep in each cattle to sheep ratio treatment (3:1, 1:1, 1:3 & 0:1) through the 1989/90 grazing season for the high stocking rate treatment

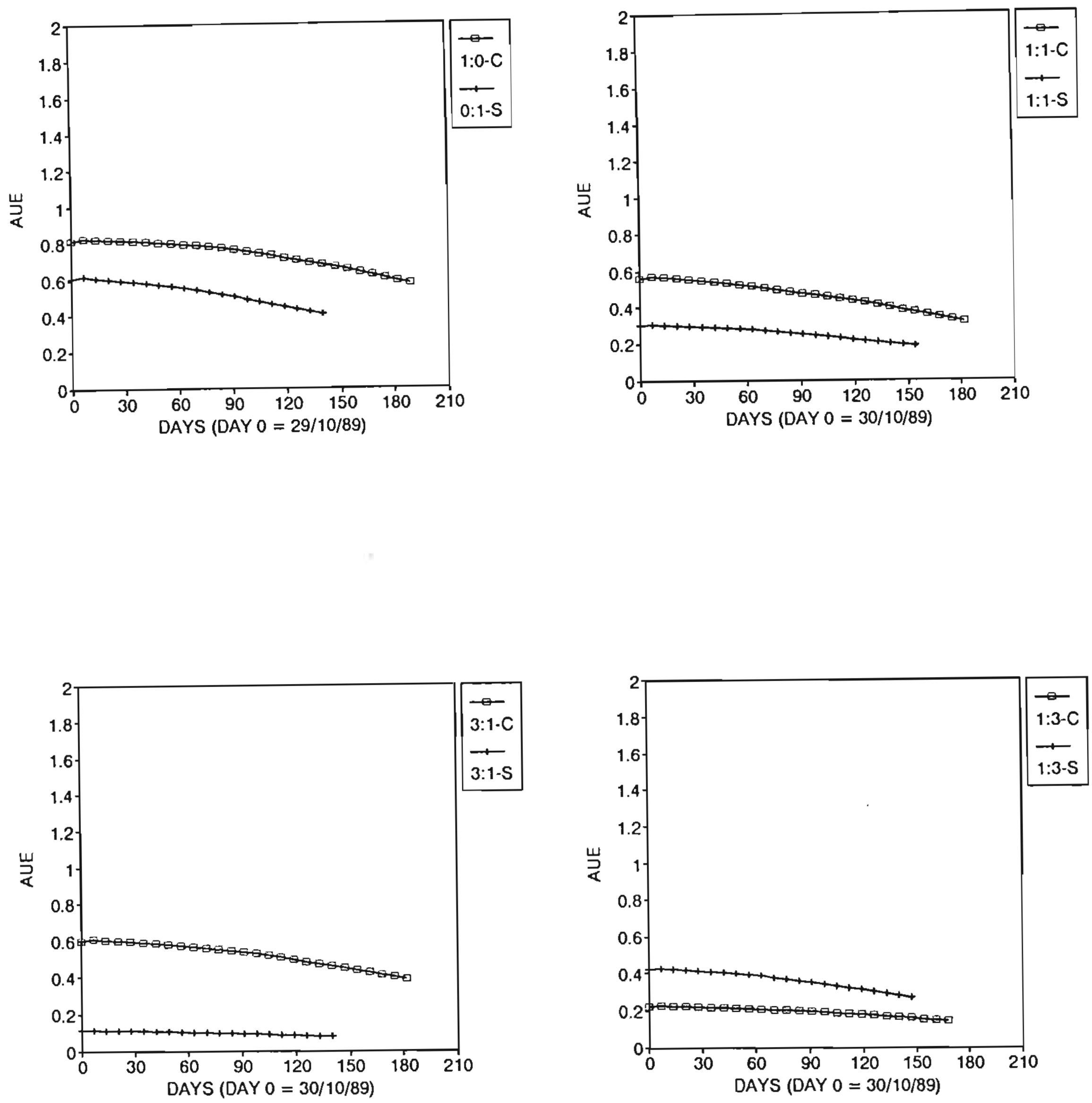


Figure 6.7a Seasonal trends in AUE ha^{-1} of cattle (C) and sheep (S) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for the low stocking rate treatment during the 1989/90 grazing season

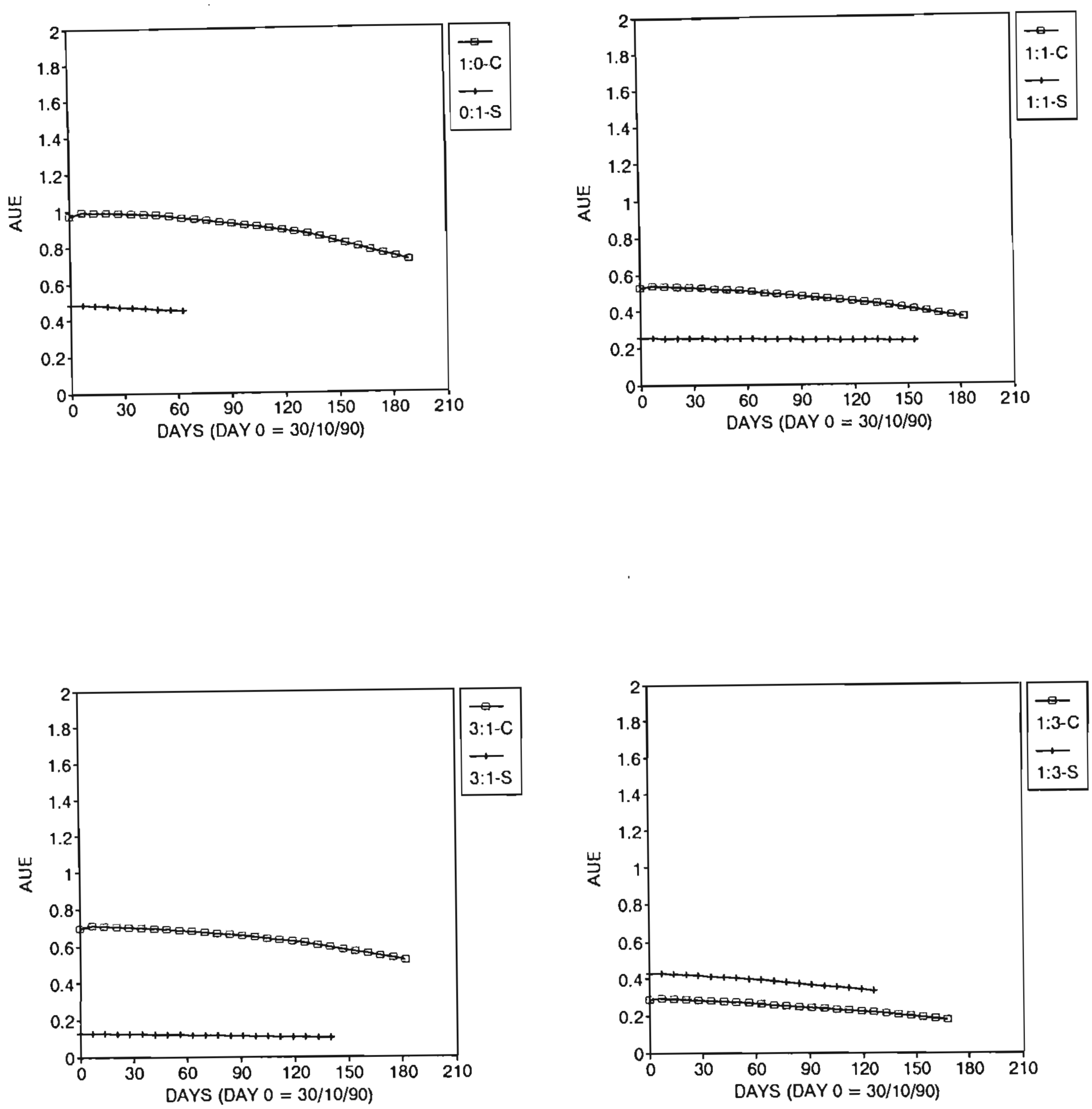


Figure 6.7b Seasonal trends in AUE ha^{-1} of cattle (C) and sheep (S) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for the low stocking rate treatment during the 1990/91 grazing season

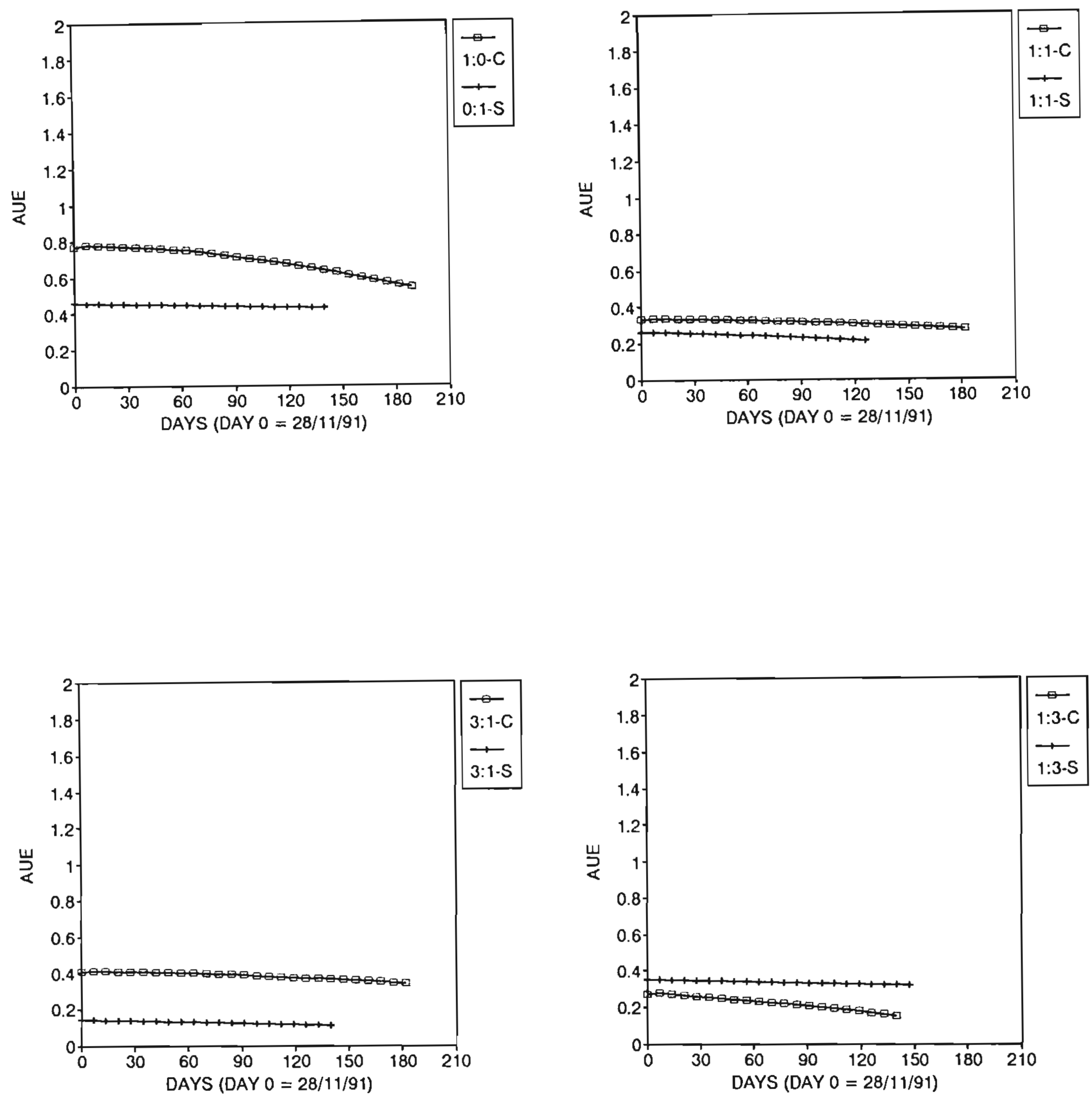


Figure 6.7c Seasonal trends in AUE ha^{-1} of cattle (C) and sheep (S) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for the low stocking rate treatment during the 1991/92 grazing season

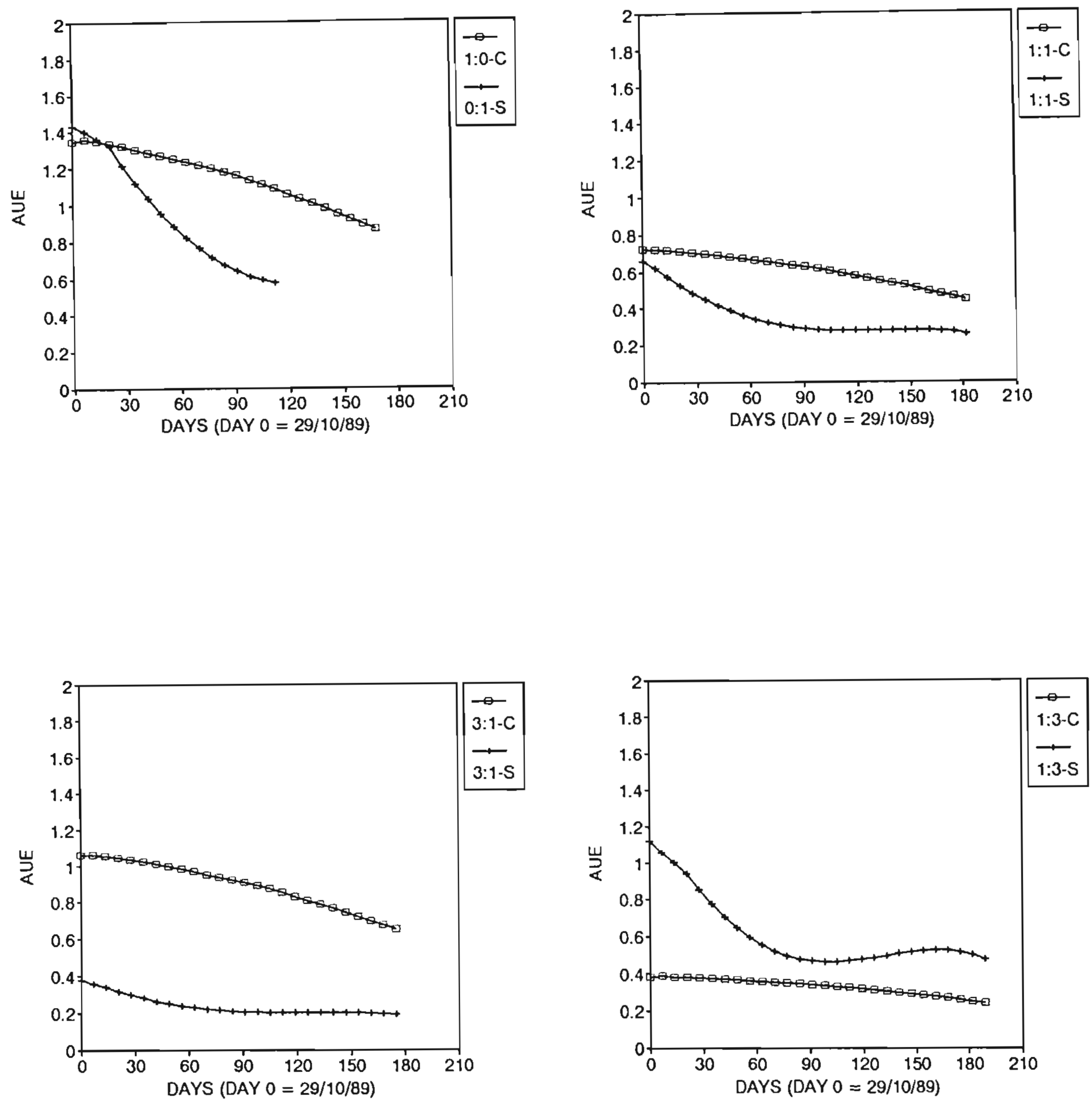


Figure 6.8a Seasonal trends in AUE ha^{-1} of cattle (C) and sheep (S) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for the medium stocking rate treatment during the 1989/90 grazing season

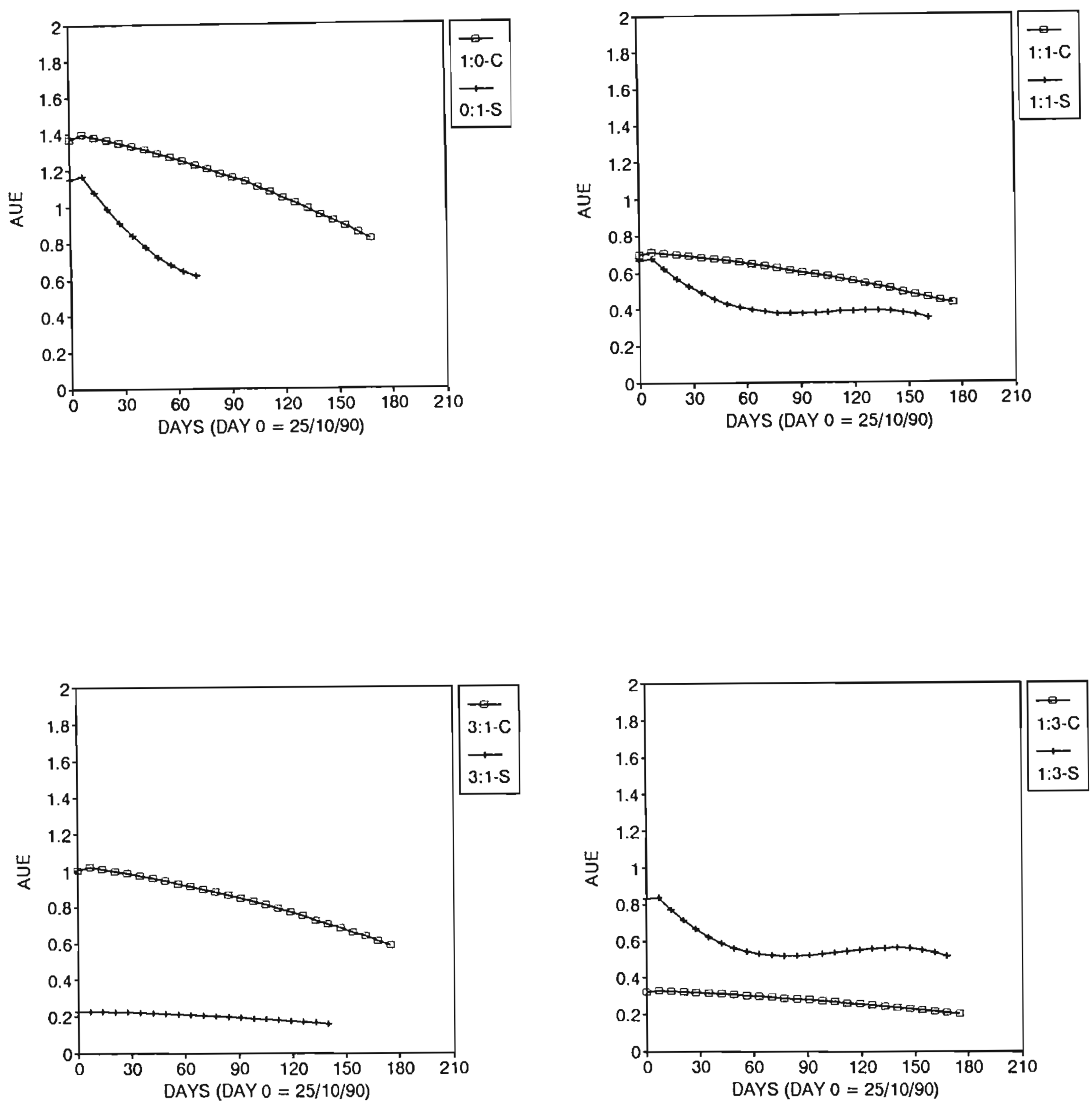


Figure 6.8b Seasonal trends in AUE ha^{-1} of cattle (C) and sheep (S) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for the medium stocking rate treatment during the 1990/91 grazing season

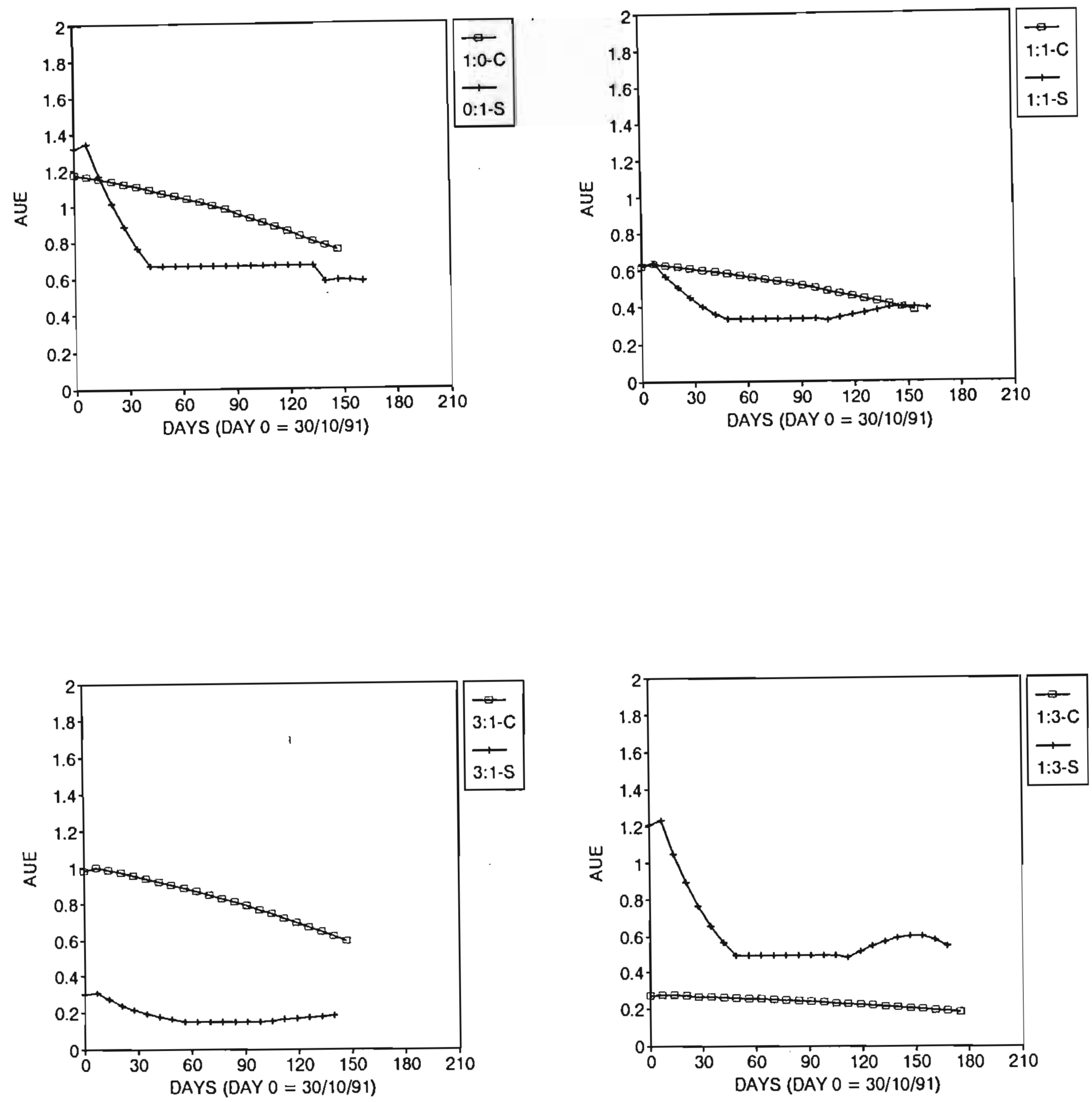


Figure 6.8c Seasonal trends in AUE ha^{-1} of cattle (C) and sheep (S) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for the medium stocking rate treatment during the 1991/92 grazing season

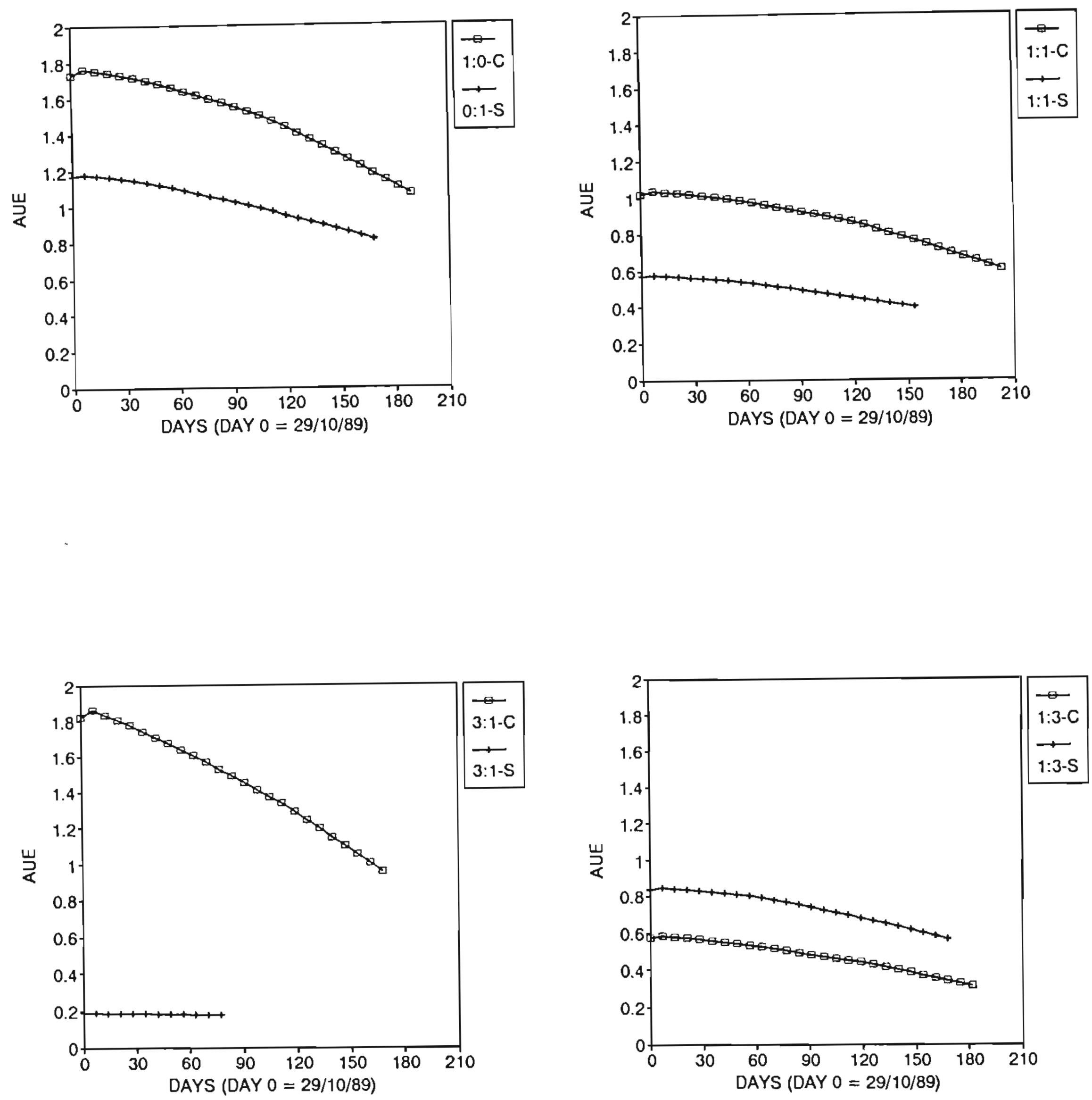


Figure 6.9a Seasonal trends in AUE ha^{-1} of cattle (C) and sheep (S) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for the high stocking rate treatment during the 1989/90 grazing season

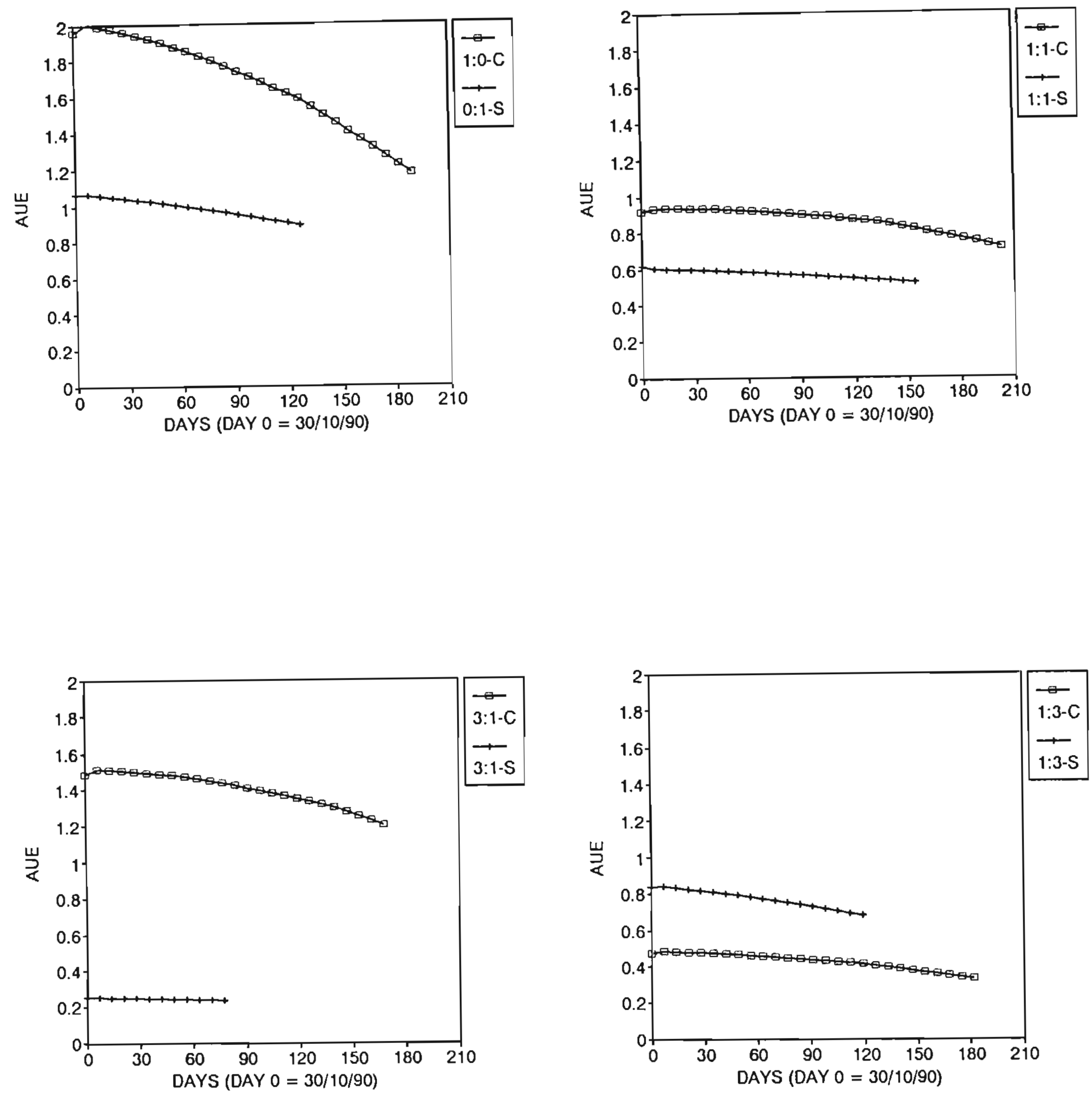


Figure 6.9b Seasonal trends in AUE ha^{-1} of cattle (C) and sheep (S) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for the high stocking rate treatment during the 1990/91 grazing season

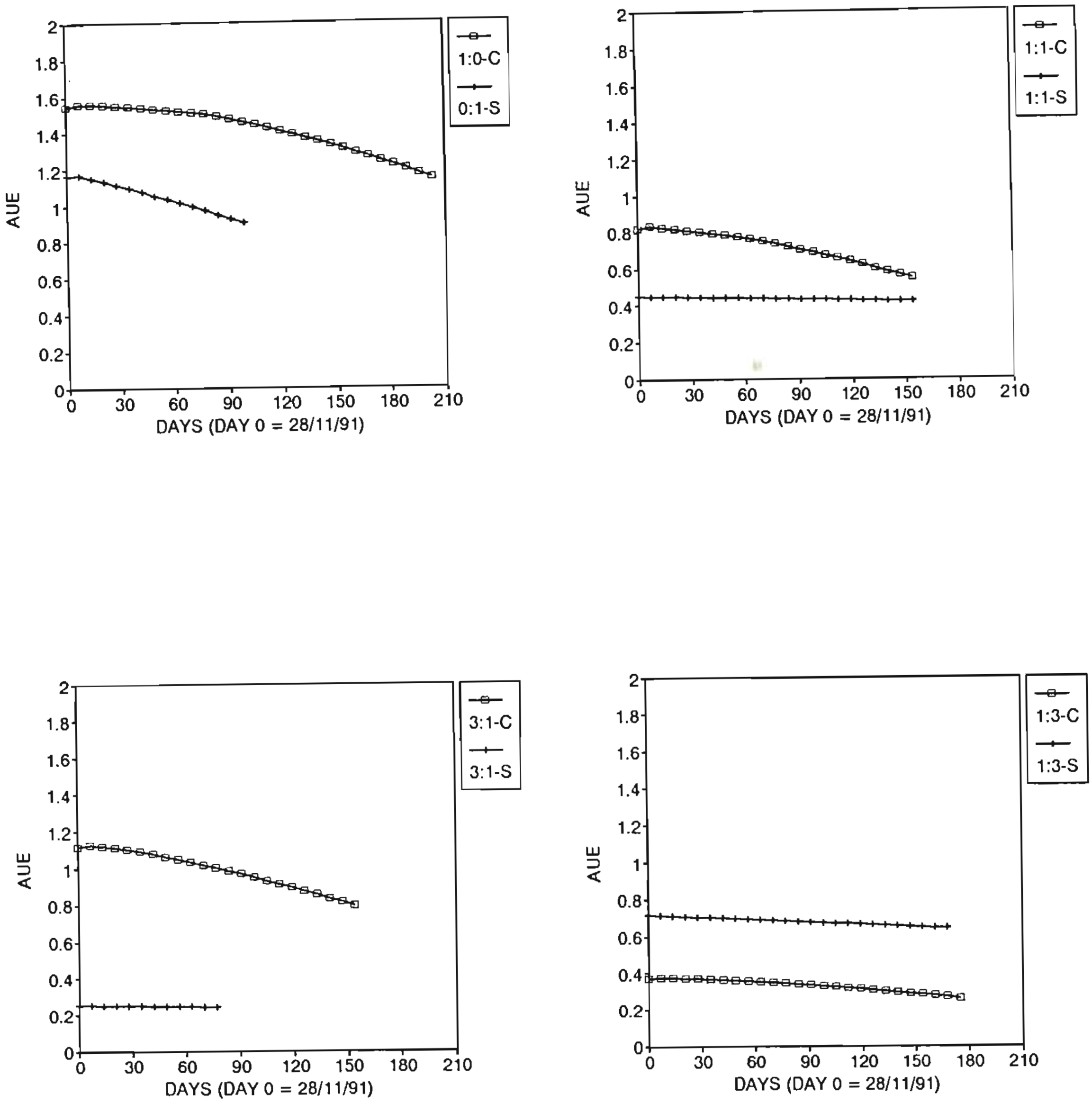


Figure 6.9c Seasonal trends in AUE ha^{-1} of cattle (C) and sheep (S) in each cattle to sheep ratio treatment (1:0, 3:1, 1:1, 1:3 & 0:1) for the high stocking rate treatment during the 1991/92 grazing season

