ENVIRONMENTAL SELECTION OF PASTURE SPECIES AT LAKE TEKAPO

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Nilo Covacevich

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ABSTRACT

Thirty environments resulting from the combination of five soil fertility regimes, three stocking rates and two grazing methods were imposed on multi-species mixtures overdrilled into hawkweed-dominated short tussock grassland at Lake Tekapo.

Legume species dominated during the three year trial period covered by this study. The most important legume from 0 to 250 kg fertiliser ha^{-1} yr^{-1} was Russell lupin (*Lupinus polyphyllus*), used here as a pasture species. The second most important species was alsike clover, followed by red and white clovers, the latter only under irrigation and high fertilisation.

The most important experimental factor affecting the relative ranking of species during the experimental period was soil fertility regime; secondly, stocking rate and last, grazing methods.

Introduced and resident species were significantly related to environments defined as follows:

- Fescue tussocks, mouse-ear hawkweed and adventive grasses with unimproved soils and light grazing;
- Russell lupin with little-amended soil conditions and moderate grazing pressure;
- White clover with fully developed conditions;

- Red and alsike clover with increasing grazing pressure and lower soil fertility regimes.

Hieracium did not disappear as a consequence of soil improvement and grazing but appeared to be favoured by hard grazing.

Tussocks within dense legume swards did not seem to play any role of importance; if the canopy was open they became more conspicuous, but always at the lower range of relative abundance. A supplementary experiment showed that in the absence of other vegetation shelter, the shelter provided by silver tussocks to shorter grasses resulted in increased relative growth rates in swards, providing that a rather sparse tussock distribution (plants 120 cm apart) was maintained. A closer tussock canopy could produce an opposite effect.

Sheep grazing preferences were detected at all situations, but actual total utilisation of pasture did not present important differences between introduced species. True rejection occurred only for mouse-ear hawkweed at soil improved treatments.

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Chapter 1

GENERAL INFORMATION

1.1 THE PROBLEM

The pastoral history of the high country in South Island, New Zealand, can be divided into three stages. First, an exploitative phase starting before 1860, when grasslands were stocked with increasing numbers of sheep which reached a peak on unimproved range by about 1880. Secondly, a deterioration period, marked by a decrease in sheep numbers from the 1880's to early 1950's and accompanied by large and fluctuating rabbit populations. Finally, a restoration stage from the 1950's to the early 1980's (O'Connor, 1980; O'Connor, Lochhead and Kerr, 1986), during which rabbit populations were controlled and livestock numbers were restored and increased, generally with grassland development practices. Since the early 1980's, rabbit populations have often expanded out of control and ecologic and financial uncertainty have both increased.

Exploitative pastoralism, as practised during the establishment and deterioration periods involved burning and grazing unimproved native vegetation. Consequently, important physiognomic changes, leading to what today are known as 'short tussock grasslands', may have occurred during the early days of the grazing activity. A new physiognomy was evolved, with more discrete short tussocks and increasing rosette and mat-forming plants, together with some small grasses (O'Connor, 1982, 1986).

The peak in sheep population reached by the early 1880's was based on the 'capital' represented by organic matter and nutrients accumulated during the previous centuries. However, the environment provided only a meagre annual growth 'interest', which became lower as grasslands were depleted. This situation apparently could not be sustained on unimproved grasslands and it was followed by a reduction in both sheep numbers and production parameters. Higher mortality, and low livestock performance became accepted features of sheep production in the high country through the long period of deterioration of both the pastoral industry and the pastoral lands.

The grasslands known as short tussock grasslands which have occupied the lowland and montane zones have always had greater economic significance for pastoralism than the higher altitude tall tussock grasslands (Cockayne, 1927, 1928). Depletion of these short grasslands by pastoral pressures was followed by successive increase of both native and adventive species, many of which have been unacceptable to livestock, especially in the unimproved state. Included among these are *Celmisia spectabilis* and *Raoulia* spp. and, more recently, *Hieracium pilosella.*

Despite the degeneration of pasture and accompanying rabbit plagues, traditional pastoralism survived. Technological advances such as improved rabbit control, topdressing, oversowing and fencing from 1950 onwards, produced a conceptual change more akin to farming situations. The subsequent restoration of productivity raised stock numbers steadily to the present level of 2.6 million livestock units within the high country (Kerr, 1983). It also brought about a new trend in vegetational mosaic in the montane zone, sometimes towards increased vigour and size of fescue tussock (O'Connor, 1966), but more frequently towards dominance by exotic pasture legumes and grasses (O'Connor, 1982; O'Connor, Lochhead and Kerr, 1986).

Chionochloa tussocks have low nutritive values (McRae and O'Connor, 1970) except after burning (Williams and Meurk, 1977). Dryden and Archie (1980) have indicated similarly for *Festuca novae-zelandiae.* Many tussock species show slow growth rates (O'Connor, 1966; Scott, 1970) or poor adaptation to grazing, which in some cases may lead to their total depletion (Hughes and O'Connor, 1977; Abrahamson, 1989). Furthermore, tall tussocks at higher altitudes are not very responsive to fertilisers (O'Connor, 1963). Although there are exceptions, such as blue tussocks (*Poa colensoi*) at higher altitudes (Allan, 1985), short tussock grasses induced from tall tussock grassland are low yielding in general and not very responsive to fertilisers (Scott, 1979). They therefore impose a low ceiling to carrying capacity and are likely to be inherently ineffective in maintaining the rate of nutrient cycling essential for productive pastures (O'Connor, 1966; 1981).

Despite grassland development on easier terrain, extensive pastoralism appears an alternative where the environment is extremely harsh, or where development costs are high. Yet, in the high country situation, the hope that the grazing process in itself could be a sufficient tool to sustain profits is a questionable matter in the light of past experience. It seems especially questionable in the face of rapid increase in hawkweeds in recent years.

It follows that, in some areas, pastoral farming may not be convenient or even possible. Alternative uses have been proposed (O'Connor, 1982). The general suggestion remains that sustained and economical animal production requires intensified grazing systems to ensure nutrient economy (O'Connor, 1981). Such intensification is conceived in terms of fertilisation and oversowing, together with more intensified grazing management in improved grasslands (O'Connor, 1966; O'Connor, Costello and Abrahamson, 1982; Allan, 1985). Under these conditions the persistence of tussocks is not ensured, even though some species could be at least temporarily invigorated (O'Connor, 1966; Hughes and O'Connor, 1977; Scott, 1979).

On the other hand, early observations as well as recent research, indicate that tussock plants have an ecological role in providing microclimatic conditions that affect the inter-tussock vegetation. This applies to the distribution of small native species (Scott, 1962), the establishment phase of introduced species (Scott and Archie, 1976; Scott and Wallace, 1978) and the growth of cocksfoot (Radcliffe, 1974). Farmers value tussocks as a source of emergency fodder and physical shelter for both plants and animals, and tend to suggest a desirable tussock cover of 15% on improved areas (Abrahamson, 1989).

Since most of the arguments in favour of maintaining a tussock canopy refer to shelter in the unimproved or early development situation, the question has needed to be asked whether they, or other species, would accomplish a similar function under improved pasture conditions.

So far, reference has been made to an intensification of sheep production in the high country as a general trend. In fact, many systems may arise from different levels of input in management factors such as fertilisation, oversowing, irrigation and subdivision. Each such system represents a different set of environmental conditions to pasture plants. Many pasture species show promise or are already shown to be adequate for general and particular conditions in the high country (O'Connor, 1959; Douglas, 1974; White, 1973; Scott, 1979; Wills, 1984; Scott *et al.* 1985). A description of the relative advantages of each species for many sets of conditions is still lacking. Thus, a closer definition of the role of different pastures species within the high country, as well as of the influence of tussocks as structural components of the environment will be the guidelines of the present work.

1.2 AIMS OF THE STUDY

The main purpose of this work was to study the relative success of introduced and native pasture species under a range of fertiliser, stocking rate and stocking method environments, each one being a possible management alternative in itself.

The first objective was to describe vegetational changes which occurred during the first three years following the establishment of multi-species mixtures in a high country locality.

The second objective was to examine the shelter effects of tussocks on the relative growth rate of a sown inter-tussock pasture. To establish this experiment tussocks were transplanted at different densities into an improved sward. Shelter classes were defined by a particular tussock plant density, plant proximity and orientation.

The third objective was to assess the acceptability to sheep of species considered in the first study. This will provide further support to understand the relative success of species and their consequences in sheep production.

Chapter 2

ENVIRONMENTAL SELECTION OF SPECIES

2.1 OBJECTIVES

Most experiments in species introduction which consider environment, assign paramount importance to the soil and climate of a locality. Only after an initial screening of material are the promising species tested under further environmental effects. Species sown alone or in selected mixtures, go through a sequence of soil and grazing management alternatives, aimed at devising the environment which best suits that particular species or combination of species. Further research will tend to integrate these conceived environments into total farming systems.

In the work to be described the testable hypothesis states that there is no difference among a number of species over a wide range of environments. If this hypothesis is rejected, then it is expected that some species will sort themselves out, according to their particular ecological strategy within the environments they encounter that best suit them. The agricultural objective is to determine for the conditions of the high country what species persist best within a range of soil fertility and stocking rate/grazing intensity environments.

The experimental approach used generates a range of environments as they may actually occur, inserting a range of species into them in the form of multiple species mixtures, and allowing natural selection to show which are the most successful ones. Results are expressed as yield or as high to low ranking of species abundance.

All promising species are tested at the one time in different soil and grazing management alternatives. In a way, this is an integration of what could take many years of relatively simple discrete trials. The selection process is measured in terms of differential vegetational change over particular periods.

2.2 REVIEW OF LITERATURE

2.2.1 Introduction

Papers such as those edited by Whittaker (1973), McIntosh (1978), the Committee on Developing Strategies for Rangeland Management (1984); and reviews by Randall (1978), Miles (1979), Silvertown (1982) and Kershaw and Looney (1985), show that there are no simple answers to questions such as: What is a plant community? Or, why do species occur in non-random proportions and patterns?

The general impression, however, is that in spite of conceptual difficulties (and even controversy), practical approaches are available for descriptive and functional vegetational studies, either in natural ecosystems or intensive agriculture. Unfortunately, within extensive grazing systems, methods are not so clear-cut. In the zone between the ecology of natural grasslands and that of sown agricultural pastures, concepts applicable to either extreme situation lose interpretative power.

The selection of parameters and methods used in the analysis of vegetational change involves a compromise with theories on population dynamics. The objective of this review will be to identify concepts suitable to explain vegetational change within grazing systems in the high country of South Island, New Zealand.

2.2.2 Early theory

At the onset of modern ecology, two currents of thought emerged in relation to the description of vegetational trends. The more accepted at the time, represented by Clements (1936), proposed that vegetation evolved, like an organism, towards maturity. At that mature stage, called climax, an equilibrium was achieved between a particular vegetation and the climate of an area. Thus, the notion of a predictable and directional succession determined mainly by climate became very influential.

The alternative (and more controversial) theory considered vegetation as a temporary aggregation of plants, where environment and historical factors resulted in an association which "... is not a organism, scarcely even a vegetational unit, but merely a coincidence" (Gleason, 1926). This approach was termed 'individualistic', since the emphasis was put on the individual species.

2.2.3 Description of vegetation

Within the climax concept, a vegetation, like an organism, was thought to present a definite structure at each developmental stage. In consequence, classification procedures were conceived to characterise such stages, basically through their distinctive vegetational units. However, under the individualistic approach, vegetation was conceived as being continuous both in time and space, which rendered classification procedures inappropriate. Thus, ordination procedures, where units are arranged into uni- or multi-dimensional orders, appeared as the alternative to classification procedures, where units are organised within discrete classes.

The most influential classification school has been that of Braun-Blanquet. It does not adhere to an orthodox clementsian approach, yet it is based in the floristic recognition of associations through diagnostic species. Followers developed this theory to a point where it became compatible with more modern trends (Van der Maarel, 1975). In New Zealand these principles can be recognized in the work of Connor (1964), classifying short tussock grasslands, sometimes with rather abrupt conceptual changes between units.

Ordination techniques were less convenient in practice because they required sophisticated and rather experimental mathematical analyses. Factor analysis is an early example (Goodall, 1954). Nevertheless, further works allowed more scientists to accept that, as pointed by Whittaker (1962), a classification is "...a process of interaction between a phytosociologist and vegetation...": Gleason's theories were somewhat redeemed.

Meeker and Merkel (1984) have reviewed current conceptions on this subject, concluding that the notions of climax pattern (Whittaker 1975) and site climax are more compatible with present needs in resource management. Both ideas share basic principles where soil and geomorphological maturity are not required for a plant community to be considered 'climax'. The main difference is that the climax pattern theory follows the continuum approach, whereas the site climax thought takes the more convenient view of discontinuous classifications, widely used by American range managers. Elsewhere phytosociologists, while accepting that vegetation is likely to be continuous, incline to the more practical classification of recognisable aggregations (McIntosh, 1978). However, recent advances in computational facilities render ordination procedures more accessible and counter this pragmatic trend e.g. Ter Braak (1986).

2.2.4 Environmental control

Many of the approaches in vegetational ecology have operated in scales of time and space inappropriate for agricultural situations. Furthermore, there has not been general explicit acknowledgement of agricultural practices as valid environmental factors: e.g. fertilisation and grazing. In recent years, however, there has been increasing evidence of both population ecology and systems ecology being applied to agricultural and pastoral situations in which environmental control is exercised through such factors as fertilisation and grazing.

Billings (1974) emphasised environmental control in vegetational processes, applying his principle of 'trigger factors'. These are factors which when removed or added to an environment start a chain reaction that will eventually affect the whole ecosystem. Trigger factors are relatively easy to determine in mono-specific crops; yet in the multi-species situation of grazing systems these factors may vary in time and intensity for each particular species. They may help to understand the boundary of presence and absence of species, but not so its range of relative dominance. It would seem that the introduction of grazing to a grassland lacking mammals and the later introduction of fertilising and oversowing to such grasslands lend themselves to interpretation as trigger factors in the broad context.

Although the relations between environment and vegetation are very complex, interactions are mediated through specific physiological processes controlled by only a few variables. This is particularly so in agricultural systems, where those key factors can be isolated (Scott, 1974; 1977). Environmental gradients, their relation with pasture production and the success of pasture species have been described for hill and high country situations in New Zealand. Here the important gradients are: fertility, soil moisture and temperature in relation to altitude (Scott, 1979; Scott *et al.* 1985). Problems related to the design and conduct of research in these relationships have been discussed by Scott (1974).

2.2.5 Plant strategies

The relative success of species has been related to their environment in terms of environmental strategies. The link is provided by the concept of '**r**', the intrinsic rate of increase of a population. If the environment does not restrict growth in any respect at all, the response will be exponential. Obviously, in nature the expanding species will always encounter a limit, an environmental carrying capacity (McArthur, 1964). '**K**' was used to designate the situation where population density reached equilibrium with resources. Species thriving under that condition (otherwise 'climax' species) were termed '**K**' strategists, long-lived and allowing little expenditure of resources to reproductive effort. Likewise, plants thriving in unstable or 'free' environments (otherwise 'pioneer' species), were termed '**r**' strategists, probably with a short life expectancy and a large energy allowance for reproductive effort.

Whittaker (1975), used the concept of diminishing returns to explain further the response of a species population within an environmental gradient. As the population increases past its middle range, the gain in numbers per unit improvement in environment decreases. The reverse occurs if the population diminishes past its middle range: a unit change for the worse in environment reduces the population by smaller quantities. As **K** represents the upper density-dependent limit, a new concept, '**L**', stands for the lower limit or 'threshold' population. Below this limit population becomes extinct. Exceeding **K**, on the other hand, results in an unstable population. This author does not favour the view of classifying species according to strategies adequate to each situation (**L**, **r** and **K**). Rather, he thinks these should be considered labels to characterise circumstances of selection, namely:

- saturation or interaction selection where the environment is relatively stable and occupied by other organisms;
- exploitation selection where conditions are intermittently or temporarily favourable; and
- adversity selection if population growth is seldom permitted at all.

Under this interpretation, because species may have to endure all of these circumstances through their evolution, they may form a continuum, with different proportions of genes determined by the relative importance of the selection type. Therefore, **r** would be the result of selective trade-off between the advantages of a larger progeny and the expense of an increased reproductive effort.

A conception of strategies by Grime (1979) seems more complete in that it covers the full range of plant ecology. 'Selection circumstances' are clarified because he classifies environmental factors directly in relation to plant success or failure, as those causing stress and those causing disturbance to plants. **Stress** is caused by factors limiting the production of biomass (e.g. nutrient deficiencies); whereas **disturbance** is caused by factors which may destroy site or biomass (e.g. trampling, burning). Stress and disturbance would define quite different selection processes favouring particular types of life history and physiology. Later (Grime, 1984), he has emphasised **competition** as a possible third selection process operating under low intensities of stress and disturbance, where consequently rapid rates of resource capture and growth are possible.

The response of species is presented as three inter-related strategies:

- **'Competitive'**, adapted to capture resources in low stress/low disturbance environments;
- **'Ruderal'**, which quickly diverts resources into a large production of seeds in low stress/high disturbance environment; and
- **'Stress tolerant,'** which enables species to retain resources under high stress/low disturbance conditions. It is to be noted that under the fourth combination i.e. high stress/high disturbance, there is no valid species strategy.

Grime reconciled his proposal with the **r-K** continuum, remarking that the most substantial difference is the recognition of stress tolerance as a distinct strategy, evolved under extremely unproductive conditions, or resource-depleted by vegetation itself.

'Competition' is not a term accepted by all. Harper (1964) had proposed the alternative concept of 'interference', which encompasses all reciprocal effects between plants and their environment. These effects would result in particular plant association patterns. This approach has been applied to grasslands studies using the technique of the nearest neighbour in a series of experiments by Aarsen, Turkington and Cavers in Canada (1979; 1985). They found significant correlations between species, but thorough explanation is difficult, either because of environmental patchiness or because of the difficulties met in increasing interference below ground (Berendse, 1979).

After a review of current debate on this issues, Welden and Slauson (1986) take the view that no pre-eminence should be ascribed to competition as an explanation for community structure. Abiotic stress, disturbance, predation or other processes could be of similar relative importance. Therefore, the process to be emphasised will depend on a decision related to the specific objective of a particular research work.

2.2.6 Conclusions

Methodologies to study vegetational change meet many practical constraints which require a compromise with an underlying ecological theory. Agricultural research calls for flexibility in both the theoretical and practical approach, which is reflected by the wide range of available methods. Probably each of these is more suitable than others to a particular purpose.

The theory of environmental plant strategies is especially reconcilable with high country grazing systems. Grazing intensity and frequency become conveniently enclosed within the notion of disturbance, whereas stress is integrated by factors such as radiation, temperature, and soil moisture and nutrients.

Each species is considered to respond in its own way within an environmental gradient, where large numbers of interactions may be condensed in a comprehensible number of situations with a clear agricultural meaning.

2.3 MATERIALS AND METHODS

2.3.1 Site

2.3.1.1 Location

The experiment covered 2.4 hectares at the experimental site of DSIR Grasslands on Mt. John Station, 3 km NW of Tekapo township, Mackenzie country (lat: 43° 59'S; long; 170° 27'E). The landscape of the area, at an approximate altitude of 600 m, is gently rolling moraine, including what was formerly a small infilled lake.

2.3.1.2 Climate

The area belongs to an inter-montane semi-continental basin, where winters are cold with some snow, and where summers are hot, dry and windy. Mean annual rainfall from Mt. John climate station (lat: 43°50'S; long: 170° 28'E, but nearly 300 m higher), is 560 mm. Mean temperatures for January and July (1927-1980) from the Lake Tekapo station (lat: 43°59'S; long: 170° 28'E, same altitude as the experimental site) are 14.8 and 1.6°C. and the annual rainfall is 606 mm; yet the calculated summer moisture deficit is one of the highest in the Waitaki (O'Connor, 1976).

2.3.1.3 Soils

The soils in the experimental area are formed from loess and till derived from greywacke and argillite rocks. They are a variant of the Pukaki or Tekapo series, but differ in having thin topsoil, more yellow B horizon with less organic matter, and slightly greater compaction in the lower subsoil (Webb, Bennett and Robertson, 1982). Results from the quick soil test analysis of topsoil are: pH = 5.3; Olsen P = 26.4 ppm; P retention = 27%; Ca = 375 ppm; K = 120 ppm and Mg = 65 ppm (units converted from quick test values according to Cornforth and Sinclair, 1984).