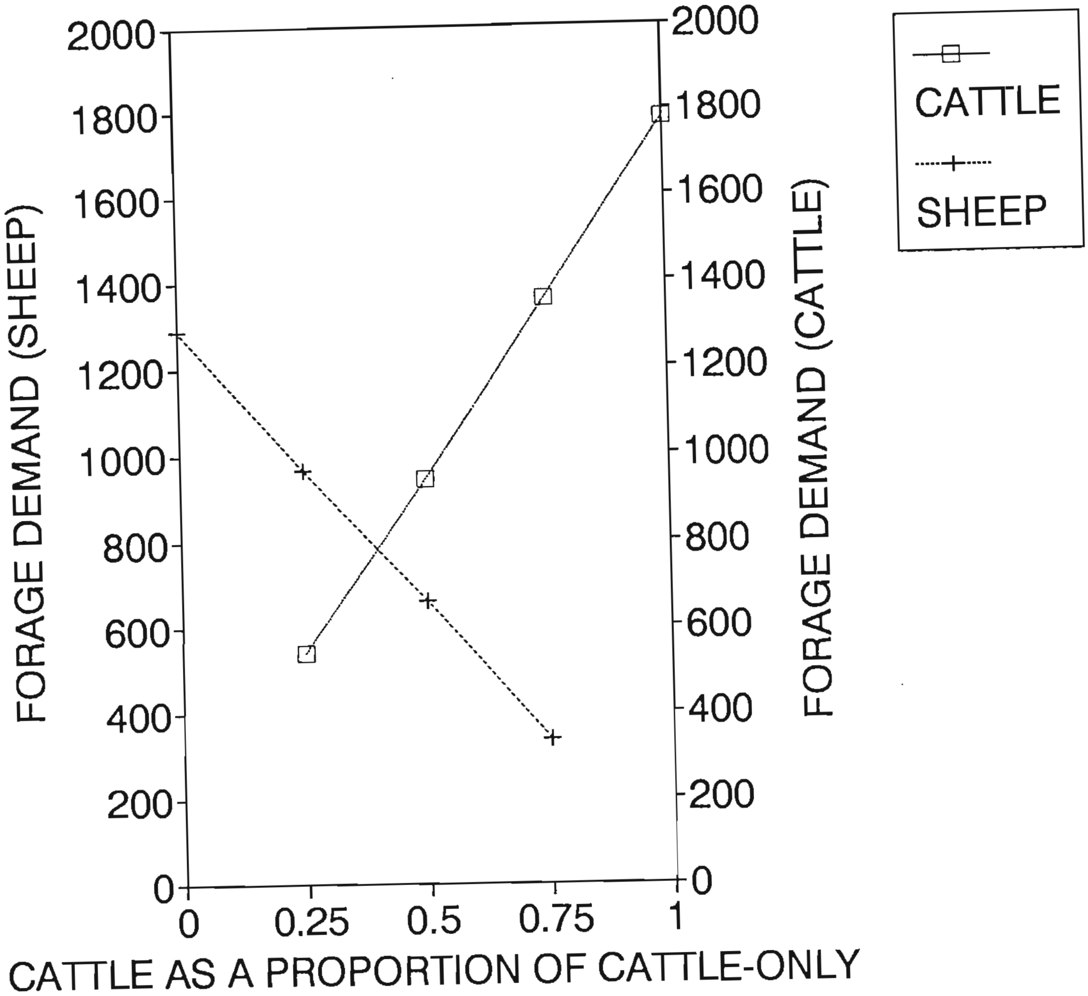


Figure 6.10 Predicted seasonal forage demand (kgDM ha^{-1} a^{-1}) for the cattle and the sheep as a function of the proportions of cattle relative to the cattle-only stocking rate - see text for more detail on stocking rates of cattle and of sheep

CHAPTER 7

THE EFFECT OF CATTLE TO SHEEP RATIO AND STOCKING RATE ON DEFOLIATION PATTERNS OF THREE GRASS SPECIES

The purpose of this chapter is to present a characterization of the impact of grazing, on individual grass plants, by cattle and sheep in Highland Sourveld.

7.1 Procedure

Point-based measures have been applied by several workers to record the degree of selection for, and the intensity of grazing of, individual plant species within livestock production systems. One approach has been to identify, at each of a number of systematically placed points, the plant nearest to the point and place it into a utilization category (Kruger & Edwards 1972). An alternative approach has been to identify a group of target species prior to the survey and then to locate the nearest individual of each of the target species to the point and record their utilization category (O'Reagain & Mentis 1989a). The data obtained from such surveys have been used to index the relative palatability and acceptability of the different species encountered. A similar approach was applied in the present study.

Surveys were conducted in all paddocks of the simulated component (N2) and in each of the 'test' paddocks in the animal production component (S5) of the trial in May/June at the end of the first, second and third grazing seasons. As dictated by the management system (see chapter 4), these selected paddocks were burned only once during the three year period, i.e. before the start of the first growing season. Residual herbage therefore accumulated from one season to the next, its amount and distribution being a function of grazing treatment.

A systematic point-sampling procedure was applied to ensure an even distribution of observations within each paddock. At each of 100 point positions the nearest individual of each of three target species (*Themeda triandra*, *Tristachya leucothrix* and *Alloteropsis semialata*) was observed and placed into one of five defoliation categories. The categories were: not grazed (U), grazed leniently but partially (LP), grazed leniently and uniformly (L), grazed severely but partially (SP), and grazed severely and uniformly (S). Tufts were considered to be uniformly grazed if, by visual estimation, more than two thirds of the tillers had been grazed. Partial defoliation was differentiated from uniform defoliation as both defoliation categories are commonly observed in grazed veld. Furthermore, the regrowth potential and the reaction of plants to grazing is likely to be influenced by uniformity of defoliation (Olson & Richards 1988). Defoliation was classed as 'severe' if the grazed portion of the tuft was <2.5cm above crown height for *T. triandra* and *T. leucothrix* and <3.5cm above ground level for *A. semialata*. These 'cutoff' levels were selected on the basis of the results of a preliminary study which indicated that the minimum heights to which cattle (stocked at <1.0 AU ha^{-1}) would graze *T. triandra* and *T. leucothrix*, and *A. semialata* were >3.0cm and >4.0cm respectively, whilst sheep stocked at the same levels would graze these species to a lower mean height.

The choice of *T. triandra* and *T. leucothrix* as target species was based on preliminary observation which indicated that the probability of encountering these species within a radius of 15cm of a randomly placed point in the study area was >0.95. *Alloteropsis semialata* was selected as a target species because its growth habit and leaf structure made it relatively easy to locate in dense swards. Search time at each point was therefore minimised.

The proportion of the three target species, expressed as a percentage of total species composition in each of the sample paddocks, was determined at the start of the trial (Table 7.1).

7.2 Data analysis

The defoliation patterns on the three target species were examined as a function of the **actual** (see Chapter 6) cattle-to-sheep ratio and stocking rate treatments.

7.2.1 Log linear analysis

Log linear analyses (Tabachnick & Fidell 1989) were performed on the data for each species to examine the main and two-factor interaction effects of stocking rate, ratio and year on defoliation patterns.

7.2.2 Canonical correspondence analysis

Canonical correspondence analysis (CCA; ter Braak 1986), an ordination technique, was used to examine and illustrate the relationship between the variation in defoliation pattern across sites and the actual stocking rate and ratio treatments implemented at each site over three years. Separate CCAs were performed for each of the target species, with grazing categories as the dependent variable, and stocking rate, ratio and time as the independent environmental variables. For purposes of the analyses the ratio of cattle to sheep was expressed as the percentage of sheep (AUE ha^{-1}) in each treatment. Data from the SP and S defoliation categories were combined for *T. triandra* and *A. semialata* as the SP category was poorly represented for these two species in all three years.

7.2.3 Graphical summary of data

The defoliation category data were summarised to illustrate the main, and interactive, effects of stocking rate and ratio on defoliation pattern. The following procedure was applied. First, data collected at the end of the third grazing season (1991/92) were examined on the assumption that these data reflected the combined effects of grazing over all three seasons. Second, the data were re-arranged to form three broad defoliation categories for each species viz. U, LP+L and SP+S. Third, stocking rates and ratios were recalculated as the mean stocking rates and ratios actually applied over the three year period for each treatment (Table 6.5). Fourth, for ease of comprehension and discussion, treatments with mean AUE cattle to AUE sheep ratios of 1.7:1, 1.5:1 and 1.7:1 ratios (see Table 6.5) were labelled as 2:1, and the 1:1.6, 1:2.2 and 1:1.8 ratios (see Table 6.5) were labelled as 1:2.

7.3 Results and discussion

7.3.1 Log linear analysis

Chi-squared values derived from the log linear analyses were adjusted to account for heterogeneity in the data sets (Finney 1964). The magnitude of a chi-squared value provides an indication of the relative contribution of the associated factor in influencing the dependent variable (Clarke pers. comm.). Stocking rate, cattle-to-sheep ratio and year, and their interactions (excepting the year*stocking rate interaction) had highly significant effects ($P < 0.001$) on the proportional composition of defoliation categories (Table 7.2). It is clear that for *T. triandra* and *T. leucothrix* stocking rate has a major influence on defoliation pattern, while for *A. semialata* both stocking rate and cattle-to-sheep ratio have a similar influence on defoliation pattern. These effects are, however, better illustrated from the results of the CCA.

7.3.2 Canonical correspondence analysis

In all three species, CCA axes 1 and 2 represented over 99% of the variation in defoliation category composition that could be explained by stocking rate (SR), ratio and time (year). Of particular note is that axis 1, in all three species, explained a far greater proportion of the variance (inertia) than axis 2 (Table 7.3). Defoliation categories were therefore plotted according to their rankings on the first two CCA axes only (Figure 7.1).

Also displayed in Figure 7.1 are the directions of maximum change in ordination space of the independent environmental variables (SR, ratio and year). The length of the arrow indicates how strongly each environmental variable is related to the ordination axes, and hence to the displayed pattern in defoliation categories. Perpendicular projection of any defoliation category's position in ordination space onto a particular environmental arrow indicates the relative centroids of abundance of the defoliation category along that environmental variable (ter Braak 1986).

Stocking rate was highly correlated with CCA axis 1 in all three species (Table 7.4). The dominant defoliation pattern (CCA axis 1) on *A. semialata* and to a lesser extent on *T. triandra*, was also related to ratio (Table 7.4). In none of the species was there a significant relationship between year and axis 1 (Table 7.4). A gradient in grazing intensity running from ungrazed plants (U), through leniently grazed plants (LP & L), to severely grazed plants (SP & S), was directly related to increasing stocking rate in all three species (Figure 7.1 a-c).

Regarding the influence of ratio on defoliation pattern for all three species, increasing the proportion of sheep in a treatment resulted in a larger proportion of ungrazed plants of *T. triandra* (Figure 7.1a) whilst, for *T. leucothrix*, a high proportion of sheep in the ratio resulted in a sward in which the U and S defoliation categories were more abundant than the other defoliation categories (Figure 7.1b). Results for *A. semialata* indicate that ratio is almost as important as stocking rate in determining the defoliation pattern for this species. Sheep tend to avoid *A. semialata* as indicated by the position of the U category along the ratio gradient (Figure 7.1c).

Although time is significantly correlated with CCA axis 2 in *T. triandra* and *T. leucothrix*, this axis represents little of the variation in defoliation category composition (Table 7.4).

7.3.3 Graphical presentation

The effects of stocking rate and ratio on defoliation pattern for each of the three grasses are presented in Figure 7.2. The proportion of ungrazed plants (U) generally declines with increasing stocking rate for all three species (Figure 7.2). Ratio had little effect on the proportion of ungrazed plants for *T. triandra* and *T. leucothrix*, with similar proportions of ungrazed plants at any given stocking rate for all ratios (Figures 7.2a & b). The proportion of ungrazed plants of *A. semialata* (Figure 7.2c) differs between ratios at low stocking rates but the effect of ratio declines as stocking rate increases above approximately 0.9 AUE ha^{-1}. These patterns, which reflect those of the CCA analysis, suggest that *T. triandra* and *T. leucothrix* are equally acceptable to cattle and to sheep but that *A. semialata* is more acceptable to cattle than to sheep.

The more informative patterns of defoliation are those presented in Figures 7.2d to 7.2i. For both *T. triandra* and *T. leucothrix* the cattle dominated ratios resulted in a high proportion of leniently grazed plants (LP+L), except at the highest (1.53 AUE ha^{-1}) stocking rate (Figures 7.2d & 2e). By contrast, the sheep dominated ratios tended to have fewer leniently grazed plants. Of particular interest was the high proportion of severely grazed plants (SP+S) for the 1:0 and 0:1 ratios at the highest stocking rates for these ratios (Figures 7.2g & 2h). These patterns indicate that while more than 50% of *T. triandra* and *T. leucothrix* plants were severely grazed for the sheep-only ratio (0:1) at a stocking rate of approximately 1.0 AUE ha^{-1}, stocking rate was increased by almost 60% before the same proportion of plants were severely grazed at the cattle-only ratio (1:0). Alternatively, at a stocking rate of approximately 1 AUE ha^{-1}, grazing with cattle-only (1:0) resulted in far fewer severely grazed plants than were recorded at the 0:1 ratio. These results suggest that plants which are acceptable to both cattle and sheep are grazed more severely by sheep than by cattle when the animals are stocked at equivalent (AUE based) stocking rates.

The defoliation pattern of *A. semialata* differed from that of the two other species. At low stocking rates ratio appears to have had a greater influence on the proportion of ungrazed and leniently grazed plants than did stocking rate (Figures 7.2c and 2f), while stocking rate appears to have had an overriding effect on defoliation pattern at the high stocking rates (Figures 7.2c, 2f & 2i).

There were also similarities in defoliation pattern between treatments. Grazing with sheep only (0:1 ratio) or with a high proportion of sheep relative to cattle (1:2 ratio) at the lowest stocking rate treatments for these ratios, resulted in similar defoliation patterns for all three target species (Figure 7.2). For *T. triandra*, at a stocking rate of approximately 1.1 AUE ha^{-1}, the 1:0 ratio had the same effect on defoliation pattern as the 1:2 ratio. Similarly, the 1:0 ratio at a stocking rate of approximately 1.0 AUE ha^{-1} had a similar effect on defoliation pattern as the 2:1 ratio at a stocking rate of approximately 1.3 AUE ha^{-1} for both *T. leucothrix* and *A. semialata* (Figure 7.2).

7.4 General discussion and conclusions

While stocking rate had the greatest influence on defoliation pattern (Figures 7.1 & 7.2, Tables 7.2, 7.3 & 7.4), this was due, in part, to the method used to quantify the stocking rate and ratio treatments applied. These treatments were determined, *a posteriori*, as a function of the mass and performance of the animals within each treatment. Sheep, stocked at the same number of AUE ha^{-1} as the cattle at the start of the season, did not maintain the same number of AUE ha^{-1} as the cattle through the season (Table 6.5). Animal performance was therefore confounded with stocking ratio and the effects of stocking rate on defoliation pattern incorporate, in part, the effects of ratio. This suggests that stocking ratio has a two-fold effect on defoliation pattern in that it influences both the forage demand and the intensity of grazing on selected plants.

The differences in defoliation pattern between treatments have important implications for the management of Highland Sourveld. As stated in Chapter 3, the grazing capacity estimate for any area is based on the idea that, in the long term, the productivity of the veld will be maintained if the 'correct' stocking rate is applied, irrespective of the type of animal used. However, data derived from the present study indicate that it is not only the number of AUE per hectare that is important, but also the animal types that are used in making up those AUE.

The current grazing capacity estimates for most grassveld types in southern Africa probably derive from observation, experience and limited experimentation on the management requirements for cattle production systems. When sheep form an important component of the livestock production system the number of sheep that may be carried per hectare is often calculated from tables which accommodate the conversion of AUE cattle to AUE sheep (e.g. Meissner, *et al.* (1983)). Results of the present study suggest that the simple substitution of an AUE of cattle by an AUE of sheep will not result in the same defoliation pattern (and thus the same grazing impact) on each grass species as would have occurred had the substitution not been made. For sheep production systems, therefore, the grazing capacity estimates for sourveld are probably misleading and, if applied using currently recommended veld management systems (as was the case in the present study), are likely to promote, rather than prevent, further degradation of the grazing resource.

Few studies have attempted to characterize the pattern of defoliation on various grass species, or the sward as a whole, as a function of the grazing management system applied. Such information is essential for an understanding of the effects of various grazing management strategies on important forage and indicator plant species and, therefore, for the development of appropriate grazing management recommendations for any vegetation type. It is suggested that the technique applied in this study provided useful information on defoliation pattern, and thus the potential grazing impact on individual species. An important feature of the results is that despite wide variation in characteristics such as acceptability, availability, relative abundance and growth habit between the target species used in the study, similar patterns of variation between treatments were obtained from the data for each species (Figure 7.1). It is therefore suggested that the technique may also provide a useful index of the effects of grazing treatment on defoliation pattern within the sward as a whole.

Table 7.1 Relative abundance (%) of the three target species in each stocking rate (AUE ha^{-1}) and ratio (AUE cattle: AUE sheep) treatment

STOCKING RATE	RATIO	RELATIVE ABUNDANCE (%)		
		T. triandra	*T. leucothrix*	*A. semialata*
0.67	1:0	26	17	4
	3:1	31	20	5
	1:1	37	21	3
	1:3	22	31	6
	0:1	26	34	6
0.95	1:0	29	15	1
	3:1	23	24	4
	1:1	21	26	4
	1:3	31	18	3
	0:1	31	20	1
1.33	1:0	36	20	5
	3:1	25	35	9
	1:1	32	28	3
	1:3	28	26	7
	0:1	23	26	4

Table 7.2 Chi-squared values for the effects of stocking rate, ratio and year, and their interactions, on the defoliation patterns of *Themeda triandra* (TTR), *Tristachya leucothrix* (TLE) and *Alloteropsis semialata* (ASE). The degrees of freedom (DF) associated with each factor is also presented

Factor	TTR	TLE	ASE	DF
stocking rate	606^{***}	436^{***}	431^{***}	8
ratio	298^{***}	131^{***}	570^{***}	16
year	125^{***}	117^{***}	80^{***}	8
stocking rate*ratio	113^{***}	82^{***}	148^{***}	32
year*ratio	60^{***}	45^{***}	46^{***}	16
year*stocking rate	25^{ns}	39^{ns}	31^{ns}	32

^{ns} = non significant (P>0.05) *** = P < 0.001

Table 7.3 The total inertia (variation) and the eigen values of axes one and two of a Canonical Correspondence Analysis of the defoliation pattern on three grass species

	Axis		
	1	2	
Species	eigen value		total inertia
Themeda triandra	0.255	0.046	0.453
Tristachya leucothrix	0.176	0.040	0.368
Alloteropsis semialata	0.342	0.026	0.561

Table 7.4 The correlation between environmental variables and axes one and two of a Canonical Correspondence Analysis of the grazing pattern on three grass species

	Axis	
environmental variable	1	2
Themeda triandra		
stocking rate	0.99^{***}	-0.04^{ns}
ratio	-0.51^{***}	-0.42^{**}
year	-0.15^{ns}	-0.84^{***}
Tristachya leucothrix		
stocking rate	0.91^{***}	-0.39^{**}
ratio	-0.17^{ns}	0.88^{***}
year	0.17^{ns}	0.50^{***}
Alloteropsis semialata		
stocking rate	0.92^{***}	-0.35^{*}
ratio	-0.72^{***}	-0.68^{***}
year	0.07^{ns}	0.20^{ns}

ns = non significant
* = $P < 0.05$
** = $P < 0.01$
*** = $P < 0.001$

a

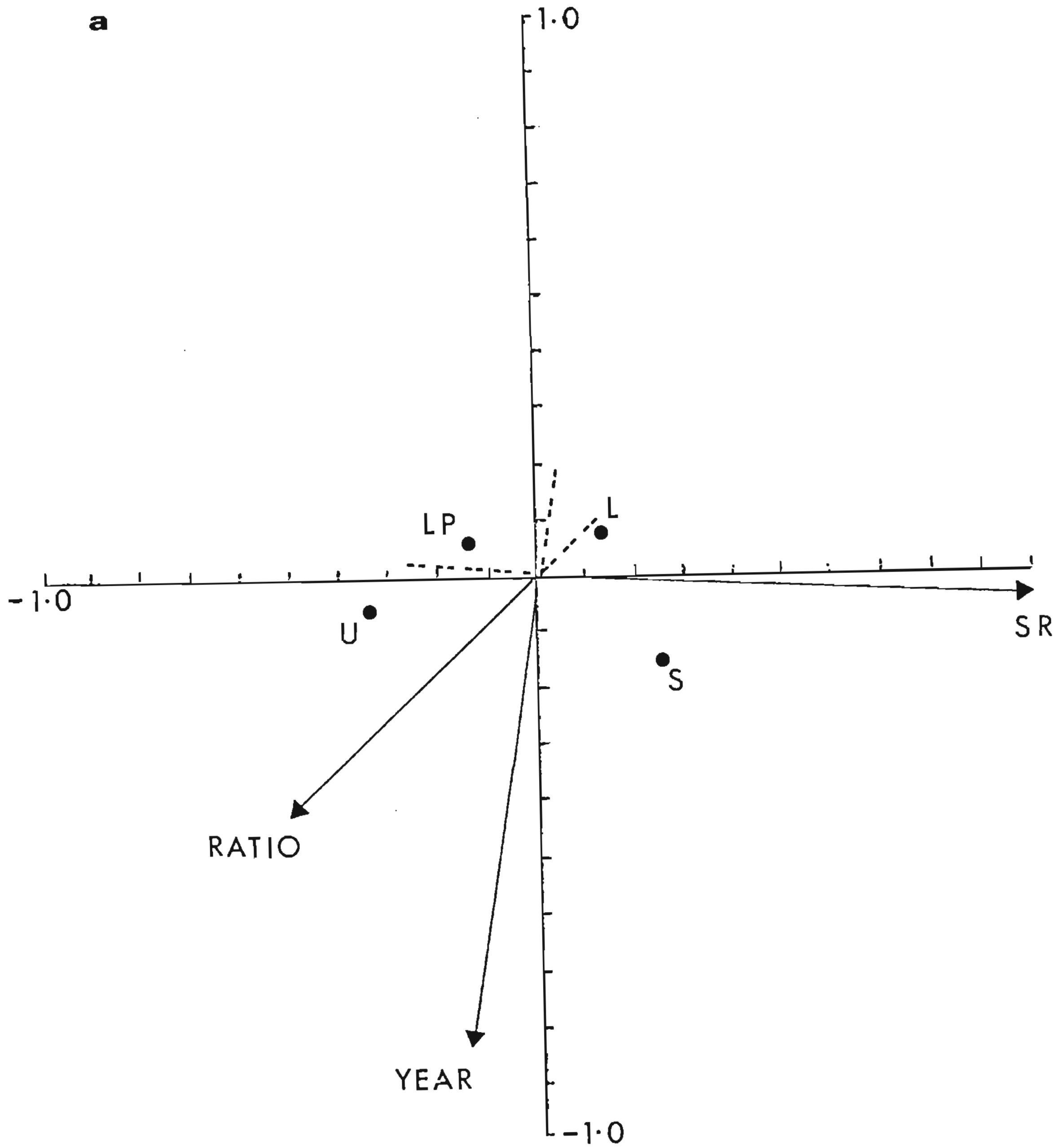


Figure 7.1 The position of defoliation categories (see text for details) along Canonical Correspondence Analysis axes one and two, for *Themeda triandra* (a), *Tristachya leucothrix* (b) and *Alloteropsis semialata* (c). Arrows represent environmental variables (SR = stocking rate, Ratio = percentage sheep and YEAR = time).

b

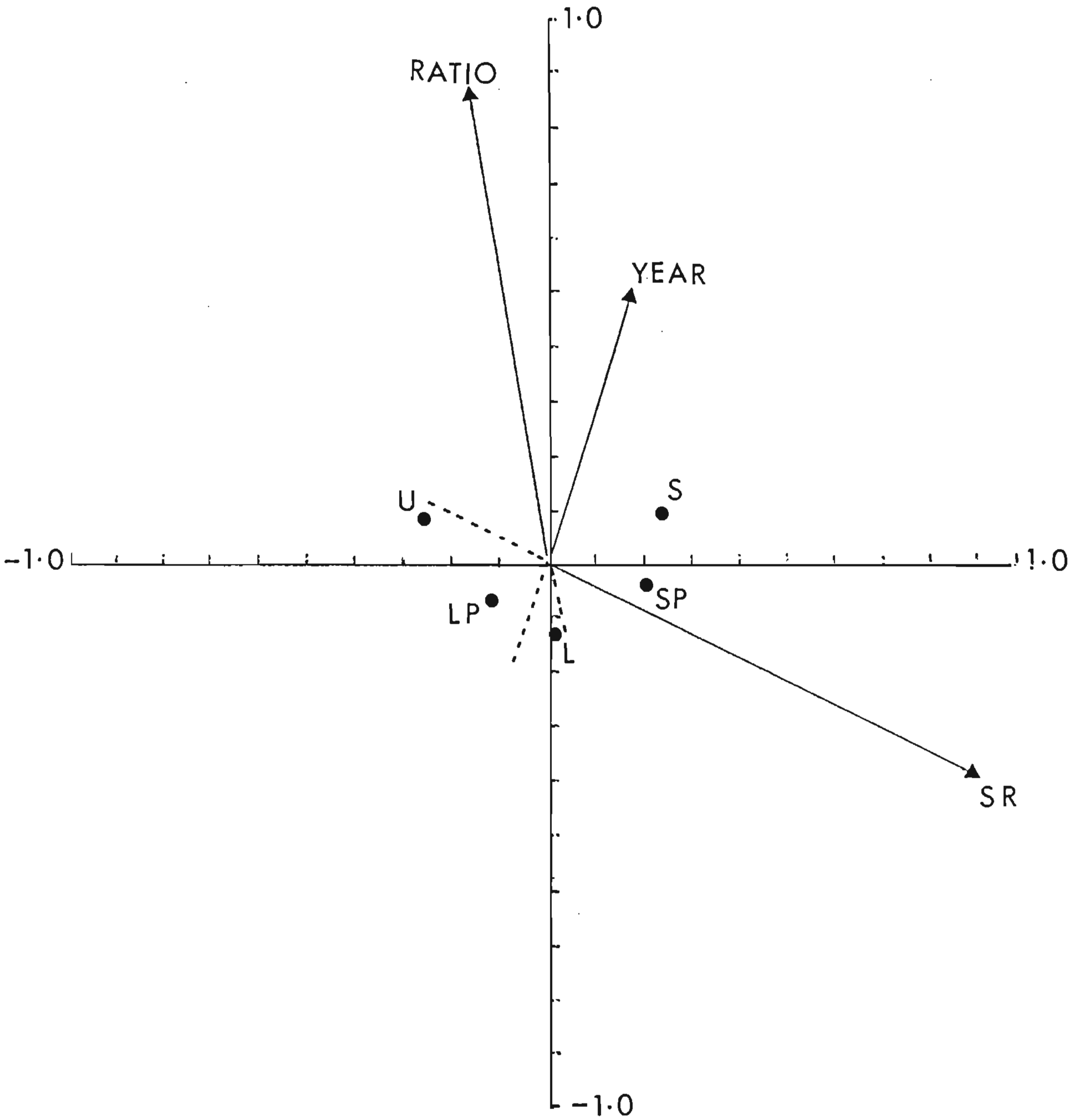


Figure 7.1 (cont.)

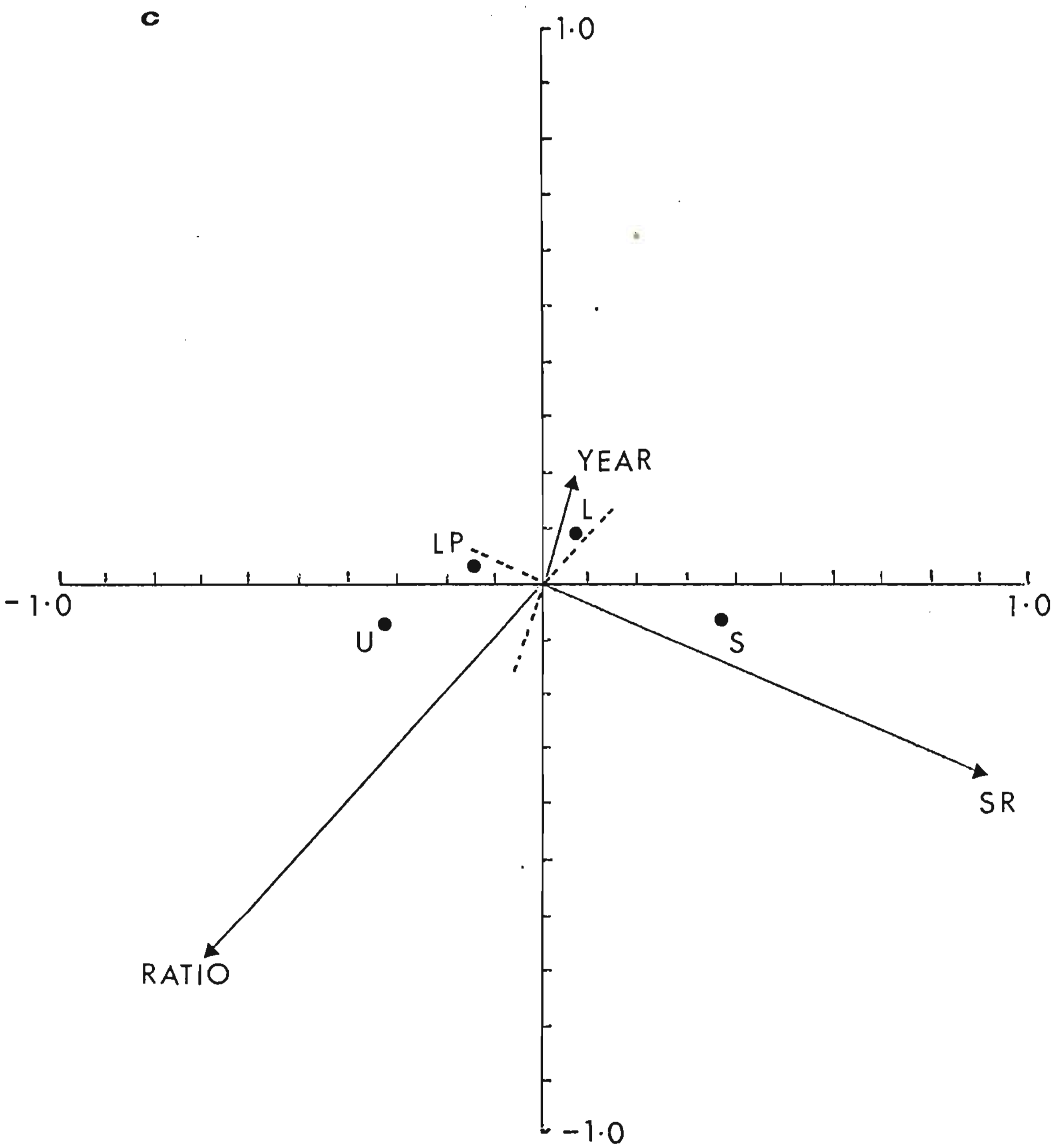


Figure 7.1 (cont.)

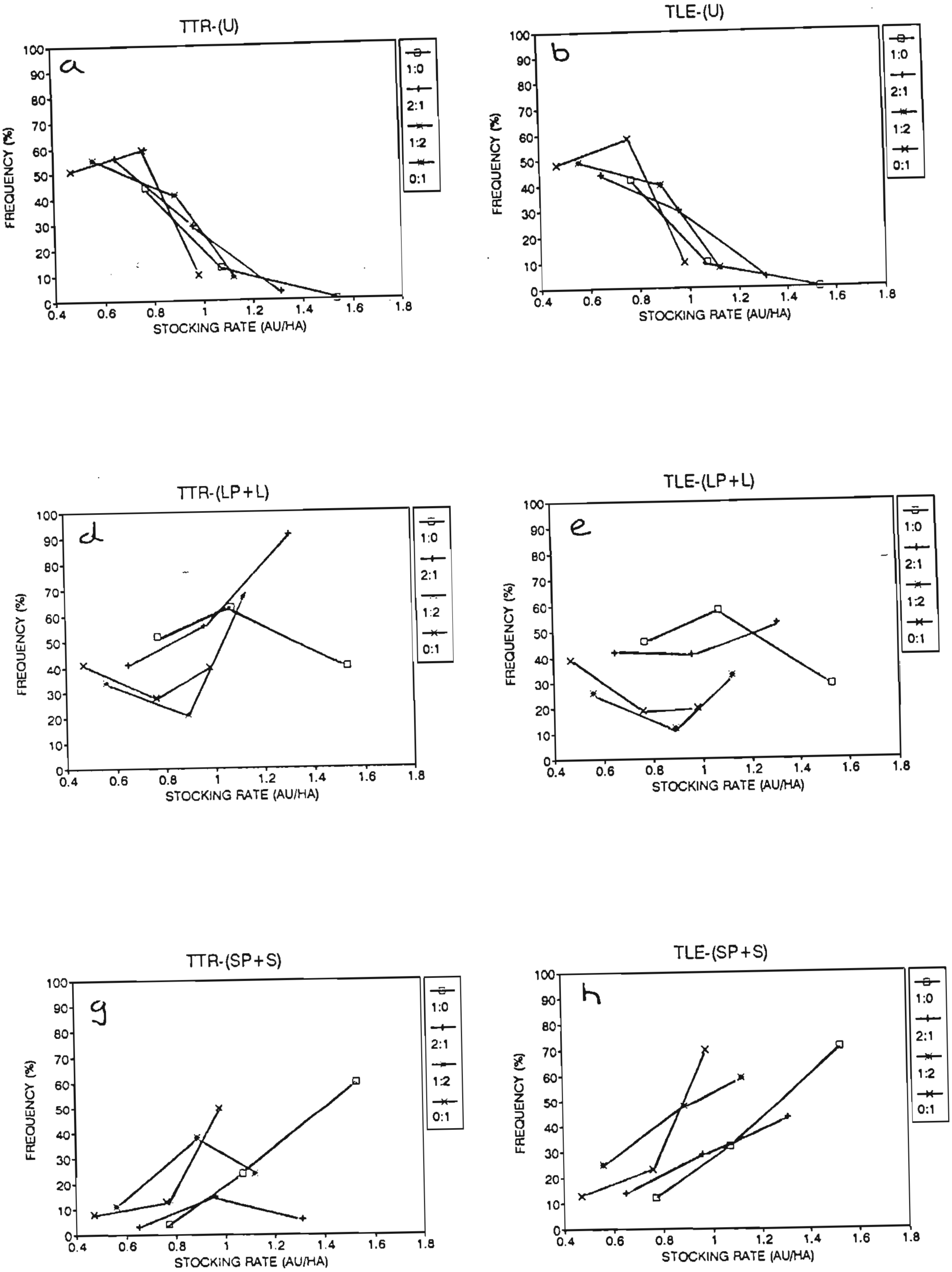
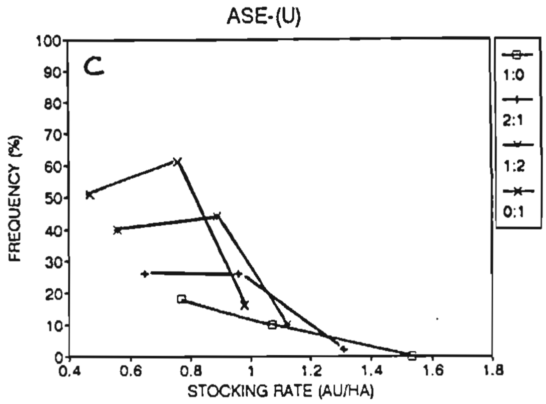
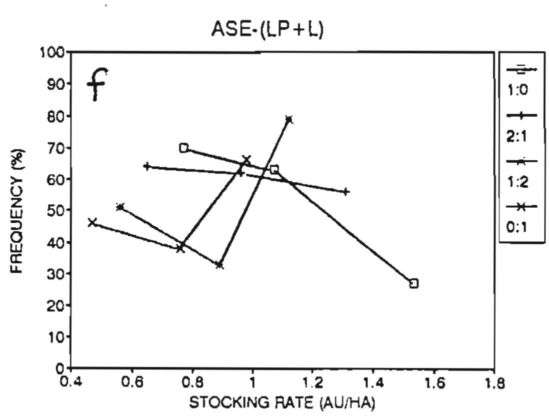


Figure 7.2 Defoliation pattern (frequency [%]) on *Themeda triandra* (TTR - a, d & g), *Tristachya leucothrix* (TLE - b, e & h) and *Alloteropsis semialata* (ASE - c, f & i) for each of three defoliation categories U, LP+L & SP+S respectively, due to stocking rate (AUE ha^{-1}) and ratio (AUE cattle: AUE sheep) - see text for a description of the defoliation categories.





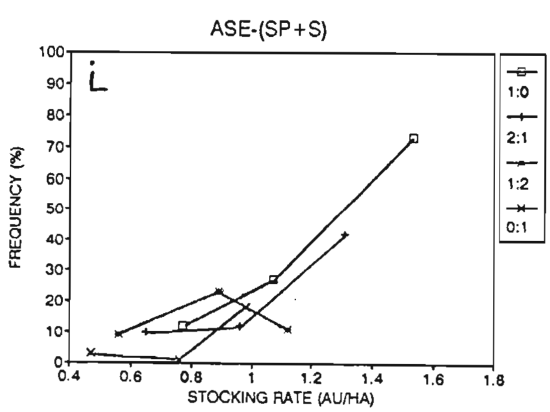


Figure 7.2 (cont.)

CHAPTER 8

THE EFFECTS OF CATTLE TO SHEEP RATIO AND STOCKING RATE ON THE EXTENT AND SEVERITY OF PATCH GRAZING

8.1 Introduction

The selective grazing habits of large herbivores are widely recognised (e.g. Heady 1964; Bedell 1971; Stobbs 1973; Edwards 1981c; O'Reagain & Mentis 1989a; Barnes & Dempsey 1992). Differences in the nutrient content, morphology, physical strength and structure of grass species influence large-herbivore selection patterns (Heady 1964; Theron & Booysen 1966; Westoby 1974; Gammon & Robberts 1978a; O'Reagain & Mentis 1989a,b; 1990; Stoltsz & Danckwerts 1990; O'Connor 1992).

At the plant community level, selective grazing patterns are influenced by differences in soil, topography, aspect and species composition (e.g. Bedell 1971; Ring, *et al.* 1985; Danckwerts 1989a). Moreover, those areas of a sward grazed early in the grazing season continue to be grazed whilst the areas which were initially ungrazed may be ignored (Weaver & Tomanek 1951, cited by Ring, *et al.* 1985). Such grazing results in differentially grazed patches (Bakker, *et al.* 1983; Ring, *et al.* 1985; Hatch & Tainton 1990). Grazed patches are repeatedly defoliated through each grazing season due to the animals' preference for green leafy forage which is free of dead or mature herbage (Cook, *et al.* 1953; Reppert 1960; van Dyne & Heady 1965b; Heady 1975; Barnes & Dempsey 1992). Ungrazed patches tend to remain ungrazed, and the grasses become increasingly mature and moribund. This further reduces the likelihood of previously ungrazed patches being grazed (e.g. Moorefield & Hopkins 1951; Willms, *et al.* 1980). However, as the availability of forage declines animals are likely to graze less selectively (Stoltsz & Danckwerts 1990). The major factor affecting forage availability, within a given forage production system, is stocking rate (e.g. Bartholomew 1985). Stocking rate should therefore affect the extent to which animals graze selectively (Stoltsz & Danckwerts 1990) and thus the extent and severity of grazing.

Continued grazing of patches within the sward, combined with trampling and changing micro-environmental conditions, could result in soil compaction and associated changes to species composition (Macdonald 1978; Hatch & Tainton 1990). This process has been referred to as "spot over-grazing" (Stoddart, *et al.* 1975) and may lead to the development of permanent patches (Hatch & Tainton 1990). Whilst patch grazing may lead to changes in species composition and productivity of grazed patches, the species composition and productivity of non-grazed patches are also likely to change. In Highland Sourveld, plant species such as *Themeda triandra* tend to die out whilst species such as *Tristachya leucothrix* tend to increase in abundance when patches remain ungrazed (or undefoliated) for a number of growing seasons (Scott 1947; Foran, *et al.* 1978; Tainton 1981).

Both cattle and sheep graze selectively (Scott 1947; de Jager & Joubert 1968; Malherbe 1971; Daines 1980; Gammon & Twiddy 1990) but general experience suggests that veld stocked with cattle is usually less closely and more evenly grazed than veld stocked with sheep (Barnes 1992). Furthermore, small herbivores, such as sheep, are anatomically and physiologically adapted to grazing more selectively and closely than cattle (Heinemann 1970; Mentis 1980). It has been suggested that cattle cannot graze closer than approximately 1.3 to 1.5 cm from the soil (Voison 1959; Heinemann 1970), whilst sheep may graze to soil level (Hafez & Scott 1962). In general, cattle tend not to graze closer than 5cm from ground level except when forage availability becomes limiting (Heinemann 1970). Data obtained from the cattle-only ratio of the medium stocking rate treatment, where quantity of herbage limited animal performance (Chapter 5), indicated that severely grazed tufts of *T. triandra* and *T. leucothrix* were grazed to a mean height of approximately 2.5cm (Peddie 1994). Reports that sheep tend to graze plants more severely than cattle

(Scott 1947; Botha 1953; de Jager & Joubert 1968) are corroborated by the results of the analyses of defoliation patterns on three grass species presented in Chapter 7. These results, and local experience, suggest that veld stocked with sheep is likely to have a larger number of small, severely grazed, patches than veld stocked with cattle at the same stocking rate. Patch-grazing by sheep would therefore be expected to have a greater negative impact on sward composition and productivity than patch-grazing by cattle.

Patch grazing is thus a widely recognised phenomenon. Various grazing management strategies have been proposed which aim to minimize the negative effects of selective grazing (for species and/or patches) on sward productivity and composition, and animal performance [e.g. non-selective grazing - NSG (Acocks 1966), controlled selective grazing - CSG (e.g. Booysen 1969), and grazing cattle together with sheep at a narrow cattle to sheep ratio (Ebersohn 1966; duToit 1967; Malherbe 1971)]. However, few studies have attempted to quantitatively describe the effects of grazing management on the development of patch grazed areas within a livestock production system (Ring, *et al.* 1985; Hatch & Tainton 1990).

The objective of the present study was to test the recommendation that cattle should graze together with sheep in order to limit the extent and severity of patch grazing. This objective was aimed at answering questions relating to **what** effects cattle to sheep ratio and stocking rate would have on the development of patch-grazed areas in the sward rather than answering questions relating to **why** patch-grazed areas developed.

The specific objectives of this study were to:

1 characterise and compare the extent and severity of patch grazing as influenced by the cattle to sheep ratio and stocking rate treatments applied in the current trial, and
2 compare the patch size distributions between treatments.

A patch is defined here as a relatively discrete spatial pattern without constraint on size, internal homogeneity or discreetness (Pickett & White 1985; Lütge B. pers. comm.). The **extent** of patch-grazing refers to the proportion of the total area allocated to a treatment which comprises a 'patch' whilst the severity of patch-grazing refers to the height to which grazing occurred within a 'patch'.

8.2 Procedure

The study was conducted at the end of the 1991/92 grazing season in each of the 'test' paddocks of the animal production component of the trial and in all paddocks in the simulated component i.e. all 15 cattle to sheep ratio and stocking rate treatments. Stocking rate and ratio treatments were expressed in terms of both the 'planned' treatments, and the mean 'actual' AUE ha^{-1} of cattle and of sheep carried by each treatment over the first three grazing seasons of the trial (see Table 6.5).

Two data collection procedures were applied.

1 Line transects were placed 20m apart in each treatment, ensuring that there were at least two, 40m long, transects per treatment. Three categories of 'patch' were identified; a) grazed areas with a maximum leaf table height (LTH) of 3cm, b) grazed areas with a range in LTH of >3cm to <5cm, and c) grazed or ungrazed areas with a LTH greater than 5cm. Leaf table height was defined as the height above ground level below which 80% of the leaves (when extended) were subjectively judged to occur (O'Reagain & Mentis 1989b). The three categories (<3cm, >3cm to <5cm, and >5cm) were referred to as severely grazed patches (severe), moderately grazed patches (moderate) and leniently or ungrazed patches (lenient) respectively. Severe and moderate categories were distinguished in an attempt to differentiate between the effects of patch grazing by cattle and by sheep. The proportion of each treatment comprising patches was estimated from the length (cm) of each line transect intercepted by each of the three categories of patch.

Multiple linear regression was used to examine the main effects of the dependence of the estimated proportion of the area of each treatment comprising each of the three categories of patch, on the mean 'actual' stocking rate (AUE ha^{-1}) and ratio treatments applied over the first three grazing seasons. These data were also presented graphically. For ease of comprehension and discussion, treatments with mean AUE cattle to AUE sheep ratios of 1.7:1, 1.5:1 and 1.7:1 (Table 8.1) were labelled as 2:1 while the 1:1.6, 1:2.2 and 1:1.8 ratios (Table 8.1) were labelled as 1:2 in Figures 8.1 and 8.5.

Patch size distribution was determined for each treatment from the number of each category of patch intersected and the intercept length of each patch within a category.

2 While the line transect data provides some insight into the severity of grazing in each treatment, a more detailed analysis of grazing height was considered necessary in order to clearly differentiate between the effects of cattle and of sheep on the severity of grazing within patches. A modified step-point method (Evans & Love 1957; Mentis 1981b) was applied to obtain additional data relating to the severity of grazing in each treatment. At each of 200 randomly located points per treatment the LTH of grass plants within a circular quadrat (10 cm in diameter) was recorded. When a grass tuft was not present within a quadrat an additional placement was made to ensure 200 LTH data records per treatment. Leaf table height was recorded in centimetres, rounding up to the nearest centimetre.

The frequency of occurrence of observations in each class (cm) of LTH was determined for each treatment. Kolmogorov-Smirnoff two-sample tests (Seigel 1956) were used to test the null hypothesis of no significant differences in the distribution of LTH between any two treatments.

8.3 Results and discussion

As discussed in the previous chapter, the stocking rate and ratio treatments were confounded due to the differential performance of cattle and sheep in all treatments. Within each of the 'planned' stocking rate treatments the mean stocking rate calculated for the grazing season increased as the proportion of cattle in the species-mix increased. It was therefore impossible to directly compare the effects of ratio treatments on patch development for any particular, 'planned', stocking rate treatment. Presentation and discussion of the results thus relates to general trends in the data sets.

8.3.1 Extent of patch grazing

The estimated proportion (%) of the area of each cattle to sheep ratio and stocking rate treatment comprising each category of patch is presented in Table 8.1. Ratio was expressed as the proportional contribution of sheep (in AUE ha^{-1}) to the total 'actual' (cattle + sheep) stocking rate (AUE ha^{-1}) calculated for each treatment. Parameter estimates for the multiple linear regression of the dependence of the proportion of each treatment's area comprising each category of patch on the applied stocking rate and ratio treatments are presented in Table 8.2.

For all three categories of patch, ratio did not significantly influence the proportion of each treatment comprising a patch ($P > 0.05$). However, the proportion of a treatment area comprising the severe and lenient categories of patch was significantly ($P < 0.001$) influenced by stocking rate (Table 8.2). There was a non-significant ($P > 0.05$) relationship between the % area comprising the moderate category of patch and stocking rate. Whilst the combined effects of ratio and stocking rate treatments on patch area were significant for the <3cm and >5cm patch categories ($P < 0.001$) the contribution of ratio to the regression was not significant ($P > 0.05$) (Table 8.2). A further attempt was made to investigate the influence of different cattle to sheep ratios on the extent of patch grazing without specifically defining cattle to sheep ratio as an independent variable. Simple and multiple linear regression procedures were used to distinguish between the effects of stocking rate of cattle and stocking rate of sheep on each of the three categories of patch (Table 8.3).

Cattle stocking rate (on its own) was significantly correlated with the proportion of each treatment comprising patches in the <3cm ($P < 0.05$) and >5cm ($P < 0.01$) categories. Sheep stocking rate (on its own) was not correlated ($P > 0.05$) with any category of patch (Table 8.3). However, the combined effects of cattle and sheep stocking rates were highly and significantly correlated ($P < 0.001$) with both the <3cm and >5cm categories of patch. Moreover, the stocking rate of sheep provided a significant contribution to the regression equation for both categories of patch (Table 8.3). Comparison of the coefficients associated with stocking rate of cattle and of sheep in the **combined** regression equation suggests that sheep had a greater influence on the extent of patch grazing than the stocking rate of cattle (Table 8.3). Thus within a particular stocking rate, as the relative contribution of sheep to the stocking rate increased so the proportion of the <3cm category increased whilst the proportion of the area comprising patches of the >5cm category decreased. These trends are, however, better illustrated in Figure 8.1.

The effects of ratio can be most easily seen in the stocking rate range of 0.8 AUE ha^{-1} to 1.2 AUE ha^{-1}. At a stocking rate of approximately 1.0 AUE ha^{-1} there was a consistent increase in the proportion of the area comprising the severe category as the ratio increasingly favoured sheep (Figure 8.1c). Reference to Figure 8.1c shows that the areas of the sheep-only (0:1) treatment comprising the severe category was as much as 3 times that of the cattle-only (1:0) treatment. Similarly, trends in the proportion of the moderate category suggests that, at a stocking rate of approximately 1.0 AUE ha^{-1}, a greater area of the treatment was grazed into this category as the ratio increasingly favoured cattle.

The proportion of each area comprising the lenient (>5cm) category appears to be an approximate linear function of stocking rate, for ratios which included cattle. As stocking rate increased so the proportion of each area comprising the lenient (>5cm) category decreased (Figure 8.1).

8.3.2 Patch size

It must be stressed that patches could not be distinguished as discrete entities. For example, at the high stocking rate sheep-only treatment, there was a mosaic of interlinking, severely grazed patches with a large number of ungrazed tufts of unpalatable species dispersed within the 'patch'. The line intercept approach therefore simply recorded the intercept length for each category of patch intercepted and **not** the dimensions of the patch. Patch size was simply indexed by intercept length.

Patch size distributions are illustrated in Figure 8.2 for each of the three categories of patch. The size classes used were <1m, >1m to <2m, >2m to <4m, and >4m (represented as 1, 2, 3 and >4 in Figure 8.2). The number of observations in each size class was expressed as a proportion (%) of the total number of 'patches' recorded within each of the patch categories. For the sake of clarity, stocking rate and ratio treatments are expressed in terms of the 'planned' treatments (see Table 8.1).

At the **low** stocking rate (Figure 8.2 a, b & c) there was little variation in patch size distribution between ratio treatments within both the severe and the moderate categories of patch grazing. The highest proportion of patches were in the <1m size class. Reference to Table 8.1 reveals that for the cattle-only (1:0) treatment 20.8% of the treatment area was estimated to be in the **severe** category whilst 8.8% of the sheep-only (0:1) treatment area was estimated to be in the same category. In the severe category, therefore, the sheep-only (0:1) treatment had approximately half the number of patches in each size class as the cattle-only (1:0) treatment. At face value this would indicate that a greater number of patches developed in the cattle-only than in the sheep-only treatments. However, further inspection of Table 8.1 reveals that the 'actual' stocking rate applied in the cattle-only (1:0) treatment was approximately 1.6 times the 'actual' stocking rate applied in the sheep-only (0:1) treatment, suggesting that the greater number of patches in the cattle-only treatment was probably a function of stocking rate. These data therefore suggest that cattle and sheep have a similar potential to create similar size patches where the cattle and sheep were stocked at less than 0.77 and 0.47 AUE ha^{-1} respectively. Mixing cattle and sheep whilst maintaining the same 'low' stocking rate did not alter the patch size distribution of patch-grazed areas in the severe or moderate categories.

Patch size distributions in the lenient category (>5cm) differed between ratio treatments (Figure 8.2c). While the trends were not consistent the sheep-only ratio had the highest proportion of patches in the >4m size class whereas the cattle-only ratio had the lowest proportion of patches in this size class. This result reflects the observation that cattle tend to spread their grazing over an area whilst sheep tend to concentrate their grazing on specific areas and 'patches' and avoiding larger areas/'patches' of leniently or ungrazed herbage.

In the severe category of the medium stocking rate the cattle-only (1:0) and sheep-only (0:1) treatments again had similar patch size distributions (Figure 8.2 d) with the highest proportion of patches in the <1.0m size class. The stocking rate of the cattle-only treatment was approximately 1.4 times that of the sheep-only treatment (Table 8.1) and the proportion of the cattle-only treatment area comprising the severe category of patch was approximately 2.3 times that of the sheep-only treatment (Table 8.1). These data support the argument presented above that cattle and sheep have a similar potential for patch grazing (in the size classes shown in Figure 8.2). It should be stressed, however, that these trends must be seen in the context of the stocking rate of cattle (1.07 AUE $^{-1}$) and of sheep (0.76

AUE ha^{-1}) in the cattle-only (1:0) and sheep-only (0:1) treatments.

In contrast to the low stocking rate, grazing cattle together with sheep at the **medium** stocking rate altered patch size distribution within the severe category of patch (Figure 8.2d). For the three treatments in which cattle and sheep grazed together, a greater proportion of each treatment area was in the severely patch-grazed category (Table 8.1), and patches tended to be larger (Figure 8.2d), than in the cattle-only or the sheep-only ratio treatments. Grazing cattle and sheep together at the 'planned' 3:1, 1:1 and 1:3 ratios, therefore, appeared to exacerbate rather than minimise the patch grazing impacts of single-species grazing by cattle or sheep.

Remaining with the **medium** stocking rate treatment, there was a consistent trend for leniently or ungrazed patches to decrease in size as the ratio increasingly favoured cattle (Figure 8.2f). As the proportion of sheep in the species mix increased, the proportion of large (>4m) areas in the lenient/ungrazed category increased.

In the severe category of the **high** stocking rate treatment the patch size distribution of the sheep-only treatment was similar to the patch size distribution of the sheep-only ratios of the medium and low stocking rates (cf Figures 8.2g, a & d). The proportion of the sheep-only treatment area comprising the severe category was, however, between 6 to 8 times greater in the high stocking rate than in the medium and low stocking rate treatments respectively (Table 8.1). The large increase in stocking rate of sheep in the sheep-only grazing treatment resulted in a larger number of small (<1m) patches in the severe patch-grazing category rather than an increased size of patch.

In contrast, not only was more than 80% of the area allocated to the 1:0 and 3:1 (cattle:sheep) ratio treatments in the severe category (Table 8.1), but a high proportion of patches were found in the >4m size class (Figure 8.2g). Increased stocking rate of cattle beyond 1.07 AUE ha^{-1} resulted in large patches in the severe category.

As the ratio treatment increasingly favoured sheep (in the high stocking rate treatment) so the proportion of the treatment area in the lenient category tended to increase (Table 8.1). Patch size distribution patterns for this category of patch, however, were similar for all treatments except for the 3:1 ratio treatment (Figure 8.1i). This implies that as the ratio increasingly favoured sheep the number of small (<1m) patches in the lenient category increased. These patterns were consistent with observation and experience of the effects of grazing sheep at wide cattle-to-sheep ratios and high stocking rates, on the 'patchiness' of grazing in Highland Sourveld.

Statistical analyses were conducted in an attempt to determine the main effects of ratio (expressed as the proportional contribution of sheep to the total 'actual' stocking rate) and stocking rate (AUE ha^{-1}) on the proportion of each treatment comprising a particular patch size class, within each of the three categories of patch. Simple and multiple linear regression were applied to the data from two patch size classes viz. patches <1m and patches >4m in extent.

Parameter estimates for the dependence of the proportion of each treatment area comprising patches in the <1m and >4m size classes, within each of the three categories of patch viz. <3cm (severe), >3cm to <5cm (moderate), and >5cm (lenient), on ratio and stocking rate, are presented in Tables 8.4 and 8.5 respectively. For all three categories of patch, the relationship between the proportion of patches in the <1m and the >4m size classes, and ratio treatment was not significant ($P > 0.05$). The relationship between the proportion of patches in the <1m size class and stocking rate was significant for the severe ($P < 0.001$), moderate ($P < 0.01$) and lenient ($P < 0.01$) categories of patch, while the effect of stocking rate on the proportion of patches in the >4m size class was significant ($P < 0.05$) for the <3cm and >3cm to <5cm categories of patch (Tables 8.4 & 8.5). As with the analysis of the 'extent of patch grazing' data set (section 8.3.1), simple and multiple regression procedures were used to partition the effects of stocking rate of cattle and of sheep on the proportion of patches in the <1m and >4m size classes for each category of patch (Tables 8.6 and 8.7).

From the simple linear regression analyses, stocking rate of cattle was significantly correlated with the proportion of patches in both size classes for the severe and moderate patch categories while sheep stocking rate was not correlated with any of the categories (Tables 8.6 and 8.7). Considering the combined effects of cattle and sheep stocking rate on the proportion of patches in both size classes, stocking rate of cattle provided a significant ($P < 0.05$) contribution to all **significant** ($P < 0.05$) multiple regression functions while the contribution of sheep stocking rate was non-significant in all cases except for the <1m size class in the >5cm category of patch.

Further insight into the effects of stocking with sheep-only on patch grazing was obtained from inspection of patch size distribution patterns for the severe category of patch. Patch size distribution for patches of <1m, in 20 centimetre size classes, are presented in Figure 8.3 for each stocking rate and ratio treatment. In all three ('planned') stocking rate treatments the patch size distribution in the sheep-only (0:1) ratio treatment indicates that sheep tend to create smaller patches than cattle. For all stocking rates, grazing by sheep appears to result in a high proportion of patches in the 20cm to 40cm size class. This trend, however, must be considered while bearing in mind the fact that the 'actual' sheep-only stocking rate treatments were lower than the 'actual' stocking rates of the other ratio treatments (Table 8.1).

8.3.3 Severity of grazing

The chi-squared values and their associated levels of significance derived from the Kolmogorov-Smirnoff two-way sample tests for comparisons of leaf table height (LTH) distributions between all combinations of stocking rate and ratio treatments are presented in Table 8.8. Stocking rate and ratio treatments were expressed in terms of the 'planned' treatments for ease of interpretation. Reference to Table 8.1 provides the 'actual' stocking rate and ratio treatments (in terms of AUE ha^{-1}) applied for any two of the comparisons presented in Table 8.8. It is important to note that cattle to sheep ratios remained in similar proportion for all three stocking rate treatments (Table 8.1). All LTH data points recorded in each treatment were used in the analysis, without transformation.

Within stocking rate comparisons of the LTH distributions between ratio treatments are illustrated in Figure 8.4. For the purposes of graphical representation, stocking rate and ratio treatments were expressed in terms of the 'planned' treatments. It should be remembered that the 'actual' stocking rates (in terms of AUE ha^{-1} - Table 8.1) declined as the proportion of sheep in the species mix increased for each of the 'planned' overall low, medium and high stocking rate treatments. The LTH distributions for each treatment were smoothed by adjusting the LTH data to produce 8 LTH classes which ranged from <4cm (4) to >26cm <32cm (32) (Figure 8.4). The number of observations in each height class was expressed as a percentage of the total number of observations recorded in each treatment.

There were no significant differences ($P > 0.05$) in LTH distributions between ratio treatments within the **low** stocking rate treatments (Table 8.8 and see Figure 8.4a). Such lack of significance implies that, at the sward level, the severity of grazing by cattle and by sheep was similar when stocked at the 'low' stocking rate applied in the present study. Differences in LTH distribution between the LSR and HSR for all ratio treatments were significant in all cases (Table 8.8). In comparing the LTH distribution between the LSR and MSR treatments however, the main trend was that LSR ratios which had a high proportion of cattle were significantly different from all MSR ratios which included cattle. Furthermore, the LTH distributions for the 1:0 and 3:1 ratios of the MSR treatment were significantly different from the LTH distributions of all ratios of the LSR treatment. Differences in the severity of grazing between the LSR and MSR were therefore mainly a function of cattle stocking rate. These results also indicate that a similar range in the severity of grazing on the sward occurred between the LSR and MSR treatments when sheep grazed alone or in high proportion with cattle (the 0:1, 1:3 & 1:1 ratios - Table 8.8) despite the higher stocking rate of the MSR treatment (see the 'actual' stocking rates applied in these ratio treatments - Table 8.1).

Within the **medium** stocking rate, the LTH distribution of the sheep-only (0:1) ratio was significantly different ($P < 0.01$) from the ratios which had a high proportion of cattle (viz. 1:0, 3:1, and 1:1) (Table 8.8). Inspection of Figure 8.4b reveals that the proportion of the LTH data in the range 12cm to 32cm was consistently higher in the sheep-only (1:0) treatment than in any of the other ratios. All remaining between-ratio comparisons of LTH distributions were non-significant ($P > 0.05$) indicating similar severity of grazing from these ratios when stocked at the 'medium' stocking rate.

Within the **high** stocking rate treatment the 1:0 and 3:1 ratios (high proportion of cattle) had significantly different LTH distributions ($P < 0.01$) than the 1:1, 1:3 and 0:1 ratio treatments (except for the 1:0 vs 0:1 comparison) (Table 8.8). The LTH distributions for the 1:0 & 3:1 ratios of the HSR were significantly different from all ratios in the MSR whilst the 0:1 ratio of the MSR also differed significantly from all ratios of the HSR treatment. Here, as the proportion of sheep in the HSR increased, there was greater similarity in the range in severity of grazing between the MSR and HSR treatments (except for the MSR 0:1 ratio).

Further analyses of the LTH data for height classes smaller than three centimetres were conducted in an attempt to determine the differential effects between cattle and sheep on the severity of grazing. Stocking rates were expressed in terms of the **'actual'** stocking rates applied in each treatment (AUE ha^{-1} - Table 8.1). Cattle to sheep ratios were expressed in the same format (see section 8.2) as was used in developing in Figure 8.1. Three classes of LTH were used viz. <1cm, <2cm and <3cm. The number of LTH observations in each class within a stocking rate treatment was expressed as the percentage of the total number of LTH records for the treatment. These data provide an estimate of the proportion of each treatment area which comprises each of the LTH classes. The results are presented in Figure 8.5.

As stocking rate increased there was a general increase in the proportion of a treatment's area comprising all three height classes. It is clear, however, that stocking ratio also had an influence on the proportion of each treatment area within a height class. For example, at a stocking rate of approximately 1 AUE ha^{-1} and for the <1cm height class, there was an increase in the proportion of treatment area comprising the <1cm height class as the ratio treatment increasingly favoured sheep. In the sheep-only (0:1) treatment it was estimated that approximately 30% of the treatment area was grazed to <1cm whereas for the cattle-only (1:0) treatment only 1% of the treatment area was grazed to <1cm. These trends were repeated in the <2cm and <3cm height classes (Figure 8.5).

A second important observation regarding the effect of ratio treatment was that, for stocking rates less than approximately 0.9 AUE ha^{-1}, the proportion of the treatment area comprising any LTH class was greater for the 1:2 ratio than for the sheep-only (0:1) ratio when grazing at the same stocking rate (Figure 8.5). This observation suggests that, at a ratio of 1:2 and a stocking rate of less than 0.9 AUE ha^{-1}, the cattle would graze a relatively larger area of the sward than would have been grazed by the sheep which the cattle had replaced, and that sheep would then keep this grazed area short.

Inspection of Figure 8.5 also reveals that cattle, when stocked at a high stocking rate, are capable of grazing to within <1cm of ground level. For example, at a stocking rate of 1.53 AUE ha^{-1}, an estimated 24% of the cattle-only ratio (1:0) treatment area was grazed to a height of <1cm while 60% of the area was grazed to a height of <2cm when cattle-only were stocked at the same stocking rate.

8.4 General discussion and conclusions

Contrary to expectation, the extent of patch grazing was primarily a function of stocking rate (expressed as AUE ha^{-1}), despite the differences in animal species (Figure 8.1). As stocking rate increased so the extent of patch grazing increased. However, partitioning stocking rate to investigate the effects of stocking rate of cattle and of sheep separately indicated that animal species had a small but significant effect on the extent of patch development (Table 8.3). This effect was most apparent at a stocking rate of approximately 1.0 AUE ha^{-1} (Figure 8.1). In general, the higher the proportion of cattle in the species mix the lower was the proportion of a treatment's area comprising patches of the <3cm (severe) category at a stocking rate of approximately 1.0 AUE ha^{-1}. Within this stocking rate the recommendation that cattle and sheep should be grazed together, to reduce the extent of the development of severely grazed patches in the sward, is therefore supported. At stocking rates below 0.8 AUE ha^{-1} however, there were only small differences between the sheep-only (0:1) and the 1:2 and 2:1 cattle to sheep ratios on the extent of patch development in the severely grazed category.

As with the extent of patch grazing, patch size was also primarily a function of stocking rate. Furthermore, stocking rate of cattle had a greater influence on patch size than stocking rate of sheep (Figure 8.2 and Tables 8.6 and 8.7). For the <3cm patch category, increased cattle stocking rate decreased the proportion of a treatment's area comprising patches in the <1m size class. As stocking rate increased, patches interlinked, thus increasing in size. Within patches of the <1m size class there was a higher proportion of patches in the >20cm to <40cm size class due to sheep grazing than in the remaining treatments (Figure 8.3). Referring to Figure 8.3, it should be remembered that the stocking rate range of the sheep-only and cattle-only treatments were quite different (Table 8.1). For stocking rates of approximately 1.0 AUE ha^{-1} therefore, the perception that veld stocked with sheep would have a larger number of severely grazed small (<1m) patches per area than veld stocked with cattle at the same stocking rate was therefore not corroborated.