2.3.1.4 Vegetation

The vegetation of the area, prior to the trial, was a depleted fescue tussock grassland (*Festuca novae-zelandiae*), dominated by mouse-ear hawkweed (*Hieracium pilosella*). Other noticeable inter-tussock components included browntop (*Agrostis capillaris*) and sweet vernal (*Anthoxanthum odoratum*). These are noted as principal resident species found in the area in Table 2.3.1.

2.3.2 TREATMENTS

2.3.2.1 Sown species

Just prior to the author's involvement, the trial area had been overdrilled with pasture mixtures of 27 species. These were sown in the spring of 1982, with a Hunter rotary strip seeder in two coulter mixtures which included seven to eight species each. The rotary drill cultivated approximately half of the area over which it passed, allowing the other half of the resident vegetation to survive. The species were sown in 22 different mixtures and each species was present in at least a half

Table 2.3.1: Principal resident species and sown species with their seeding rates used in the grazing trial.

Species	Common Name	Cultivar	kg ha^{-1}
Residents			
Agrostis capillaris	Browntop		
Anthoxanthum odoratum	Sweet vernal		
Festuca novae-zelandiae	Fescue tussock		
Hieracium pilosella	Mouse-ear hawkweed		
Legumes			
Coronilla varia	Crown vetch		0.02
Lotus corniculatus	Birdsfoot trefoil	Cascade	0.4
Lotus corniculatus	Birdsfoot trefoil	Maitland	0.5
Lotus pedunculatus	Lotus	Maku	2.1
Lotus corn. x ped.	Hybrid lotus	G4712	2.1
Lupinus polyphyllu	Lupin	Russell	2.1
Medicago sativa	Lucerne	Saranac	1.8
Trifolium ambiguum	Caucasian clover	Prairie	2.1
Trifolium hybridum	Alsike clover	Tetra	0.4
Trifolium hybridum	Alsike clover		0.4
Trifolium medium	Zig-zag clover		1.9
Trifolium pratense	Tetraploid red clover	Pawera	1.1
Trifolium repens	White clover	Huia	0.3
Grasses			
Agrostis capillaris	Browntop		0.6
Arrhenatherum elatius	Tall oat grass		1.2
Bromus catharticus	Prairie grass	Matua	0.2
Bromus scoparius			1.0
Cynosurus cristatus	Crested dogstail		1.3
Dactylis glomerata	Cocksfoot	Apanui	5.0
Festuca arundinacea	Tall fescue	Roa	4.7
Festuca rubra commutata	Chewings fescue		1.4
Holcus lanatus	Yorkshire fog	Massey Basyn	1.2
Lolium perenne	Perennial ryegrass	Nui	3.5
Lolium x hybridum	Hybrid ryegrass	Ariki	3.5
Phalaris aquatica	Phalaris	Maru	4.7
Phleum pratense	Timothy	Kahu	1.3
Others			
Sanguisorba minor muricata	Sheeps burnett		3.0

of these mixtures. A list of the species considered and their mean sowing rates for the whole trial area is also in Table 2.3.1. Legumes were inoculated with appropriate rhizobia and coated.

2.3.2 Manipulated environments

Different environments were imposed on the sown species as individually fenced plots (50 x 8.3m). They resulted from the combination of three stocking rates (**SR**) and two grazing methods (**GM**) upon five situations of soil fertility or growth potential (**F**). The latter were basically defined by the five fertility regimes that follow. All are expressed in kg element per hectare per year. The first four were applied on non-irrigated soil and the fifth (**F5**) on spray irrigated ground: (**F1**) No fertiliser; (**F2**) P:S = 4.5:10; (**F3**) P:S = 9:20; (**F4**) P:S = 25:27; and (**F5**) P:S = 50:55. These applications were doubled in the establishment year and made at the nominated rate each spring thereafter. Sulphur superphosphate (50 and 100 kg ha^{-1} yr^{-1} for **F2** and **F3**) and superphosphate (250 and 500 kg ha^{-1} yr^{-1} for **F4** and **F5**) were used.

The three stocking rates were 'moderate' or 'best guess', being the number of sheep estimated to be required to graze the plot at what was considered the best grazing height down to the best regrowth height (**SR = 2**); a 'light' stocking rate with 50% fewer sheep (**SR = 1**); and a 'heavy' stocking rate with 50% more sheep than the moderate level (**SR = 3**).

The two grazing methods (**GM**) were: '**Mob stocking**', with sufficient sheep to graze the Moderate stocking rate level in four to five days; and a '**Sustained stocking**', which in practice were one, two or three sheep maintained at the Light, Moderate and Heavy stocking rates for as long as possible. Dry Merino ewes were used. There were two Replicates.

2.3.2.3 Management

The sowings were allowed an establishment period of one and a half years before imposition of the experimental grazing treatments. Grazing treatments were applied in groups of three, corresponding with the three stocking rates within a particular fertiliser level and grazing method. Management decisions were based on the criteria for the moderate stocking rate treatment. Therefore, grazing within each group of three plots was largely independent of the remaining plots in the trial. The grazing periods extended from late October to early May each year. Each year vegetation was allowed to grow from August to October, prior to recording of vegetation composition.

2.3.2.4 Measurements

The main observations were measurements of change in vegetation composition as an indication of the relative importance of the different species (full details in next section). There were also subsidiary estimates of total pasture production through recording of sheep grazing days and occasional direct measurements of herbage mass. These last were determined during the grazing season 1984/1985 with a pasture capacitance probe. One hundred readings were taken per plot immediately before and after each grazing period. Calibration curves were calculated monthly.

Monthly rainfall and mean soil temperature at 0.5 m below ground were recorded at the meteorological station maintained by DSIR Grasslands at the experimental site.

2.3.3 Technique for the visual ranking of species

2.3.3.1 Introduction

It is commonly accepted that the botanical composition of a pasture can be determined in an objective and exact way through manual separation and dry matter determination of species clipped within a quadrat. Boswell *et al.* (1978), reported standard deviations up to 7.4%, which is sufficiently accurate for most grazing experiments. Nevertheless, this method is so time-consuming as to be sometimes inefficient or even impossible to apply. This is particularly evident in grazing trials where plots are usually large and where replicate estimates of botanical composition are needed for statistical confidence. Many indirect techniques have been proposed. From the literature it appears that for almost any experiment there might be a technique more suitable to its particular objectives than any other. Tothill (1978) has reviewed this subject.

The most rapid way to describe vegetation is to record the species within a sample area, giving to each of them an assessment of abundance. Many workers have used variants of this approach in plant ecology. Nevertheless, such procedures have been criticized because they may involve a very large error (Kershaw and Looney, 1985). It may also be alleged that they induce confusion between the notions of physiognomical dominance (the most abundant species) and sociological dominance (most influential species within the community). Although a species may be 'dominant' in both senses, this may not be always the case.

Obviously, practical constraints common in agricultural research make visual methods very attractive. These are constantly being improved, even for the more quantitative approach of dry matter determination (Carande and Jameson, 1986). Grace and Scott (1974) have used one such method for improved and unimproved high country grasslands. These data were also used (Hughes, 1975) as the basis for estimating grazing preference of sheep. In the present study, visual ranking of species contribution to yield, as described by Scott (1989) was used. 1990 in refs.

A comparison of visual versus harvest dissection methods for different pastures (*Phalaris aquatica* and *Trifolium subterraneum*) showed that the Dry-Weight-Rank method of t'Mannetje and Haydock (1963) took between 1.6 and 3.4 minutes, whereas the clipping and dissection of 1 m^2 quadrat required from 54 to 396 minutes (Silva, 1985). The field technique of t'Mannetje and Haydock (1963) is comparable to visual ranking as described in the next section.

In the present trial, assessments by Kong and Scott (D. Scott, pers. comm.) showed that time involved in visual estimates averaged five minutes per sample, as compared with 20 minutes for 0.1 m^2 diameter quadrats clipped for total yield, and 2.5 hours for dissection of harvest for individual species yield. Because of the sowing of species in adjacent two-coulter mixtures there was considerable local variation in pasture composition. Many clipped quadrats would have been needed to integrate information to give comparable validity with the visual integrating possible with the ranking technique.

2.3.3.2 Procedure

Vegetational composition was determined through the visual ranking of species, according to their estimated contribution to the bulk of pasture yield. In the field, the most abundant species was given rank one; the second most abundant was given a value of two, and so on, down to the tenth species. In the data matrix, all other present species received a common value of 11. The ratio of the relative abundance of the fifth to the first ranked species was also recorded. This estimate is required to fit a mathematical model which relates ranking with actual dry matter contribution to total yield, as detailed in the next section. It should be noted that rank scoring, in this sense, only gives a measure of the relative importance of each species at each plot, and it is not a measure of absolute contribution to total yield.

In this case, the sampling unit was an integrated assessment across the whole plot. For the main measurement , in the late spring of each year, rankings were assessed independently by three or four observers. In those opportunities, ground cover was also ranked, from one to five, for bare ground, sown legumes, sown grasses, mouse-ear hawkweed and others.

Daily measurements recorded during mob-grazing periods and the occasional ones in sustained grazing were done only by the author.

2.3.3 Relation with total yield

Visual ranking as defined here estimates the relative abundance of one species in relation to total vegetation. Work in both natural vegetation and agricultural pastures show that generally there is a fixed relationship between ranking and percentage contribution of a species. t'Mannetje and Haydock (1963) showed this for subtropical pastures. They proposed three coefficients to weight the relative frequency of the three most abundant species, as ranked by their estimated dry matter yield in quadrats.

The original multipliers were re-determined (Table 2.3.2) particularly in connection with the development and validation of BOTANAL. This is a sampling and computing procedure for the estimation of pasture yield and composition which incorporated the method of dry weight ranks (Hargreaves and Kerr, 1975).

Table 2.3.2: References giving relationships between species rank and percentage contribution to total yield.

Author	Rank		
	1	2	3
t'Mannetje and Haydock (1963)	70.2	21.1	8.7
Jones et al. (1969)	71.4	24.7	3.9
Jones and Hargreaves (1979)	70.5	23.8	5.7
Mansilla et al. (1985)	77.0	15.0	6.0

These coefficients have been determined from a wide variety of pastures. Perhaps the only variation, pointed out by Mansilla *et al.* (1985), is that when two species add up to a dominance well in excess of 90%, then it is feasible to use only two coefficients, the contribution of the third species being negligible. The same authors commented on the empirical nature of these coefficients. Therefore, ideally, they should be redetermined again for each pasture with a different structure.

Scott (1989) showed that these empirical constants occurred because of the existence of an underlying relationship reported between rank and relative abundance of species in general plant and animal ecology (Whittaker, 1962). Of these relationships, the geometric series was proposed as the most suitable for pasture studies, using the ratio of two species, preferably the first and the fifth ones. Thus, the percentage contribution (%) of a species of a rank "R" is:

% = 100* (1-P) *P** (R-1), where P = (R1/R5)** 0.25

In this study the determination was done using the ratio R1/R5, and also R1, for each observation. From the comparison (Appendix I), R5/R1 was a good estimator, and indicated that transformations (e.g. arcsin) did not improve it. The mean value for the ratio R5/R1 across all treatments and species was 0.0088 (SD = 0.024).

By substituting this value in the equation above the coefficients for ranks one, two, and three are: 72.4; 21.9; and 6.7. These values are similar to those in Table 2.3.2. Furthermore, the first three ranks in this case were forced to add up to 100% to make the comparison. In fact, because the geometric series is infinite, it could provide estimates for all of the species. The complete series is: R1 = 69.4%; R2 = 21.3%; R3 = 6.5%; R4 = 2.0%; R5 = 0.6%; R6 (the sum of remaining ranks) = 0.2%. Using six ranks, for all practical effects the cumulative contribution adds to 100%. These are the equivalences that will be presented in plots, on the same axis as ranks.

2.4 STATISTICAL ANALYSIS

2.4.1 Experimental design

The basic field design was a randomised complete block with two replications for the five fertiliser levels. Each plot was 50 x 50 m. Later, with the imposition of the grazing treatments, this basic design became a split-plot applied to a three factors arrangement with two replications (5 x 3 x 2 x 2) as 60 50 x 8.3m fenced plots. Fertility was the main plot effect, with Stocking Rate and Grazing Method randomised in combination as sub-plot factor. The inclusion of time introduced a simulated sub-sub-plot effect, so the original design became a split-split-plot on a three factors factorial.

The experiment was divided in two phases:

- an establishment period (spring 1982 to spring 1984), and
- a grazing period (spring 1984 to spring 1985).

Each period could be conveniently divided further into four sub-periods designated 'Seasons' (S), grouping the sampling dates. Thus, the establishment period included the spring of 1983; autumn 1984; early spring 1984 and mid-spring 1984. Likewise, the grazing period comprised the spring of 1984; summer 1985; autumn 1985 and spring 1985.

2.4.2 Analysis of rank data

2.4.2.1 Introduction

The analysis of variations in botanical composition implies the correlation of the response variables, namely the proportions of species. In this case, if a given species increased rank in time, necessarily another species had to decrease, because rank classes are exclusive. Some authors consider that negative correlations should be taken into account in a valid analysis, for which multivariate procedures have been recommended (Stroup and Stubbendieck, 1983). However, in the biological context of this experiment, such analytical problems are not a major constraint. It is conceived that species were responding independently within an environment as a function of a particular strategy. Furthermore, it has been claimed that a fixed relationship may exist between the proportions of the species constituting the pasture. At any rate, the more accessible multivariate analysis of variance (MANOVA) meets computational problems (rank variables summing to a fixed total) and a somewhat weaker explanatory power for the behaviour of an individual species. In the light of these comments, univariate methods were preferred.

Only eleven species were sufficiently abundant to be considered in the analysis: alsike, red, white, and caucasian clovers; Russell lupin; birdsfoot trefoil; yorkshire fog; browntop; sweet vernal; fescue tussock and mouse-ear hawkweed.

Species had been ranked in the field from one to 10, but for the purposes of the analysis the scale was reduced from one to six. All ranks with magnitudes greater than six were included in that class.

2.4.2.2 Statistical procedures

The selection of statistical methods should depend on the nature and distribution of effect and explanatory variables (Scott, 1969). In the present study, it must be noted that ranks do not represent continuous variables, but rather a limited number of ordinal classes. Strictly, a linear model approach developed for the analysis of such ordinal data should be used. Nevertheless, the relationship between ordinal rank classes and percentage contribution allows for the possibility of transformation and treatment as quantitative continuous data. A discussion and comparison of different statistical approaches is given in Appendix 1. It is sufficient for the main results presented in this chapter that all of them gave essentially the same levels of significance for different treatment effects, and that the ANOVA procedure has the attraction of familiarity. Therefore, ranks were treated as continuous variables and analysed within the framework of an ANOVA in a General Linear Model's approach (McCullagh and Nelder, 1983; Crosbie and Hinch, 1985).

In the analysis of variance the significance levels were determined using a type III sum of squares. These are equivalent to Yates' weighted squares of means analysis (Gomez and Gomez, 1984), also called 'complete least-squares analysis'. It is a conservative test for significance because effects are tested only after all variables in the model have been adjusted for. This allows for the comparison of main effects even in the presence of interactions, since each effect is adjusted for all other effects. In this case, soil growth potential (F) and 'Stocking Rate' (SR) were adjusted for the interaction 'F x SR'. However, in the present situation, the main advantage of type III SS was that they are unrelated to cell frequencies. These were variable during the grazing period, because grazing cycles were determined independently for each treatment. The analysis was applied as specified for the procedure entitled "GLM" in Version 5 of the Statistical Analysis System (SAS user's guide; statistics, 1985).

2.4.2.3 Graphical description

It is convenient to present the rank variation of species between treatments graphically, to picture a trend for each species per season within each phase of the trial (pre- or post-grazing). Graphs describe the behaviour of each species through each phase in terms of its monthly rate of mean rank variation. If that mean rate of change is zero, then rankings did not vary between measurements, and therefore the species remained "static" in terms of relative abundance (regardless of variations in total yield). If the mean rate of rank change is less than zero, then ranks became smaller; therefore the species is now more abundant (low values of ranking, e.g. one, two, represent the most abundance). On the contrary, if the mean rate is positive, then ranks increased through time, and the species is becoming relatively less abundant. These concepts, which refer to variations in community structure, may qualify the 'importance' of competition because they concern its products (Welden and Slauson, 1986).

The mean rate of change was calculated as the slope of the regression on time versus rank. Units are considered meaningless and only the sign of the response is of interest. Monthly intervals were convenient since the measurements covered more than one year in each phase of the trial.

To plot the rankings, the first ranked species was assigned the numerical score '1'. To maintain the logic of an increase in abundance plotted as a linear positive increase, the axis for ranks was reversed e.g. rank '1', which represent the highest abundance, was plotted on the upper part of the graph. Rank data on ground cover are presented graphically only.

2.4.3 Vegetational change during the establishment period

Measurements were grouped in the following seasons: Spring, 1983; Autumn, 1984; Early Spring, 1984; and Mid-Spring,1984.

The analysis was done as a split-plot on a randomized complete block arrangement, with soil growth potential (F) as a whole plot or main plot effect, and 'Seasons' (S) as split-plot or sub-plot effect. An outline of the ANOVA table is in Table 2.4.1. Each species was analysed separately.

Table 2.4.1: Outline of ANOVA for mean rank variations in one species during the establishment phase (five fertiliser rates x four seasons x two replicates).

Sources of Variation	Degrees of freedom
Replications	1
Main Plot:Fertiliser	4
Error (a)	4
Sub-plot:Season	3
Season x Fertiliser	12
Error (b)	12

To examine the relationship between fertiliser rates (or soil growth potentials) and species response in terms of mean ranks, trend comparisons were to be determined through the method of orthogonal polynomials. Seasonal rank means were subject to a multiple comparison through the Waller-Duncan option (Waller and Duncan, 1969; SAS manual, 1985).

2.4.4 Vegetational change with grazing

2.4.4.1 Comparisons between species

The association between species, as it may be related to similarities and differences in response, was shown by factor analysis. The procedure entitled 'FACTOR' in Version 5 of SAS was used (SAS user's guide: statistics, 1985).

The aim of this analysis was to explore associations between species as to form groups mathematically related to some common, though initially undefined, factor. Furthermore, an overall comparison of ranks across all treatments, species and seasons, was used to order the species according to their mean abundance. The analysis was a one-way ANOVA, and the significance levels for the multiple comparison of species mean ranks was determined through the Waller-Duncan Modified 't' test.

2.4.4.2 Response of individual species

Measurements were grouped in four seasons: Spring 1984; Summer 1985; Autumn 1985 and Spring 1985. The responses were expressed as the mean of measurements taken before the start of a grazing period. They covered roughly a whole season, with the exception of the spring of 1985, when only the first measurements were available.

The field design had a sub-plot effect which resulted from the combined randomisation of 'Stocking Rate' and 'Grazing Method' within the main plot 'Fertility'. However, for the analysis, the design was extended to accommodate 'Grazing Method' as a further split effect, which increased the precision of the corresponding error term. 'Seasons' was also included in this way, which introduced a further error term. The design became a split-split-split-split plot.

An outline of the ANOVA is in Table 2.4.2.

Table 2.4.2: Outline of ANOVA for mean rank variation in one species after grazing management was imposed (5F x 3SR x 2GM x 4S x 2R).