The severity of patch grazing was influenced by both stocking rate and cattle-to-sheep ratio. An important trend illustrated in Figure 8.5 was that as the ratio increasingly favoured cattle so the proportion of a treatment's area grazed to <1cm decreased. At a stocking rate of about 1.0 AUE ha^{-1}, approximately 30%, 10% and 1% of the areas allocated to the 0:1 (sheep-only), 2:1 and 1:0 (cattle-only) treatments respectively, had been grazed to <1cm (Figure 8.5). Detailed analysis of the severity of grazing by sheep on individual tufts of *T. triandra* and *T. leucothrix* (in an independent study within the present study) indicated tuft mortalities of 30% and 12% respectively for the 0:1 and 2:1 ratio treatments. In these ratio treatments, the mean height of severely grazed tufts was approximately 1cm above ground level (Peddie 1994). The potential negative effects of sheep grazing on their own are well illustrated by these data.

Recommendations that sheep should be grazed together with cattle to limit the severity of grazing by the sheep are therefore supported. However, the cattle should be stocked in higher proportion to sheep and the overall stocking rate should be approximately 1.0 AUE ha^{-1} on this type of veld. In species mixes where sheep are in higher proportion to cattle (on the basis of AUE) the presence of cattle may exacerbate rather than limit the severity of grazing (Figure 8.5).

Table 8.1 Stocking rate (SR in animal unit equivalents [AUE] per hectare) and ratio (AUE cattle:AUE sheep) treatments at the start of each season (PLANNED), the mean SR of cattle and sheep, the actual SR and ratio (expressed as the proportion of sheep (PROP. SHEEP)) for each treatment over the three grazing seasons, and the estimated proportion (%) of the area of each treatment comprising each of three categories of patch viz. <3cm (A - severe), >3cm to <5cm (B - moderate), and >5cm (C - lenient)

PLANNED		MEAN SR		ACTUAL		PROP.			
SR	RATIO	CATTLE	SHEEP	SR	RATIO	SHEEP	A	B	C
0.67	1:0	0.77	–	0.77	1:0	–	20.8	16.5	62.7
0.67	3:1	0.51	0.11	0.62	4.6:1	0.18	9.9	8.2	81.9
0.67	1:1	0.41	0.24	0.65	1.7:1	0.37	8.5	7.4	84.1
0.67	1:3	0.22	0.34	0.56	1:1.6	0.61	21.2	7.1	71.7
0.67	0:1	–	0.47	0.47	0:1	1.00	8.8	3.5	87.7
0.95	1:0	1.07	–	1.07	1:0	–	25.2	27.6	47.2
0.95	3:1	0.83	0.20	1.03	4.1:1	0.19	41.9	14.1	44.0
0.95	1:1	0.58	0.38	0.96	1.5:1	0.40	29.2	19.1	51.7
0.95	1:3	0.28	0.61	0.89	1:2.2	0.69	38.3	9.2	52.5
0.95	0:1	–	0.76	0.76	0:1	1.00	11.4	4.5	84.1
1.33	1:0	1.53	–	1.53	1:0	–	90.4	7.5	2.1
1.33	3:1	1.25	0.21	1.46	5.9:1	0.14	82.7	6.6	10.7
1.33	1:1	0.82	0.49	1.31	1.7:1	0.37	45.5	28.1	26.4
1.33	1:3	0.40	0.72	1.12	1:1.8	0.64	40.7	13.6	45.7
1.33	0:1	–	0.98	0.98	0:1	1.00	65.0	4.8	30.2

Table 8.2 Parameter estimates for the dependence of the proportion of a treatment's area comprising the <3cm, >3cm to <5cm and >5cm categories of patch on the proportion of sheep in each cattle to sheep ratio treatment (Ratio - expressed in terms of AUE ha^{-1}), total stocking rate (SR - AUE ha^{-1}) and their combined effects

PATCH CATEGORY	INDEPENDENT VARIABLES	COEFFICIENT	t VALUE	SIGNIFICANCE LEVEL
<3cm	Constant	43.9	4.07	0.001
	Ratio	-17.9	-0.93	0.367
	adjusted r^2	[1]–		
	DF	13		
	Constant	-31.8	-2.96	0.011
	SR	71.7	6.65	<0.001
	adjusted r^2	75.5***		
	DF	13		
	Constant	-43.0	-3.03	0.011
	Ratio	12.2	1.18	0.260
	SR	77.9	6.58	<0.001
	adjusted r^2	76.3***		
	DF	12		
>3cm <5cm	Constant	16.7	35.69	<0.001
	Ratio	-10.6	-2.05	0.061
	adjusted r^2	18.6^{ns}		
	DF	13		
	Constant	3.8	0.60	0.561
	SR	8.7	1.35	0.201
	adjusted r^2	5.6^{ns}		
	DF	13		
	Constant	12.2	1.49	0.163
	Ratio	-9.1	-1.53	0.153
	SR	4.1	0.60	0.562
	adjusted r^2	14.3^{ns}		
	DF	12		
>5cm	Constant	39.7	3.72	0.003
	Ratio	28.4	1.50	0.157
	adjusted r^2	8.2^{ns}		
	DF	13		
	Constant	128.1	17.46	<0.001
	SR	-80.3	-10.88	<0.001
	adjusted r^2	89.4***		
	DF	13		
	Constant	131.1	12.87	<0.001
	Ratio	-3.3	-0.44	0.667
	SR	-82.0	-9.65	<0.001
	adjusted r^2	88.6***		
	DF	12		

^{ns} = non significant *** = $P < 0.001$
[1]– = residual variance exceeds variance of Y variate

Table 8.3 Parameter estimates for the dependence of the proportion of a treatment's area comprising the <3cm, >3cm to <5cm and >5cm categories of patch on the stocking rate of cattle (SR cattle AUE ha^{-1}), stocking rate of sheep (SR sheep AUE ha^{-1}) and their combined effects

PATCH CATEGORY	INDEPENDENT VARIABLES	COEFFICIENT	t VALUE	SIGNIFICANCE LEVEL
<3cm	Constant	16.6	1.83	0.091
	SR cattle	33.6	2.07	0.018
	adjusted r^2	31.1*		
	DF	13		
	Constant	35.9	3.20	0.007
	SR sheep	0.3	0.01	0.989
	adjusted r^2	1_		
	DF	13		
	Constant	-36.5	-2.99	0.011
	SR cattle	72.8	6.63	<0.001
	SR sheep	82.7	4.88	<0.001
	adjusted r^2	75.0***		
	DF	12		
>3cm <5cm	Constant	7.8	2.51	0.026
	SR cattle	7.3	1.72	0.109
	adjusted r^2	12.3ns		
	DF	13		
	Constant	14.8	4.56	<0.001
	SR sheep	-7.7	-1.11	0.287
	adjusted r^2	1.6ns		
	DF	13		
	Constant	7.0	0.97	0.350
	SR cattle	7.9	1.22	0.247
	SR sheep	1.2	0.12	0.903
	adjusted r^2	5.1ns		
	DF	12		
>5cm	Constant	75.7	9.03	<0.001
	SR cattle	-40.7	-3.56	0.004
	adjusted r^2	45.4**		
	DF	13		
	Constant	49.6	4.27	<0.001
	SR sheep	7.1	0.29	0.778
	adjusted r^2	1_		
	DF	13		
	Constant	129.7	15.24	<0.001
	SR cattle	-80.7	-10.51	<0.001
	SR sheep	-84.1	-5.10	<0.001
	adjusted r^2	88.6***		
	DF	12		

ns = non significant * = $P < 0.05$ ** = $P < 0.01$ *** = $P < 0.001$
1_ = residual variance exceeds variance of Y variate

Table 8.4 Parameter estimates for the dependence of the proportion of each treatment comprising patches in the <1m size class, within the <3cm, >3cm to <5cm and >5cm patch categories, on the proportion of sheep in each cattle to sheep ratio treatment (Ratio expressed in terms of AUE ha^{-1}), stocking rate (SR AUE ha^{-1}) and their combined effects

PATCH CATEGORY	INDEPENDENT VARIABLES	COEFFICIENT	t VALUE	SIGNIFICANCE LEVEL
<3cm	Constant	52.4	7.26	<0.001
	Ratio	24.7	1.94	0.075
	adjusted r^2	16.5^{ns}		
	DF	13		
	Constant	105.9	9.75	<0.001
	SR	-45.1	-4.13	0.001
	adjusted r^2	53.4^{***}		
	DF	13		
	Constant	14.8	6.60	0.011
	Ratio	10.8	0.85	0.413
	SR	-12.3	-3.29	0.006
	adjusted r^2	52.4^{**}		
	DF	12		
>3cm <5cm	Constant	69.1	14.26	<0.001
	Ratio	12.1	1.41	0.183
	adjusted r^2	6.5^{ns}		
	DF	13		
	Constant	99.4	13.18	<0.001
	SR	-26.5	-3.49	0.004
	adjusted r^2	44.4^{**}		
	DF	13		
	Constant	97.3	9.25	<0.001
	Ratio	2.3	0.30	0.770
	SR	-25.3	-2.89	0.014
	adjusted r^2	40.2^{*}		
	DF	12		
>5cm	Constant	68.6	10.48	<0.001
	Ratio	-17.1	-1.47	0.165
	adjusted r^2	7.7^{ns}		
	DF	13		
	Constant	27.6	2.65	0.020
	SR	35.4	3.39	0.005
	adjusted r^2	42.8^{**}		
	DF	13		
	Constant	31.4	2.17	0.050
	Ratio	-4.2	-0.40	0.697
	SR	33.3	2.76	0.017
	adjusted r^2	38.9^{*}		
	DF	12		

^{ns} = non significant * = $P < 0.05$ ** = $P < 0.01$ *** = $P < 0.001$

Table 8.5 Parameter estimates for the dependence of the proportion of each treatment comprising patches in the >4m size class, within the <3cm, >3cm to <5cm and > 5cm patch categories, on the proportion of sheep in each cattle to sheep ratio treatment (Ratio expressed in terms of AUE ha^{-1}), stocking rate (SR AUE ha^{-1}) and their combined effects

PATCH CATEGORY	INDEPENDENT VARIABLES	COEFFICIENT	t VALUE	SIGNIFICANCE LEVEL
<3cm	Constant	12.4	2.81	0.015
	Ratio	-9.9	-1.27	0.227
	adjusted r^2	4.1^{ns}		
	DF	13		
	Constant	-11.7	-1.55	0.144
	SR	20.9	2.76	0.016
	adjusted r^2	32.2^{*}		
	DF	13		
	Constant	-9.6	-0.91	0.380
	Ratio	-2.3	-0.30	0.766
	SR	19.7	2.26	0.044
	adjusted r^2	27.1^{ns}		
	DF	12		
>3cm <5cm	Constant	7.4	2.42	0.031
	Ratio	-5.9	-1.09	0.296
	adjusted r^2	1.3^{ns}		
	DF	13		
	Constant	-7.6	-1.42	0.179
	SR	13.1	2.44	0.030
	adjusted r^2	26.1^{*}		
	DF	13		
	Constant	-6.6	-0.89	0.393
	Ratio	-1.0	-0.19	0.851
	SR	12.6	2.02	0.066
	adjusted r^2	20.2^{ns}		
	DF	12		
>5cm	Constant	10.4	1.60	0.134
	Ratio	9.3	0.81	0.432
	adjusted r^2	[1]_		
	DF	13		
	Constant	35.3	2.95	0.011
	SR	-22.0	-1.83	0.090
	adjusted r^2	14.4^{ns}		
	DF	13		
	Constant	34.4	2.05	0.063
	Ratio	1.0	0.08	0.936
	SR	-21.5	-1.54	0.149
	adjusted r^2	7.3^{ns}		
	DF	12		

^{ns} = non significant * = $P < 0.05$
[1]_ = residual variance exceeds variance of Y variate

Table 8.6 Parameter estimates for the dependence of the proportion of each treatment comprising patches in the <1m size class, within the <3cm, >3cm to <5cm and >5cm patch categories, on the stocking rate of cattle (SR cattle AUE ha^{-1}) and stocking rate of sheep (SR sheep AUE ha^{-1}) and their combined effects

PATCH CATEGORY	INDEPENDENT VARIABLES	COEFFICIENT	t VALUE	SIGNIFICANCE LEVEL
<3cm	Constant	80.4	13.86	<0.001
	SR cattle	-29.6	-3.74	0.002
	adjusted r^2	48.1**		
	DF	13		
	Constant	56.0	7.15	<0.001
	SR sheep	19.9	1.19	0.225
	adjusted r^2	2.9ns		
	DF	13		
	Constant	99.2	8.29	<0.001
	SR cattle	-43.5	-4.03	0.002
	SR sheep	-29.3	-1.76	0.104
	adjusted r^2	55.3**		
	DF	12		
>3cm <5cm	Constant	83.7	19.97	<0.001
	SR cattle	-16.0	-2.80	0.015
	adjusted r^2	32.8*		
	DF	13		
	Constant	71.3	13.92	<0.001
	SR sheep	8.5	0.78	0.451
	adjusted r^2	1_		
	DF	13		
	Constant	97.0	11.17	<0.001
	SR cattle	-25.9	-3.31	0.006
	SR sheep	-20.8	-1.72	0.111
	adjusted r^2	41.6*		
	DF	12		
>5cm	Constant	50.8	8.14	<0.001
	SR cattle	17.7	2.07	0.058
	adjusted r^2	19.1ns		
	DF	13		
	Constant	62.0	8.71	<0.001
	SR sheep	-2.5	-0.16	0.874
	adjusted r^2	1_		
	DF	13		
	Constant	26.5	2.19	0.049
	SR cattle	35.7	3.26	0.007
	SR sheep	37.9	2.24	0.044
	adjusted r^2	38.3*		
	DF	12		

ns = non significant * = $P < 0.05$ ** = $P < 0.01$
1_ = residual variance exceeds variance of Y variate

Table 8.7 Parameter estimates for the dependence of the proportion of each treatment comprising patches in the >4m size class, within the <3cm, >3cm to <5cm and >5cm patch categories, on the stocking rate of cattle (SR cattle AUE ha^{-1}) and stocking rate of sheep (SR sheep AUE ha^{-1}) and their combined effects

PATCH CATEGORY	INDEPENDENT VARIABLES	COEFFICIENT	t VALUE	SIGNIFICANCE LEVEL
<3cm	Constant	-0.1	-0.03	0.974
	SR cattle	14.2	2.72	0.018
	adjusted r^2	31.4*		
	DF	13		
	Constant	11.9	2.62	0.021
	SR sheep	-10.4	-1.07	0.303
	adjusted r^2	1.1ns		
	DF	13		
	Constant	-8.0	-0.94	0.364
	SR cattle	20.0	2.62	0.023
	SR sheep	12.2	1.04	0.320
	adjusted r^2	31.8*		
	DF	12		
>3cm <5cm	Constant	-0.2	-0.09	0.931
	SR cattle	8.7	2.34	0.036
	adjusted r^2	24.2*		
	DF	13		
	Constant	7.0	2.26	0.041
	SR sheep	-6.1	-0.92	0.374
	adjusted r^2	1_		
	DF	13		
	Constant	-5.4	-0.89	0.390
	SR cattle	12.6	2.29	0.041
	SR sheep	8.1	0.96	0.358
	adjusted r^2	23.7ns		
	DF	12		
>5cm	Constant	19.6	3.01	0.010
	SR cattle	-8.9	-1.00	0.334
	adjusted r^2	1_		
	DF	13		
	Constant	15.7	2.35	0.035
	SR sheep	-3.4	-0.24	0.817
	adjusted r^2	1_		
	DF	13		
	Constant	38.3	2.77	0.017
	SR cattle	-22.8	-1.82	0.093
	SR sheep	-29.1	-1.51	0.157
	adjusted r^2	9.0ns		
	DF	12		

ns = non significant   * = $P < 0.05$
1_ = residual variance exceeds variance of Y variate

ble 8.8 Chi-squared values derived from Kolmogorov-Smirnov two-way sample tests for comparisons of leaf table height distributions between all combinations of stocking rate viz. low (LSR), medium (MSR) and high (HSR), and cattle to sheep ratio (1:0, 3:1, 1:1, 1:3 and 0:1) treatments. Stocking rate and ratio treatments are expressed in terms of the planned treatments. Refer to Table 8.1 for the actual treatments applied

OCKING RATE	RATIO	LSR 1:0	LSR 3:1	LSR 1:1	LSR 1:3	LSR 0:1	MSR 1:0	MSR 3:1	MSR 1:1	MSR 1:3	MSR 0:1	HSR 1:0	HSR 3:1	HSR 1:1	HSR 1:3	HSR 0:1
	1:0	–														
	3:1	10	–													
R	1:1	2	14	–												
	1:3	9	14	4	–											
	0:1	5	4	4	3	–										
	1:0	58**	77**	74**	49**	62**	–									
	3:1	62**	83**	79**	55**	69**	1	–								
R	1:1	30	44*	42	26	36	8	8	–							
	1:3	46*	49*	41	21	30	10	12	10	–						
	0:1	27	13	29	22	15	76**	92**	50**	38	–					
	1:0	190**	205**	185**	139**	156**	55**	50**	72**	55**	177**	–				
	3:1	253**	269**	231**	177**	108**	74**	85**	112**	88**	216**	4	–			
R	1:1	102**	121**	115**	87**	207**	10	6	22	34	137**	34*	55**	–		
	1:3	49**	72**	55**	36*	48**	22	21	16	14	92**	46**	79**	13	–	
	0:1	88**	98**	86**	56**	67**	37	36	29	14	88**	20	42**	22	6	–

$P < 0.05$ ** = $P < 0.01$

e: All comparisons were non significant ($P > 0.05$) unless otherwise indicated

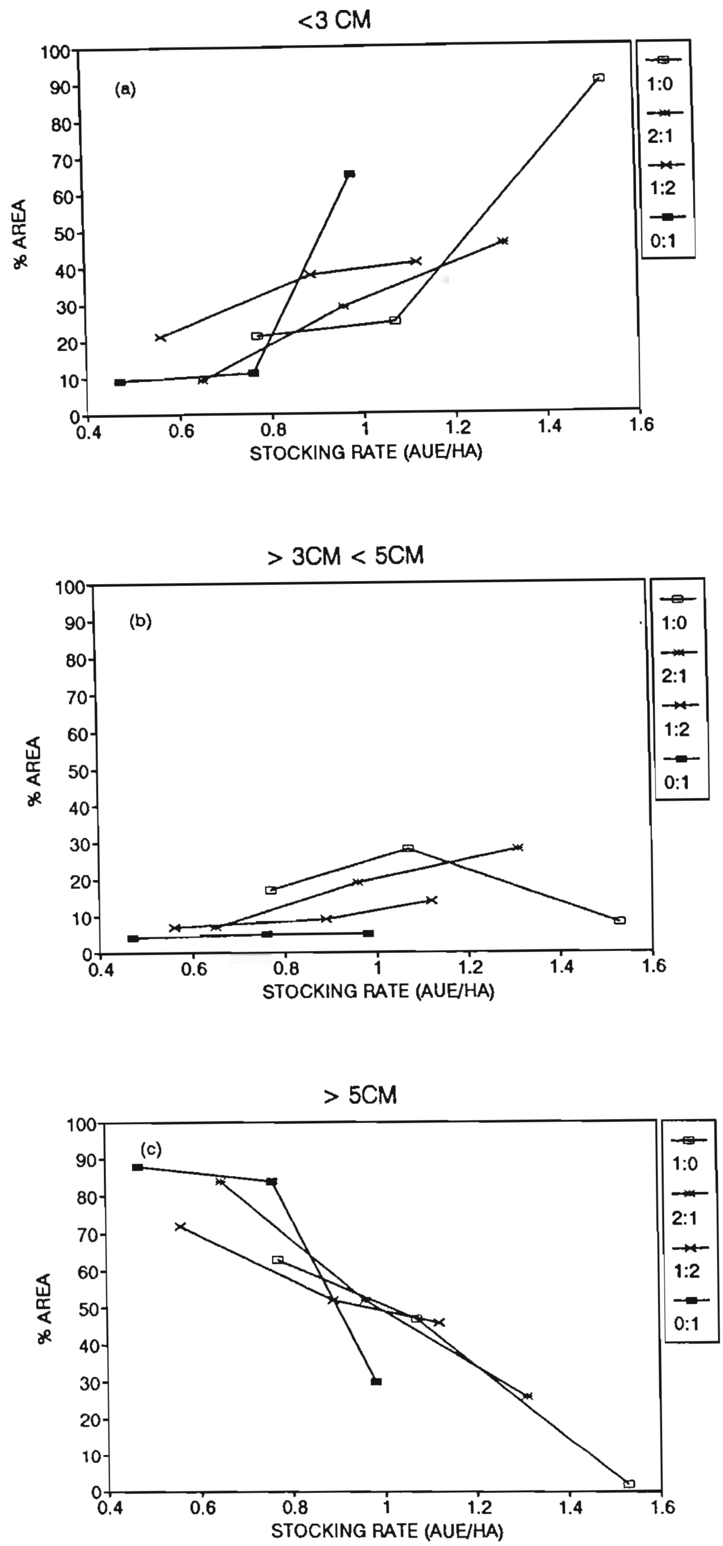


Figure 8.1 The effect of stocking rate (AUE/HA) and cattle to sheep ratio (AUE cattle:AUE sheep) treatments on the estimated proportion (% AREA) of each treatment comprising patches in the categories; a) <3cm, b) >3cm to <5cm, and c) >5cm. See text for the definition of a patch.

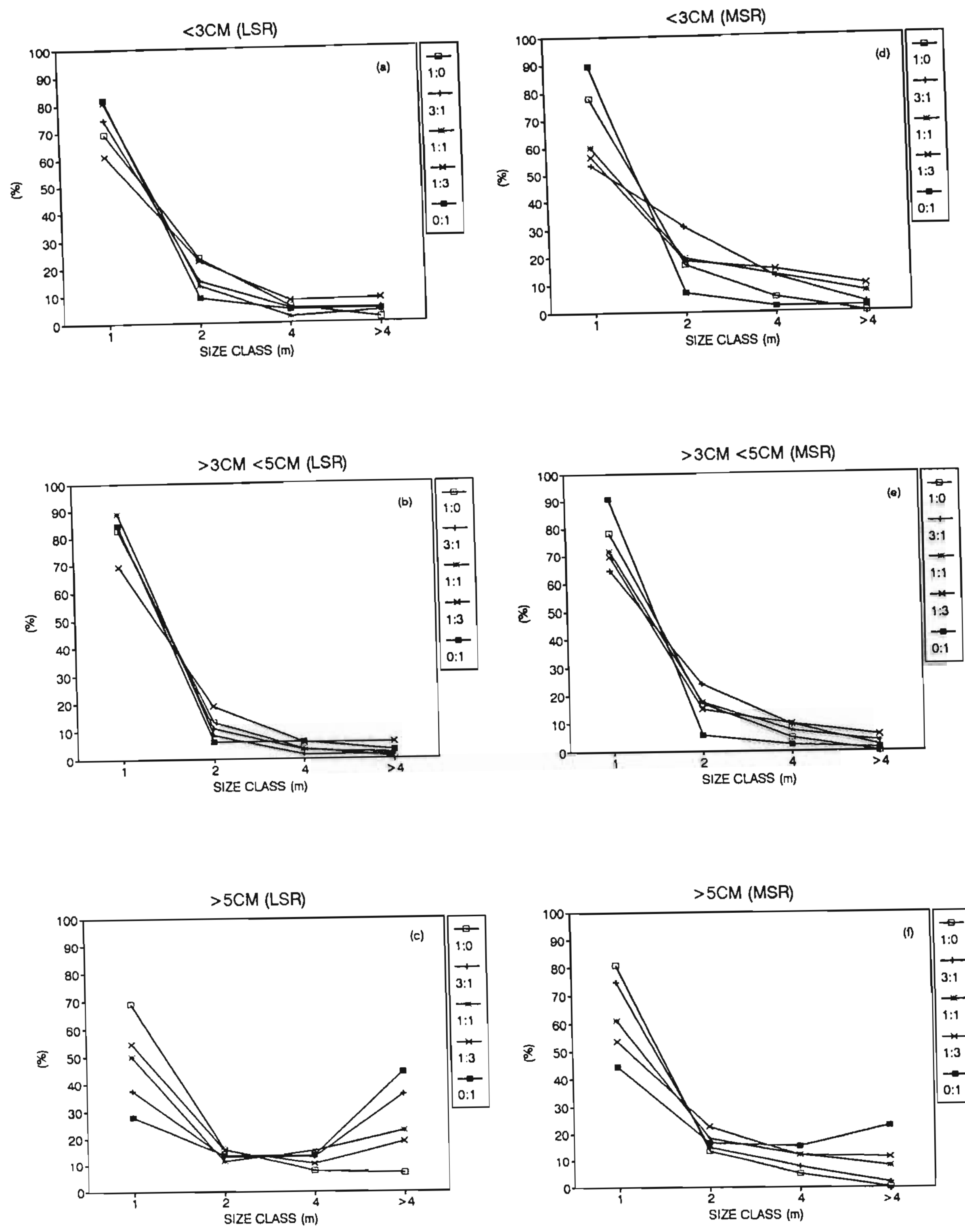


Figure 8.2 The effect of cattle to sheep ratio (1:0, 3:1, 1:1, 1:3 and 0:1) on patch size distributions (frequency (%) per size class) for each of the three categories of patch (viz >5cm, >3cm <5cm, and <3cm) in the low (LSR - a, b & c), medium (MSR - d, e & f) and high (HSR - g, h & i) stocking rate treatments. Ratio and stocking rate treatments are expressed in terms of the planned treatments

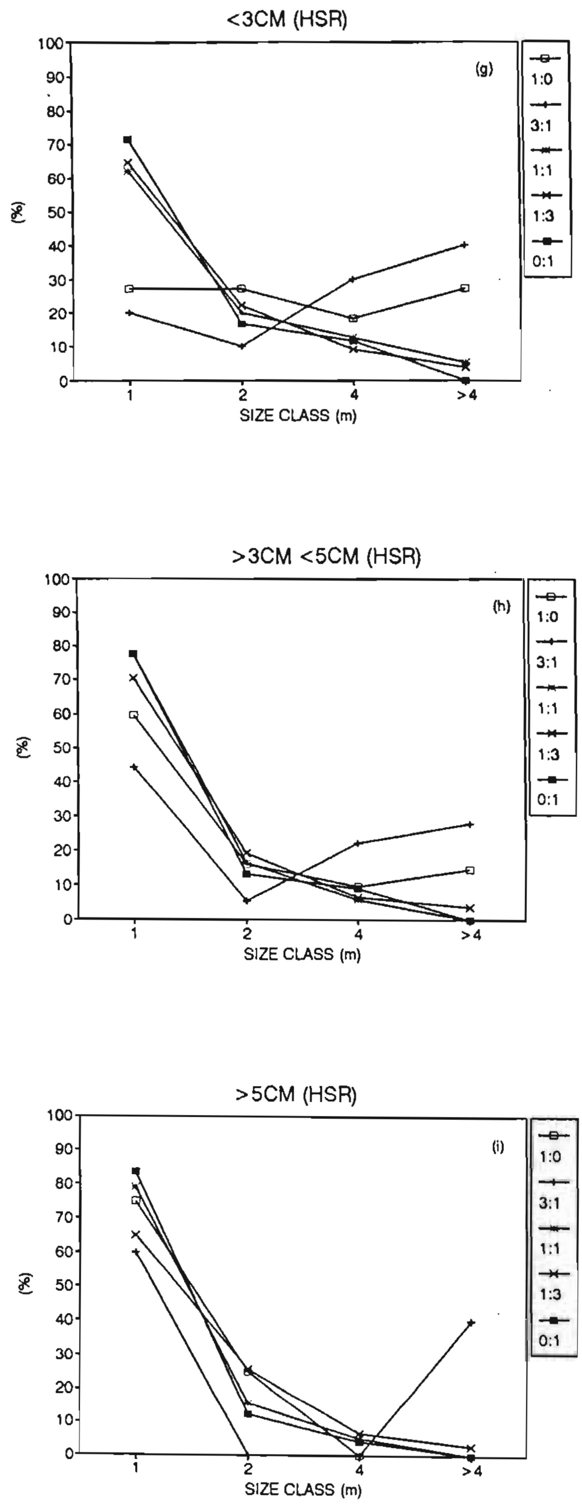


Fig 8.2 (cont.)

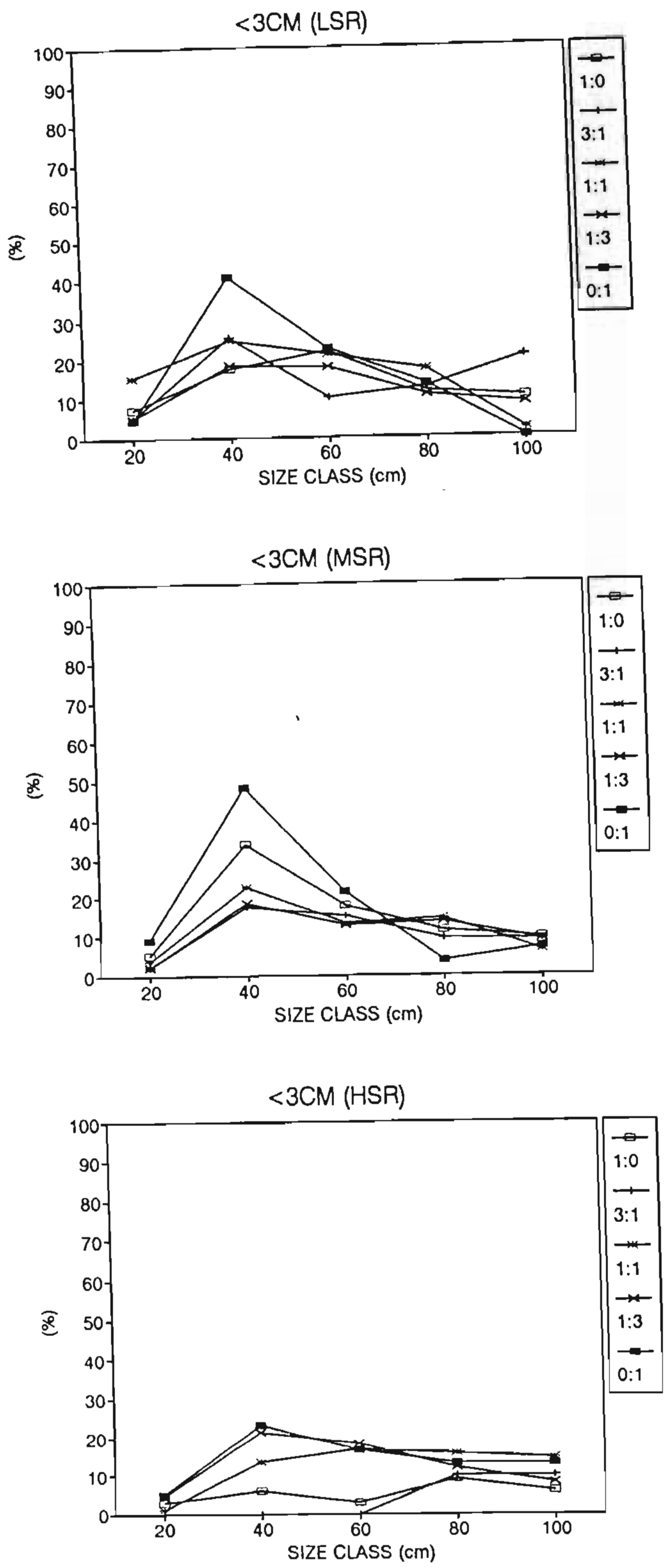


Figure 8.3 Patch size distributions (frequency (%) per size class) for patches of <1m, in 20cm size classes, for each stocking rate (low - LSR, medium - MSR and high - HSR) and cattle to sheep ratio (1:0, 3:1, 1:1, 1:3 and 0:1) treatment within the severe (<3cm) category of patch. Ratio and stocking rate treatments are expressed in terms of the planned treatments

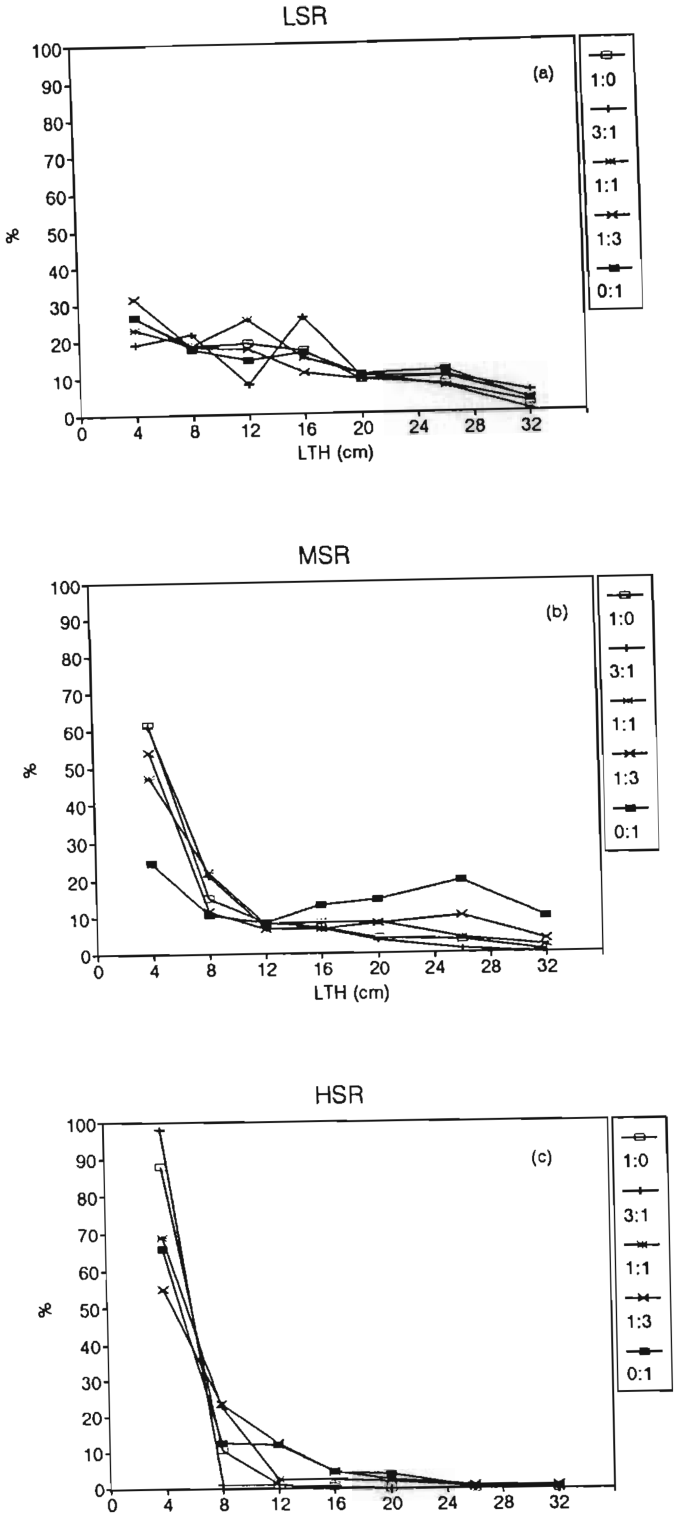


Figure 8.4 Leaf table height (LTH in cm) distributions (frequency (%) in each LTH class) in the low (LSR - a), medium (MSR - b) and high (HSR - c) stocking rate treatments for each of the planned cattle to sheep ratio (1:0, 3:1, 1:1, 1:3 and 0:1) treatments