Sources of variation	Degrees of Freedom
Replication (R)	1
Main plot:Fertiliser (F)	4
Error (a): R x F	4
Sub-plot: Stocking Rate (SR)	2
Main plot x sub-plot: F x SR	8
Error (b): R x F x SR	8
Sub-sub-plot factor: Grazing Method (GM)	1
Main plot x Sub-sub-plot: F x GM	4
Main plot x Sub-sub-plot x sub-sub-plot: F x SR x GM	8
Error (c): R x F x SR x GM	8
Sub-sub-sub-plot factor: Season (S)	3
S x F	12
S x F x SR	24
S x F x SR x GM	24
Error (d): S x F x SR x GM x R	24

2.4.4.3 Total pasture yield

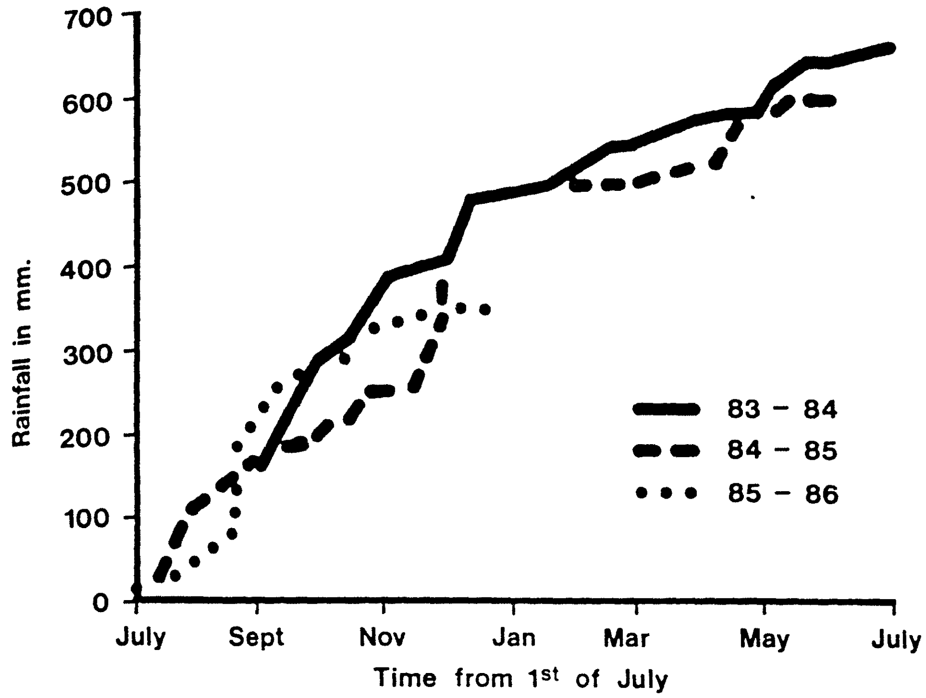
Total dry matter, either before the start of the grazing years 1984 and 1985, or expressed as the mean of dry matter accumulated between all grazing cycles in 1984 (mean of dry matter on offer before each grazing cycle) are presented graphically only. This is because of difficulties arising from the design, which for this case becomes extremely unbalanced due to the different grazings and hence sampling frequencies in the different treatments. However, measurements are supported by a large number of capacitance probe readings integrated in each observation.

2.5 RESULTS

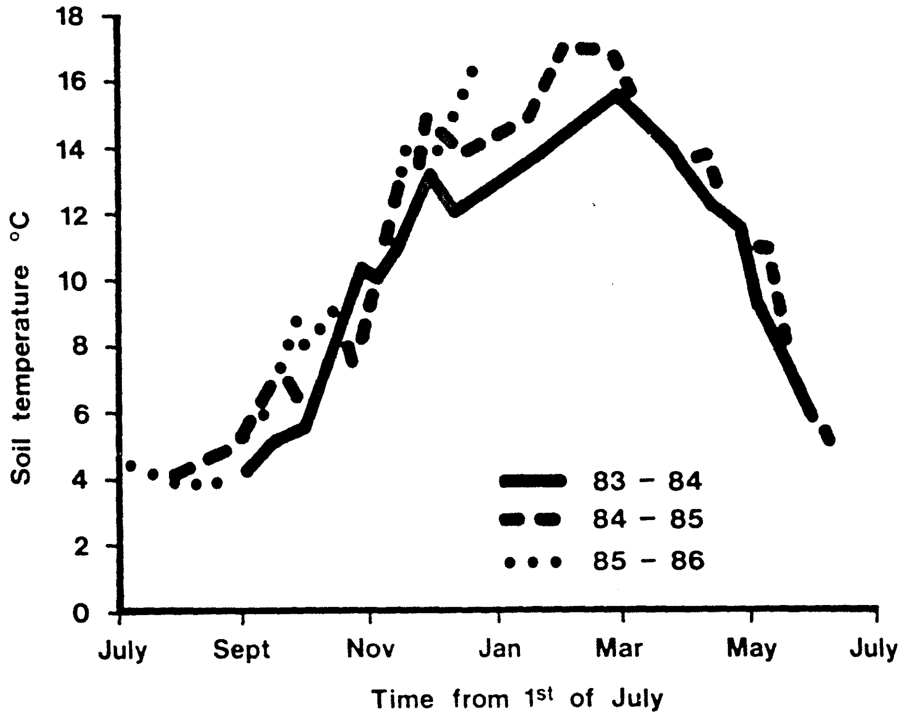
2.5.1 Meteorological observations

Total rainfall and soil temperature means were available from the meteorological station at the experimental site since September 1983. Figure 2.5.1(a) displays the accumulated rainfall on a monthly basis for the agricultural years (July to July) of 1983 and 1984; and for 1985 until January. These correspond to the second, third and beginning of the fourth season of the experiment.

Totals were within the range expected from the longterm of Mt. John and Lake Tekapo records. An important between-years difference was given, not by the totals, but by rainfall accumulated to October of 1984 and 1985. Measurements for the spring of 1985 indicate about 100 mm more than for the spring of 1984.



a) Accumulated monthly rainfall (mm).



b) Mean soil temperatures (0.5 cm).

Figure 2.5.1: Meteorological data for the agricultural years (July to July) 1983-1985, obtained at the experimental site in Mt. John station.

This difference was enhanced by mean soil temperature at 0.5 m below-ground for the same season (Figure 2.5.1.b). Throughout September and October, these were nearly two degrees warmer for the period 1985 (7° to 9°c) as compared with the same period in 1984 (5° to 7°c).

2.5.2 Ground cover ranking

Growth was limited the first season (1982-1983) with sown plants reaching only two to four cm height. Resident species, namely mouse-ear hawkweed and fescue tussocks were still dominant.

Changes in ground cover, however, became apparent by the second spring. On the basis of ranks, where one represents the largest and five the least area covered, mouse-ear hawkweed was relatively dominant only if fertility was below 250 kg ha^{-1} yr^{-1}, above which sown legumes had a greater relative importance. Sown grasses remained as a less important component (Figure 2.5.2.b).

The relative importance of sown legumes kept increasing through time, and by the fourth spring they had become dominant at all levels but the unfertilised. Grasses were starting to increase only within the higher soil growth potential situation, that is at 500 kg ha^{-1} yr^{-1} of fertiliser plus irrigation. Mouse-ear hawkweed remained as an important component of ground cover, although showing a trend to decrease under high fertility plus irrigation (Figure 2.5.2.b).

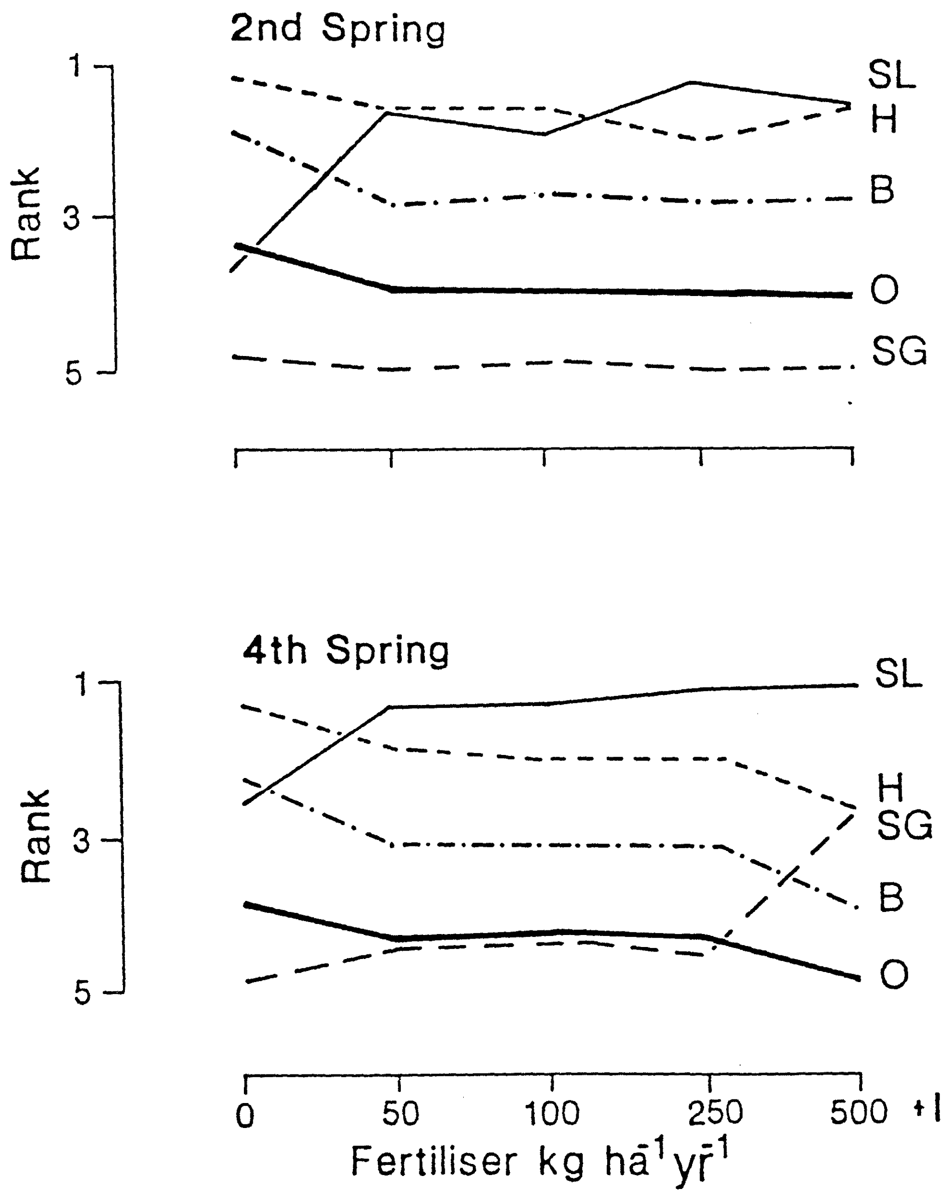


Figure 2.5.2: Ranking of ground cover types at the beginning of the second spring for sown legumes (SL), mouse-ear hawkweed (H), bare ground (B), sown grasses (SG) and other species (O). Also, ranking of the same ground cover types, in relation to soil fertility treatments, at the beginning of the fourth spring (1985).

2.5.3 Ranking of species in relation to environmental factors

Similarities and differences between the ten most abundant species were explored applying factor analysis on their rank values for all measurements prior to a grazing period. Factor analysis (Figure 2.5.3) attempts to replace and explain the total variation in rank of the ten species as a function of two as yet undefined factors, which explain most of that variation.

Factor analysis has been used to enclose 'ecological groups', that is , sets of species that show a similar distributional response to environmental gradients and may present their centres of distribution, in relation to those gradients, which are close together (Whittaker, 1975). The grouping is rather arbitrary, because common factors are defined solely as mathematical entities.

In the diagram, the proximity of species names indicates similarity in the response to some of such common factor: e.g. the grouping of yorkshire fog, sweet vernal and browntop clustered together; a looser grouping of fescue tussock, mouse-ear hawkweed and Russell lupin. Conversely, the contrast between white clover, alsike clover and Russell lupin suggests quite different responses.

In this case, two factors accounted for 72% of the initial common variance, and the convergence criterion was met. This means that the analysis was mathematically satisfactory, although the solution was weakened by the possibility that the structure of the data was not entirely appropriate for a common factor model (Kaiser's MSA = 0.18). Further computation of additional factors did not improve this result.

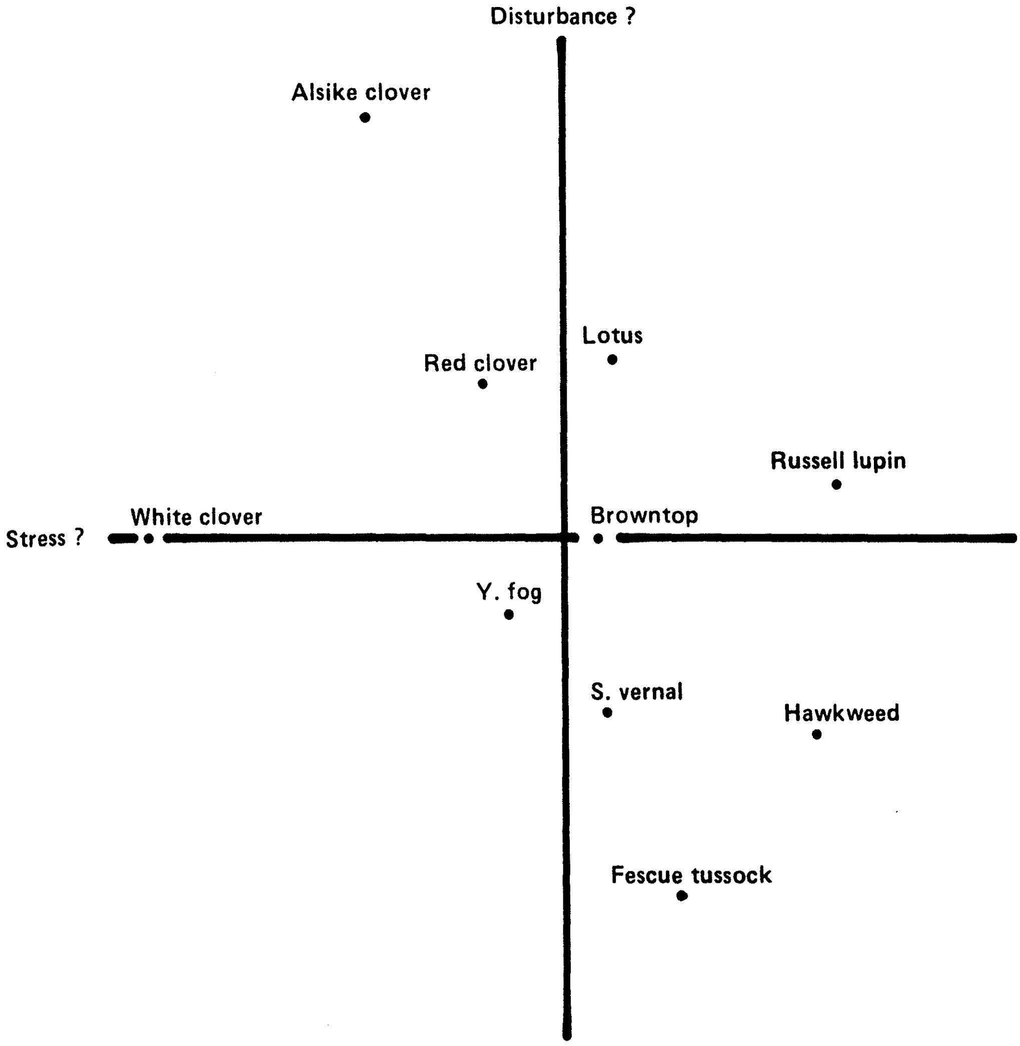


Figure 2.5.3: Factor analysis of association between species for combined data from all treatments.

The next stage is to determine whether these entities, otherwise derived only from species rank data, may be accounted for by a biological explanation. It is conceivable that those two factors are relating the response of species to environmental factors. In particular, it is suggested they may correspond to Grime's concept of stress and disturbance. On the premise that the two factors represented by the axes in Figure 2.5.3 synthesise treatment variables within the notions of stress (horizontal axis) and disturbance (vertical axis), then species should locate according to their degree of 'overlapping' with these factors. The implication here is not that a species was necessarily the most abundant within a particular situation; the suggestion, instead, is that each species showed a more consistent relationship with a particular environment.

Resident species show affinity with the range of situations associated with traditional pastoral management: moderate to high stress, as found in unimproved high country; and the moderate to low disturbance of a conservative grazing management. Fescue tussocks are related to very lenient grazing and poor growth conditions; resident grasses accepted a higher soil quality, whereas mouse-ear hawkweed adapted to impoverished soils and moderate grazing.

The four clovers adapted well to developed environments associated with intensive grazing and higher levels of soil management; or, in other words, to low stress and high disturbance. White clover appeared as the best option if growth conditions were optimal and grazing was moderate to moderate-high; alsike clover was less demanding in soil conditions and accepted more intensive grazing; whereas red clover and caucasian clover approximated to a lower level of intensification, with lower inputs in fertiliser and moderate grazing management.

Other legumes, such as birdsfoot trefoil belonged to a situation of low fertility and more demanding grazing conditions. Finally, Russell lupin appeared located within the environment which is closer to the practical limit to production of forage: high stress and moderate disturbance. Or, in other words, low fertility input and moderate grazing.

2.5.4 Overall dominance of species

In general, legumes were dominant over grasses throughout the experimental period. Grasses presented an overall mean ranking across all seasons and treatments of more than 5.5 (Table 2.5.1), which practically denotes only presence. The main species were, in descending order of relative importance: Russell lupin (rank 2.0); alsike clover (rank 2.9); mouse-ear hawkweed (rank 3.0); fescue tussock (rank 5.1); white clover (rank 5.3); and birdsfoot trefoil (rank 5.4).

A multiple comparison of means from separate analyses of variance for each stocking rate within each fertility level is presented in Table 2.5.1. It shows that Russell lupin was the dominant species below 500 kg ha^{-1} yr^{-1} of fertiliser plus irrigation, and that white clover responded to irrigation and high fertilisation, sharing a second place in abundance with red clover for that situation. Alsike clover ranked second at most of the levels between 50 and 250 kg ha^{-1} of fertiliser, but became the most important species at the highest fertility level. Mouse-ear

Table 2.5.1: Multiple comparison of mean ranks between eleven pasture species at fertilser x stocking rate treatments (Waller-Dancan modified t-test).

Fertility	SR	LSD	Lupin	Alsike c.	Hawkweed	Tussock	Red c.	White c.	Birds. t.	Cauc. c.	Yorkshire fog	Browntop	Sweet vernal
0	1	0.17	1.52^{a}	5.14	1.70^{b}	2.80^{c}	4.62	6.00	5.82	5.96	5.76	5.92	5.92
0	2	0.24	1.42^{a}	4.92	1.82^{b}	3.46^{c}	4.50	6.00	5.48	5.88	6.00	5.96	5.96
0	3	0.27	1.65^{a}	4.88	1.46^{a}	4.65^{b}	4.40^{b}	6.00	5.40	5.90	5.80	5.92	5.92
50	1	0.27	1.00^{a}	3.00^{b}	3.39^{c}	5.19	3.48	5.92	5.24	5.97	6.00	5.95	5.95
50	2	0.30	1.21^{a}	3.04^{c}	2.68^{b}	5.58	4.24	5.95	5.04	5.92	5.97	5.92	5.92
50	3	0.39	2.36^{a}	3.02^{b}	2.41^{a}	5.85	3.73^{c}	5.87	5.02	5.97	5.87	5.87	5.87
100	1	0.33	1.08^{a}	2.57^{b}	3.74^{c}	5.25	3.80	5.85	5.45	5.60	5.71	5.91	5.91
100	2	0.35	1.41^{a}	2.91^{c}	2.55^{b}	5.58	4.42	5.94	5.11	5.97	5.61	5.94	5.94
100	3	0.48	2.50^{a}	2.28^{a}	2.53^{a}	5.89	4.21	5.46	5.00	5.96	5.71	5.85	5.85
250	2	0.33	1.53^{a}	2.78^{b}	2.80^{b}	5.53	4.07	5.80	5.19	5.80	5.70	5.80	5.80
250	3	0.36	1.53^{a}	2.32^{b}	3.21^{c}	5.82	3.96	5.60	4.96	5.85	5.96	6.00	6.00
250	1	0.27	1.04^{a}	2.41^{b}	2.68^{c}	5.21	3.90	5.90	5.48	5.53	6.00	6.00	5.85
500	1	0.36	2.94^{b}	1.38^{a}	5.58	6.00	3.36^{c}	3.44^{c}	5.69	5.47	6.00	5.85	6.00
500	2	0.39	4.34	1.25^{a}	4.57	5.88	3.31^{b}	3.08^{b}	5.74	5.62	5.97	6.00	6.00
500	3	0.32	5.63	1.28^{a}	3.71	5.94	3.42^{b}	3.21^{b}	5.31	6.00	6.00	6.00	6.00
Mean			2.9	2.9	3.0	5.1	4.0	5.3	5.4	5.8	5.8	5.9	5.9
S.D.			1.6	1.7	1.6	1.3	1.2	1.3	0.9	0.6	0.7	0.5	0.3

* Means with the same letter are not significantly different. Significance is given only for the three more abundant species.

hawkweed was always important below 500 kg ha^{-1} of fertiliser plus irrigation, but attained highest rank at fertility levels 0 to 250 kg ha^{-1} only under the highest stocking rate.

Table 2.5.1 also provides a partial confirmation of the previous diagram in that the order of relative dominance of the species in relation to treatment variables corresponds to what is suggested by factor analysis: clovers do well under moderate stocking rates and high soil growth potential; Russell lupin dominates if fertility and stocking rates are low; mouse-ear hawkweed is consistently dominant with undeveloped, heavily grazed conditions; whereas adventive grasses remained inconspicuous. Yet, this table refers to an order of relative abundance for each species in relation to each stocking rate within each fertility level; the previous diagram attempted to relate the affinity of each species with a management situation as defined by the wider concepts of stress and disturbance.