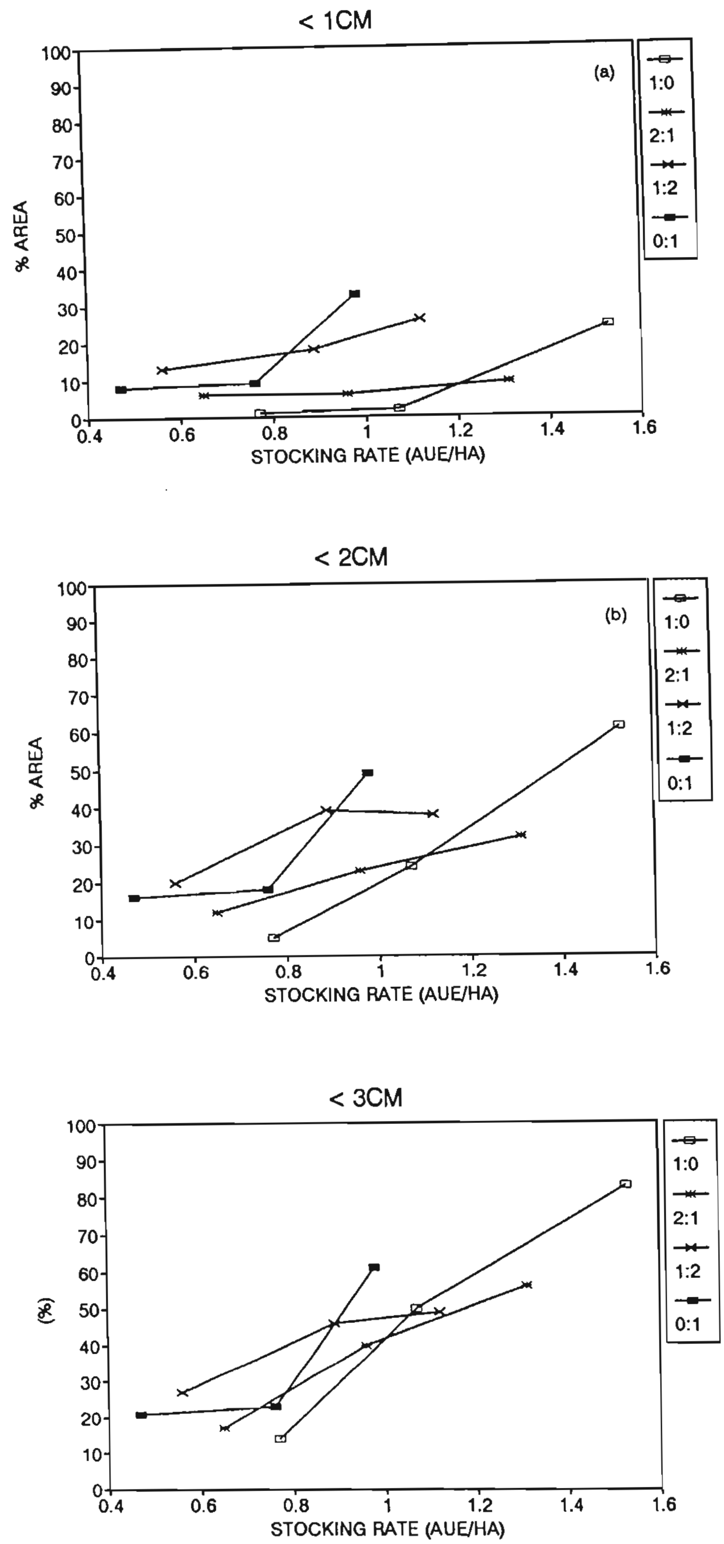


Figure 8.5 The effect of stocking rate (AUE/HA) and cattle to sheep ratio (AUE cattle:AUE sheep) treatments on the estimated proportion (% AREA) of each treatment grazed to a leaf table height of a) <1cm, b) <2cm and c) <3cm

CHAPTER 9

SHORT-TERM EFFECTS OF CATTLE-TO-SHEEP RATIO AND STOCKING RATE ON PROPORTIONAL SPECIES COMPOSITION AND BASAL COVER

9.1 Introduction

As stated earlier in this dissertation, several studies have indicated that sheep have a greater potential to cause veld degradation than cattle (e.g. O'Reagain & Turner 1992). Data relating to the patterns of grazing on three grass species and area selection patterns reported on in Chapters 7 and 8 provide some insight into the potential impacts of the applied treatments on the sward.

There is a poor empirical data base providing information on the effects of mixed-grazing by cattle and by sheep on species composition and basal cover in sour grassveld. Malherbe (1971) reported that there was no change in species composition after 12 years of grazing, at a stocking rate of 1.15 ha per large stock unit, for a range of cattle-to-sheep ratios. By contrast, du Toit (1967) reported that grazing with sheep lowered the basal cover, increased weed density and lowered the herbage production potential of veld compared to grazing with cattle. O'Reagain and Turner (1992) point out, however, that du Toit's (1967) conclusions may have been due to differences in stocking density between cattle and sheep rather than the species of livestock used in the trial.

There is some empirical evidence that stocking rate has a major influence on species composition and thus veld condition (van Niekerk, *et al.* 1984; Hardy & Hurt 1989; Morris, *et al.* 1992). In humid grasslands, as stocking rate increases the proportional composition of palatable species declines whilst the proportional composition of unpalatable, grazing tolerant species increases (e.g. Foran, *et al.* 1978). These effects tend to be long-term (>8 years) with rapid (<4 years) changes in species composition occurring only at exceptionally high stocking rates (> 2.0 AUE ha^{-1}) (e.g. van Niekerk, *et al.* 1984). O'Reagain and Turner (1992) suggest that species composition may remain constant for a range of stocking rates below a "threshold" stocking rate for any specific plant/climate/soil environment. Once the threshold has been exceeded, species composition is likely to change.

Few studies have aimed to investigate the effects of stocking rate on basal cover despite considerable circumstantial evidence that basal cover is likely to decrease as stocking rate increases. The lack of such data may be due to the lack of an efficient method for determining basal cover in humid grasslands (e.g. Mentis 1982). However, basal cover data were obtained from a long-term grazing trial conducted in the Dohne Sourveld. These data suggested that basal cover may be a more sensitive indicator of the effects of grazing on sward dynamics than species composition (du Toit & Aucamp 1985). This suggestion is supported by the author.

The objective of the study reported on in this chapter was to investigate the short-term effects of cattle to sheep ratio and stocking rate on proportional species composition and basal cover of the sward.

9.2 Procedure

Species composition data were obtained from permanently marked 30m x 30m sample sites in the 'test' paddocks of the animal production component and all paddocks of the simulated component of the trial. Each of the paddocks was stratified and sample sites were randomly located within strata to ensure an even distribution of sample sites over each paddock. Species composition was determined from at least 200 observations per sample site, using the step-point method (Mentis 1981b) and the nearest plant approach (Foran 1976; Everson & Clarke 1987). For each point observation, when the nearest plant was not a grass, the presence of the non-grass was noted and the nearest grass plant was identified and recorded.

No efficient[6] method for obtaining estimates of basal cover were available during the planning phase of the trial. An independent study was therefore undertaken in an attempt to develop an appropriate technique for monitoring basal cover in a tufted grassland. The procedure followed and results obtained are presented in Appendix Chapter 1. Basal cover was determined in each sample site using the proposed method (Appendix Chapter 1). Briefly, the method requires measurement of the distance to the edge of the nearest plant and the plant's diameter, for each placement of the point in a point survey. Both measurements are rounded up to the nearest centimetre. If the point falls within the circumference of a plant the distance is recorded as 1cm. Basal cover (BC) is calculated, for each sample site, from the mean point to plant distance (D), the natural log of D ($\log_e D$), mean tuft diameter (d) and the natural log of d ($\log_e d$) using the following equation:

$$BC = 19.8+0.39(D)-11.87(\log_e D)+0.64(d)+2.93(\log_e d)$$

The method used for collecting basal cover data in the present study thus allowed for the simultaneous collection of species composition and basal cover data in each sample site.

Each sample site was sampled during January/February (FEB) 1990 and again during December (DEC) 1991 by the same observer. The data collected therefore reflect the effects of stocking rate and cattle-to-sheep ratio on proportional species composition and basal cover after approximately two years of treatment. Species composition data from each sample site within a treatment were pooled to produce a 'mean proportional species composition' for each treatment. These data were subjected to detrended correspondence analysis (DCA) (Hill & Gauch 1980).

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[6]Efficient in the present context refers to obtaining a high level of precision of an estimate within an acceptable time frame. An acceptable time was considered to be the time required to determine proportional species composition from a 200 point survey of a standard 30m x 30m sample site i.e. <60 minutes.

Temporal changes in proportional species composition for each treatment were mapped in two-dimensional ordination space using site trajectories (e.g. Hardy & Hurt 1989; Martens, *et al.* 1990; Morris, *et al.* 1992). Data from both surveys were analyzed together, thus allowing an assessment of the relative direction and magnitude of change of proportional species composition for each treatment.

Note: Treatments refer to the 'planned' cattle to sheep ratio and stocking rate treatments applied in the trial.

9.3 Results and discussion

Species composition data derived from both survey dates are presented in Tables 9.1, 9.2 & 9.3 for the low, moderate and high stocking rate treatments respectively. Twenty seven grass species were encountered in the surveys with two species, viz. *T. triandra* and *T. leucothrix* together accounting for approximately 50% of the proportional species composition of all treatments.

The first four axes derived from the DCA yielded eigen values of 0.17, 0.04, 0.02 and 0.01. DCA axis 1 thus accounted for by far the largest proportion of the variation in the data set. Patterns of variation within and between treatments were plotted by the first two DCA axes (Figure 9.1).

The patterns exhibit distinct differences in proportional species composition of the sward between the moderate stocking rate treatment (the animal production component of the trial) and the low and high stocking rate treatments (the simulated component of the trial). Examination of Tables 9.1 to 9.3 provides some explanation of these differences (refer to species data presented in bold type). Whilst *T. triandra* and *T. leucothrix* comprise a major proportion of total species composition of all treatment areas, species such as *Setaria nigrirostris*, *Eulalia villosa* and *Alloteropsis semialata* were more abundant in the low and high stocking rate treatments than in the moderate stocking rate treatment. Furthermore, *Elionurus muticus* and *Harpochloa falx* were less abundant in the low and high stocking rate treatments than in the moderate stocking rate treatment (Tables 9.1, 9.2 & 9.3). A species plot by the first two DCA axes corroborates these observations (Figure 9.2). In Figure 9.2, *S. nigrirostris*, *A. semialata* and *Eulalia villosa* are located to the left of the ordination diagram, *E. muticus* and *H. falx* are located on the right, and *T. triandra* and *T. leucothrix* are located near the centre (refer to Table 9.1 for detail on the species codes). The main pattern of variation on DCA axis 1 therefore reflects the inherent differences in overall species composition between the two treatment areas used in the trial.

For most treatments the main direction of change in proportional species composition between the two survey dates appears to be associated with DCA axis 2 (Figure 9.1). However, the magnitude of change was small, exceeding 30 units in only one treatment i.e. the 1:1 high stocking rate treatment (code 13) while in other treatments the change was less than 10 units (e.g codes 3, 5, 7 & 9). A difference of 30 units represents 0.3 "standard deviations of species turnover" (SD) (Hill & Gaugh 1980) where 4.5SD represents a complete species turnover. The <0.03SD observed for all treatments, except one, therefore indicates minor differences in proportional species composition between survey dates. Such small differences will also reflect a degree of sampling error (Hardy 1986; Hardy & Walker 1991).

The lack of any consistent trends of change in proportional composition of dominant species e.g. *T. triandra* and *T. leucothrix*, together with the low magnitude of change indicated by the trajectories presented in Figure 9.1, suggests that, for the time period concerned, the cattle to sheep ratio and stocking rate treatments applied in the present trial had no effect on the proportional species composition of the sward.

Basal cover estimates for all treatments and for both survey dates are presented in Table 9.4. Estimates for the low stocking rate treatment indicated that basal cover had declined between the two survey dates for all cattle to sheep ratios. This trend, however, was not maintained for the two remaining stocking rate treatments (Table 9.4). Within a stocking rate treatment, cattle to sheep ratio had no consistent influence on differences in basal cover between survey dates. Inspection of the magnitude of differences in estimated basal cover between survey dates reveals that these differences were largely within the between-observer error recorded during the development of the technique for estimating basal cover in tufted grasslands (Appendix chapter 1 - Table 4). Consequently, it was concluded that the cattle to sheep ratio and stocking rate treatments applied in the trial had not affected basal cover over the time period concerned.

9.4 Conclusion

As suggested earlier in this chapter, the humid grasslands of the Highland Sourveld are relatively stable and significant changes in species composition and basal cover have generally been recorded only after several years of intensive grazing. Results from the present study support the statement that these grasslands are stable. In the short-term, despite intensive grazing of individual tufts and patches (refer to chapters 7 and 8) by both sheep and cattle, species composition and basal cover were not affected by the applied treatments.

Table 9.1 The mean proportional species composition of each cattle to sheep ratio (1:0, 3:1, 1:1, 1:3 & 0:1) treatment for the FEB 1990 (A) and DEC 1991 (B) point surveys of sample sites in the low stocking rate treatment. Stocking rate and cattle to sheep ratio are expressed in terms of the planned treatments

	RATIO									
	1:0		3:1		1:1		1:3		0:1	
SPECIES	A	B	A	B	A	B	A	B	A	B
ASE *Alloteropsis semialata*	4.3	3.3	4.5	5.3	3.0	6.2	5.6	7.0	6.0	7.0
BSE *Brachiaria serrata*	1.5	1.8	0.5	1.3	0.8	0.7	0.5	0.3	0.3	1.0
DDI *Digitaria diagonalis*	1.8	0.0	2.0	1.5	0.8	0.8	0.6	0.5	2.0	1.7
DSE *Digitaria setifolia*	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.9	0.0	0.7
DSP *Digitaria* species	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DTR *Digitaria tricholaenoides*	0.0	0.3	0.0	1.0	0.5	0.3	0.0	0.0	0.0	0.0
DAM *Diheteropogon amplectens*	2.3	2.8	3.8	1.5	1.7	1.2	1.4	1.0	0.0	0.7
DFI *Diheteropogon filifolius*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
EMU *Elionurus muticus*	1.8	0.8	1.5	2.0	1.7	1.2	1.1	1.0	0.7	1.0
ECA *Eragrostis capensis*	0.5	0.5	0.3	2.0	0.2	0.5	0.0	0.9	0.3	0.3
ECU *Eragrostis curvula*	0.5	0.5	0.3	2.0	0.0	0.3	1.1	2.1	0.7	1.0
EPL *Eragrostis plana*	0.0	0.3	2.3	1.3	0.3	0.7	0.4	0.4	0.7	2.0
ERA *Eragrostis racemosa*	1.5	1.5	0.5	1.5	0.7	0.8	0.3	0.3	0.0	0.0
EVI *Eulalia villosa*	7.3	5.8	2.0	2.3	4.7	6.0	4.3	3.3	2.7	4.3
HFA *Harpochloa falx*	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.4	0.0	0.0
HTU *Helictotrichon turgidulum*	0.3	0.3	0.0	0.5	0.2	0.2	0.0	0.1	0.3	0.3
HCO *Heteropogon contortus*	0.3	0.5	2.3	3.3	0.0	0.7	2.0	2.9	1.3	3.3
KCA *Koeleria capensis*	5.0	5.8	1.0	2.8	1.3	3.2	1.4	3.4	0.3	4.7
MCA *Microchloa cafra*	5.5	6.8	5.5	9.8	5.0	4.0	12.3	13.6	2.0	6.0
PEC *Panicum ecklonii*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SFL *Setaria flabellata*	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0
SNI *Setaria nigrirostris*	12.8	9.8	9.8	7.8	13.0	9.8	4.3	2.4	15.7	12.0
SSP *Setaria* species	0.3	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SAF *Sporobolus africanus*	0.5	1.8	1.0	0.8	1.0	1.7	0.9	1.4	1.0	1.7
TTR *Themeda triandra*	25.8	30.3	30.3	26.5	37.0	33.2	22.5	25.0	25.7	16.7
TSP *Trachypogon spicatus*	10.8	8.5	12.8	6.0	7.0	8.8	9.1	5.5	6.7	5.3
TLE *Tristachya leucothrix*	17.5	18.8	19.5	20.8	21.0	19.0	30.9	27.3	33.7	30.3

Table 9.2 The mean proportional species composition of each cattle to sheep ratio (1:0, 3:1, 1:1, 1:3 & 0:1) treatment for the FEB 1990 (A) and DEC 1991 (B) point surveys of sample sites in the medium stocking rate treatment. Stocking rate and cattle to sheep ratio are expressed in terms of the planned treatments

	RATIO									
	1:0		3:1		1:1		1:3		0:1	
SPECIES	A	B	A	B	A	B	A	B	A	B
Alloteropsis semialata	0.5	0.3	3.6	3.4	3.8	3.8	2.5	2.4	1.0	0.8
Brachiaria serrata	0.0	0.3	0.5	0.0	0.0	0.3	0.0	0.0	0.5	0.3
Digitaria diagonalis	0.0	0.0	0.0	0.6	0.8	0.3	0.0	0.1	0.0	0.0
Digitaria setifolia	0.3	0.3	0.0	0.3	0.0	0.5	1.0	2.0	0.3	1.8
Digitaria species	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Digitaria tricholaenoides	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diheteropogon amplectens	0.0	0.0	0.1	0.1	0.0	0.0	0.3	0.3	0.0	0.0
Diheteropogon filifolius	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Elionurus muticus	10.5	14.0	7.3	6.9	9.8	9.8	9.4	12.4	12.3	12.3
Eragrostis capensis	3.0	1.5	2.0	1.8	1.5	0.3	2.0	2.5	2.0	2.5
Eragrostis curvula	0.0	0.0	0.4	0.5	0.0	0.1	0.1	0.8	0.0	0.0
Eragrostis plana	0.0	0.0	0.1	0.3	0.1	0.6	0.5	0.3	0.5	0.5
Eragrostis racemosa	0.0	0.0	0.0	0.3	0.1	0.1	0.4	0.8	0.0	0.0
Eulalia villosa	0.0	0.0	1.5	1.1	1.0	0.3	2.3	2.1	0.0	0.0
Harpochloa falx	12.3	10.3	11.1	15.0	7.6	7.5	3.3	2.9	7.8	7.5
Helictotrichon turgidulum	0.5	0.3	0.0	0.3	0.3	0.3	0.3	0.1	0.5	0.0
Heteropogon contortus	2.3	5.0	2.1	2.6	1.8	1.5	4.3	5.4	1.0	1.8
Koeleria capensis	7.8	9.5	9.0	5.9	6.5	5.6	3.0	5.3	6.5	5.8
Microchloa cafra	8.5	9.0	8.9	8.9	5.1	6.9	12.3	15.4	8.8	10.8
Panicum ecklonii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Setaria flabellata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Setaria nigrirostris	4.8	2.5	1.5	0.8	3.0	2.0	0.9	1.0	3.8	2.0
Setaria species	0.3	0.0	0.3	0.0	0.0	0.0	1.1	0.0	0.0	0.0
Sporobolus africanus	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.5	0.0	1.0
Themeda triandra	29.0	27.8	22.8	19.9	20.9	24.9	30.8	18.3	30.8	31.5
Trachypogon spicatus	6.0	3.8	4.9	2.1	12.0	5.9	8.4	4.1	4.8	5.0
Tristachya leucothrix	14.5	15.5	24.0	28.6	25.9	29.5	17.5	22.1	19.8	16.8

Table 9.3 The mean proportional species composition of each cattle to sheep ratio (1:0, 3:1, 1:1, 1:3 & 0:1) treatment for the FEB 1990 (A) and DEC 1991 (B) point surveys of sample sites in the high stocking rate treatment. Stocking rate and cattle to sheep ratio are expressed in terms of the planned treatments

	RATIO									
	1:0		3:1		1:1		1:3		0:1	
SPECIES	A	B	A	B	A	B	A	B	A	B
Alloteropsis semialata	5.7	5.0	8.7	6.3	2.3	2.5	6.7	7.5	1.0	4.0
Brachiaria serrata	1.0	0.7	0.3	1.0	0.8	1.3	0.8	1.0	0.0	1.5
Digitaria diagonalis	0.0	0.3	1.3	0.7	0.3	0.0	0.3	0.2	0.5	0.5
Digitaria setifolia	0.0	0.0	0.3	1.0	0.0	0.0	0.3	0.0	0.0	0.0
Digitaria species	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Digitaria tricholaenoides	2.0	3.0	0.0	0.0	1.5	3.5	0.0	0.0	0.0	2.0
Diheteropogon amplectens	1.7	1.0	0.3	1.7	0.8	1.3	0.7	0.3	2.0	0.5
Diheteropogon filifolius	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Elionurus muticus	1.0	2.7	1.3	3.0	0.5	0.0	1.8	2.0	1.5	1.5
Eragrostis capensis	0.3	3.0	1.0	0.7	1.3	0.8	0.3	0.3	1.5	1.5
Eragrostis curvula	1.3	2.7	0.3	0.7	0.5	1.0	0.7	1.3	1.5	5.5
Eragrostis plana	0.3	0.3	0.3	0.7	0.5	0.5	0.3	0.3	0.5	0.0
Eragrostis racemosa	0.0	0.3	0.0	0.7	0.3	5.5	0.5	0.3	0.0	0.5
Eulalia villosa	0.0	0.0	1.3	2.0	5.0	3.8	3.2	2.5	3.0	2.0
Harpochloa falx	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Helictotrichon turgidulum	0.0	0.7	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.5
Heteropogon contortus	2.3	4.0	0.3	0.7	0.5	3.5	0.2	0.3	2.0	6.0
Koeleria capensis	2.3	1.0	2.0	2.7	1.3	3.3	1.0	3.0	0.5	0.5
Microchloa cafra	6.3	6.0	8.0	14.3	5.0	4.3	4.8	7.8	11.0	14.5
Panicum ecklonii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Setaria flabellata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Setaria nigrirostris	9.0	10.7	7.7	9.0	11.0	6.0	16.7	11.2	6.0	3.5
Setaria species	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.0
Sporobolus africanus	0.0	1.7	0.7	3.0	0.3	1.5	1.3	1.2	0.5	2.0
Themeda triandra	32.7	35.7	24.7	19.0	32.0	39.3	27.7	30.7	29.0	23.5
Trachypogon spicatus	8.0	1.7	6.7	2.3	8.5	4.5	6.8	4.2	9.0	3.0
Tristachya leucothrix	23.3	19.3	34.7	30.7	27.5	16.8	25.5	25.2	30.0	26.5

Table 9.4 Basal cover (%) estimates for each cattle to sheep ratio (1:0, 3:1, 1:1, 1:3 & 0:1) and stocking rate (LSR, MSR & HSR) treatment for the FEB 1990 (A) and DEC 1991 (B) point surveys of sample sites. Stocking rate and cattle to sheep ratio are expressed in terms of the planned treatments

STOCKING RATE	RATIO	BASAL COVER (%)		
		A	B	DIFFERENCE
LSR	1:0	16.6	14.8	-1.8
	3:1	17.9	15.8	-2.1
	1:1	16.3	15.3	-1.0
	1:3	17.2	15.4	-1.8
	0:1	17.1	13.2	-3.9
MSR	1:0	18.2	18.3	0.1
	3:1	18.9	18.7	-0.2
	1:1	17.2	17.3	0.1
	1:3	18.2	17.6	-0.6
	0:1	18.0	18.3	0.3
HSR	1:0	17.5	18.8	1.3
	3:1	18.0	16.9	-1.1
	1:1	17.1	17.5	0.4
	1:3	17.4	15.5	-1.9
	0:1	17.7	16.7	-1.0

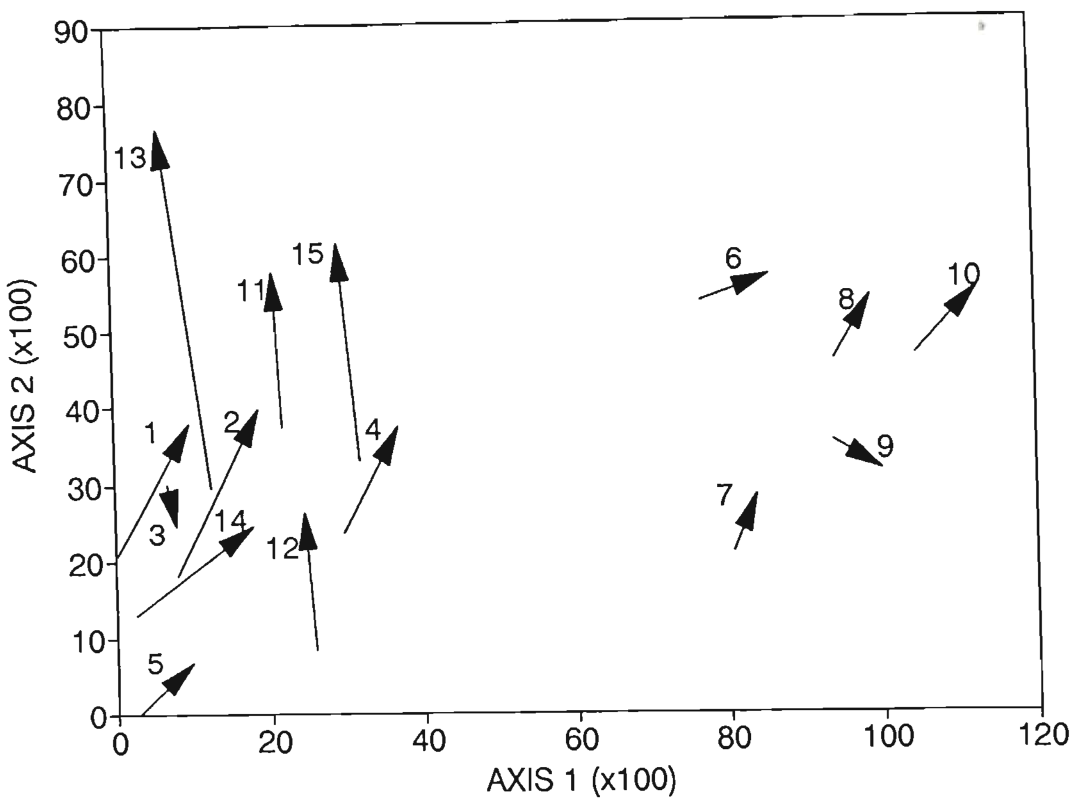

Figure 9.1 Trajectories in two-dimensional detrended correspondence analysis (DCA) ordination space for the low (codes 1 to 5), medium (codes 6 to 10) and high (codes 11 to 15) stocking rate treatments. The codes (in ascending order) refer to the cattle to sheep ratio treatments (viz. 1:0, 3:1, 1:1, 1:3 & 0:1 respectively) applied in each stocking rate treatment. The arrows indicate the position of each treatment in ordination space at the first and second (arrow head) survey dates respectively

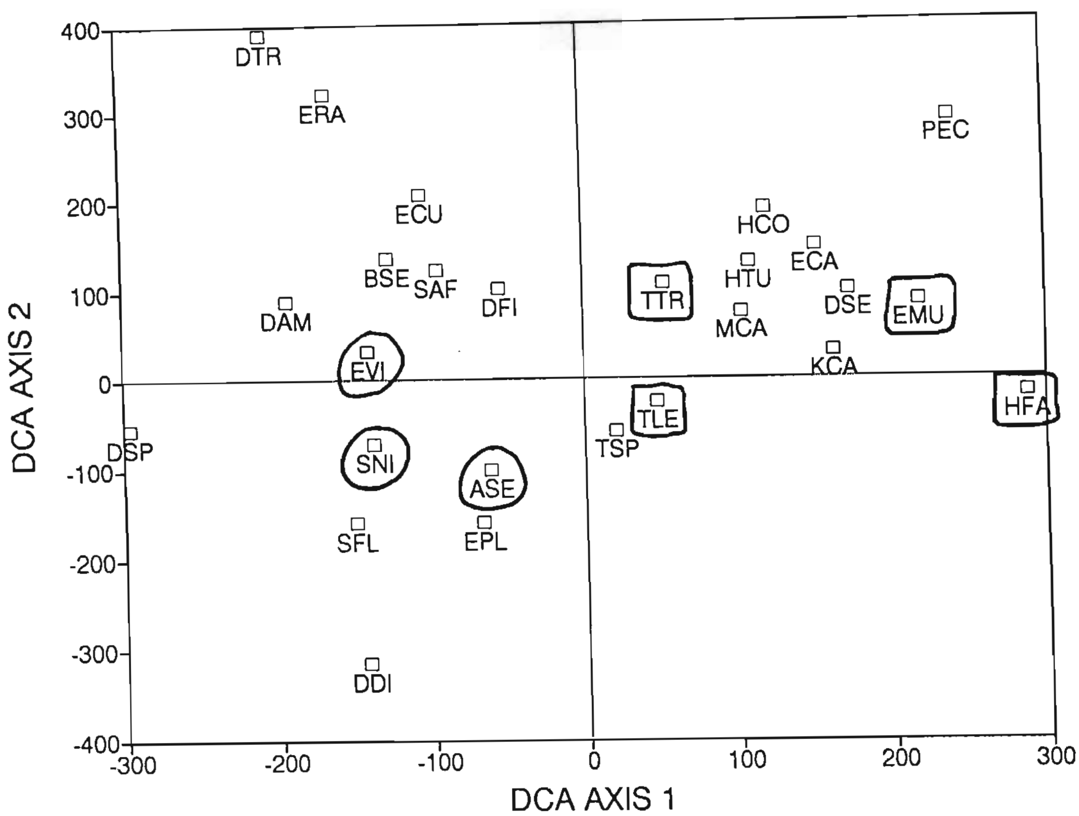

Figure 9.2 The position of each species in two-dimensional detrended correspondence analysis (DCA) ordination space from the data presented in Tables 9.1, 9.2 & 9.3. Species codes are presented in Table 9.1

SECTION 5

GENERAL DISCUSSION AND CONCLUSIONS

CHAPTER 10

GENERAL DISCUSSION AND CONCLUSIONS

10.1 Introduction

The research programme reported on in this thesis aimed to investigate the short-term implications of mixed-species grazing by cattle and sheep in Highland Sourveld.

Numerous veld management strategies have been proposed for livestock production systems for the humid grassveld regions of South Africa. Principles governing some of these strategies have been based on several years of experience and observation, and an insight into ecological theory (e.g. the non-selective grazing (NSG) approach suggested by Acocks (1966), later referred to as high utilization grazing (HUG) by Booysen (1969)). Other strategies have been based on an understanding, both theoretical and empirical, of plant morphology, physiology and growth habit (e.g. high-performance grazing (HPG) - (Booysen 1969)), and on competitive interactions between and within plants and their response to the frequency and intensity of defoliation (e.g. controlled selective grazing (CSG) - (Pienaar 1968)). A further proposal was to integrate the HUG/HPG systems into a flexi-camp grazing system (Venter & Drewes 1969). Savory (1978) suggested short-duration grazing which claims to incorporate many of the principles presented in the HUG, HPG and flexi-camp grazing systems. Where both cattle and sheep have been involved in a livestock production system, the grazing management proposals have not been altered from those recommended for cattle-only systems. It has merely been suggested that the cattle and sheep should be grazed together at a ratio (AUE cattle:AUE sheep) of 1:1 or a ratio which favours cattle (du Toit 1967; Malherbe 1971).

In all cases the proposed management systems were aimed at ensuring the maintenance or improvement of veld condition and acceptable animal performance. However, whilst several studies have investigated the effects of such grazing systems on animal performance, few have focused on the impacts of the proposed grazing systems on veld condition (i.e. species composition and plant vigour) and, therefore, on herbage production potential. The attainment of the stated aims of maintaining or improving veld condition through implementation of the various proposed veld management strategies mentioned above has not been tested. In fact, a number of component studies have indicated that some of the principles upon which the grazing management systems are based do not necessarily hold (e.g. Gammon & Roberts 1978a, b & c; Gammon & Twiddy 1990).

It is not possible, in any one trial, to investigate more than only a small number of the interacting factors which operate when animals graze veld. Implicit in this, therefore, is that component research needs to be undertaken on parts of the total system to identify various impacts. Such knowledge needs then to be incorporated into total systems. However, it needs to be accepted that such systems can probably never be fully tested in any stringent way.