2.5.5 Performance of individual species

2.5.5.1 Russell lupin (*Lupinus polyphyllus*)

a) Establishment

Russell lupin is referred to as *L. polyphyllus* through the text, although it is a hybrid between *L. polyphyllus, L. arboreus* and perhaps other species. It was not grazed between sowing in the spring of 1982 and the spring of 1984. Pre-grazing measurements started in the spring of 1983 and were repeated during the autumn of 1984 and early and mid-spring of 1984.

The upper left-hand side graph of Figure 2.5.4 shows the relative ranking of lupin in the spring of 1983, one year after sowing. At this stage, the experimental plots only differed in fertiliser rates. Lupin was already approximately the third ranked species at all treatments except at 500 high fertility plus irrigation (F5), where it was scarcely present. Six months later, in autumn 1984 (Figure 2.5.4.b), Russell lupin tended to become first ranked species at intermediate levels of soil fertility, while still being among the first three ranked species under extreme treatments (high and low fertility). This curvilinear pattern was to be confirmed in subsequent measurements during the spring of 1984 (Figure 2.5.4.c and d).

It is apparent that lupin increased its relative importance through this pre-grazing period. The graph describing rates of rank variation, in the upper righthand-side of Figure 2.5.4 shows that throughout the whole period rank differences were positive and different from zero. In fact, seasonal means express a significant increase ($p = 0.00$, Table 2.5.2d).

The effects of fertility are shown in the over-all behaviour of lupin, which performed as an increaser: dominant under moderate to low fertility levels; still ranking third or fourth with high fertilisation plus irrigation and being first or second in the unimproved soil condition. Seasonal effects are significant also ($p = 0.00$), but the interaction with fertility is confounded due to the establishment phase.

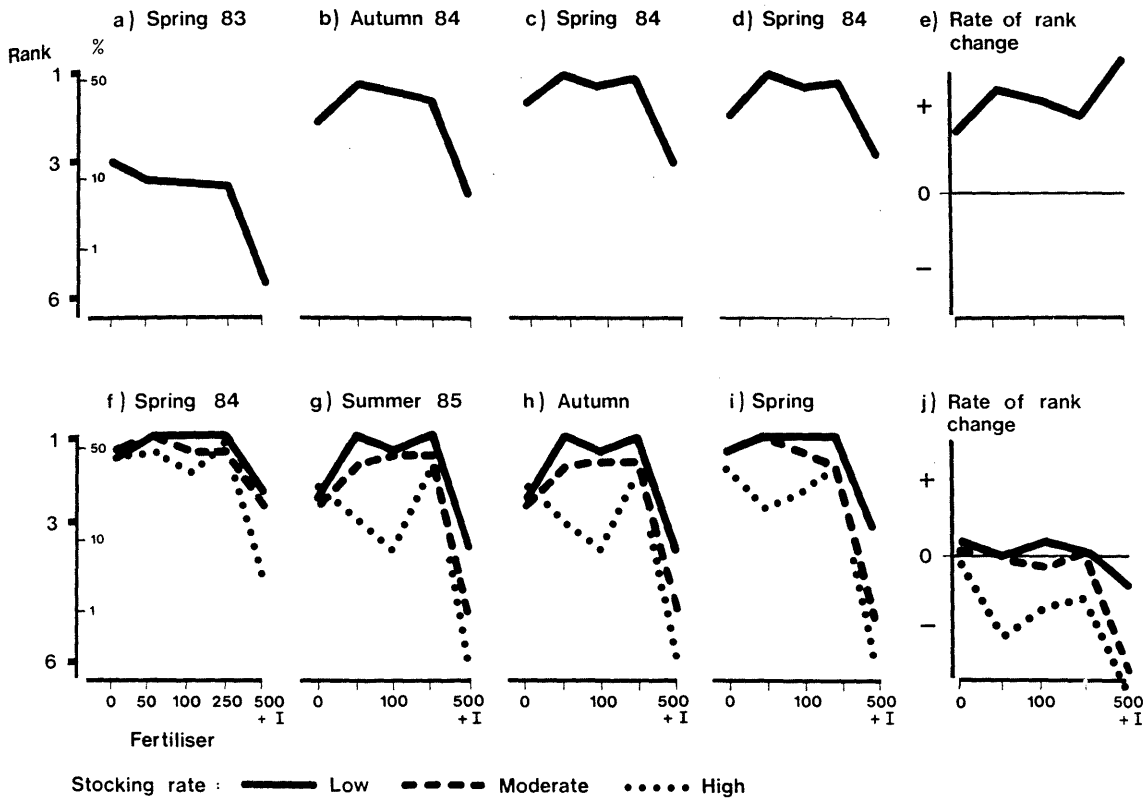


Figure 2.5.4: Variations in ranking of Russell lupin in relation to soil fertility at four instances during establishment phase (a)-(d)) and at four instances during grazing phase also in relation to stocking rate (f)-i)). Also mean rate of rank change during establishment phase (e) and during grazing phase (j).

b) Grazing period

The imposing of grazing management, starting in the spring of 1984, produced immediate differences in ranking under the different treatments. Results of the analysis in Table 2.5.3 show that fertility, stocking rate and season, affect significantly (p = 0.00) and in that order the ranking of lupin, but not due to grazing methods (p = 0.13). Therefore, leaving aside that effect, Figure 2.5.4 shows differences in seasonal mean ranks, starting with the first season of grazing and measured at each of the three stocking rates at each soil fertility level.

Table 2.5.2: ANOVA table for mean rank variations of Russell lupin in response to soil fertility treatment before grazing (from a split-plot on a randomised complete block design). Degrees of freedom (df), sum of squares (SS), and significance probability of F ratio (pF) to two significant places.

	Source	df	SS	pF
a)	**Summary**			
	Model	24	476.2	0.00
	Error	303	140.9	
	Corrected total	327	617.1	
b)	**Main effects and interactions**			
	Rep (R)	1	17.9	0.03
	Fertility (F)	4	194.9	0.00
	Error a (R x F)	4	3.9	0.00
	Stocking rate (SR)			
	Grazing method (GM)			
	Error b (R x F x SR x GM)			
	Seasons (S)	3	216.6	0.00
	F x S	12	3.2	0.00
c)	**Trend comparisons for fertility**			
	Linear	1	146.2	0.00
	Quadratic	2	190.8	0.00
d)	**Multiple comparison of seasonal means** (Waller-Duncan t-test)			

Season	Mean
spring 83	3.9a
autumn 84	2.1b
early spring 84	1.7c
spring 84	1.6c

Means with the same letter were not significantly different.
LSD = 0.2 df = 303 F = 155.3

Table 2.5.3: ANOVA table for rank variation of Russell lupin in response to soil fertility treatments and grazing management (from a split-plot on a 5 x 3 x 2 randomised complete block design). Degrees of freedom (df), sum of squares (SS) and significance probability of F ratio (pF) to two significant places.

Source	df	SS	pF
a) Summary			
Model	149	1514.7	0.00
Error	462	208.5	
Corrected total	611	1723.1	
b) Main effects			
Rep (R)	1	13.5	0.15
Fertility (F)	4	403.2	0.00
Error a (R x F)	4		
Stocking rate (SR)	2	161.7	0.00
Grazing method (GM)	1	7.9	0.13
Error b (R x F x SR x GM)	15	46.3	0.00
Seasons (S)	3	5.7	0.00
c) Trend comparisons for main effect			
F quadratic	2	373.7	0.00
SR Linear	1	154.0	0.00
d) First order interactions of seasonal means			
F x SR	8	86.7	0.00
F x GM	4	92.9	0.00
F x S	12	41.6	0.00
SR x GM	2	87.9	0.00
SR x S	6	13.4	0.00
e) Higher order interactions			
F x SR x S	24	21.6	0.00
F x GM x S	12	24.9	0.00
SR x GM x S	6	5.9	0.04
F x SR x GM x S	24	22.7	0.00
f) Polynomial effects within interactions			
F in SR1 linear	1	30.5	0.00
F in SR2 linear	1	106.4	0.00
F in SR3 linear	1	191.5	0.00
Quadratic	1	60.4	0.00
Cubic	1	72.9	0.00

Lupin was generally dominant at low and medium fertility levels, but less so under the unimproved condition (F1) and rather inconspicuous with high fertility plus irrigation (F5). This quadratic response ($p = 0.00$) to soil growth potentials kept the trend observed during the pre-grazing period; yet, inspection of the graphs confirms differences between stocking rates within each season as well as between seasons, as reported in Table 2.5.3.

Following the evolution of the response to fertilisers through time, from spring 1984 (in the lower left hand-side of Figure 2.5.4) to spring 1985, relative abundance was consistently higher in the lower stocking rate. In the spring of 1984 rankings for lupin was between one and two at all levels, except F5, where it still ranked close to second. As the grazing season progressed towards summer and autumn of 1985, the relative importance of lupin decreased dramatically at F5, as well as under the no fertilisation treatment, though here decrease was less important. Later data for the spring of 1985 show that the winter-spring spell period allowed lupin without fertilisation to recover a position of high relative abundance, similar to the initial one at all levels but high fertility plus irrigation, where it remained relatively unimportant.

Stocking rates and their interactions with fertility and seasons determined differences which are summarised in Figure 2.5.4j. The rate of rank change, that is the tendency to increase, maintain or decrease relative ranking through time, indicates the following trends:

- With a low stocking rate (SR1) lupin remained dominant throughout the experimental period (0 or positive change), except at F5, where the trend is to become less abundant.
- With moderate stocking rate (SR2) lupin behaved similarly, but there was a relative drop at F5.
- With a high stocking rate (SR3) lupin declined steadily at all levels except no fertilisation. The importance of lenient grazing for the regrowth of lupin is stressed in Figure 2.5.4, which illustrates a better spring recovery for the low stocking rate.

Summing up, lupin was dominant under conditions of low to moderate fertility as defined in the trial (50 to 250 kg $ha^{-1} yr^{-1}$ of fertiliser), without irrigation and at low to moderate stocking rates. High stocking rates are detrimental to this species, as well as extremely favourable conditions of growth, where other species become able to express their potential.

It must be noted that all the previous comments do not refer to treatments on grazing methods. Main effects for these were not statistically significant, but all interactions were (Table 2.5.3b, d and e). Mean ranks from a cross tabulation for grazing methods by stocking rates by fertility (Table 2.5.4) show lupin was abundant under sustained grazing except at higher stocking rates which produced a greater decline in the relative abundance of Russell lupin than under mob-stock grazing. Grazing preferences must be taken into account to interpret these results.

Table 2.5.4: Mean ranks and standard error for Russell lupin at two grazing methods, by stocking rate and fertility levels.

	GRAZING METHODS											
	Sustained stocking						Mob stocking					
SR	1		2		3		1		2		3	
Fertility	x	se	x	se	x	se	x	se	x	se	x	se
0	1.5	0.5	1.7	0.4	1.6	0.3	1.4	0.3	2.0	0.3	1.2	0.5
50	1.2	0.1	1.5	0.0	3.1	0.1	1.1	0.0	1.2	0.2	1.2	0.1
100	1.3	0.2	1.7	0.1	1.9	0.0	1.4	0.1	1.2	0.1	1.5	0.2
250	1.2	0.0	1.8	0.1	2.0	0.1	1.3	0.4	1.4	0.2	1.4	0.2
500	2.2	0.1	3.3	0.2	5.0	0.1	3.9	0.4	3.7	0.1	4.6	0.2
Mean	1.6	0.2	1.9	0.1	3.3	0.1	1.9	0.1	2.0	0.1	2.0	0.2

2.5.5.2 Alsike clover (*Trifolium hybridum*)

a) Establishment

Mean ranks for alsike clover one year after sowing are in the graph labelled "Spring 83" in Figure 2.5.5. There was a good response to fertilisation (Table 2.5.5c), which does not mean that alsike clover was dominant at all treatments, but that it was clearly discernible.

Measurements through the following seasons showed the response maintained a curvilinear trend, but tending to a more directly proportional response to fertility which became a feature by the spring of 1984. Ranks changed from season to season with increased relative abundance as a general response, but with a clear detrimental effect of autumn (Figure 2.5.5e and Table 2.5.5). Results showed that alsike clover during the pre-grazing period responded to fertility as an increaser species, more dominant under high fertiliser inputs and irrigation.

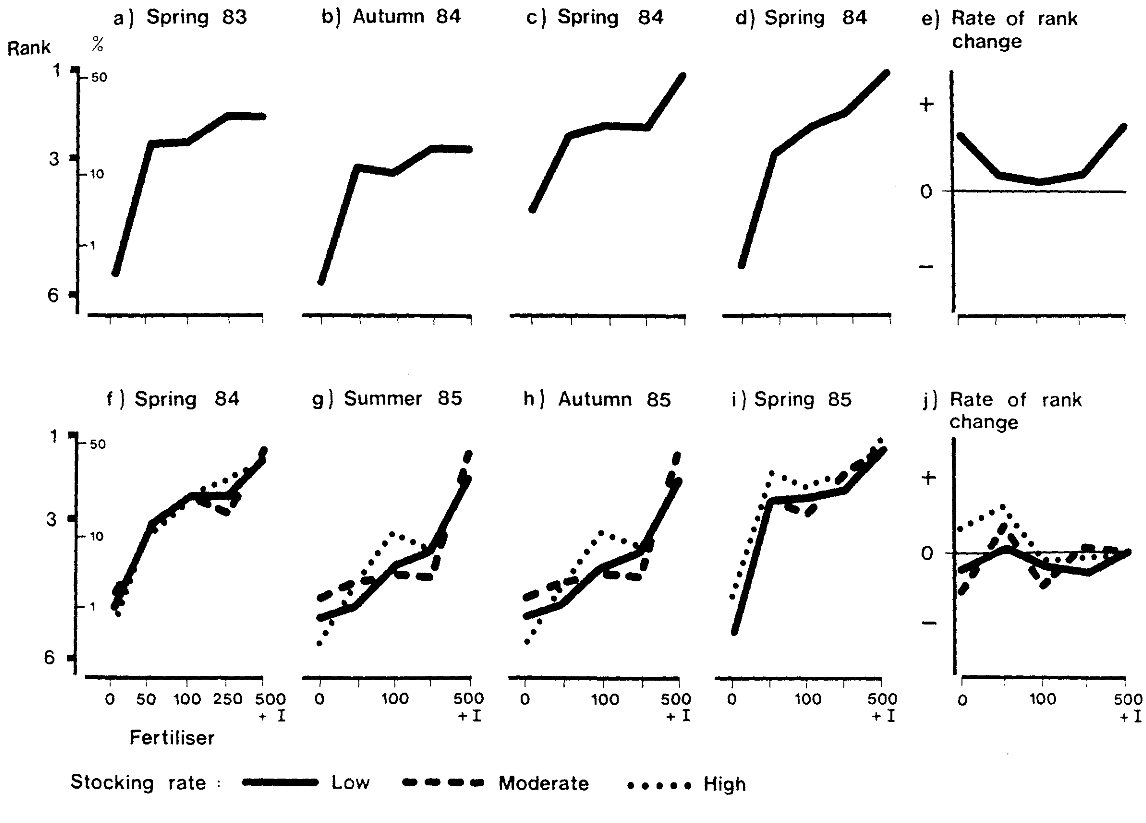


Figure 2.5.5: Variations in the relative ranking of alsike clover during a) the establishment phase and b) the grazing period.

Table 2.5.5: ANOVA for variation in rank of alsike clover in response to soil fertility treatment before grazing (from a split-plot on a randomised complete block design). Degrees of freedom (df), sum of squares (SS) and significance probability of F ratio (pF) to two significant places.

	Source	df	SS	pF
a)	**Summary**			
	Model	24	607.0	0.0
	Error	303	182.2	
	Corrected total	327	789.3	
b)	**Main effects and interactions**			
	Rep (R)	1	1.2	0.21
	Fertility (F)	4	464.3	0.00
	Error a (R x F)	4	2.9	0.31
	Seasons (S)	3	70.7	0.00
	F x S	12	28.0	0.00
c)	**Trend comparisons for fertility**			
	Linear	1	244.3	0.00
	Quadratic	2	308.0	0.00

d) **Multiple comparison of seasonal means** (Waller-Duncan t-test)

Season	Mean
Spring 83	3.0a
Autumn 84	3.6b
Early spring 84	2.7c
Spring 84	2.4d

Means with the same letter were not significantly different.
LSD = 0.6 df = 303 F = 39.2

b) Grazing period

Graphs in the lower part of Figure 2.5.5 describe the effects of grazing management upon fertility trends, which still dominated the over-all response. Grazing management affected that response through statistically significant effects of stocking rates ($p = 0.05$), which was not the case for grazing methods ($p = 0.57$; Table 2.5.6b).

Table 2.5.6: ANOVA for rank variations of alsike clover in response to soil fertility treatment and grazing management (from a split-plot on a 5 x 3 x 2 randomised complete block design). Degrees of freedom (df), sum of squares (SS) and significance probability of F ratio (pF) in two significant places.

	Source	df	SS	pF
a)	**Summary**			
	Model	149	1346.5	0.00
	Error	462	366.5	
	Corrected total	611	1712.9	
b)	**Main effects**			
	Rep (R)	1	22.0	0.22
	Fertility (F)	4	728.0	0.00
	Error a (R x F)	4	42.2	0.00
	Stocking rate (SR)	2	5.8	0.05
	Grazing method (GM)	1	0.3	0.57
	Error b (R x F x SR x GM)	15	11.7	0.57
	Seasons (S)	3	56.8	0.00
c)	**Trend comparisons for main effects**			
	F linear quadratic	2	564.3	0.00
	SR linear	1	2.6	0.09
d)	**First order interactions**			
	F x SR	8	19.3	0.03
	F x GM	4	9.6	0.05
	F x S	12	56.8	0.00
	SR x GM	2	9.2	0.01
	SR x S	6	4.3	0.14
e)	**Fertility trends within stocking rates**			
	F in SR 1 linear	1	151.2	0.00
	F in SR 2 linear	1	157.3	0.00
	F in SR 3 linear	1	149.5	0.00
f)	**Higher order interactions**			
	F x SR x GM	8	26.2	0.00

The first graph in the lower row of Figure 2.5.5, describing results of the spring of 1984, shows that stocking rates at that stage did not produce major changes in the pattern of the response set during the pre-grazing period. However, as the grazing season progressed towards summer first, and autumn later, ranks at medium fertility rates (50 to 250 kg ha^{-1} yr^{-1} of fertiliser) reflected a decrease, although the general linear trend of the response was preserved. By the next spring (1985), there was evidence that there were differences due to stocking rates, although the response was always linear and positive.

Interactions involving grazing methods were significant, but first order interactions were dominated by the combined effects of fertility and season (Table 2.5.6d), which stresses the summer-autumn decline observed at intermediate fertilisation rates (Figure 2.5.5f-i). Nevertheless, the response to fertilisation is positive and linear within each stocking rate, (Table 2.5.6d and e).

Alsike clover responded to fertilisation becoming one of the first three ranked species, even at the lower fertility treatment. It was the dominant species under high fertility plus irrigation. Its performance in terms of relative abundance was better under hard grazing as compared to situations where stocking rates were moderate to low.

The outcome of fluctuations through the experimental period is depicted in the graph on the lower right handside corner of Figure 2.5.5. At the treatment of high fertility plus irrigation ranks did not vary (mean rate of change = 0), meaning that alsike clover remained on the top of the relative scale of abundance within that situation. Otherwise, this species appears to be favoured by heavy grazing, since under the heavy stocking rate (SR3) at both the unimproved and the lower fertility level the final balance was higher than zero. This denotes an overall trend of increase in relative terms. On the other hand, moderate and lenient stocking rates resulted in a relative decrease of alsike clover at the 0, 100 and 250 kg ha^{-1} yr^{-1} of fertiliser, but not so at 50.

As in the previous case, it is difficult to isolate the effects of grazing methods, because not being dominant as yet, they appear rather obscured by interactions with a very low contribution to the total sum of squares.

2.5.5.3 Mouse-ear hawkweed (*Hieracium pilosella*)

a) Establishment

The graph for the spring of 1983 in Figure 2.5.6 shows how this species, the more abundant of the residents, declined in relative importance in response to fertiliser inputs ($p = 0.00$). This was apparent only from autumn 1984 onwards, when the sown species had already established (Table 2.5.7d).

It must be noted that mouse-ear hawkweed was always the first ranked species under the unimproved situation, and that it also maintained some relative importance at the other fertiliser treatments. In fact, it is unlikely that the absolute biomass of this species had decreased through this period. It remained as an important component of the basal stratum; yet, the general trend as interpreted through mean rates of rank change clearly indicates a tendency to decrease in relative terms (Figure 2.5.6e).

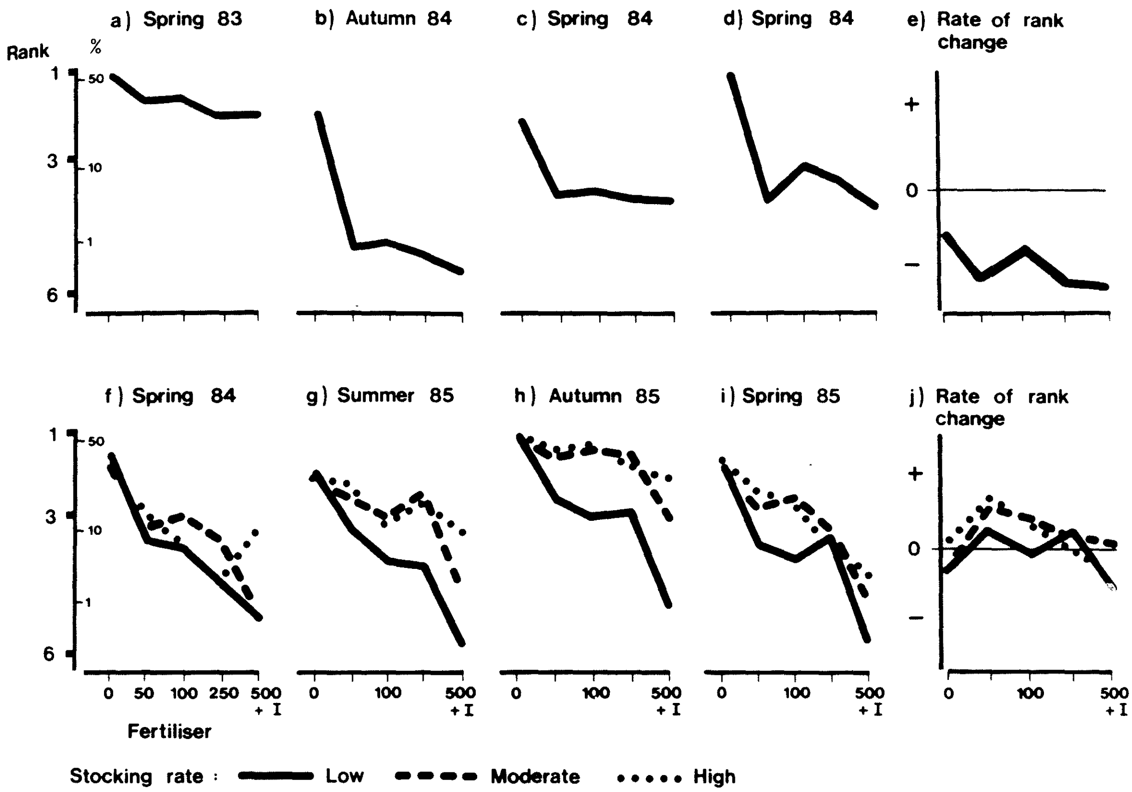


Figure 2.5.6: Variations in the relative ranking of mouse-ear hawkweed during a) the establishment phase and b) the grazing period

Table 2.5.7: ANOVA for rank variations of mouse-ear hawkweed in response to soil fertility treatment before grazing. Degrees of freedom (df), sum of squares (SS) and significance probability of F ratio (pF) to two significant places.

	Source	df	SS	pF
a)	**Summary**			
	Model	24	656.4	0.00
	Error	303	375.0	
	Corrected total	327	1031.4	
b)	**Main effects and interactions**			
	Rep (R)	1	11.5	0.08
	Fertility (F)	4	240.3	0.00
	R x F	4	8.9	0.13
	Seasons (S)	3	305.0	0.00
	F x S	12	48.3	0.00
c)	**Trend comparisons for fertility**			
	Linear	1	95.4	0.00
	Quadratic	2	134.9	0.00

d) **Multiple comparison of season means** (Waller-Duncan t-test)

Season	Mean
Spring 83	1.7a
Autumn 84	4.4b
Early spring 84	3.6c
Spring 84	3.1d

Means with same letter were not significantly different.
LSD = 0.32 df = 303

b) Grazing period

As with previous species, the imposition of grazing treatments did not obscure the importance of soil fertility treatment as the main factor in determining the relative abundance of mouse-ear hawkweed.

Always within a significant linear trend to decrease with increasing fertility (Table 2.5.8c), graphs from spring 84 to spring 85 in Figure 2.5.6 show that the response at each stocking rate was not the same, although throughout seasons hawkweed was consistently less conspicuous at the lower stocking rate. On the other hand, differences between seasons are statistically significant ($p = 0.00$), and hawkweed is particularly apparent in the graph labelled 'autumn 85' in Figure 2.5.6g. Because the scale of abundance is a relative one, the decrease of some species must result in the increase of others. Mouse-ear hawkweed appears to be more abundant, in these relative terms, in autumn, because others decreased; the true vegetational importance of this species is depicted in the graph labelled 'spring 85' (Figure 2.5.6i).

The over-all influence of grazing methods was small, though statistically significant. Linear trends to decrease in abundance are more important for mob stocking than for sustained grazing (Table 2.5.8b and e).

It is important that, in spite of these trends, the over-all outcome in terms of rank variations through time suggest that this species is not a true decreaser, except under high fertility plus irrigation (Figure 2.5.6j). Otherwise, mouse-ear hawkweed tended to maintain a vegetational importance which was set early, during the first grazing season (spring 84 and spring 85 in Figure 2.5.6).

Table 2.5.8: ANOVA for rank variations of mouse-ear hawkweed in response to soil fertility treatment and grazing management. Degrees of freedom (df), sum of squares (SS), and significance probability of F ratio (pF) to two significant places.

	Source	df	SS	pF
a)	**Summary**			
		149	1174.6	0.00
	Model	462	326.4	
	Error	611	1501.0	
	Corrected total			
b)	**Main effects**			
	Rep (R)	1	17.1	0.19
	Fertility (F)	4	410.6	0.01
	Error a R x F	4	24.9	0.00
	Stocking rate (SR)	2	104.8	0.00
	Grazing method (GM)	1	55.8	0.00
	Error b (R x F x SR x GM)	15	32.1	0.00
	Seasons (S)	3	124.5	0.00
c)	**Trend comparisons for main effects**			
	F linear	1	322.6	0.00
	F quadratic	2	349.8	0.00
	SR linear	1	99.4	0.00
d)	**First order interactions**			
	F x SR	8	55.8	0.00
	F x GM	4	12.0	0.27
	F x S	12	25.6	0.00
	SR x GM	2	8.5	0.17
	SR x S	6	12.5	0.00
e)	**Fertility trends within stocking rates and grazing methods**			
	F linear in SR 1	1	186.9	0.00
	F linear in SR 2	1	97.9	0.00
	F linear in sustained stocking	1	126.0	0.00
	F linear in mob stocking	1	206.4	0.00
f)	**Higher order interactions**			
	F x GM x S	12	22.0	0.00

2.5.5.4 Red clover (*Trifolium pratense*)

a) Establishment

Twelve months after sowing, red clover was still ranking low, although showing a positive response to fertilisation (Spring 83, Figure 2.5.7a). The general pattern of

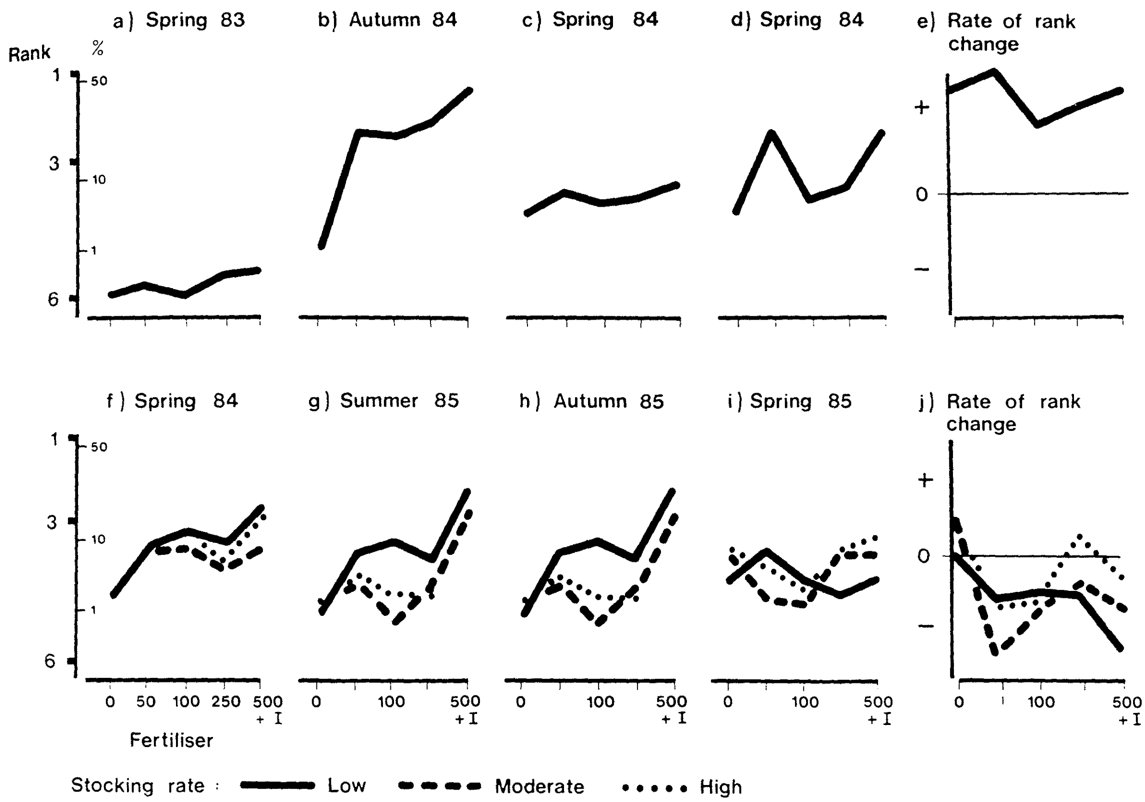


Figure 2.5.7: Variations in the relative ranking of red clover during the establishment phase (upper) and the grazing period (lower).

a positive, linear relation between rank abundance and fertility was to be confirmed later, although this relation was somewhat blurred by seasonal effects (Table 2.5.9b).

Yet, a general trend to increase at all fertility levels is seen by inspecting both the sequence of graphs Spring 83 - spring 84 (Figure 2.5.7 a to d) and the summary of these changes expressed as mean rates of rank change through time (Figure 2.5.7e). Also, overall seasonal means changed in a time sequence, being all significantly different (Table 2.5.9d).

Table 2.5.9: ANOVA for rank variations of red clover in response to soil management before grazing.

	Source	df	SS	pF
a)	**Summary**			
	Model	24	615.3	0.00
	Error	303	312.3	
	Corrected total	327	927.3	
b)	**Main effects and interactions**			
	Rep (R)	1	30.3	0.00
	Fertility (F)	4	107.0	0.00
	R x F	4	1.7	0.80
	Season (S)	3	374.2	0.00
	F x S	12	90.9	0.00
c)	**Trend comparisons for fertility**			
	Linear	1	60.8	0.00
	Quadratic	2	63.3	0.00
d)	**Multiple comparison of seasonal means** (Waller-Duncan t-test)			

Season	Mean
Spring 83	5.7a
Autumn 84	2.7b
Early spring 84	3.8c
Spring 84	3.1d

LSD = 0.3 df = 303 F = 120.9

In absence of grazing, red clover behaved as an increaser, roughly following a linear relation with fertility inputs, which was enhanced during autumn.

b) Grazing period

The superimposition of different grazing management practices upon the soil fertility treatments, as seen in graphs for rank variations of spring 1984, summer and autumn of 1985 in the lower part of Figure 2.5.7, did not alter the trends set during the pre-grazing period. A tendency to a linear increase in relative abundance of red clover with fertility inputs still is significant ($p = 0.03$), as well as the effects of stocking rate ($p = 0.02$).

During these first three seasonal phases, the main difference is shown by rank values for mid-fertility, which were below or close, to ranks for low fertility inputs under stocking rates moderate and heavy. With lower stocking rates, however, in those same mid-fertility situations there was higher relative abundance, depicted in Figure 2.5.7g, and in Figure 2.5.7i, with a curve bent upwards instead of downwards as in the previous case.

It must be noted that by spring 1985 the relative importance of red clover under higher fertility conditions was reduced. Interpretation of general trends is clarified through Figure 2.5.7j. Red clover under grazing management is a decreaser, except under hard grazing (SR3) with high fertility without irrigation (250 kg ha^{-1} yr^{-1}).

Table 2.5.10: ANOVA for rank variations of red clover in response to soil and grazing management.

	Source		df	SS	pF
a)	**Summary**				
	Model		149	451.3	0.00
	Error		146	480.7	
	Corrected total		611	932.0	
b)	**Main effects**				
	Rep (R)		1	9.3	0.30
	Fertility (F)		4	97.8	0.09
	Error a R x F		4	23.0	0.00
	Stocking rate (SR)		2	13.2	0.00
	Grazing method (GM)		1	9.3	0.00
	Error b (R x F x SR x GM)		15	8.1	0.30
	Seasons (S)		3	20.1	0.00
c)	**Trend comparisons for main effects**				
	F linear		1	63.8	0.03
	Linear and quadratic		2	63.9	0.07
	SR linear		1	3.5	0.02
d)	**First order interactions**				
	F x SR		8	10.2	0.07
	F x GM		4	10.3	0.01
	F x S		12	67.6	0.00
	SR x GM		2	13.6	0.00
	SR x S		6	20.0	0.00
e)	**Fertility trends within grazing method**				
	F linear:	in mob stocking	1	15.1	0.00
		in continuous stocking	1	58.0	0.00
f)	**Higher order interactions**				
	F x GM x S		12	4428	0.00

Although the response of red clover is controlled principally by the effects of the fertility treatments, seasons and the other treatment factors, stocking rates and grazing methods were also highly significant. These must be regarded with caution, because they account for a very low proportion of the sum of squares of a model which, in itself, only accounts for 48.4% of the total. (Table 2.5.10e). Nevertheless, the interaction of fertility by season is interesting, although it may reflect detrimental medium term effects of hard grazing rather than a seasonal effect as such.

2.5.5.5 White clover (*Trifolium repens*)

a) Establishment

In the spring of 1983 the presence of white clover was discernible at all treatments with fertilisation, but it was important only under 500 kg ha^{-1} of fertiliser plus irrigation (Figure 2.5.8). Yet, there is a significant linear trend to increase in relative abundance as fertiliser inputs get higher ($p = 0.00$). Nevertheless, after an initial phase of increasing relative abundance, this fertility response trend declines considerably through time. White clover could be considered as a decreaser in absence of grazing, which is shown in the rate of rank variation through the establishment period (Figure 2.5.8e). Such decrease in relative abundance in time is confirmed by the multiple comparison of seasonal rank means, which were all sequentially and significantly different, ranging from 4.5 in Spring 83 to 5.8 in the spring of 84 (Table 2.5.11d).

b) Grazing period

Grazing produced an important change in the trends observed during the pre-grazing season. The graph for Spring 84, in the lower left-hand side of Figure 2.5.8 shows an increase in relative abundance for treatments under high fertility plus irrigation. Later, in summer and autumn 1985 this situation was confirmed; white clover ranked third in high fertility plus irrigation, but probably due to seasonal effects related to moisture, ranking for white clover in other treatments only indicated low presence of white clover. By the spring of 1985 hard grazing had resulted in further increase in relative ranking: at the higher soil fertility treatments, ranks indicated lower relative abundance at lenient than at harder grazing, with

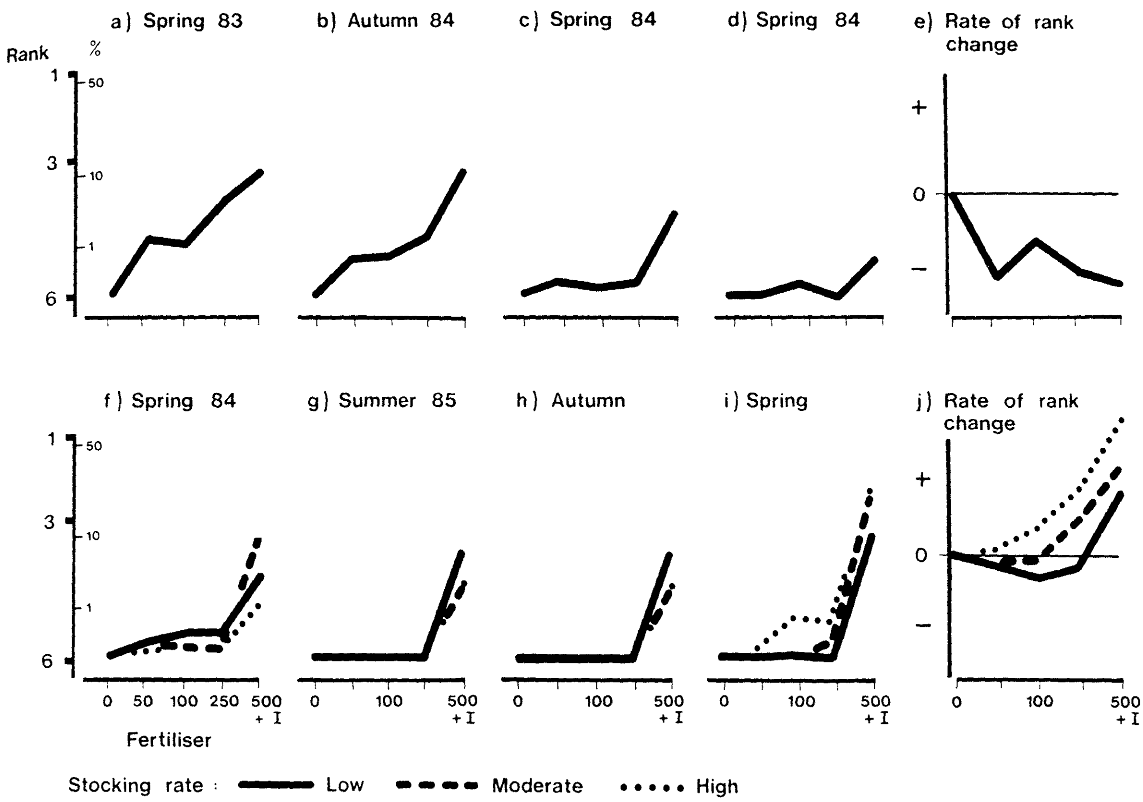


Figure 2.5.8: Variations in the relative ranking of white clover during the establishment phase (upper) and the grazing period (lower).

Table 2.5.11: ANOVA for rank variation of white clover in response to soil fertility treatments before grazing.

Source	df	SS	pF
a) Summary			
Model	24	293.4	0.00
Error	303	199.0	
Corrected total	327	492.4	
b) Main effects and interactions			
Rep (R)	1	10.7	0.07
Fertility (F)	4	153.6	0.00
R x F	4	7.1	0.03
Season (S)	3	61.2	0.00
F x S	12	30.8	0.00
c) Trend comparisons for fertility			
Linear	1	143.9	0.00
Quadratic	2	144.7	0.00

d) Multiple comparison of seasonal means (Waller-Duncan t-test)

Season	Mean
Spring 83	4.5a
Autumn 84	4.9b
Early spring 84	5.5c
Spring 84	5.8d

LSD = 0.2 df= 303 F = 31.0

intermediate values for moderate grazing intensity. This was discernible also for the other treatments as seen in Figure 2.5.8j. These relations were not statistically significant, probably due to the influence of previous seasons on the calculations (Table 2.5.12).

Statistics in Table 2.5.12 indicated that grazing methods were a more important component than stocking rates alone. Table 2.5.13 confirms the evidence in Figure 2.5.8, showing that white clover was important only under 500 kg ha^{-1} yr^{-1} of fertiliser plus spray irrigation. In addition, it also shows that mob stocking was more favourable to this species. Fertility trends at mob stocking treatments show a more significant linear relation with ranks (Table 2.5.12e).

Table 2.5.12: ANOVA table for rank variations of white clover in response to soil and grazing management.