One of the main problems associated with testing grazing systems is that long-term data sets are required, particularly when attempting to answer questions related to vegetation change and sustainable livestock production from veld. However, in the course of such long-term trials, the short-term patterns of animal performance and grazing impact, which emerge as functions of the applied treatments, provide formal guidance regarding which of the plant/ animal/climate/soil factors and their interactions are likely to sensitively influence the sustainability of the system. Such long-term trials also provide the facility for multi-disciplinary research efforts. Once the important variables have been identified, component research may be initiated, either within the formal structure of the long-term trial or in trials designed to answer the specific question concerned.

This was the approach adopted in the present investigation. The trial was designed to meet the long- and short-term objectives stated in Chapter 1. Once clear patterns relating to the grazing impact had been established, further component work (conducted by other researchers and not reported on here) was initiated. Two hypotheses were tested, namely i) that the grazing pattern established during the first season after a burn would be maintained through the following two seasons, and ii) that a single full growing season's rest allows plants the opportunity to regain any vigour they may have lost due to grazing in previous seasons (see Peddie 1994).

Currently recommended grazing management for humid grasslands, where sheep form an important component of the livestock production enterprise, have been discussed previously (see Chapters 1 & 2). In summary, it is recommended that cattle and sheep should graze together at a ratio of 1 AUE cattle to 1 AUE sheep, or at a ratio which favours cattle, within a four-paddock rotational grazing system and that the stocking rate should not exceed the estimated grazing capacity of the area. While there is some empirical evidence which supports the need to stock at a ratio which favours cattle in order to ensure acceptable sheep performance, there is no empirical base to the contention that applying the appropriate ratio will ensure maintenance or improvement of veld condition.

The analyses and discussion presented in this thesis attempt to provide a sound empirical base to the short-term implications of stocking at different cattle-to-sheep ratios and stocking rates within a rotational grazing system in Highland Sourveld. An understanding of such short-term implications is likely to allow for the prediction of many of the long-term effects of such systems on the veld. The results may therefore be used, together with those of other published empirical studies to suggest a potential alternative to ensuring sustainable sheep production from Highland Sourveld and similar Veld Types.

10.2 Animal performance

During all four seasons trends in animal performance corroborated the findings of du Toit (1967) and Malherbe (1971). As the proportion of cattle in the species-mix increased so the performance (ADG animal^{-1}) of the sheep improved (Table 5.7, Figures 5.12 & 5.13). It has been suggested that this result may be due to cattle complementing sheep by grazing the coarser herbage, thus providing a more nutritious diet for the sheep from regrowth of the defoliated plants (Peart 1962, cited by Nolan & Connolly 1977), and/or the reduction of intraspecific competition by the sheep (Nolan & Connolly 1977). Both of these may contribute to improved sheep performance.

In years of 'normal' rainfall with rapid growth and maturity of the sward, the low proportion of the area of the sheep-only treatment which was grazed to a height of <5cm (26% of the area), large amounts of residual herbage, and the poor performance of the sheep, indicates high intraspecific competition by the sheep for the kind of herbage preferred by them. The inclusion of cattle (and concomitant reduction of the stocking rate of sheep) reduced such intraspecific competitive effects. Ratios with a high proportion of cattle have a larger percentage of the treatment area grazed to a height more suited to the grazing habits of sheep (<5cm) than the sheep-only ratio (Table 8.1). Since in ratios with a high proportion of cattle the stocking rate of sheep (animal ha^{-1}) was low (Table 5.7), fewer sheep could spread their grazing over larger areas of short herbage when compared to ratios with higher proportions of sheep. Not only would there have been a greater quantity of new high quality regrowth available per treatment, but the sheep would also have had a greater opportunity to select for the higher quality herbage on offer to them. Hence their improved performance in ratios with a high proportion of cattle (Figure 5.12). Also apparent from the modelling component of the analyses, was that for a specific stocking rate of sheep, an increase in the stocking rate of cattle resulted in an improvement in the performance of the sheep (Figure 5.12). The addition of cattle into a sheep-only grazing system, without changing the stocking rate of sheep, would therefore potentially increase the outputs (animal products) from the system i.e. complementary effects may occur (Nolan & Connolly 1977). Inspection of the forage demand and amount of herbage on offer in the sheep-only ratio treatment (Table 6.6 & Figure 5.4 respectively) indicates that for the 'normal' rainfall grazing seasons, production per hectare could have been improved had cattle been added to this ratio treatment. While such a conclusion may be considered realistic, it must remain speculative, since the animal production component of the present trial was not designed to consider such complementary effects.

During the 'dry' grazing season (1992/93) however, whilst sheep performance was best when the sheep were stocked in low proportion to cattle, as the stocking rate of cattle and/or sheep increased so predicted sheep performance declined (Figure 5.13). In the 'dry' grazing season, therefore, where plant growth rate was slow compared to the 'normal' rainfall season and forage quality remained high for longer into the season, both intra- and interspecific competitive effects appeared to influence sheep performance.

Cattle performance was influenced more by the stocking rate of cattle than the ratio treatments applied in the trial. Animals in the cattle-only treatment were under greater nutritional stress than animals in the other ratios as indicated by the fact that in all grazing seasons they showed the poorest performance (Table 5.7 & Figure 5.10) and were the first to achieve maximum mass (Table 5.8). In general, as the stocking rate of cattle (animals ha^{-1}) decreased so cattle performance improved, particularly in the 'dry' grazing season. Intraspecific, rather than interspecific, competition for available herbage therefore had a major influence on cattle performance. However, modelling cattle performance as a function of stocking rate of both cattle and sheep indicated that for a specific stocking rate of cattle, as sheep stocking rate increased cattle performance declined (Figures 5.12 & 5.13). A degree of interspecific competition for available herbage is therefore indicated. Such interspecific competition requires further testing since the animal performance component of the present trial was not designed to address the effects of introducing sheep while maintaining a constant stocking rate of cattle.

Several trials (associated with cultivated pastures) have indicated that by grazing cattle and sheep together, output per hectare may be improved when compared with single-species grazing (Nolan & Connolly 1977; Baker & Jones 1985; Lambert & Guerin 1989). Results of the present trial indicate that such improvement does occur relative to sheep-only grazing but generally does not occur relative to cattle-only grazing (Table 5.7). Livestock production per hectare was improved, through mixed-species grazing, relative to production for a cattle-only grazing system only during the 'dry' grazing season. This result is in accordance with Bennett, *et al.* (1970) and Hamilton & Bath (1970) who observed that sheep performed relatively better than cattle during periods of reduced herbage availability.

Reasons for improved performance of sheep when grazing together with cattle relative to sheep-only grazing were not directly apparent from the results of this trial. The similarity in the quality (%CP & %DOM) of ingesta between ratio treatments indicates that the improved performance must reflect a greater quantity of intake by sheep as the proportion of cattle in the species-mix increased. The increased quantity of intake was probably a function of two main factors viz. i) the reduced stocking rate of sheep and ii) the increased area of short regrowth in a treatment as the ratio increasingly favoured cattle.

There was no clear trend in wool production per sheep whether the sheep grazed alone or together with cattle. Reference to Table 5.7 reveals that in the second and third season wool products per animal exceeded livemass gain per animal in the sheep-only treatment. Over the full grazing season therefore, the animals in this ratio treatment either maintained or lost body mass whilst producing a similar amount of wool as sheep in the other treatments. Even when large livemass gains were achieved during the 'dry' grazing season, wool production was similar across treatments and between the 'dry' and other grazing seasons (Table 5.7). It is important to highlight the (obvious) fact that, as the stocking rate of sheep increased, wool production per hectare increased.

The multiple regression approach of Connolly (1987) and Nolan & Connolly (1989) provided a useful means of identifying the importance of inter- and intraspecific competitive effects on the performance of animals in the mixed- and single-species treatments. Despite the limited nature of the present data set trends in animal performance were apparent from the analyses. For the 'general' model, relative resource totals (RRT) clearly indicate that, for the grazing system applied in the present trial and relative to sheep-only grazing at a low stocking rate, the introduction of cattle into the system allowed for an increase in stocking rate of sheep while maintaining the performance of the sheep (see section 5.2.5.2.2). Relative to sheep-only grazing therefore, these calculations allow for the development of an understanding of how the carrying capacity of a farm may be improved without changing the management system or introducing other capital intensive improvements to the farm.

Substitution rates (R_1 & R_2) provided an insight into the relative importance of the removal or inclusion of species in a mixed-species grazing system. In the present case, the R_1 and R_2 values for the 'general' and 'dry' season models predicting the performance of cattle and sheep, provided a clear indication that sheep performance was sensitively influenced by the presence of cattle, and that cattle performance was not influenced by the presence of sheep (see section 5.2.5.2.2). The above discussion must be seen in the context of the ratio treatments applied in the present trial.

Application of the 'multiple regression approach' and the concepts of RRT, R_1 and R_2 in the present trial have highlighted the limitations of the trial in terms of examining the effects of cattle-to-sheep ratio and stocking rate on animal performance. In mixed-species grazing experiments, where the main question relates to animal performance, each mixed-species treatment should be applied at a range of stocking rates. Alternatively, and since stocking rate has been repeatedly shown to have an over-riding effect on animal performance, attention should be focused on first identifying an appropriate range of single-species stocking rates and then adding units of the other species in developing the mixed-species treatments. Data derived from such studies should clearly show the results of mixed- vs single-species grazing in the livestock production system being studied.

10.3 The grazing impact

Sustainability of a livestock production enterprise depends mainly on whether or not the resource base is negatively impacted by the production system. There are, of course, other factors such as the economic viability of the enterprise which will influence its sustainability. However, in the present context interest lies in identifying which combinations of stocking rate and cattle-to-sheep ratio are most likely to ensure maintenance of veld condition and thus allow for sustainable livestock production within a four-paddock rotational grazing management system in Highland Sourveld. Veld condition is influenced by the vigour of individual plants and species composition of the sward (e.g. Tainton, *et al.* 1980). Plant vigour and species composition are, in turn, affected by the intensity and extent of grazing.

Grazing impact was characterized in this study in terms of forage demand (Chapter 6), the intensity of grazing on individual plants

(Chapter 7), patch development (Chapter 8), and the extent of patch grazing (Chapter 8). Since, after a two years of grazing, proportional species composition of the sward was shown not to have been influenced by the applied treatments, changes in species composition *per se* will not be considered in the following discussion. Suffice to say that the analyses supported the contention that Highland Sourveld comprises a relatively stable species composition. It should also be pointed out that despite the small but clear differences in species composition between the simulated and animal production components of the trial, trends in grazing impact (forage demand, and the extent and intensity of grazing of individual species and patches) remained consistent between stocking rate treatments.

One of the main results of the study was that stocking rate rather than ratio had a major influence on grazing impact. Whilst this was not unexpected it had been assumed, from experience and theory, that ratio on its own would have significantly influenced the grazing impact. However, as pointed out in Chapter 7 (section 7.4), the effects of stocking rate incorporate the effects of ratio due to the differential performances of the cattle and sheep in each treatment (compare, for example, the AUE of cattle and sheep within each ratio treatment through each grazing season from the animal production component of the trial - Figure 6.8a to 6.8c).

Estimated forage demand by the cattle and sheep (e.g. Table 6.7) allow for more meaningful interpretation of the intensity of defoliation data (Figures 8.1 and 8.5). Calculations of AUE ha^{-1} are directly related to forage demand - as stocking rate (AUE ha^{-1}) increases so forage demand increases (Table 6.7). Ratio treatments with the same AUE ha^{-1} would therefore have had similar demands on forage, any differences being small and dependent on the quality (%DE concentration) of dry matter intake (Meissner, *et al.* 1983). At a stocking rate of 1AUE ha^{-1} for example, while forage demand would have been equivalent between the sheep-only and cattle-only treatments, most of the sheep-only treatment area was severely grazed (70% grazed to <3cm) while the remainder was leniently grazed (approximately 30% with a LTH >5cm) (Figure 8.1). In contrast, less than 30% of the cattle-only area was severely grazed whilst the remainder of the area was either moderately (<30%) or leniently (>40%) grazed (Figure 8.1). These data, together with the results discussed in Chapters 7 and 8, support statements that cattle, when stocked at the same number of AUE ha^{-1} , tend to graze less intensively and over a larger area than sheep. Whilst it was noted that some plants in the cattle-only treatments were severely grazed (<3cm), this occurred (to any significant extent) only at high stocking rates (Figures 8.1 & 8.5). As has been discussed, cattle in the cattle-only treatment were under nutritional stress during all grazing seasons when stocked at the medium stocking rate (1.74 animals per hectare), and were the first to start losing mass at the end of each grazing season. It is unlikely therefore, that under practical commercial livestock production systems, a stocking rate of 1.74 animals ha^{-1} would be exceeded for the class of animal used in the trial. A stocking rate of approximately 1 animal per hectare would be more common. In 'normal' cattle-only production systems in Highland Sourveld, a low proportion of the area would therefore be expected to be severely grazed.

In the sheep-only treatments, the veld was either severely grazed (<3cm) or leniently grazed (>5cm - it should be remembered that the lenient category included ungrazed plants) (Figure 8.1 & Table 8.1). At low stocking rates i.e. <0.8 AUE ha^{-1}, a small percentage of the treatment area was grazed to <3cm. Common practice in sheep production areas however, is to burn veld at the start of the grazing season and to graze at heavy stocking rates to ensure that the veld is kept short through the season. Experience suggests that such practice results in an extent and intensity of grazing similar to that obtained in the heavy stocking rate sheep-only treatment of the present trial. Few farmers are likely to manage the veld such that poor quality herbage accumulates through the grazing season and (particularly where the veld has been burnt) accept the concomitant poor performance of the sheep which appears to be an inevitable consequence of a sheep-only low stocking rate system (Chapter 5).

Grazing cattle together with sheep resulted in an improved performance of the sheep and a lower proportion of a treatment's area grazed to <3cm relative to sheep-only, except at the low stocking rate 1:2 ratio treatment (Figure 8.1). Clearly, the more sheep in the species-mix the more severe the grazing (Figure 8.5). It appears, however, that the main effect influencing the extent and severity of grazing is stocking rate of sheep, and that at low stocking rate in particular, the addition of cattle merely facilitates more extensive severe grazing than occurs with sheep-only grazing.

A further interesting result was that patch size distributions for each category of patch were similar for both cattle and sheep, indicating that cattle and sheep had similar effects on patch development. Stocking rate was the main factor influencing patch size distribution.

The present study provides a characterization of the main effects of cattle-to-sheep ratio and stocking rate on livestock production from, and the grazing impact on, veld. How then do these result add to our knowledge base relating to sustainable cattle and sheep production from Highland Sourveld? Sustainability relates to the maintenance or improvement of the forage production potential of the sward. Peddie (1994) conducted a research programme within the current trial which investigated i) the utility of a full growing season's rest for restoring the vigour of plants which were either severely (<4cm) or leniently (>4cm) grazed relative to ungrazed plants and ii) patterns of grazing on *T. triandra* and *T. leucothrix*. He concluded that a full growing season's rest was sufficient time for the severely grazed *T. triandra* plants (after two years of grazing) to regain vigour to the same level as plants which were leniently or ungrazed but that this was not necessarily true for *T. leucothrix*. In the second study (conducted within the medium stocking rate treatment) tufts of *T. triandra* and *T. leucothrix*, marked as having been severely grazed at the end of the first grazing season, continued to be severely grazed in the second and third grazing seasons. Thirty and 14 per cent of the marked *T. triandra* plants died in the sheep-only and the 'planned' 1:1 ratio treatment respectively whilst none of the marked *T. triandra* plants died in the cattle-only treatment. A similar trend occurred with the *T. leucothrix* plants although the levels of mortality were not as high as the levels observed for *T. triandra*. Plants which died were replaced by less desirable plants with low forage production potential (Peddie 1994). Interestingly, for the severe grazing category, the mean heights to which *T. triandra* plants had been defoliated after three years of grazing were 10.8mm, 13.3mm and 24.5mm for the 0:1 (sheep-only), 1:1 and (1:0 (cattle-only) ratio treatments respectively. Grazing heights for the same category of *T. leucothrix* plants were 7.3mm, 11.3mm and 23.5mm for the sheep-only (0:1), 1:1 and cattle-only (1:0) ratio treatments respectively. These data appear to corroborate data from the LTH distribution patterns presented in Figure 8.5.

It appears that, within a four-paddock rotational grazing system which includes sheep, plants which were severely grazed during the first season after a burn will continue to be grazed and that such grazing may result in a relatively high mortality of these plants. While a full growing season's rest may have allowed for the recovery of vigour of plants which were severely grazed in previous seasons, a slow run-down of the system seems inevitable where sheep form part of the production enterprise. Run-down, or loss of production potential, is likely to be slow at low stocking rates of sheep and more rapid at higher stocking rates. The rate of change will also be a function of the availability/presence of the propagules of the species, usually pioneer species, which are adapted to establish themselves under such circumstances (Hardy & Hurt 1989).

Therefore, in the long-term, a four paddock rotational grazing system which includes sheep as an integral component of the production enterprise, would not be sustainable. Further testing of the consequences of severe grazing by sheep on individual plants is necessary to provide corroborative evidence of plant mortalities under such circumstances. In the interim, the present trial provides strong indications that the current recommendations of grazing cattle together with sheep in order to **prevent** the degradation or loss of veld condition, which occurs in sheep-only production systems, will not succeed.

10.4 Grazing capacity and veld management

Problems associated with the application of the grazing capacity concept have been highlighted in Chapter 3. Data from the present study (Chapters 6, 7 & 8) corroborate the fact that the replacement of a unit of cattle by an equivalent unit of sheep will not result in the same impact on the sward (within the four-paddock grazing system applied in this study). The problems relate to the application of AUE, which is based on the intake of metabolizable energy, as a basis for defining the grazing capacity of an area of veld. While the AUE provides a sound scientific basis for equating different species and classes of animals (based on intake of metabolizable energy), it does not take into consideration the grazing habits and specific 'kinds' of feed required by the different species and classes of animal.

If we are serious about the maintenance or improvement of veld condition in the sourveld regions of South Africa, an alternative method for defining and applying grazing capacity estimates should be sought. Livestock production in the Highland Sourveld and similar Veld Types essentially involves cattle and sheep production enterprises. It is suggested, therefore, that it would be relatively simple (and acceptable in the farming communities) to define grazing capacity in terms of the species of livestock involved. The currently recommended grazing capacity for Highland Sourveld appears to be well suited to cattle production enterprises and the use of a four-paddock rotational grazing system. It is clearly not suited to livestock production enterprises which include sheep in a conventional four-paddock grazing system. Grazing management should therefore also be used as a qualifier in defining the grazing capacity of a particular area.

While the present study was not designed to investigate alternative methods of defining grazing capacity, results from this trial, together with the results of other experiments involving sheep in similar Veld Types, provide guidelines which would assist in formulating such a definition.

The results of the current investigation suggest that sheep should not be run on sourveld, at least not in a four-paddock rotational grazing system. However, the past and current superior profitability of sheep production enterprises, relative to beef, are likely to ensure that farmers will continue to farm with sheep in the sourveld for many years to come. It has already been stated that for cattle stocked at the appropriate stocking rate, a four-paddock rotational grazing system appears to have the potential to maintain the forage production potential of the veld. Where sheep are included in the system either together with cattle or on their own, an alternative management strategy is required. The severity of grazing and the consequences of maintaining such grazing on individual plants indicates that sheep should be prevented from grazing in areas of the farm which were grazed by sheep in the previous season. Severely grazed plants would then be given the opportunity to regain their vigour, even if cattle are allocated to these areas (since the cattle are not likely to graze individual plants to <2.5cm). Furthermore, since sheep require green, leafy grass which is free of dead herbage to maximise their performance (Barnes & Dempsey 1992), the sheep should be allocated to paddocks which were burnt prior to the start of the grazing season (in the early spring). In the simplest form, therefore, it is suggested that for sustainable sheep production in Highland

Sourveld, the sheep should graze only those paddocks which were burnt in early spring and at a stocking rate suited to the forage production potential of the area. Sheep performance would be enhanced within these areas if the sheep were grazed together with cattle at a ratio which favours cattle.

Whereas the definition of grazing capacity for cattle assumes some form of multi-paddock grazing system, the definition of grazing capacity for sheep production enterprises should also assume a management system which addresses the type of forage required by sheep (i.e. short leafy herbage) and the impact of grazing by sheep on the sward.

SECTION 6

REFERENCES

TOWARDS A TECHNIQUE FOR DETERMINING BASAL COVER IN TUFTED GRASSLANDS

APPENDIX FIGURES

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APPENDIX CHAPTER 1

TOWARDS A TECHNIQUE FOR DETERMINING BASAL COVER IN TUFTED GRASSLANDS

1.1 Introduction

Most techniques used for determining and monitoring veld condition in southern Africa require an assessment of proportional species composition and an estimate of basal cover (BC) for the sample site. Point-quadrat methods (Brown 1953; Kershaw 1964; Greig-Smith 1964; Stoddart *et al.* 1975; Tainton *et al.* 1980; Bonham 1988) are generally recommended.

Proportional species composition is determined using the 'nearest plant approach' (Foran *et al.* 1978) and expressing the abundance of a species in the sample site as a proportion of the total number of observations for the sample site. Current recommendations are that between 100 and 300 observations should be recorded (depending on the objectives for undertaking the survey) from which species composition may be calculated (Everson & Clarke 1987; Hardy & Walker 1991).

Basal cover is estimated from the number of 'strikes' recorded as a proportion of the total number of point observations for a sample site (Tidmarsh & Havenga 1955; Tainton *et al* 1980; Vorster 1982). Several authors (Tidmarsh & Havenga 1955; Mentis *et al* 1980; Mentis 1982; Friedel & Shaw 1987) have pointed out, however, that the method has two major sources of error. First, the probability of recording a 'strike' is extremely low (e.g. the probability of recording a strike in an area with a BC of 10% is 1 in 10 or 0.1). Large sample sizes are therefore required to achieve acceptable levels of precision of the estimate. Second, there is a considerable degree of variability between and within workers in the identification of a strike. The recognition of these errors has resulted in rejection of the strike approach for estimating BC in grassveld.

A possible alternative is to use distance measures (Greig-Smith 1964; Pielou 1969; Bonham 1988). Distance measures have commonly been applied for estimating the density of individuals in a sample site (e.g. McNeill, *et al.* 1977). Clarke (pers. comm.) suggested that by examining the mean and variance of distance to the nearest tuft from a point survey in grassveld, an index of 'bare area' (the reciprocal of BC) may be determined. An additional measure is to record the 'diameter' of the nearest tuft for each observation in the survey. The relationship between BC and estimates of the mean and variance of distance to the nearest tuft and tuft diameter could be examined by applying regression analyses.

The objective of this study was to examine the potential of using 'distance to the nearest tuft' and tuft 'diameter' measures for estimating basal cover in tufted grasslands.

1.2 Procedure

A two-stage approach was followed. First, a computer simulation procedure was used to develop a technique for estimating BC. Second, preliminary field surveys were undertaken to investigate the application of the technique under practical conditions.

1.2.1 Computer simulation

A computer model was used to develop the relationship between BC, and 'distance to the edge of the nearest tuft' (D) and 'tuft diameter' (d). The model simulates a 20 m x 20 m sample site which is similar in size to that generally recommended for sampling in grasslands (Tainton *et al.* 1980). User defined variables available in the model include a) basal cover (with a range in BC from 1.0% to 15.0%), and b) tuft size (the distribution of tuft sizes (tuft diameter) being based on a negative binomial distribution for a specified population mean and variance).

One hundred and eight sample sites were simulated. Basal cover ranged from 1.0 to 15.0 per cent in steps of 1 (excluding BC =

6%, 8% and 11%). For each of the BC values, variances of 3, 6 and 12; 5, 10 and 20; and 7, 14 and 28 were set for mean tuft diameters (cm) of 3, 5 and 7 respectively. For the purposes of this exercise tufts were randomly distributed within each of the simulated 20 m x 20 m sample sites. A wide range of tuft diameters and their associated variances were selected in an attempt to ensure rigour in the analyses and a robust model. Numerous field surveys of grassland sample sites, which varied widely in BC and tuft size distribution, provided a realistic basis for the simulations.

A systematic point sampling procedure, a user-defined option in the model, was conducted on each of the 108 simulated sample sites. For each survey the points were evenly distributed over the whole sample site. The following data were recorded for each point;

i) D, measured in centimetres and rounded **up** to the nearest cm. If the point fell within the area occupied by a 'tuft' a 'distance' of 1 cm was recorded. It was necessary to provide the rounding facility to simulate field conditions where it is impractical to read distances to the nearest 0.1 cm, or even the nearest 0.5 cm. In the field, rounding up to the nearest cm would seem the most practical approach. In addition, recording 1 cm for what could be recognised as a 'strike' prevents bias due to interpretive errors (regarding what constitutes a 'strike') within and between workers, and

ii) d, which was rounded **up** to the nearest cm for the same reasons given in i) above.

Mean D ($\bar{D}$) and d ($\bar{d}$), and their respective variances, were calculated for each point survey.

The precision of each estimate of $\bar{D}$ and $\bar{d}$, as influenced by BC and tuft size variation and expressed in terms of the coefficient of variation (CV%), was examined by obtaining 20 independent estimates for each of 8 sampling intensities viz. 50, 100, 150, 200, 250, 300, 400 and 500 points per survey. In addition, examination of the relationship between BC and $\bar{D}$, and BC and $\bar{d}$, indicated that a $\log_e$ transformation of the $\bar{D}$ and $\bar{d}$ data was warranted.

A step-wise multiple linear regression procedure was used to determine the relationship between BC (the known, simulated, value) and estimates of $\bar{D}$ and $\bar{d}$ (viz. $\bar{D}$, variance of D, mean/variance of D, $\log_e\bar{D}$, $\bar{d}$, $\log_e\bar{d}$ and the variance of d). While it is recognised that $\bar{D}$ and $\log_e\bar{D}$, and $\bar{d}$ and $\log_e\bar{d}$, are highly correlated they were used in the analysis to examine their influence on the predictive power of the final model. The acceptance of a regressor variable depended on two criteria;

i) that the addition of the variable significantly increased the variance accounted for by the model, and

ii) that its inclusion did not increase the standard error of the predicted values. The regression analysis was performed using estimates of $\bar{D}$ and $\bar{d}$ derived from a sampling intensity which provided acceptable levels of precision for these estimates.

The final model was then tested by examining the relationships between predicted BC and i) estimates of $\bar{D}$ and $\bar{d}$, and ii) known (computer simulated) BC.

1.2.2 Field testing

1.2.2.1 Sampling intensity

A 30 m x 30 m sample site was demarcated in a tufted grassveld community within Moist Tall Grassveld (Acocks 1988). A systematic point survey of one thousand points was conducted on the site. For each point, distance and diameter measures were recorded using the same procedure applied in the computer simulation.

There are, of course, a number of limitations to measuring the 'diameter' of a tuft. First, very few tufts could be considered to be circular. To overcome this two ways of estimating tuft 'diameter' are suggested viz. a) measuring the mean cross-section (determined visually) of the tuft or b) calculating mean diameter from measures of the shortest and longest axes of the tuft. The latter approach was used in the above field test. Second, grass tufts tend to die out in the centre and a tuft's circumference tends to break up into separate units. Simple 'rules-of-thumb' are applied in these circumstances. If the centre of the tuft has died out but the tuft's circumference is still intact then diameter of the whole tuft (including the centre) is determined. If the spaces between the units of what was once a single tuft are separated, at soil level, by more than 1 cm then the diameter of the unit nearest the point must be recorded. Often, most of the tuft appears to be dead with one or two live tillers still present. In this case the 'diameter' of the plant which could still be considered as basal cover must be recorded. If the tuft is degenerating, change in tuft dimensions will be recorded in subsequent surveys.

Two hundred sets of N paired (distance and associated diameter) observations were selected from the 1000 point population using random sampling, with replacement (Clarke pers. comm.). This was repeated for N = 10, 20, 30 ....., 200. For each of the 200 sets of N paired observations the mean and variance of D and d, and their respective $\log_e$ values, were calculated. Predictions of BC were derived by applying the formula developed from the computer modelling stage. Mean BC and associated variance were calculated for each level of sampling intensity.

1.2.2.2 Observer repeatability

Four 30 m x 30 m plots were selected to represent a range in BC. At each plot 200 paired D and d observations were recorded by each of two operators, using the method described above. Predictions of BC were derived by applying the formula developed from the computer modelling stage. A paired t-test (Rayner 1967) was applied to investigate between worker variability in predicting BC.

1.3 Results and discussion

1.3.1 Computer simulation

The repeatability of obtaining estimates of $\bar{D}$ and $\bar{d}$ was high for all levels of sampling intensity. In all cases the CVs were less than 10% even at a sampling intensity of 50 points per sample site. This result is illustrated, in Table A1.1, for a wide range in BC, and mean and variance of tuft size.

In most biological systems, an estimate with an associated CV of less than 10% is highly acceptable (Rayner 1967). For the purposes of the step-wise multiple regression, therefore, it was concluded that 100 paired D and d observations would be more than adequate for developing the relationship between BC and the estimates of $\bar{D}$ and $\bar{d}$.

The relationship between BC and estimates of $\bar{D}$ and $\bar{d}$ was highly significant (r^2 = 0.92) (Table A1.2a). Two variables viz. variance of D and variance of d, were excluded from the model as they did not add to the variance accounted for by the final model. Furthermore, as the input value of the mean/variance ratio of D never exceeded 1.5, this variable had negligible influence on the predicted BC despite its statistical significance (Table A1.2a). The mean/variance ratio of D was therefore removed from the data set and coefficients for the remaining variables were recalculated (Table A1.2b).

$\log_e\bar{D}$ accounted for 71% of the variance (r^2) while $\log_e\bar{d}$, the second variable selected in the analysis, increased the r^2 to 89%. The inclusion of $\bar{D}$ and $\bar{d}$ further increased the r^2 to 92%. The use of all four variables in the model minimised the standard error associated with the predicted BC, as indicated by the widths of the 95% prediction intervals for BC presented in Table A1.3, thus increasing the predictive power of the model.

The final model may be summarised as:

$$BC = 19.8 + 0.39(\bar{D}) - 11.87(\log_e\bar{D}) + 0.64(\bar{d}) + 2.93(\log_e\bar{d}).$$

The relationships between predicted BC for each of 3 mean tuft diameters ($\bar{d}$) and range of $\bar{D}$ are presented in Figure A1.1. Two problems associated with the predictions are apparent. First, where the $\bar{D}$ is large (e.g. >12 cm) and $\bar{d}$ is small (e.g. 3 cm), predicted BC is negative. It is therefore recommended that the model should not be used under circumstances which would result in negative values. It is suggested, however, that such circumstances are unlikely to occur in humid grasslands since $\bar{D}$ has not exceeded 7cm in numerous surveys of sample sites within such grasslands. Further development of the model must address this anomaly, especially in arid grasslands where $\bar{D}$ can be expected to exceed 12cm. Second, where $\bar{D}$ values are high, relatively large changes in $\bar{D}$ result in relatively small changes in BC (Figure A1.1). However, given that the precision of estimating $\bar{D}$ and $\bar{d}$ is high, the method nonetheless provides a sensitive index of changes in BC for high $\bar{D}$ values. As $\bar{D}$ declines so the technique becomes more sensitive but less precise, as small differences in $\bar{D}$ result in large differences in predicted BC.

The accuracy of estimating BC was evaluated by comparing predicted BC values against a range of known (computer simulated) BC values (Figure A1.2). There is a slight tendency to over-estimate BC in the range 2 to 12 per cent BC. The bias is reduced as mean tuft diameter increases. It is clear, however, that there is a close correlation between actual and predicted BC indicating that, for any estimated BC and associated estimates of the mean and variance of $\bar{D}$ and $\bar{d}$, actual BC could be predicted from such correlation with acceptable accuracy. Further analyses are required to determine the relationships between actual and predicted BC for a wide range of tuft sizes.

1.3.2 Field testing

1.3.2.1 Sampling intensity

Mean BC and associated variance for each sample size (number of points) are presented in Figure A1.3. It is clear that, as suggested by the low variance associated with estimates of $\bar{D}$ and

$\bar{d}$ from the computer simulations (Table A1.1), the minimum sample size for an acceptable degree of repeatability of the estimate of BC is less than 100 points.

1.3.2.2 Observer repeatability

Differences between observers in the estimates of basal cover for the four sites were significant ($P < 0.05$) (Table A1.4). Estimated BC was consistently higher for observer C than for observer P. This observation highlights the potential for observer bias in the technique. Further development and testing of the technique must obviously address this problem.

1.4 Conclusions

The computer based simulation approach adopted in this study has illustrated the potential of using distance measures for estimating basal cover (BC) in tufted grasslands. It is suggested that 100 paired observations of distance to the nearest tuft (D) and tuft diameter (d) during a systematic point survey of a 20 m x 20 m sample site will provide a high level of precision in indexing the BC of the sample site. There are, however, a number of shortcomings which must be addressed in the further development and testing of the technique. These shortcomings include:

i) the use of a random distribution of tufts within the simulated samples sites when, in practice, plants tend to have a clumped distribution (particularly in arid and semi-arid environments),

ii) the negative values for predicted BC when mean D ($\bar{D}$) is >12cm and mean d ($\bar{d}$) is <3cm, and

iii) the apparent bias between observers in estimating either $\bar{D}$ or $\bar{d}$, or both (although bias in estimating $\bar{D}$ is less likely), and therefore in calculating BC.

Despite these shortcomings it is suggested that in the interim the procedures outlined in this study will provide an effective means of indexing the basal cover of tufted grasslands. Alternatively, BC may be determined from $\bar{D}$ alone. While this would give a less precise estimate, such an estimate is likely to lack any bias since $\bar{D}$ is a more robust measure than $\bar{d}$.

Table A1.1 The coefficient of variation (CV%) of estimates of mean 'distance to the nearest tuft' ($\bar{D}$) and mean 'tuft diameter' ($\bar{d}$) for a range of sampling intensities (No. points) and simulated basal cover % (BC) parameters.