Source	df	SS	pF
a) Summary			
Model	149	847.7	0.00
Error	146	174.6	
Corrected total	611	1022.3	
b) Main effects			
Rep (R)	1	0.6	0.42
Fertility (F)	4	347.7	0.00
Error (R x F)	4	3.0	0.10
Stocking rate (SR)	2	1.7	0.19
Grazing methods (GM)	1	4.0	0.00
Error b (R x F x SR x GM)	15	6.7	0.24
Seasons (S)	3	25.9	0.00
c) Trend comparisons for main effects			
Fertility linear	1	306.3	0.00
Linear and quadratic	2		0.00
SR linear	1	1.6	0.08
d) First order interactions			
F x SR	8	4.9	0.30
F x GM	4	38.8	0.00
F x S	12	38.8	0.00
SR x GM	2	3.6	0.04
SR x S	6	20.3	0.00
e) Fertility trends within grazing methods			
F linear in continuous stocking	1	69.0	0.00
F linear in mob stocking	1	285.8	0.00
f) Higher order interactions			
F x SR x S	24	17.0	0.00
F x GM x S	12	10.2	0.00
SR x GM x S	6	11.9	0.00

* Only significant interactions are listed here

The summary that can be extracted from the rate of rank change through time suggests that white clover under grazing reversed the trend to be a decreaser observed in the pre-grazing period, to become an increaser under grazing management, providing there were high stocking rates and levels of soil fertility in

Table 2.5.13: Mean rank values for white clover at two grazing methods, three stocking rates and five fertiliser levels (mean = x; standard error = se.

	Sustained Stocking Rates						Mob Stocking Rates					
	1		2		3		1		2		3	
Fertility	x	se	x	se	x	se	x	se	x	se	x	se
0	6.0	0.00	6.0	0.00	6.0	0.00	6.0	0.00	6.0	0.00	6.0	0.00
50	5.9	0.1	5.9	0.1	5.8	0.1	5.6	0.1	5.7	0.1	5.7	0.1
100	5.7	0.1	5.9	0.4	4.6	0.4	5.6	0.1	5.8	0.1	5.8	0.1
250	5.8	0.1	5.6	0.2	5.0	0.3	5.5	0.1	5.5	0.2	5.6	0.2
500	4.3	0.2	3.8	0.3	4.0	0.2	3.0	0.3	3.0	0.3	3.0	0.3

excess of 50 kg ha^{-1} yr^{-1}. If stocking rates were moderate then, for white clover to be relatively increasing, fertility had to be equal to or higher than 250 kg ha^{-1} yr^{-1}; and if grazing was lenient, then white clover increased only under 500 kg ha^{-1} yr^{-1} of fertiliser plus irrigation. Mob stocking did enhance these effects.

2.5.5.6 Other species

All the other species considered in this experiment ranked between five and six at all levels of all treatments. This means that their contribution to total dry matter falls below one percent when considered individually. Also, the ranking method may be less consistent if a species is very scarce. Partly because of these reasons, the general linear model applied in the analysis lost accuracy as well. The proportion of the total sum of squares (R^2) explained by the model is below 50% for all these species. In other words, the treatments and their interaction only account for less than 50% of the variability in ranking for these species (Table 2.5.14). The brief comments that follow, therefore, are field observations supported only by graphical evidence.

Table 2.5.14: Comparative Summary of Mean Ranks for 11 Species: Means, co-efficients of variation, R^2 of the general mean model, and significance of main effects, from ANOVA tables for mean rank variations in response to Fertility (F), Stocking Rate (SR), Grazing Management (GM) and Seasons (S).

Species Mean	Mean	C.V.	R^2	F	SR	GM	S
Lupin	2.0	32.5	0.88	***	***	ns	***
Hawkweed	2.9	28.6	0.78	*	***	***	***
Alsike c.	3.0	29.6	0.78	**	*	ns	***
Red clover	4.0	25.5	0.48	ns	***	***	***
Tussocks	5.2	15.0	0.74	*	***	ns	ns
Birdsfoot	5.3	13.4	0.57	ns	**	ns	***
White clover	5.4	17.4	0.83	***	ns	**	***
Caucasian c.	5.8	8.4	0.39	ns	ns	ns	ns
Yorkshire f.	5.8	9.9	0.46	ns	ns	ns	***
Browntop	5.9	5.0	0.45	ns	ns	ns	ns
S. vernal	5.9	5.0	0.42	ns	ns	*	***

a) Caucasian clover (*Trifolium ambiguum*)

The presence of caucasian clover was discernible at all treatments, but at very low levels of relative abundance. Although inconspicuous at the beginning, it showed a clear tendency to increase, particularly under moderate fertility and lenient grazing (Figure 2.5.9). It is a species slow to establish, but one which will thrive under moderate soil fertility and grazing management.

b) Birdsfoot trefoil (*Lotus corniculatus*)

This species established relatively well, meaning that although it was a minor vegetational component, it showed a tendency to increase from low to medium levels of fertilisation (Figure 2.5.10). From the first season of grazing it appeared that these could be permanent trends. Yet, a decline in summer and autumn 1985 was not followed by a seasonal recovery next spring. The final outcome for the period, in terms of rank variations through time was a general trend to decrease.

c) Yorkshire fog (*Holcus lanatus*)

The imposition of grazing brought about the seasonal importance of this species in summer and autumn, particularly under low to medium fertility conditions and high stocking rates (Figure 2.5.11). Next season revealed that a substantial increase had occurred also at high fertility, plus irrigation, where yorkshire fog could be classified as an increaser. Otherwise, this species maintained a distinct presence under moderate to high stocking rates and lower fertility inputs. Such was not the case under the unimproved situation or under lenient grazing, where yorkshire fog practically disappeared.

d) Browntop (*Agrostis capillaris*)

The difference between resident and sown browntop could not be determined and the species is treated as one. Browntop was not apparent during the establishment period and the first season of grazing (Figure 2.5.12). Yet, summer and autumn 1985 revealed an increase at intermediate soil fertility levels that was to be maintained in the spring of 1985. In terms of rank variation, browntop was an increaser under moderate fertility, particularly if grazing was moderate (SR2).

e) Sweet vernal (*Anthoxanthum odoratum*)

Hardly discernible throughout, sweet vernal was ranked during summer and autumn when other species declined. Yet, it was always present in all treatments (Figure 2.5.13).

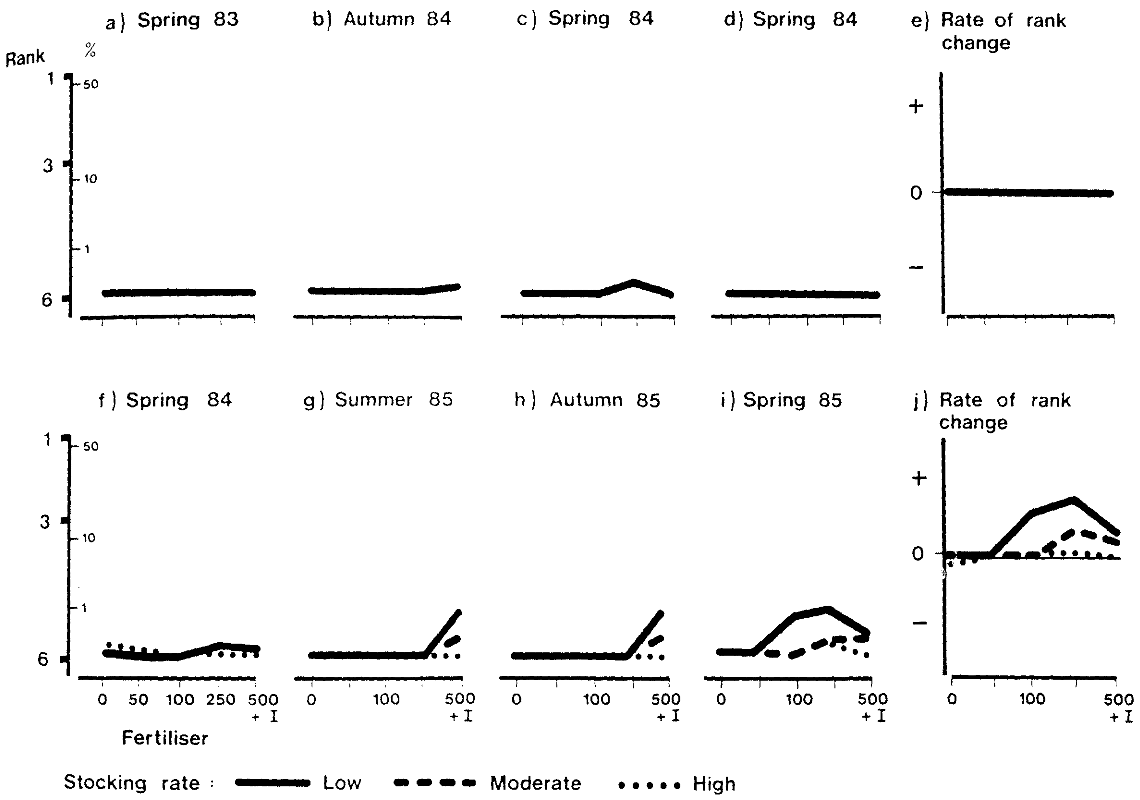


Figure 2.5.9: Variations in the relative ranking of caucasian clover (upper) during the establishment phase and (lower) the grazing period

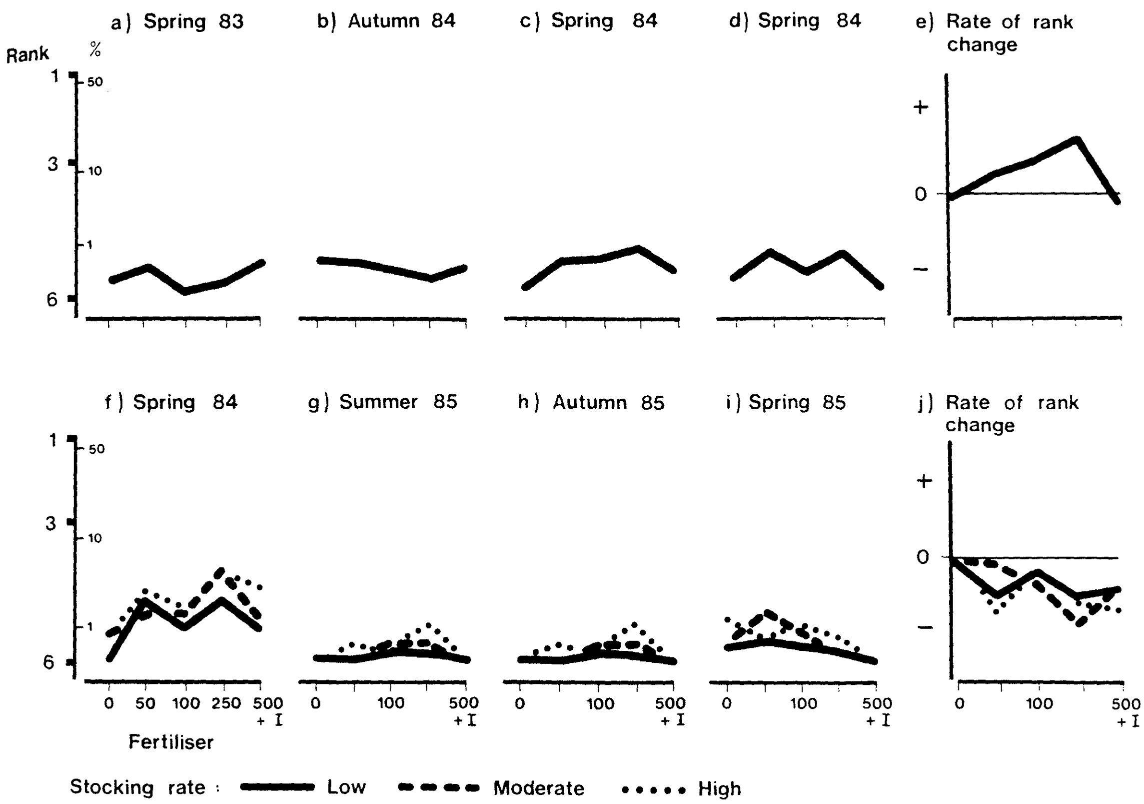


Figure 2.5.10: Variations in the relative ranking of birdsfoot trefoil during (upper) the establishment phase and (lower) the grazing period

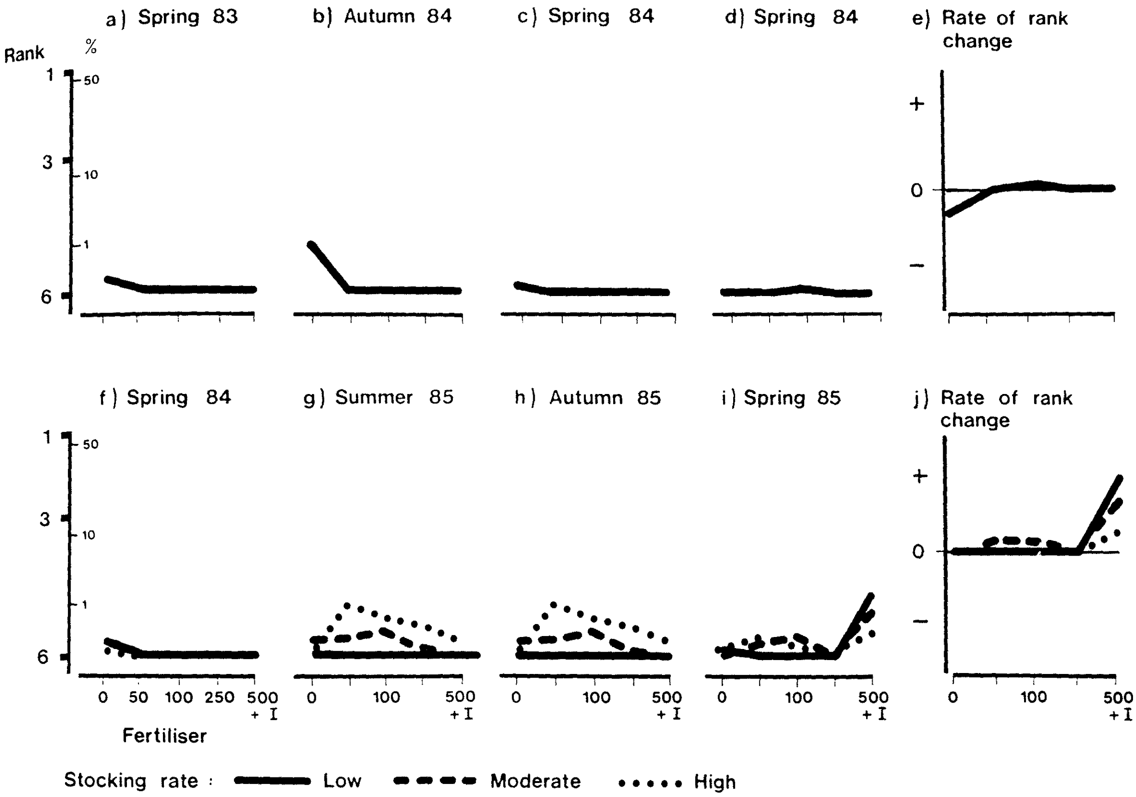


Figure 2.5.11: Variations in the relative ranking of yorkshire fog (upper) during the establishment phase and (lower) the grazing period

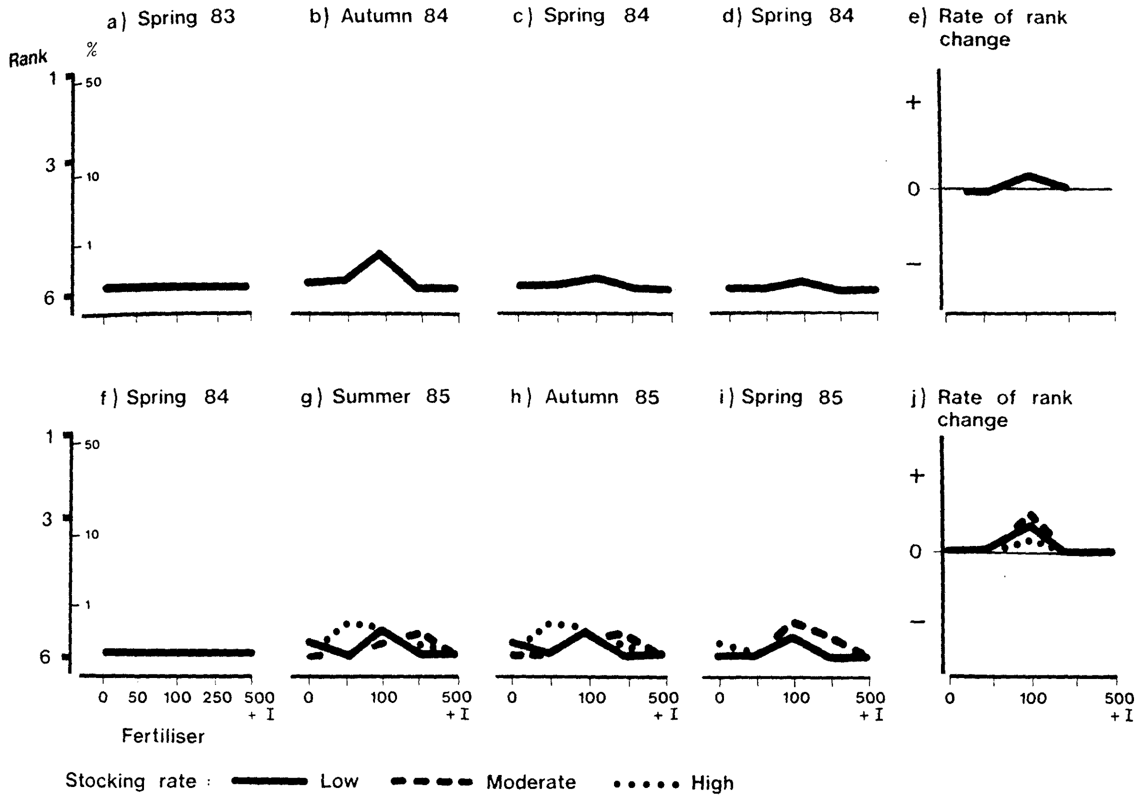


Figure 2.5.12: Variations in the relative ranking of browntop during (upper) the establishment phase and (lower) the grazing period

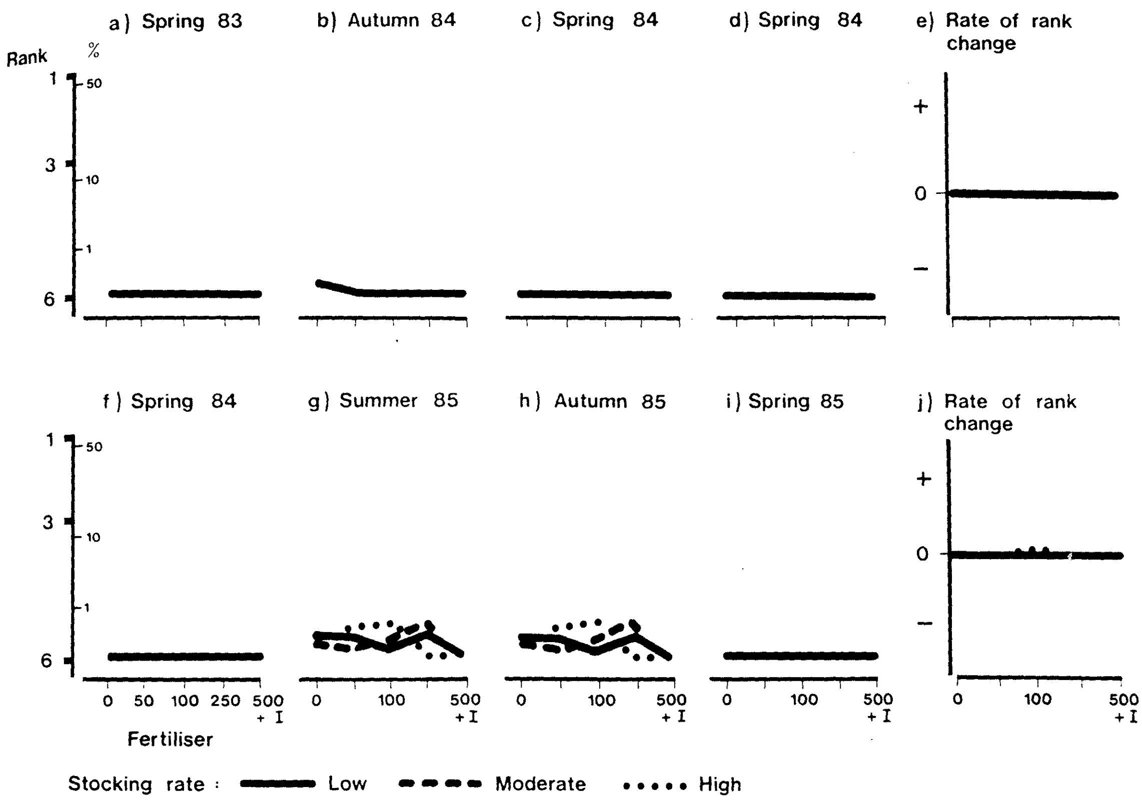


Figure 2.5.13: Variations in the relative ranking of sweet vernal during (upper) the establishment phase and (lower) the grazing period

2.5.6 Other measurements

2.5.6.1 Introduction

The experiment had a pasture management objective: to maintain an ideal situation as a 'moderate stocking' reference, where plots would be stocked and de-stocked as to ensure an optimal pasture height for maximum pasture utilisation and regrowth.