No. points	#1:7:28		7:5:10		15:3:3	
	CV%					
	$\bar{D}$	$\bar{d}$	$\bar{D}$	$\bar{d}$	$\bar{D}$	$\bar{d}$
50	7.0	6.4	5.6	5.0	5.7	9.9
100	5.1	5.0	5.3	5.6	4.4	9.5
200	4.0	3.8	4.5	4.4	4.3	4.2
300	2.4	2.6	3.3	2.8	3.0	5.0
500	2.1	2.3	2.8	2.7	2.8	4.3

Basal cover parameters - 1:7:28 refers to a BC of 1%, and a mean and variance of tuft diameter of 7 and 28 respectively

Table A1.2 Parameter estimates for the dependence of basal cover on: a) mean distance to the nearest tuft ($\bar{D}$), $\log_e\bar{D}$, the mean/variance ratio of D (m/v D), the mean tuft diameter ($\bar{d}$) and $\log_e\bar{d}$, and b) as for 2a) excluding m/vD

Independent variables	Coefficient	t-value	significance level
a)			
CONSTANT	19.97	22.46	<0.001
$\bar{D}$	0.39	15.01	<0.001
$\log_e\bar{D}$	-11.85	-39.24	<0.001
m/v D	-0.01	-2.55	<0.012
$\bar{d}$	0.67	3.39	<0.001
$\log_e\bar{d}$	2.72	2.44	<0.015

adjusted r^2 = 0.92
DF = 534

Independent variables	Coefficient	t-value	significance level
b)			
CONSTANT	19.77	22.21	<0.001
$\bar{D}$	0.39	15.02	<0.001
$\log_e\bar{D}$	-11.87	-39.12	<0.001
$\bar{d}$	0.64	3.24	<0.002
$\log_e\bar{d}$	2.93	2.63	<0.010

adjusted r^2 = 0.92
DF = 535

Table A1.3 Summary statistics (mean, minimum (min), first and third quartiles (Q1 & Q3), median and maximum (max)) for widths of the 95% prediction intervals for BC by the number of variables included in the model

Variables included in each model	mean	min	Q1	median	Q3	max
$\log_e\bar{D}, \log_e\bar{d}$	6.20	6.18	6.17	6.19	6.2	6.2
$\log_e\bar{D}, \log_e\bar{d}, \bar{D}$	5.24	5.23	5.24	5.24	5.25	5.4
$\log_e\bar{D}, \log_e\bar{d}, \bar{D}, \bar{d}$	5.21	5.19	5.19	5.20	5.21	5.4

Table A1.4 Paired t-test to determine observer (P and C) differences when applying the distance and diameter measures to estimate basal cover

	Estimated basal cover		
Site	P	C	Difference
1	11.4	12.3	0.9
2	15.2	17.0	1.8
3	11.8	13.3	1.5
4	10.8	11.3	0.5
		Mean difference =	1.2

$t(3DF) = 4.02$ ($P < 0.05$)

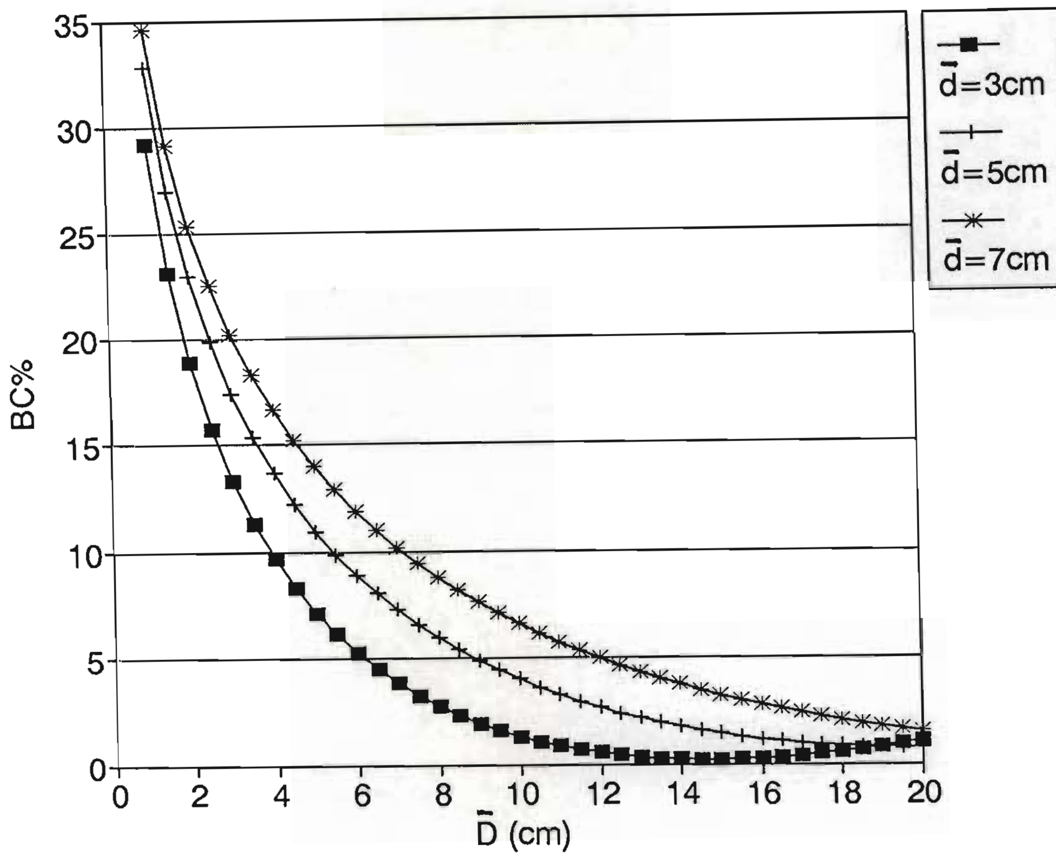


Figure A1.1 The relationship between mean distance to the edge of the nearest tuft ($\bar{D}$) and predicted basal cover (BC) for each of 3 mean tuft diameters ($\bar{d}$) (derived from the computer simulation)

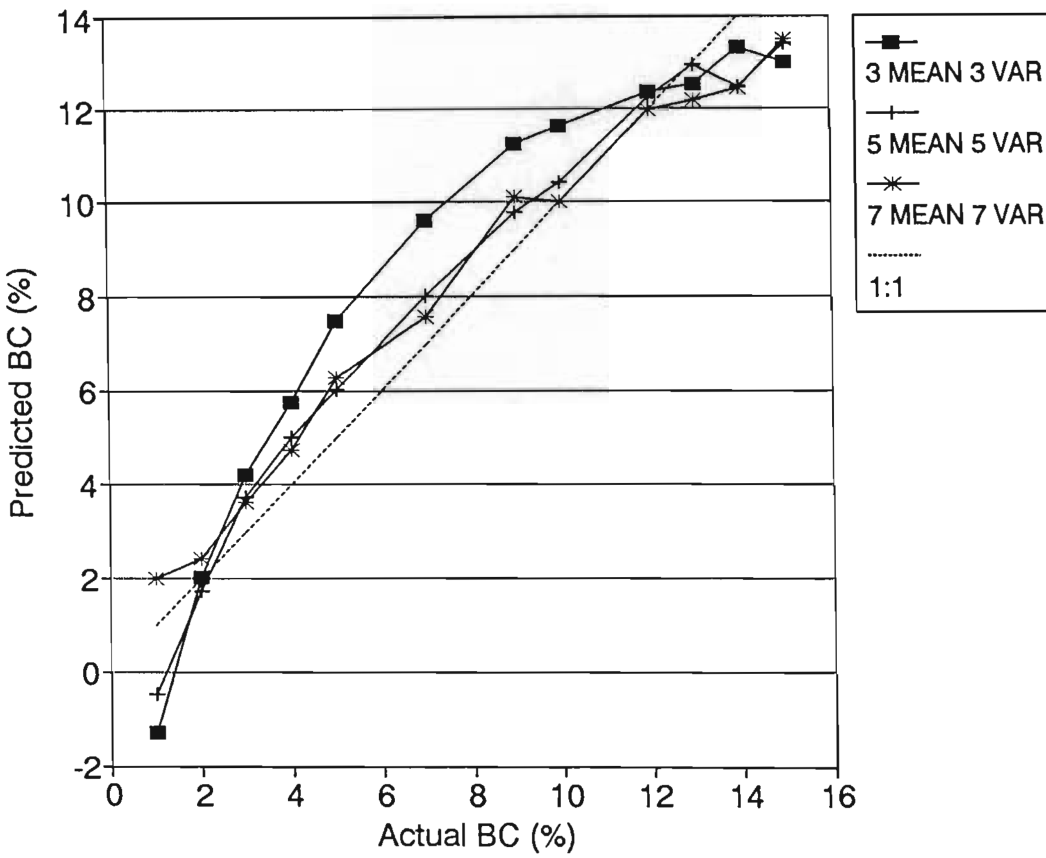


Figure A1.2 An example of the relationship between actual and predicted basal cover (BC) for each of three mean tuft diameters (MEAN) and their associated variance (VAR)

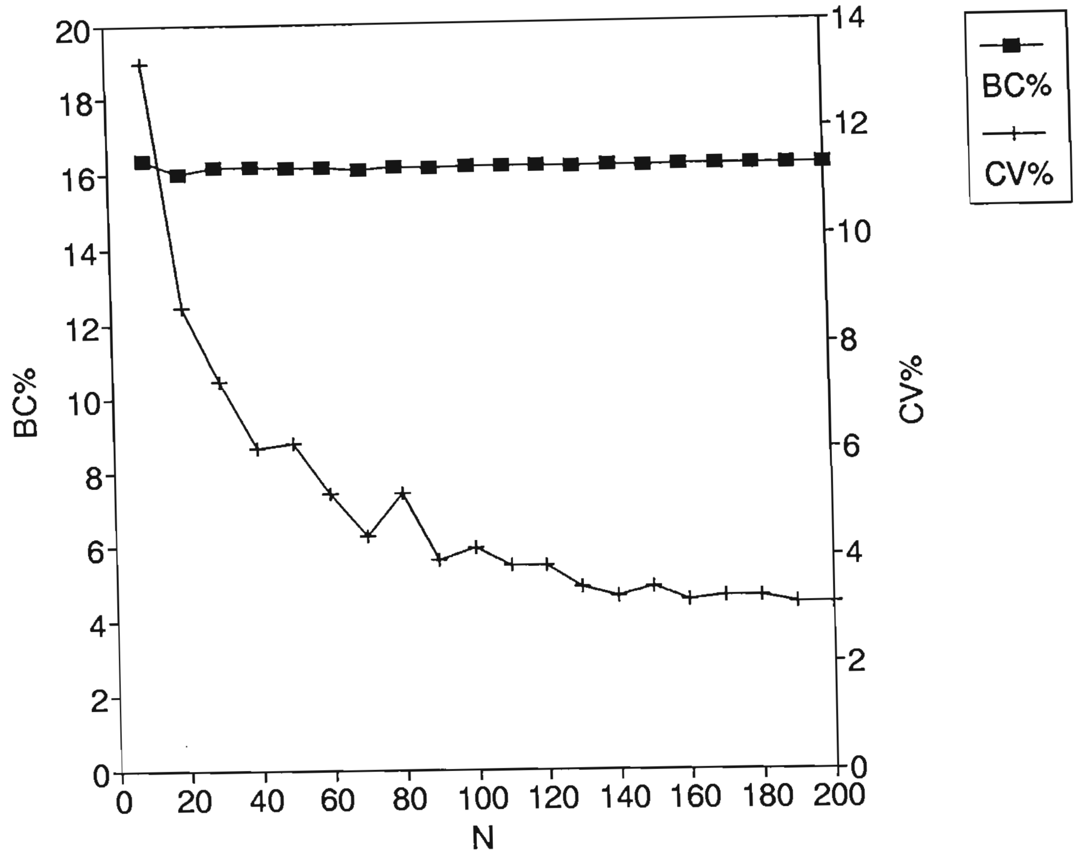
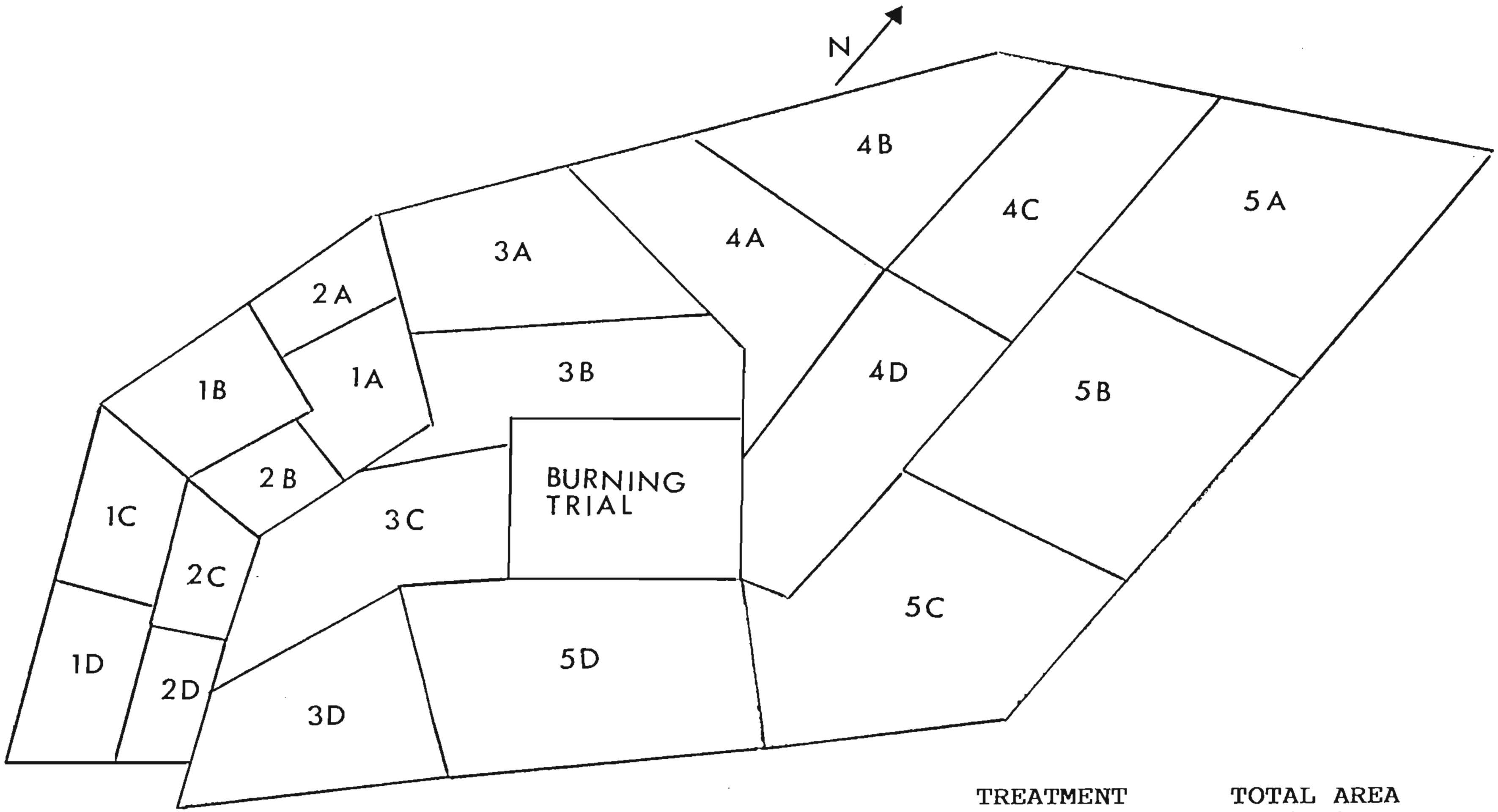
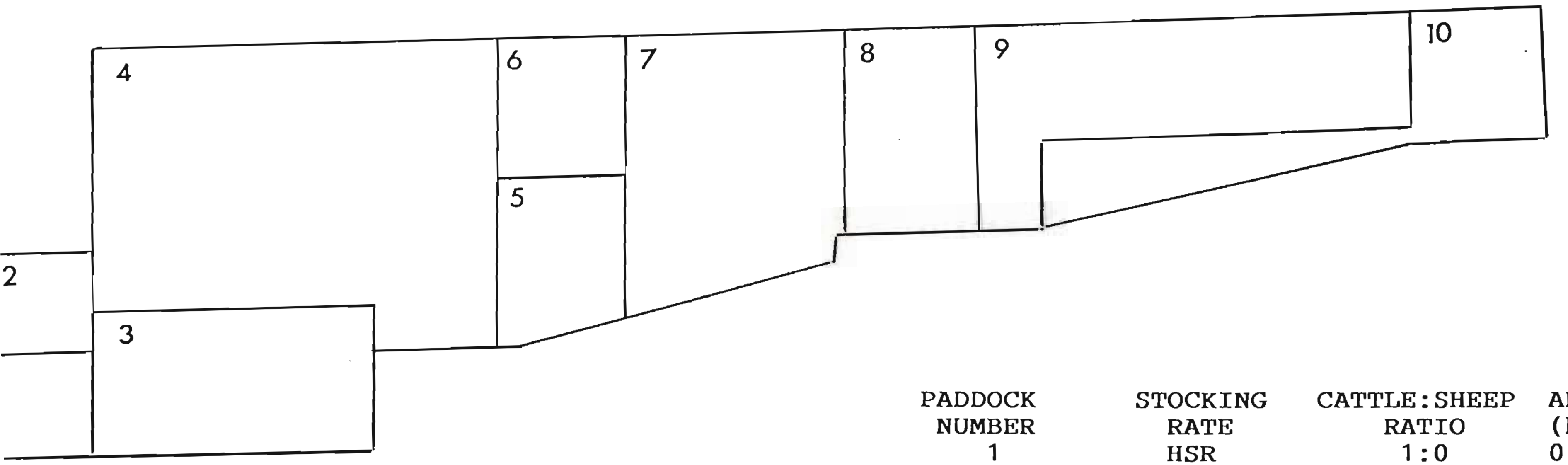


Figure A1.3 Estimates of mean basal cover (BC%) and associated coefficients of variation (CV%) for a range of sampling intensities (N = number of points)



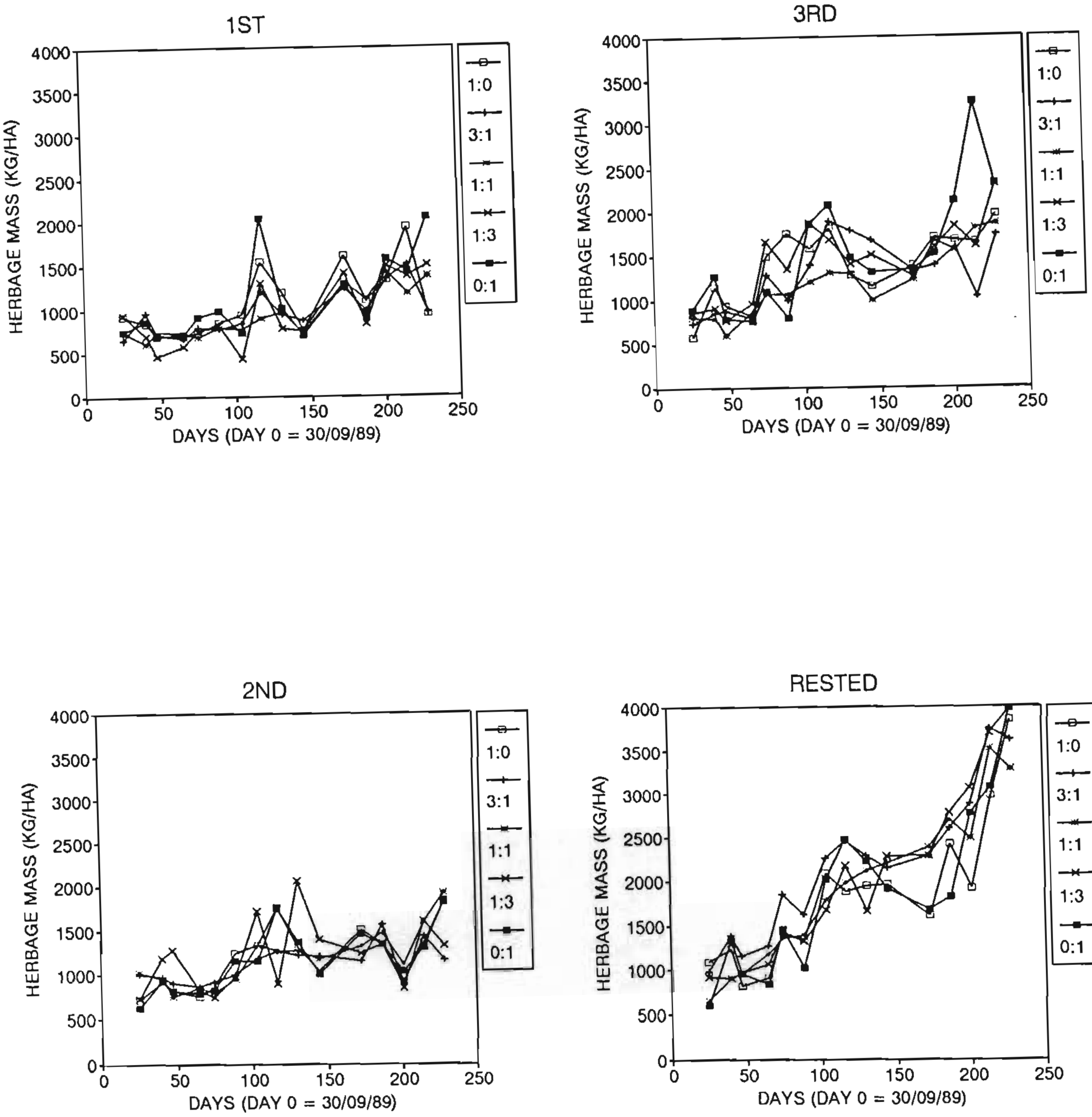
TREATMENT NUMBER	TOTAL AREA (ha)	'TEST' PADDOCKS
1	3.85	1C
2	2.09	2C
3	7.66	3C
4	8.38	4B
5	13.36	5B

Appendix Figure 4.1 The animal production (medium stocking rate) component of the trial (S5 area). Letters A to D refer to the four paddocks allocated to each of the ratio (AU cattle:Au sheep) treatments viz. 1 = 1:0; 2 = 0:1; 3 = 1:1; 4 = 3:1; 5 = 1:3.

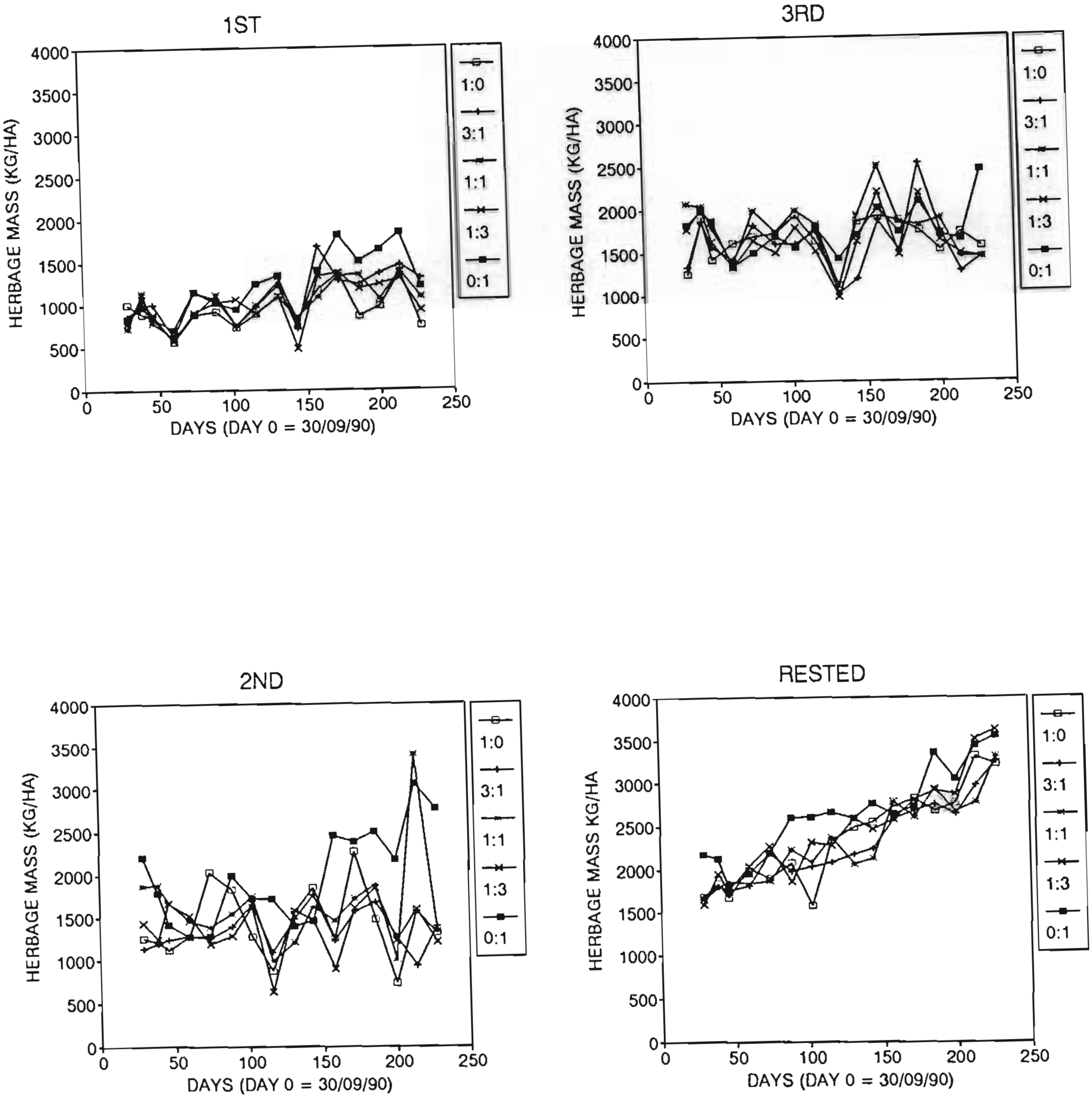


PADDOCK NUMBER	STOCKING RATE	CATTLE:SHEEP RATIO	AREA (ha)
1	HSR	1:0	0.29
2	HSR	0:1	0.20
3	LSR	3:1	0.81
4	LSR	1:3	2.16
5	LSR	0:1	0.40
6	HSR	3:1	0.36
7	HSR	1:3	1.08
8	HSR	1:1	0.54
9	LSR	1:1	1.08
10	LSR	1:0	0.54

Appendix Figure 4.2 The simulation (low - LSR, and high - HSR, stocking rates) component of the trial (N2 area).

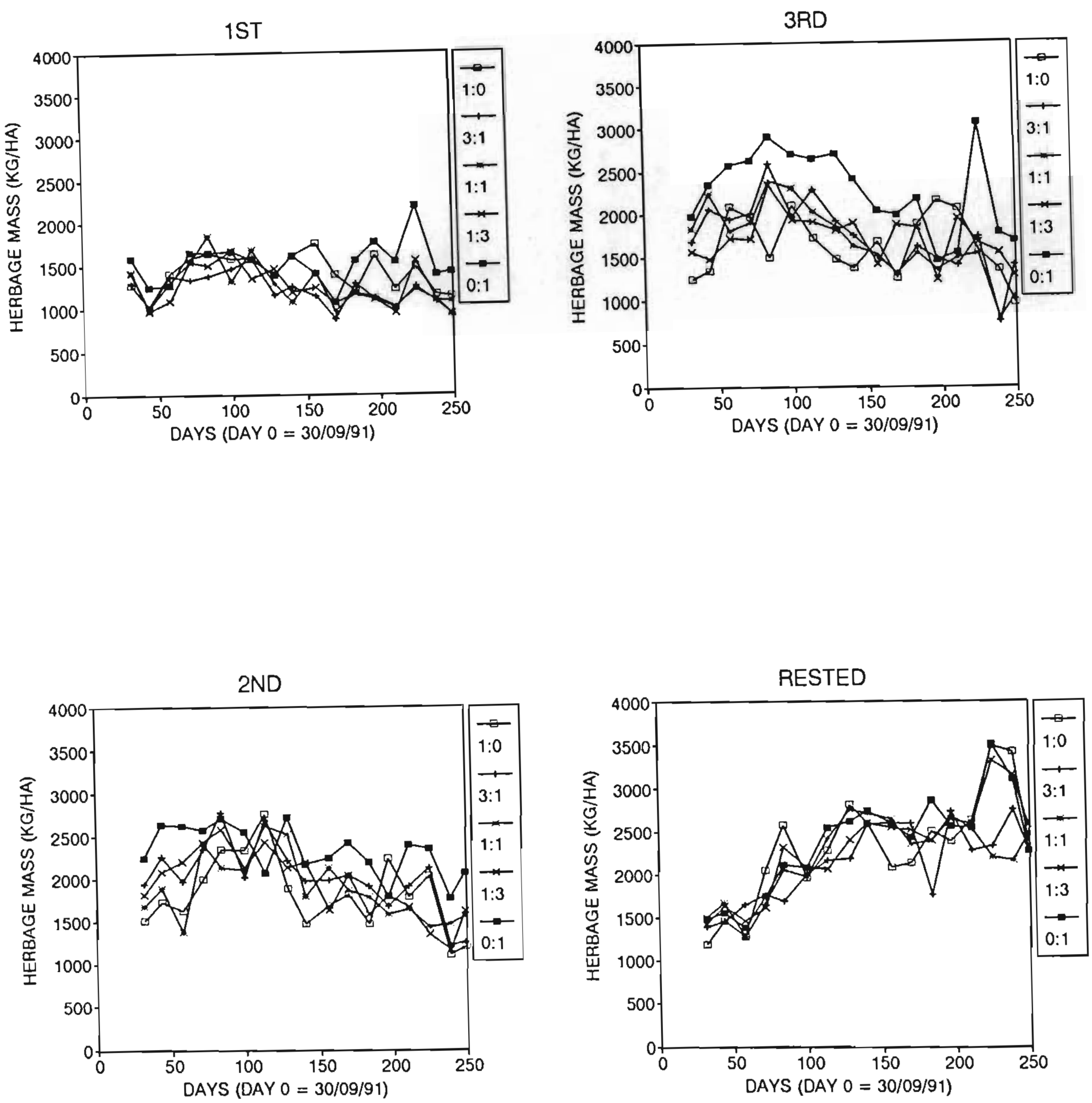


Appendix Figure 5.1a
Patterns of herbage mass accumulation in each paddock of each cattle to sheep ratio treatment (AUE cattle:AUE sheep - 1:0, 3:1, 1:1, 1:3 & 0:1) through the 1989/90 grazing season. 1st, 2nd & 3rd refer to the position of a paddock in the grazing cycle i.e. the paddock was grazed 1st, 2nd or 3rd in the grazing cycle. Data for the rest (REST) paddocks are included



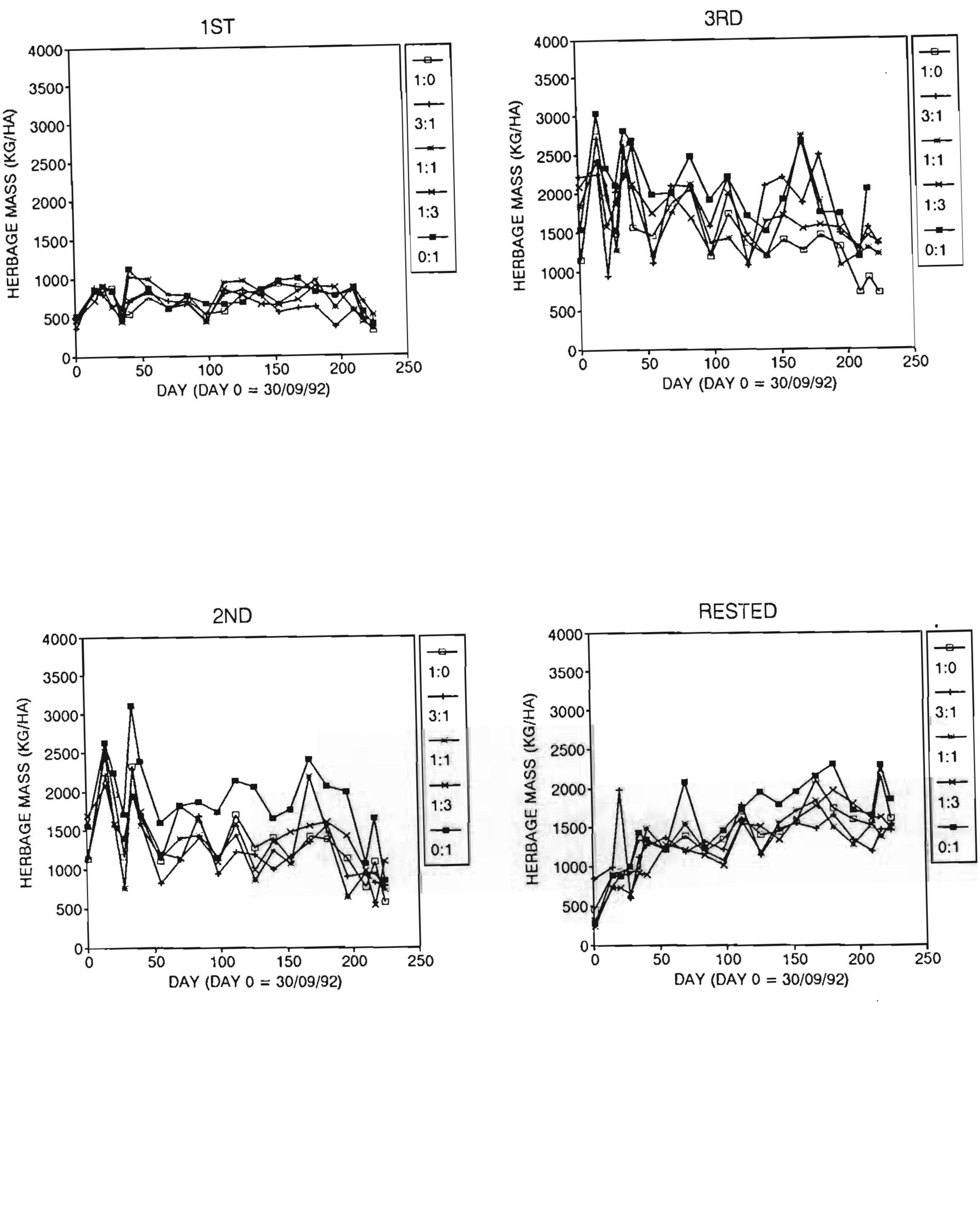
Appendix Figure 5.1b

Patterns of herbage mass accumulation in each paddock of each cattle to sheep ratio treatment (AUE cattle:AUE sheep - 1:0, 3:1, 1:1, 1:3 & 0:1) through the 1990/91 grazing season. 1st, 2nd & 3rd refer to the position of a paddock in the grazing cycle i.e. the paddock was grazed 1st, 2nd or 3rd in the grazing cycle. Data for the rest (REST) paddocks are included.



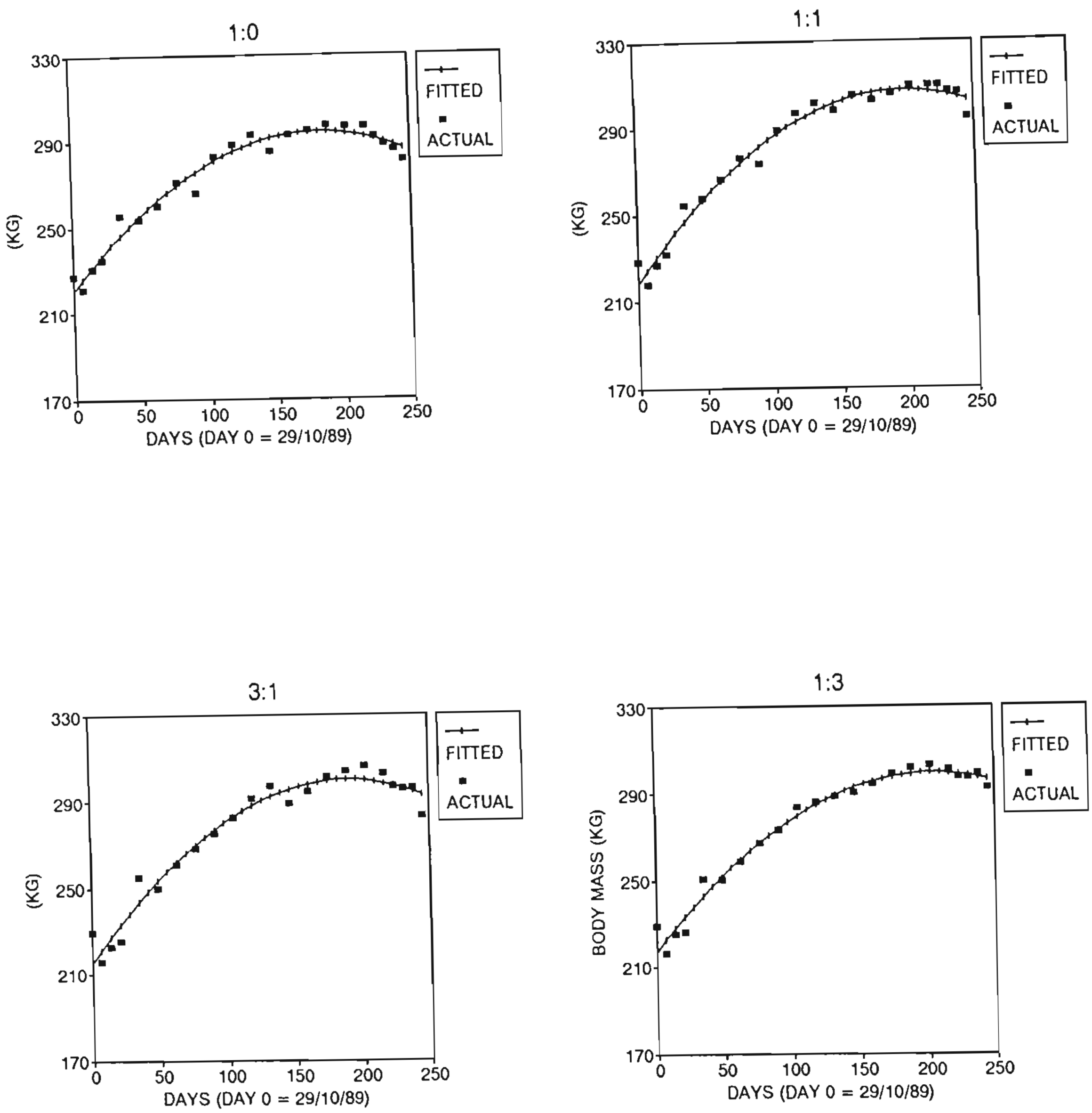
Appendix Figure 5.1c

Patterns of herbage mass accumulation in each paddock of each cattle to sheep ratio treatment (AUE cattle:AUE sheep - 1:0, 3:1, 1:1, 1:3 & 0:1) through the 1991/92 grazing season. 1st, 2nd & 3rd refer to the position of a paddock in the grazing cycle i.e. the paddock was grazed 1st, 2nd or 3rd in the grazing cycle. Data for the rest (REST) paddocks are included.

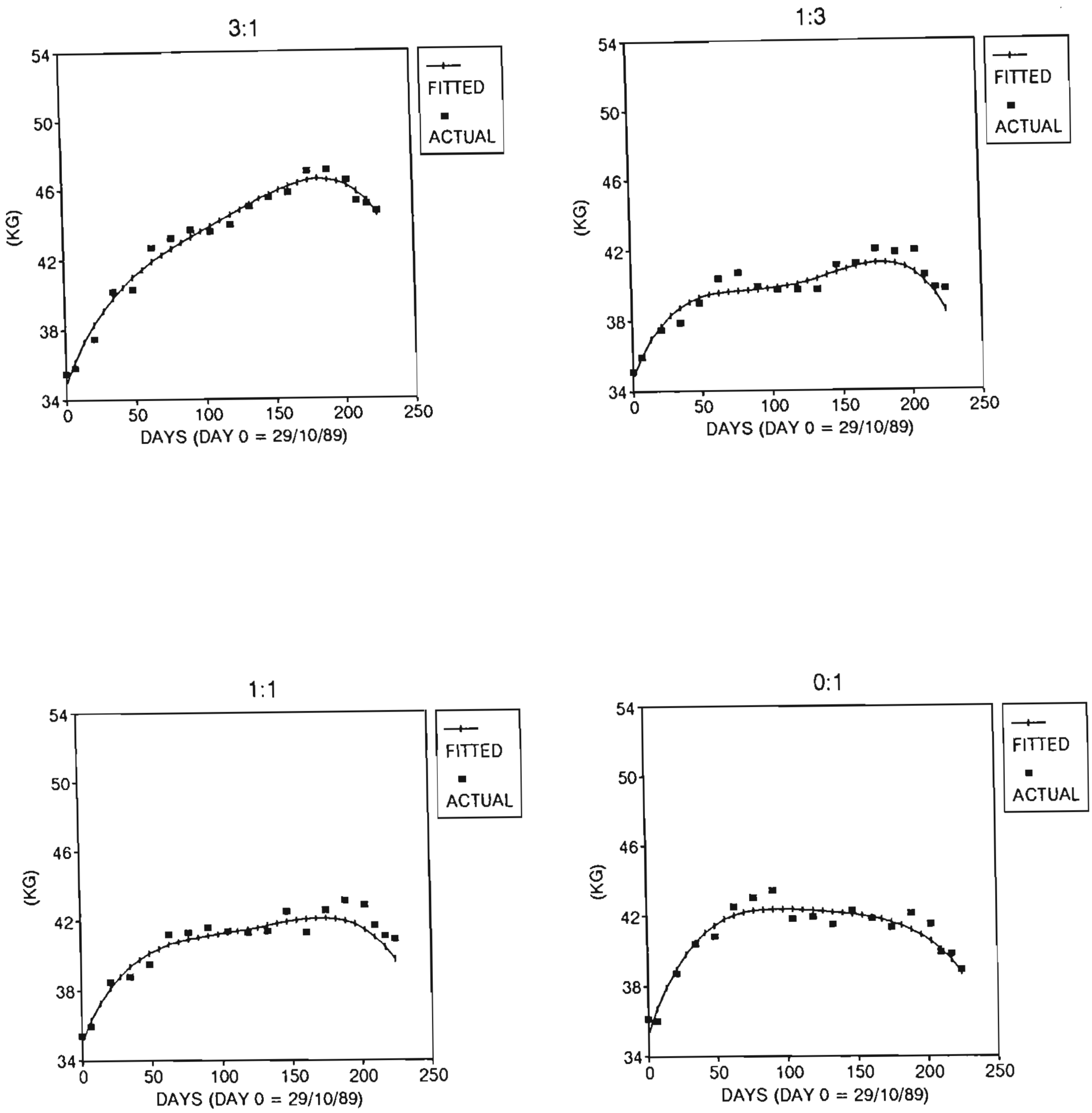


Appendix Figure 5.1d

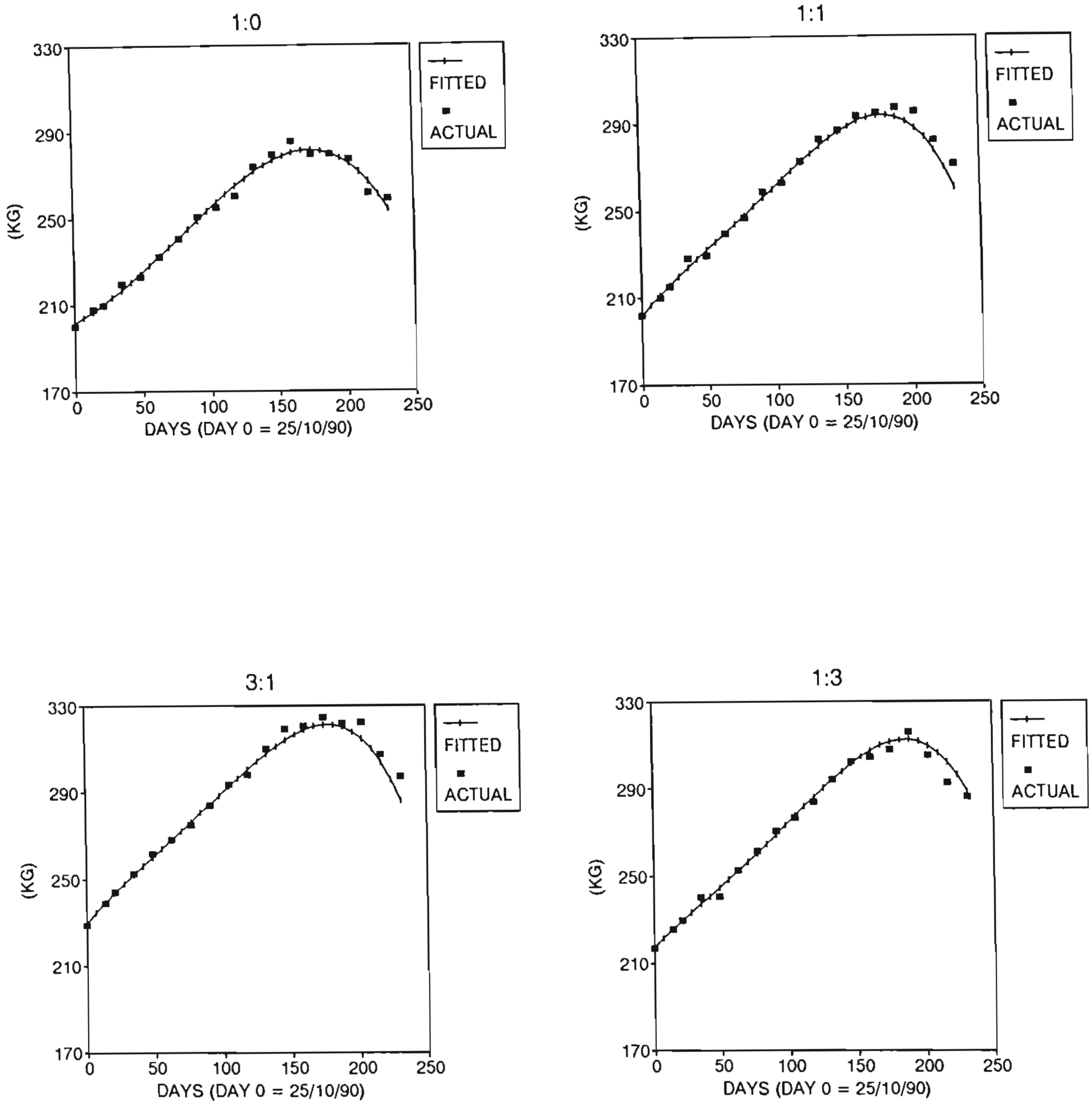
Patterns of herbage mass accumulation in each paddock of each cattle to sheep ratio treatment (AUE cattle:AUE sheep - 1:0, 3:1, 1:1, 1:3 & 0:1) through the 1992/93 grazing season. 1st, 2nd & 3rd refer to the position of a paddock in the grazing cycle i.e. the paddock was grazed 1st, 2nd or 3rd in the grazing cycle. Data for the rest (REST) paddocks are included.



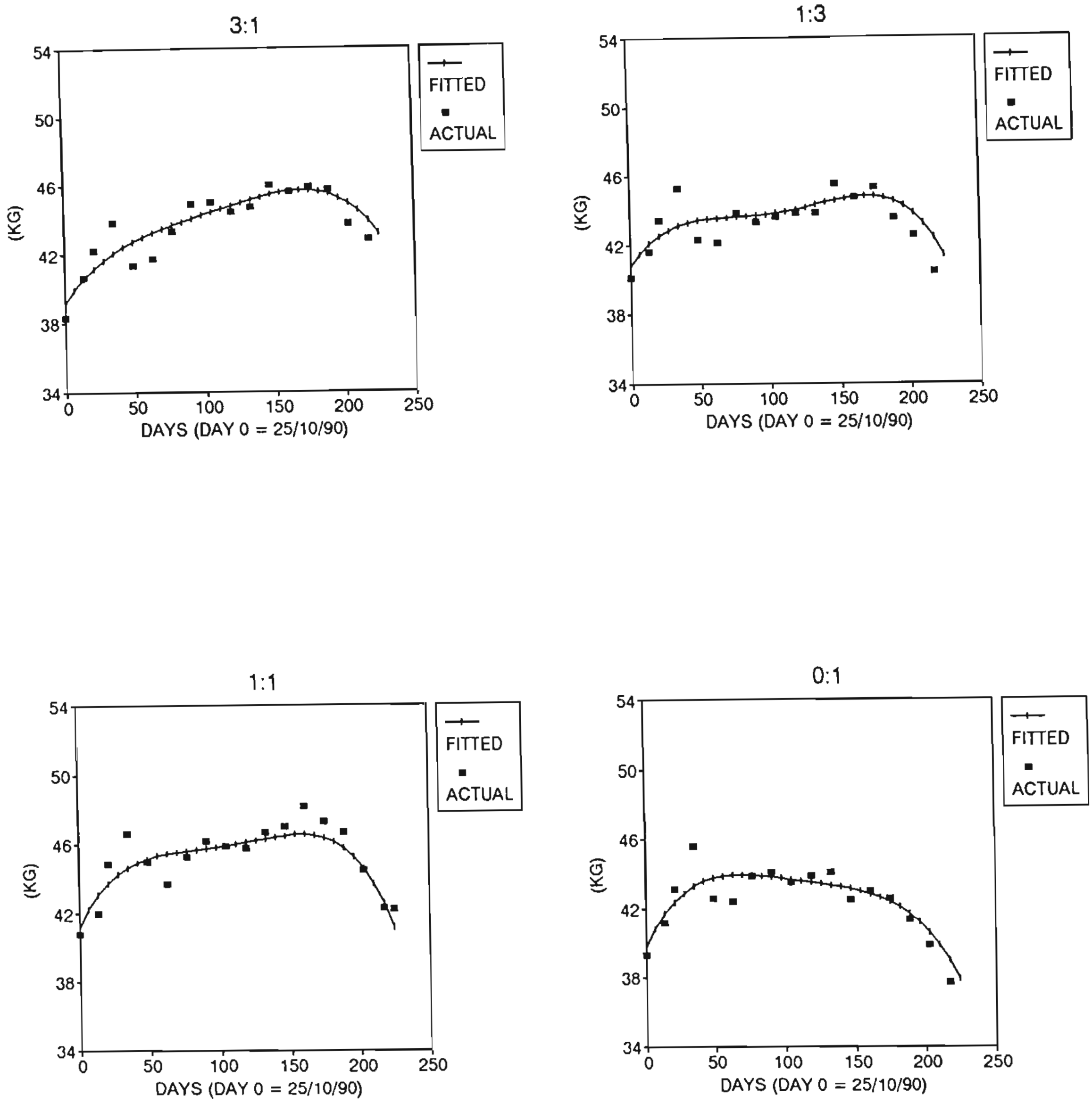
Appendix Figure 5.2a
Fitted and actual mean cumulative mass changes (KG) of cattle in each cattle to sheep ratio treatment (1:0, 3:1, 1:1 & 1:3) for the 1989/90 grazing season



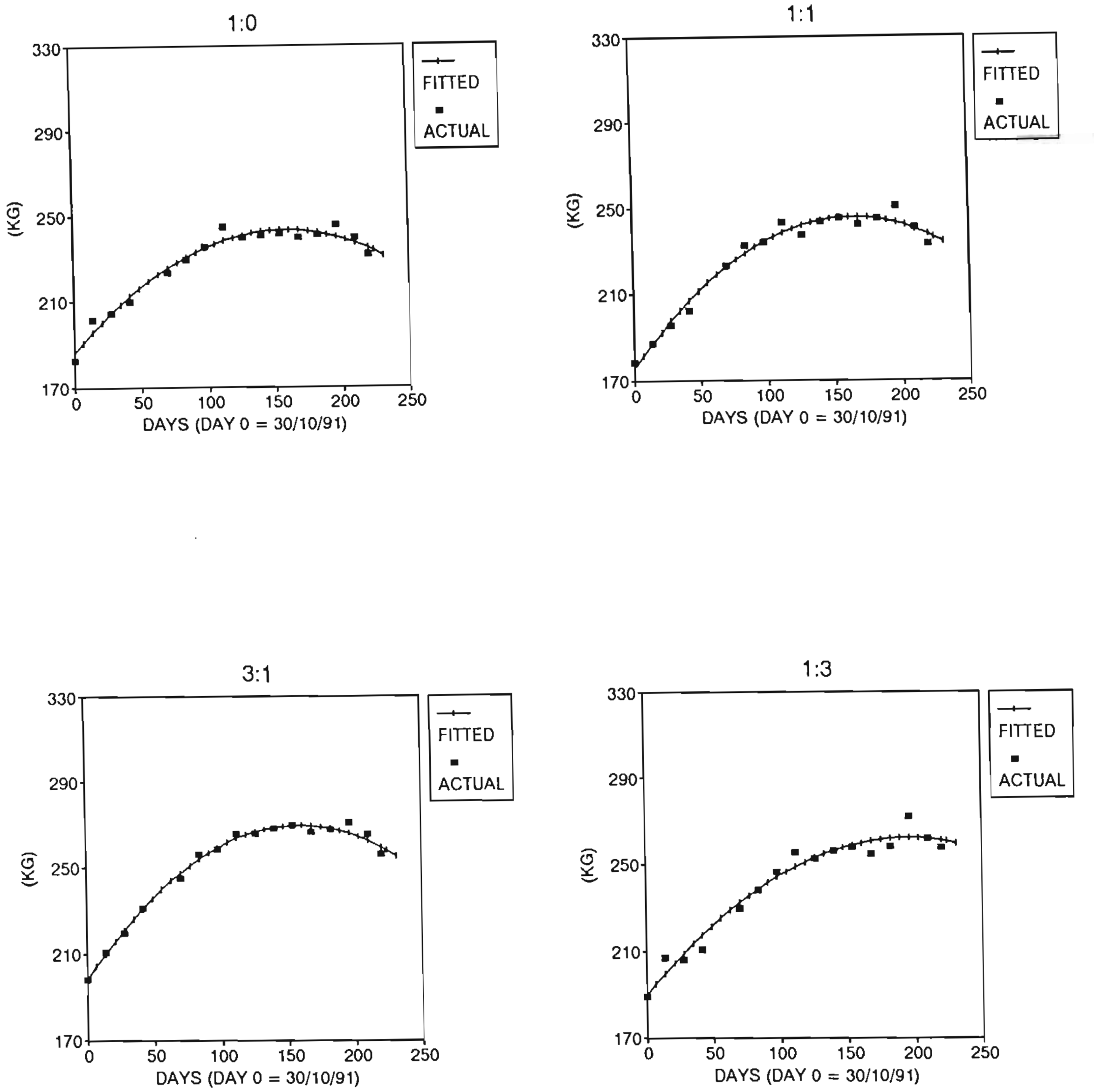
Appendix Figure 5.2b
Fitted and actual mean cumulative mass changes (KG) of sheep in each cattle to sheep ratio treatment (3:1, 1:1, 1:3 & 0:1) for the 1989/90 grazing season



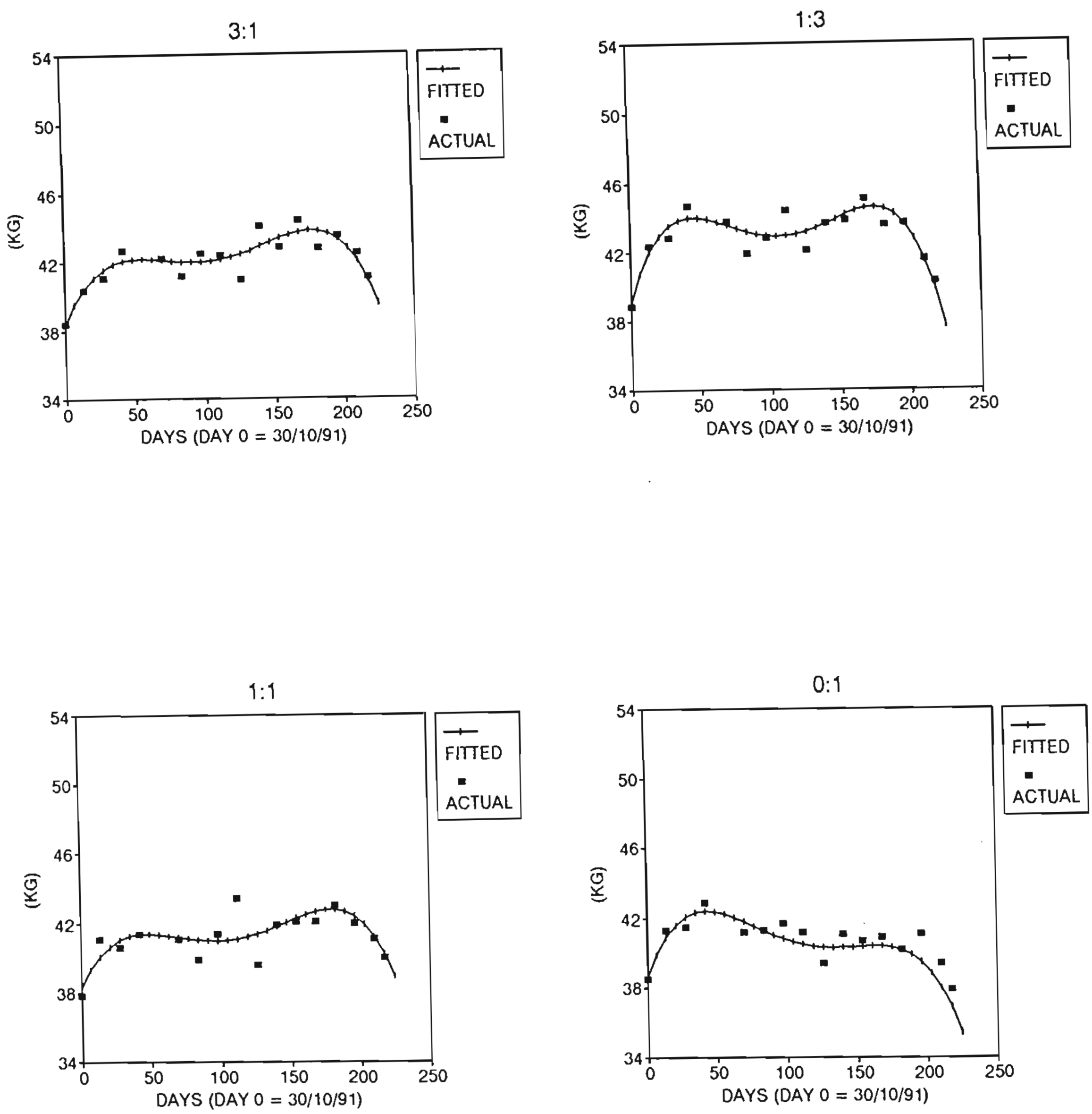
Appendix Figure 5.3a
Fitted and actual mean cumulative mass changes (KG) of cattle in each cattle to sheep ratio treatment (1:0, 3:1, 1:1 & 1:3) for the 1990/91 grazing season



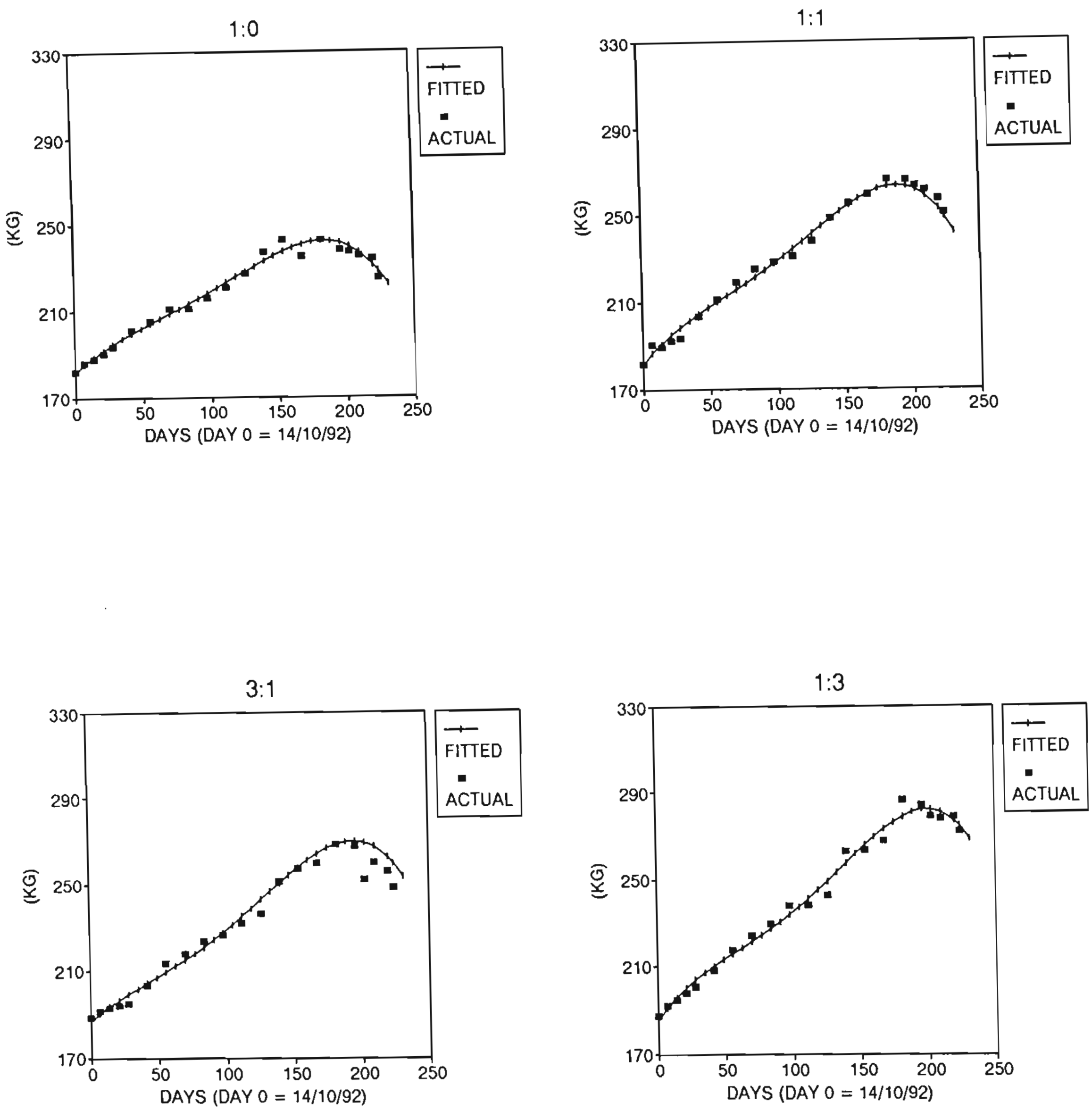
Appendix Figure 5.3b
Fitted and actual mean cumulative mass changes (KG) of sheep in each cattle to sheep ratio treatment (3:1, 1:1, 1:3 & 0:1) for the 1990/91 grazing season



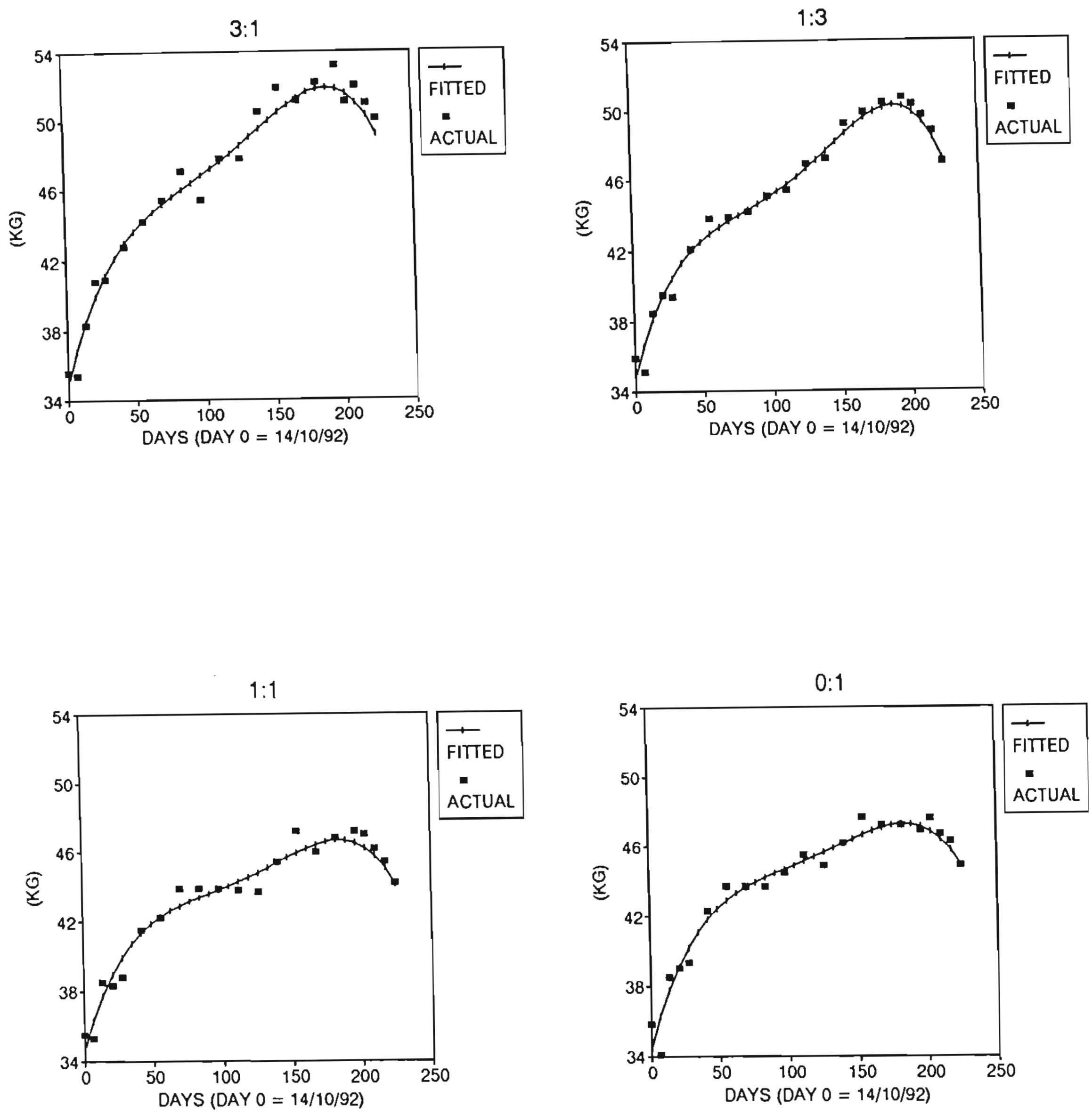
Appendix Figure 5.4a
Fitted and actual mean cumulative mass changes (KG) of cattle in each cattle to sheep ratio treatment (1:0, 3:1, 1:1 & 1:3) for the 1991/92 grazing season



Appendix Figure 5.4b
Fitted and actual mean cumulative mass changes (KG) of sheep in each cattle to sheep ratio treatment (3:1, 1:1, 1:3 & 0:1) for the 1991/92 grazing season



Appendix Figure 5.5a
Fitted and actual mean cumulative mass changes (KG) of cattle in each cattle to sheep ratio treatment (1:0, 3:1, 1:1 & 1:3) for the 1992/93 grazing season



Appendix Figure 5.5b
Fitted and actual mean cumulative mass changes (KG) of sheep in each cattle to sheep ratio treatment (3:1, 1:1, 1:3 & 0:1) for the 1992/93 grazing season