Decisions were taken upon independent visual assessments for each moderate stocking rate treatment (SR2) before each grazing cycle. Therefore, all SR2 plots should have presented a similar initial and final relative condition, **not** total pasture on offer. Strictly, the latter could be true only if growth potentials were about the same. In practice, unimproved treatments at their best could not match improved ones.

Calculated stocking rate records and dry matter measurements basically are means to check on the accomplishment of the management objective as stated, this is, to maintain the given proportion of 1:2:3, called low, moderate and high stocking rate levels within each soil fertility treatment.

2.5.6.2 Stocking rates

Final stocking rates (sheep ha^{-1} yr^{-1}) in Table 2.5.15 show that the proposed proportions 1:2:3 were maintained through the experimental period with relatively little departures. These generally arose from the occasional selection of odd numbers of sheep for the reference stocking rate. Three levels of response to soil management are also discernible in the final stocking ratio, generally following the proportion; (low) for the unimproved situation; 2.3 (medium) for fertilisation alone; and 4.9 (high) for high fertilisation plus irrigation.

The trend of the biological response need not be the pattern of economic response. An elementary short term estimate of economic response can be done accepting that:

a) gross margins per s.u. are the same for all treatments, with an 'average efficiency' at $20 per s.u. and with a 'high efficiency' at $30 per s.u.;

b) fertiliser cost is about $240 per ton on the farm;

c) increased annual costs per irrigated ha are about $261 (pers. comm. Lawson, Farm Advisory Officer, Alexandra, 1986). These assumptions lead to results in Table 2.5.15, suggesting a higher economic benefit with higher stocking rates, but within the range of fertilisers applied without irrigation. Farmers with a return of $20 per s.u. would find an optimum with 50 kg ha^{-1} yr^{-1} of fertiliser, that is 4.5 kg of fertiliser per s.u.; whereas if the return is $30 per s.u., then the best option would be 250 kg ha^{-1} yr^{-1}, or 9.7 kg of fertiliser per s.u.

The main point here is the positive response to fertilisation in terms of indicators of both animal production and profits. Under full farm level development, benefits derived from increased production need to be carefully analysed.

Table 2.5.15: Actual annual stocking rates and Economic assessments for five soil fertility level and three stocking rate treatment combinations. Actual stocking rates are expressed as sheep ha^{-1} yr^{-1}. Economic assessments are based on fertilisation and irrigation costs per hectare as shown in text and on estimated gross margins at \$20 su^{-1} (average efficiency) or \$30 su^{-1} (high efficiency).

Treatment		Actual			Economic Assessments			
					Total Return		Net Benefit	
Fertiliser	Stocking Rate	Annual Stocking Rate	Additional Cost $ ha^{-1}	Additional Cost $ su^{-1}	Average $	High $	Average $	High $
0	Low	2.2	0	-	44	66	44	66
0	Medium	2.9	0	-	58	87	58	87
0	High	4.4	0	-	88	132	88	132
50	Low	3.5	10	2.9	70	105	60	95
50	Medium	7.0	10	1.4	140	210	130	200
50	High	11.0	10	0.9	220	330	210	320
100	Low	3.8	20	5.3	76	114	56	94
100	Medium	7.5	20	2.7	150	225	130	205
100	High	11.2	20	1.8	224	336	204	316
250	Low	3.6	5-	13.9	72	108	22	58
250	Medium	6.7	50	7.5	134	201	84	151
250	High	12.7	50	3.9	254	381	204	331
500	Low	11.0	361	32.9	220	330	-141	-31
500	Medium	14.0	361	25.8	280	420	-81	59
500	High	21.0	361	17.2	420	630	59	269

2.5.6.3 Estimates of dry matter on offer (DM)

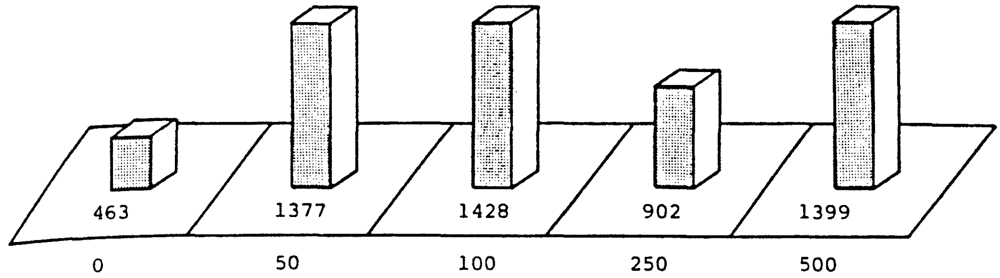
Table 2.5.16 presents a comparison of dry matter on offer for each soil fertility level and for each stocking rate for October 1984 and October 1985. In 1984, with six weeks of growth, the response to fertilisation is positive and significant, and the addition of irrigation nearly doubled that effect.

Table 2.5.16: DM availability (tons ha^{-1}) for each soil fertility level and stocking rate at October 1984 and 1985, the only point in each year with a common growth period among treatments.

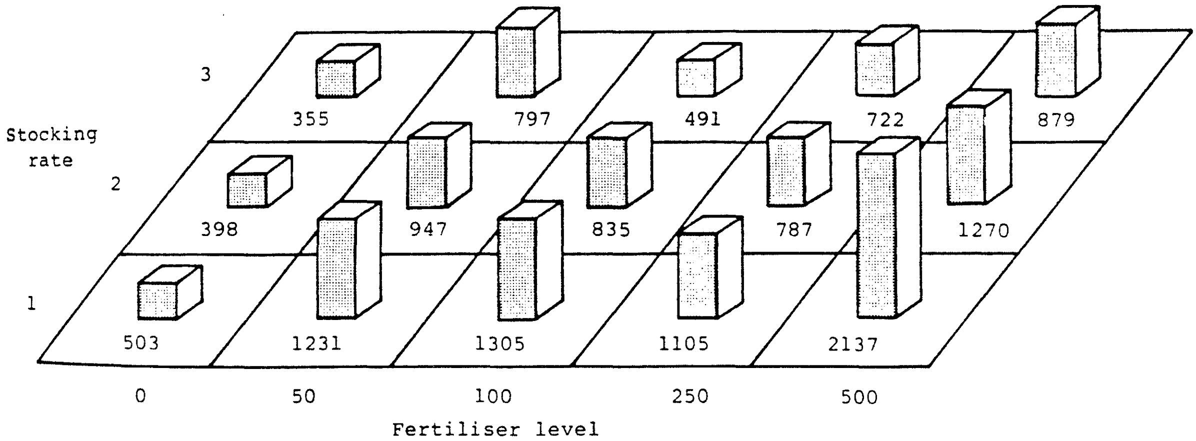
	F1		F2		F3		F4		F5	
	84	85	84	85	84	85	84	85	84	85
SR1	0.4	2.4	1.3	4.0	1.4	4.3	1.1	4.3	2.2	4.7
SR2	0.4	2.2	1.2	4.0	1.0	4.0	0.9	3.6	1.6	5.0
SR3	0.4	2.1	0.9	2.8	0.9	2.8	0.9	4.0	1.2	5.0
X	0.4	2.2	1.1	3.6	1.1	3.6	1.0	4.0	1.7	4.9

The following season (1985) reflects the result of a better established pasture, with the nominated maintenance fertilisation plus the effects of previous different grazing managements. Differences between treatments were greater than in 1984, but maintaining approximately the same trends. Overall means for fertiliser levels indicate higher absolute values, from 2.2 tons ha^{-1} at the unimproved up to 4.9 tons ha^{-1} at high fertilisation plus irrigation (Irrigation becomes more important later in the season). A tendency for a lower yield at F4 observed the previous year was not now apparent. This tendency is also exhibited in Figure 2.5.14a, before grazing treatments were applied. Variation between SR levels in October 1984 before grazing treatments were applied is also evident in Table 2.5.16.

Care is needed in interpreting Figure 2.5.14b. Figure 2.5.14b refers to mean yields prior to <u>all</u> grazing cycles within the whole season 1984-1985. There were a different number of grazing cycles in the different treatment combinations. The mean regrowth presented for each SR x F treatment combination derives from varied numbers of grazing. The measurements mostly reflect the accomplishment



a) Mean dry matter (kg ha^{-1}) at each fertiliser level before grazing treatments were applied.



b) Mean dry matter on offer (kg ha^{-1}) at the start of <u>all</u> grazing cycles in 1984 1985, in relation to stocking rates and fertiliser level.

Figure 2.5.14: Influence of (a) fertiliser alone on herbage DM and (b) of fertiliser interacting with stocking rates on herbage DM on offer at the start of grazing cycles.

of the management objective which was to have similar dry matters at the start of grazing in the SR2 series.

SR2 treatments indicate different growth potentials, because although grazings were decided at the appropriate moment in each case, three levels of maximum initial dry matter became apparent: low for the unimproved; medium for fertiliser alone, and high for high fertilisation plus irrigation. This is so for each stocking rate.

Such a comment applies most closely to mob-stock treatments; under sustained stocking dry matter on offer maintains the trend observed before grazing started. F4 induces a curvilinear trend which cannot be analysed further at this stage.

2.6 DISCUSSION

2.6.1 General response

The relative dominance of any component of a pasture mixture depends on the different adaptations of the species to the environmental conditions they must endure. If a mixture exists along environmental gradients, then the relative success of the different species will be associated with the distinctive environmental features at a given point of the gradient. Greater species diversity is to be expected at the middle range of such a gradient. The ordination of species according to their response could be simplified by ascribing environmental effects into a reduced number of factors.

In the present study, the concepts of environmental stress and disturbance could be expressed in terms of soil fertility or growth potential (a function of fertiliser input and soil moisture) and of grazing intensity (a function of stocking rate and stocking grazing method). Furthermore, low soil growth potentials and low grazing intensities were associated with undeveloped situations, whereas high levels were related to developed pastoral conditions.

A first attempt to classify in a general way species according to such criteria showed a clear distinction between species with affinity towards unimproved situation, as opposed to those more successful under developed conditions.

Under five fertiliser environments comparable with recognisable hill farming situations, species sorted themselves out of complex mixtures as follows: fescue tussocks did best under traditional pastoral management at 'average' high country soil growth potential; mouse-ear hawkweed was successful in more stressful or harsher soil conditions, always within a conventional management; Russell lupin showed affinity for conditions of minimal development, alsike clover for developed situations with medium soil fertility status, and white clover was best for fully developed areas, that is, with high fertiliser rates and irrigation.

Other species group within intermediate levels at lower rankings and may be considered companion species. These comments refer to the first seasons of this experiment and the situation could vary at later stages. Eventual changes in dominance status would depend on the balance between stress and disturbance, possibly the main regulators in species co-existence (Grime, 1979).

Affinities as presented here derived from relative rankings and the mechanisms of each strategy cannot be inferred directly from this. For instance, alsike clover could be related to high fertility and heavy grazing, either because it was less selected by grazing sheep, or because it is a fast grower under those conditions. These conditions could both apply, especially at different times of the year. Similar comments could be considered for the other species. At this stage, this success of a species within a particular environment is pointed out as an empirical fact only.

Factor analysis, ordinating species in relation to axes, provided a useful means to synthesise information for graphical presentation. This frame of reference was later verified by additional analyses. Factor analysis is but one of the techniques which can be applied to rank data (Scott, 1989). In this case, it must be considered as an exploratory approach, since results were weakened by a Heywood case (final communality estimate for white clover was 1.0). This in itself does not render the results invalid, but it is a cause for concern (SAS User's guide: statistics, version 1985).

2.6.2 Response of individual species

2.6.2.1 Russell lupin (*Lupinus polyphyllus*)

The most surprising result in terms of adaptation to an agricultural grazing condition was Russell lupin. This is a popular ornamental plant in high country gardens and is demonstrating aggressive occupation of some local riverbeds as well as persisting in roadside sowings. It has not been reported as forage here or elsewhere.

In the preliminary exercise in ordination, Russell lupin appeared linked to rather extreme management conditions: high to moderate stress and moderately high disturbance. More detailed analysis of variation in relative abundance through time indicated that high stocking rates were detrimental to this species, but that under moderate to lenient grazing it remained as overall dominant, if fertiliser inputs were in the range of 50 to 250 kg ha^{-1} yr^{-1}.

These results are consistent with a report by Davis (1981) on the nutrition and growth of legumes on high country yellow-brown earths, where Russell lupin and lotus appeared as best options. He related this success to a greater tolerance to Al concentrations, which may reach toxicity levels in this kind of soil. Because P can precipitate and detoxify Al, this tolerance could enable lupins to respond even to the lowest level of phosphate application. The importance of the comparatively large size of the seeds of this variety is also mentioned. Field observations on the trial showed Russell lupin reseeds very well, with quite a discernible amount of new plants each year.

In terms of relative abundance this species was at its best with 50 kg ha^{-1} yr^{-1} of fertiliser (F1) and lenient grazing, with a mean rank of 1.0. The lowest relative importance was reached with 500 kg ha^{-1} yr^{-1} plus irrigation (F5) and high stocking rate, with a mean rank of 5.6.

2.6.2.2 Alsike clover (*Trifolium hybridum*)

Alsike clover is well known as a common component of clover mixtures for oversowing on the high country. It can tolerate low fertility and cold acid conditions, but is not suited to continuous heavy grazing. However, it can recover quickly from small residues after grazing. Reputedly it outyields other clovers on wet soils under cold conditions (Langer, 1977).

In fact, within the conditions of the present experiment, the second most important species was alsike clover. During the first phase of vegetational change derived from grazing, alsike was dominant at high fertility plus irrigation; it was second to lupin at F4 (250 kg fertiliser ha^{-1} yr^{-1}); and only inferior to lupin or hawkweed in the remainder of the treatments.

The response to grazing management in terms of relative dominance suggests tolerance of heavy grazing (SR3) regardless of grazing method until now.

The suggested strategy for this species is of moderate to low stress and high disturbance; in other words, some addition of phosphate and relatively hard grazing.

2.6.2.3 Mouse-ear hawkweed (*Hieracium pilosella*)

That mouse-ear hawkweed reflects an environment with poor soil growth potential under moderate to heavy grazing is nowadays of common knowledge. Beyond that, within the framework of the present approach, it should be stated that mouse-ear hawkweed is the only species known to succeed under such a situation. Species known in New Zealand cannot displace hawkweed in high country environments characterised by high stress and moderate to high disturbance. If those conditions were varied, then this species would cease to dominate. This experiment did not show that mouse-ear hawkweed can be eliminated through manipulation of the grazing environment, but it did demonstrate that it may be reduced at higher fertility to the minor role of companion species within the lower stratum.

2.6.2.4 Red clover (*Trifolium pratense*)

Red clover, despite being short-lived and generally used for hay, has been useful in oversowing high country thanks to its tolerance of drought. Within the experiment, red clover was more tolerant of stress than alsike clover, but presented lower tolerance to heavy grazing. It ranked high only under high fertility plus irrigation, where it was not significantly different from white clover. Otherwise, it was discernible at all treatments, but always of lower rank than lupin, alsike clover and mouse-ear hawkweed.

Although there might be a downward trend in the longer term, relative ranking was sustained through summer and autumn without the decline observed for white and alsike clovers. Furthermore, with its reported ability to improve soil fertility, which may favour other, more demanding species at a later stage, it may become an important companion species. It is, so far, adapted to moderate stress and moderate to low disturbance.

2.6.2.5 White clover (*Trifolium repens*)

In New Zealand white clover is the most productive and persistent legume under close continuous grazing, so long as rainfall clearly exceeds 630 mm yr^{-1} (Langer, 1977). In this work white clover showed significant affinity with environments dominated by intensive grazing for short periods, preferably with high fertility and irrigation. Only in that sort of situation did white clover behave as an increaser species. In the medium term therefore alsike may be better for mid-fertility, unirrigated soil conditions.

2.6.2.6 Other species

Caucasian clover (*T. ambiguum*) was at first difficult to find, but in later stages was showing a trend to increase. As a companion species, with a strategy related to that of red clover it may well replace it in the long term.

Birdsfoot trefoil (*L. corniculatus*) came into sight but never became dominant and its relative abundance may in fact be decreasing. Indeed, its importance was obscured by the success of Russell lupin in moderate to low fertility and by clovers where soil conditions were more favourable.

Yorkshire fog (*Holcus lanatus*), browntop (*Agrostis capillaris*) and sweet vernal (*Anthoxanthum odoratum*) are related to the lower fertility and lighter grazing conditions more proper to unimproved systems. Their success, like that of cocksfoot, chewing fescue, ryegrass and to a lesser extent, phalaris and timothy, will become clearer only in subsequent seasons, as the nitrogen status of soils is improved by legumes. Four years after sowing, the ranking for all grasses indicates only sparse occurrence.

Fescue tussock (*Festuca novae-zelandiae*) will be discussed separately. Suffice to say here that this species, within the conditions and duration of this trial apparently could not be dominant under improved situations; nor could it remain prominent under unimproved conditions with grazing at greater than a lenient intensity (cf. O'Connor and Clifford, 1966; O'Connor, 1966).

Maku lotus (*Lotus pedunculatus*) is more frequent than lucerne, (*Medicago sativa*) but both species appear as occasional plants. If Al toxicity were a factor in this trial, then lotus should have been more successful at least under low fertilizer inputs.

Crown vetch (*Coronilla varia*) has never been recorded. Sheep's burnett (*Sanguisorba minor muricata*) showed good presence in the first two months, but was never recorded afterwards.

It is still premature to forecast the fate of these species, which after one year of observations appear as companion plants. In the long term they may show a link to a finer grazing system definition, or disappear altogether.

2.6.3 Total dry matter on offer

Total pasture yields increased by a factor of more than two with the addition of fertiliser, and by a factor of more than four with irrigation plus the higher fertility level. Nevertheless, differences between intermediate fertility levels were not significant. This fact is confirmed by actual stocking rates per year, which were 7.2; 7.5; and 7.6 at mid-fertility situation, compared with 3.2 and 15.7 at the extremes.

The dominance of Russell lupin in lower fertility pastures partially explains this result. The structure of such pastures is characterised by this erect, tall species which bears resemblance to a small shrub. As fertiliser inputs increase, lupins decrease in favour of red and white clovers which provide a denser but shorter pasture cover. By virtue of the strategy of these latter species, an increase of dry matter also occurs as stocking rates increase from moderate to heavy within high fertility, mob-stock treatments.

Total dry matter on offer in spring of 1985 doubled that in 1984. Recorded differences of 100 mm of rainfall and mean soil temperature of two degrees favoured the early spring of 1985.

2.6.4 Summary

Thirty 'environments', resulting from the combination of five soil growth potentials, three stocking rates and two grazing methods were imposed on a mixture of many pasture species. Results after allowing two years for their establishment, and one further year with grazing management are:

a) Each species has an affinity ('does best') at a particular point of the environmental gradient.

b) Tussocks, mouse-ear hawkweed and adventive grasses relate to unimproved conditions, whereas legumes are more related to different levels of pasture development.

c) The most important species are Russell lupin at moderate to moderately low levels of soil fertility and grazing intensity, alsike clover at moderately high to highly developed conditions, and mouse-ear hawkweed which dominates unimproved conditions and remains an important pasture component at all levels below 250 kg ha^{-1} yr^{-1} fertiliser.

d) The most important experimental factor affecting the relative ranking of species was fertiliser input. Second was stocking rate and last, grazing methods.

e) Likewise, fertiliser input was the most important experimental factor affecting dry matter on offer, although the effects of irrigation were more evident. Soil fertility and moisture together determined three levels of response: no fertiliser (low); mid-fertility (medium); and very high fertilisation plus irrigation (high). There was some correspondence between this level of response measured as total dry matter on offer at the start of the grazing season, and as integrated livestock loads for the whole grazing season.

Chapter 3

THE ECOLOGICAL ROLE OF TUSSOCKS

3.1 INTRODUCTION

Tussocks at present are physiognomically dominant or at least prominent in about three million hectares under grazing in the high country of New Zealand. In agricultural terms they have been considered comparatively unpalatable, but they remain a dominant factor in influencing smaller associated species, whether in the unimproved or the oversown and topdressed condition. However, the influence of tussocks in the stability of introduced pasture components has not been established. Furthermore, the appropriate grazing management for this type of environment is a matter still open to discussion.

This chapter is divided into two sections. The first one examines the relative abundance of tussocks under different situations of development. The second one considers the effects of tussock shelter on the growth rate of inter-tussock pasture species.

3.2 REVIEW OF LITERATURE

3.2.1 Origins of tussock grasslands

In New Zealand, tussocks are at present distributed in relation to an altitude gradient, where short tussocks (less than 60 cm in height) such as *Festuca novae-*

zealandiae and *Poa cita* are dominant below 1,000 metres. Such vegetation is characteristic of what became known as 'short tussock grasslands', which have been described as the result of a history of fire and grazing (Connor, 1964; Connor and McRae, 1969).

Nevertheless, tussock grasslands and their distinctive physiognomy are normally regarded as 'native vegetation', suggesting that this particular form of growth was also dominant in a primitive or pre-exploited condition. O'Connor (1986) examined the origins and evolution of the concept of 'tussock grasslands', concluding that particularly for the case of short tussocks, the use of this term did not emerge clearly until the second decade of this century. From early reports and photographs, he postulated that not only the dominance of some species of short tussock, but also their ostensible 'tussock' form, may have been an outcome of pastoral use.

3.2.2 Adaptations to grazing

In a general way, tussocks have been described as an ubiquitous feature of unproductive pastures (Grime, 1979), normally occurring in difficult environments, such as steppes and deserts (Moore, 1964). It should be noted, however, that such environments in many cases have been exposed to extensive grazing by livestock for a century or more.

In New Zealand, early workers of this century interpreted the persistence, or rather, the increase in relative dominance of tussock growth form, as a proof of a unique environmental adaptability. Yet, apparently they did not perceive that this 'adaptability' to grazing was due to avoidance rather than tolerance of defoliation. Grazing pressure was exerted on the inter-tussock components, probably promoting the physiognomy of grasslands with discrete short tussocks (O'Connor, 1986).

The group of species that grow as tussocks possibly represent an adaptation to resource limitations. In general, plants suited to such habitats present inherently slow growth, low respiratory and photosynthetic rates, associated with low levels of leaf protein (Coley *et al.* 1985). This generalisation is in good agreement with the research on New Zealand tussocks cited in Chapter 1.

Grime (1979) had proposed that an increase in habitat stress was related to an increase in plant defences to herbivory. Coley *et al.* (1985), in their review on the subject concluded that the anti-herbivory defensive mechanism found in most slow-growing plants was based on chemicals that also served as structural support, such as lignins or polyphenolic compounds. They appeared to deter grazing in a variety of herbivores, from monkeys to slugs. If such is the case, the absence of conspicuous herbivores during the evolution of vegetation may or may not be associated with the existence of some form of inherent grazing deterrent.

Large ungulates were not present during evolution of vegetation in New Zealand, and the reduction or disappearance of species after the onset of commercial grazing might be related to a lack of mechanisms to tolerate defoliation. However, in the light of the review by O'Connor (1986), tussocks do not come out as defenceless, being protected by a relative unpalatability, especially in conditions of poor plant nutrition. Hungry sheep will reject few species, and tussocks eventually may be grazed quite intensively. Yet, selectivity between tussock species may occur. For example, *P. colensoi* is preferred to *P. cita*, although both present a greater tolerance to grazing than *F. novae-zelandiae* (Allan, 1985; Abrahamson, 1989). It appears that *P. colensoi* may recover from periodic hard grazing, whereas *P. cita* may be seldom closely grazed. At any rate, most tussocks recover slowly from grazing and repeated defoliations may lead to their extinction.

From another point of view, applying concepts of Grime (1979), species that develop a strategy to cope with abiotic stress should be ill-prepared to compete for elements in a resource rich environment with other, neighbouring species.

It follows that in theory tussocks may not be able to cope much longer with recurrent defoliation as occurs in pastoral management; nor with the intensified grazing plus the competition of fast growing species under improved conditions. This may be true for extreme situations, but exceptions could be expected.

Research on the management of improved pastures for the specific conditions of South Island high country is limited. (O'Connor 1966; O'Connor and Clifford 1966; O'Connor *et al.* 1968; Vartha and Clifford 1971; Allan 1985). Furthermore, improvement may result in a series of systems, suited to different environmental and economic constraints, where the fate of tussocks remains to be determined.

Allan (1985), after six years of observations on the effects of nine grazing management treatments on oversown high country, reported that mass of *P. colensoi* was maintained in abundance and vigour under high stocking rates but alternating grazing regimes. He reasoned that the compromise of reduced summer grazing pressure and medium grazing intensity prevented the depletion which occurred under other managements. The range of grazing managements was derived from the combination of continuous, alternating and rotational grazing with low, medium and high stocking rates. He concluded that *P. colensoi* tussocks may play an important role in this situation when inter-tussock herbage becomes limited. He noted that White and O'Connor (1986) reached a similar conclusion through computer simulation to examine rotational grazing strategies for the same oversown tussock country.

Regarding *F. novae-zealandiae*, O'Connor (1966) reported that under periodic hard grazing fescue tussocks at high levels of fertiliser input eventually disappeared. However, under treatments with reduced grazing pressure and any of four levels of fertiliser input, tussocks improved in size and abundance in relation to the unimproved situation. He noted that this persistence was at the expense of the cyclic nitrogen flow associated with highest pasture herbage production.

3.2.3 Conclusions

A number of species characterised by a growth form in clumps, bunches or 'tussocks' are adapted to stress-dominated environments. Some of their structural components may be related to grazing avoidance. After prolonged grazing exposure or extensive pastoral management grazing avoidance may result in predominance of this tussock growth form.

As a typical stress-tolerator, *F. novae-zelandiae* species as a general rule should be expected not especially to resist disturbance nor to demonstrate competitiveness under resource-rich conditions.

3.3 RESPONSE TO GRAZING MANAGEMENT

3.3.1 Introduction

This section refers to the field response of fescue tussock (*Festuca novae-zealandiae*) in the Mount John experiment, as described in Chapter 2. Fescue tussock was one of the common resident species before the imposition of the trial with its thirty environments resulting from: five soil growth levels from nil fertiliser to high fertilisation plus irrigation (F1-F5); three stocking rates from low to high (SR1-SR3); and two grazing methods (mob versus sustained). Material and methods are described in Chapter 2.

3.3.2 Results

3.3.2.1 Response to increased soil fertility or growth potentials

Figure 3.1 describes the response of tussocks, in terms of relative abundance, to oversowing and five fertiliser levels in the absence of sheep during the two years allowed for the establishment of sown pasture grasses and legumes.

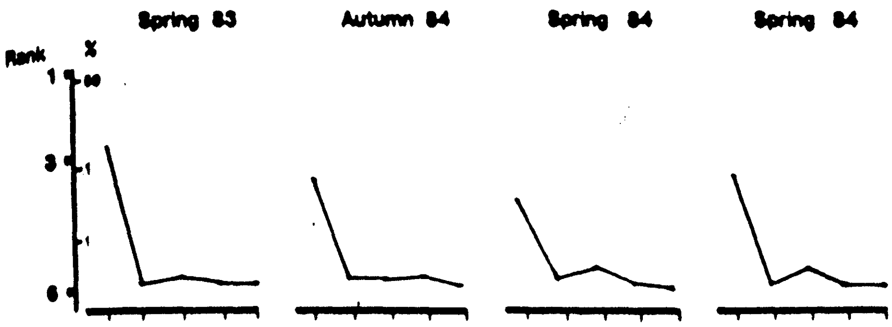


Figure 3.1: Variations in the relative ranking of fescue tussock during the establishment phase.

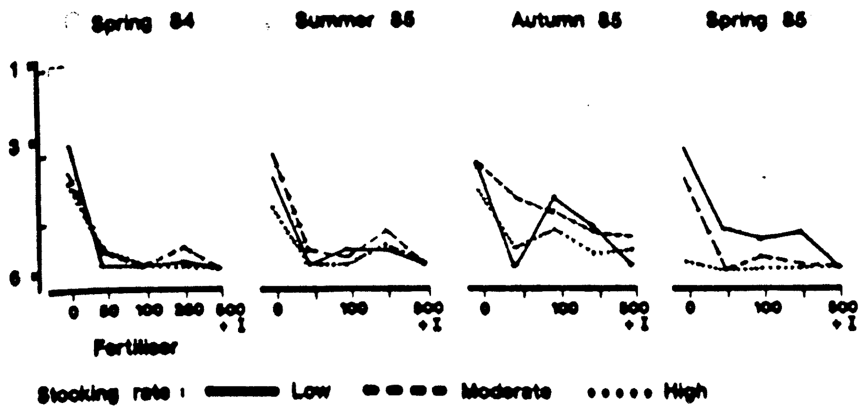


Figure 3.2: Variations in the relative ranking of fescue tussock during the grazing period.

Table 3.1: Mean rank variation of fescue tussock in response to oversowing and five fertiliser levels during a two year pre-grazing period. (ANOVA table for a split-plot design on a randomised complete block arrangement). Degrees of freedom (df), sum of squares (SS) and significance probability of F ratio (pF) to two significant places.

a) Summary			
Source	**df**	**SS**	**pF**
Model	24	369.7	0.00
Error	303	145.0	
Corrected total	327	514.6	
b) Main effects and interactions			
Rep	1	2.7	0.09
Fertility	4	341.2	0.00
R x F	4	341.2	0.00
Season	3	1.3	0.45
c) Polynomial contrasts			
Fertility			
Linear	1	107	0.00
Quadratic	1	76.7	0.00
Cubic	1	81.0	0.00

Relative ranking of *F. novae-zelandiae* showed a very strong tendency to decline sharply in response even to lowest fertiliser input. Because ranking is a relative estimate, this reflected the increase of oversown pasture species in the absence of grazing, rather than an absolute decrease in tussock mass. Dunbar (1974) has indicated the responsiveness of *F. novae zelandiae* to phosphorus as well as nitrogen.

Rank change through time indicates that in the region of medium fertility, tussocks showed a trend to increase. Graphically this is seen as a 'bump' or second inflection point in Figure 3.1, supported by a significant cubic fit in Table 3.1.c.

Within the unfertilised treatment (F1) tussocks showed a relative decrease with time, in this case due to the growth of resident grasses, namely browntop and sweet vernal, which normally would have been grazed off.

Ranking must be understood in relation to vegetational change as a whole. It is unlikely that the biomass of tussocks, in this case, had changed much. Rankings reflect the fluctuations of other species through their establishment period. The principal fact is that oversowing and fertilisation reduced the importance of tussocks to the bottom of the scale of relative abundance.

3.3.2.2 Responses to grazing management

One year after the imposing of grazing the effect of fertility was still dominant ($p = 0.02$) in that relative abundance declined with fertilisation; although with intermediate levels, tussocks were present whereas at high fertility plus irrigation they virtually disappeared.

The presence of tussocks is also significantly affected by stocking rates ($p = 0.00$), as shown in Figure 3.2 and Table 3.2. High stocking rates led to total depletion; at F1 (no fertiliser) tussock residues are discernible due to lack of other vegetation, but even in that case the bulk is below one percent of the total. Tussocks retained some relative importance only under lenient grazing (SR1), though within the general trends already described. Interactions with fertility are significant ($p = 0.02$); nevertheless fluctuations refer to an area where the amounts of contribution to total dry matter on offer are below five percent.

Table 3.2: Response of tussocks to grazing management. (ANOVA table for two 5 x 3 x 2 factorial in a split-plot design). Degrees of freedom (df), sum of squares (SS) and significance probability of F ratio (pF) to two significant places.

a) Main effects			
Source	df	SS	p F
Fertility	4	403.1	0.02
Stocking rate	2	46.0	0.00
Grazings	1	0.4	0.33
Season	3	48.7	0.00
b) First order interactions			
F x SR	8	29.4	0.00
SR x GS	4	3.1	0.06
c) Second order interactions			
F x SR x GM	8	30.0	0.00
F x SR x SS	24	25.0	0.02

3.3.2.3 Summary

Fescue tussock, one of the dominant resident species diminishes its relative importance as soil fertility levels increase and new pasture species were introduced. Possibly in that situation absolute dry matter yields do not vary much during two or three seasons.

However, the imposition of grazing is deleterious to this species. Hard grazing reduced tussocks at all fertility levels, more so under mob grazing, while they virtually disappeared under high fertilisation plus irrigation. Under mid-fertility, intermediate grazing treatments, they remained visible, scattered between other species.

3.3.3 Discussion

Fertiliser and oversowing without grazing changed the resident vegetation so the relative abundance of tussocks decreased so as to become a record of mere presence. This decline in the absence of grazing is attributable to the increase of new species. If permanently protected from grazing, tussocks might have been invigorated under medium levels of fertility, but remained always as a minor community component.

The imposition of grazing management, as other species were preferentially grazed, allowed tussocks to become more conspicuous. Hard grazing did threaten their persistence however, under moderate intensification of the system tussocks might remain, if not dominant, at least as a permanent component of the community. O'Connor and Clifford (1966), for a similar area, reported that the mass of fescue tussocks on improved country could actually be increased after four years of periodic, lax grazing. In their experiment tussock tended to disappear if grazing was hard, particularly under higher fertiliser inputs (O'Connor, 1966). Abrahamson (1989) indicates from survey of farmer attitudes that many high country runholders wish to retain short tussocks in their improved pastures. Scattered tussocks are present within all plots. Fertilisation induces a change in colour, from yellow to green, with leaves also becoming more tender.

Altogether, a general visual impression is that tussocks may be more endangered in the unimproved situation than in a situation with moderate intensification and lax grazing. This feature is related to grazing preferences and will be discussed further later.

3.4 TUSSOCKS AND SHELTER

3.4.1 Introduction

A field experiment was established at Lincoln to investigate the effects of tussock shelter on established pasture, by transplanting silver tussocks (*Poa cita*) at different densities and configurations into an established sward. Micro-climatic measurements were made in some detail.

3.4.2 The concept of exposure

Climatic conditions which may be hazardous for agricultural plants and animals are often summarised within the notion of 'exposure'. It is only in mid-latitudes that 'exposure' is specifically associated with wind. For the particular case of New Zealand high country, it is accepted that strong winds and extreme temperatures are the most significant components of this concept.

Grace (1981), while acknowledging that the notion of exposure cannot be consisely defined, suggests that a better understanding is possible if exposure is considered as a close coupling of plant parts to the atmosphere, which is amenable to quantitative analysis in terms of diffusion resistancces. However, in practice, the interpretation of results of experiments where the exposure has been manipulated remains controversial (Russell and Grace, 1979).

In New Zealand pastoral agriculture, it is understood that shelter is a means of protection of both plants and animals against exposure, normally in the form of 'shelter belts' of trees, often evergreen conifers. Different species of trees, shrubs and grasses are usually preferred to inert materials.

Geiger (1965) in a review of earlier research on the subject, states that the protection effect is a function of the height and porosity of the shelter belt and of wind speed. Better results are obtained with porosities about 50%, which prevents the turbulent return of the air, extending the downwind shelter 20 to 25 times its height. On the other hand, shelter will produce a shadowed area and the risk of night frost may be slightly increased; yet, during the day soil and air temperatures will be higher, and evaporation may be reduced. However, Grace (1981) stresses that wind does not always increase transpiration rates.

3.4.3 Shelter and grasslands

Radcliffe (1984) reviewed research on grasslands response to shelter, finding that information was scarce and often more qualitative than quantitative. Some general positive effects of shelter are outlined: reduction in soil erosion rates; a higher soil moisture regime; and increased yield in many cases, although sometimes a reduction in nutritive value was also reported.

In the harsh conditions of the high country the negative effects of exposure, particularly on introduced species are probably severe. It follows that the presence of tussocks, otherwise poor competitors, should ameliorate such effects for both stock and inter-growing pasture species.

Many biological problems might be associated with the fact that the shelter element is in this case a presumably active component of the vegetation. Scott (1975) considered an allelopathic effect of tussocks, but this or other factors seem to have been considered minor to more substantial microclimatic effects. Scott (1962), and O'Connor and Lambrechtsen (1964) reported differences in temperature due to the presence of tussocks: areas in the sunny side of the plant were hotter, decreasing through intertussock spacing towards the shady side of the next plant.

A soil moisture gradient and light intensity variations were associated with this trend (Scott and Wallace, 1978). In addition Scott (1978) showed that air movement decreased linearly below the canopy of a tall tussock-short shrubland, down to 15% of the control (2 m height).

Microclimate within tussocks exerted a positive effect on:

- summer survival of oversown species on the shaded and cooler south side of tussocks (Scott and Archie, 1976);
- initial growth of transplanted cocksfoot when tussocks were dense, or near the tussock base, sheltered from prevailing winds if densities were low (Radcliffe, 1974).

possible positive shelter effects on the yield of already established pastures, likely as they may seem, have not been demonstrated. It has been suggested that there might be a site-specific optimum tussock density which could promote growth in introduced pastures (Radcliffe, 1984). However, Scott (1978) reported for pasture species of legumes, that after legumes had been established, subsequent growth was not greatly affected by tussock proximity; furthermore, yields were generally greater away from these plants. Allan (1985) comments that in a six year grazing experiment, reduced tussock cover at higher stocking rates did not appear to result in detrimental effects on inter-tussock components.

In summary, tussocks create a microclimate which generally favours the establishment phase of introduced species. The same cannot be stated confidently about later stages of development of that pasture. The more documented shelter effects are the amelioration of extreme temperatures in the vicinity of tussocks, and protection from wind in a general way. Site exposure and season; grazing patterns; allelopathy or other factors may be interacting in a way yet to be described.

3.4.4 Material and methods

3.4.4.1 Introduction

The main independent variable to be analysed is shelter. In a first approach, shelter may be expressed as categories or discontinuous classes resulting from different densities of tussocks (number of equidistant plants per unit area). The shelter categories may be conceived as a direct function of different levels of tussock density, or, in a more involved conception, as a function of micro-site distance to tussocks and exposure within each level of density.

This does not readily allow a functional analysis of the response (pasture growth), and because in nature, tussock shelter does not occur as fixed classes, it is desirable to quantify shelter in an integrated way.

Shelter provided by shelter belts, is a function of length, height and porosity of the shelter belt components; exposure to predominant wind and distance to the sampling point. Where trees or tussocks are not arranged as a belt, they create a canopy coverage. A further effect to be included is light penetration at the sampling point. A possible way to integrate these effects is to determine for each sampling point total canopy coverage, which is a function of tussock height, density ('porosity') and orientation, being also a direct measure of light penetration.

In consequence, shelter treatments which are initially categorical could also be treated as ordinal, or even continuous, through mathematical transformation by means of an empirical equation that could produce a shelter coefficient for each shelter class.

3.4.4.2 Site

The site, at Lincoln College, was a 0.10 ha paddock, with minimal interference from buildings, shelter belts etc. It had a Nui ryegrass pasture established two seasons before the setting of the experiment, in September 1983. Before the experimental period broadleaf weeds were removed manually, followed by oversowing and spray irrigation to obtain a homogeneous pasture coverage.

3.4.4.3 Field design

Silver tussock (*Poa cita*) was used because it can establish quickly and was unlikely to be damaged by grazing animals used under mob-stocking. Plants were transplanted to the experimental site in early September, 1983. They were mixed, subdivided, fitted into pieces of plastic pipes 9 cm diameter x 5 cm deep and buried to ground level. This was to ensure a constant basal area and to reduce below ground competition. All tussocks were initially cut to a height of 30 cm.

There were four plant configurations, or densities. Tussocks were equally spaced at 30 (dense); 70 (medium); and 150 (sparse) cm apart, measured from the edge of the plastic ring fixed at the base of each plant (Figure 3.3a). A control was included without tussocks. Four replications were used on a randomised complete block arrangement. Each block was 15 x 15 m and each treatment density was on plots 7.5 x 7.5 m.

3.4.4.4 Shelter classes

From Figure 3.3a, a range of shelter situations could be defined in terms of proximity to tussocks and orientation within each density. It was decided to take measurements with 0.1 m^2 quadrats 30 cm apart in NE-SW direction. This transect is dominated by sunny and shady aspects as well as by shelter from cool south-westerlies and the also frequent north-easterlies (Coulter, 1975).

Ten positions, called shelter treatments, resulted within this transect, each of them representing a shelter class defined by a particular orientation, tussock proximity and tussock density (Figure 3.3.b and Table 3.3). It will be noted that these do not represent a shelter gradient as such. The structure of these shelter classes was later characterised through canopy photography, as described in the methods section.

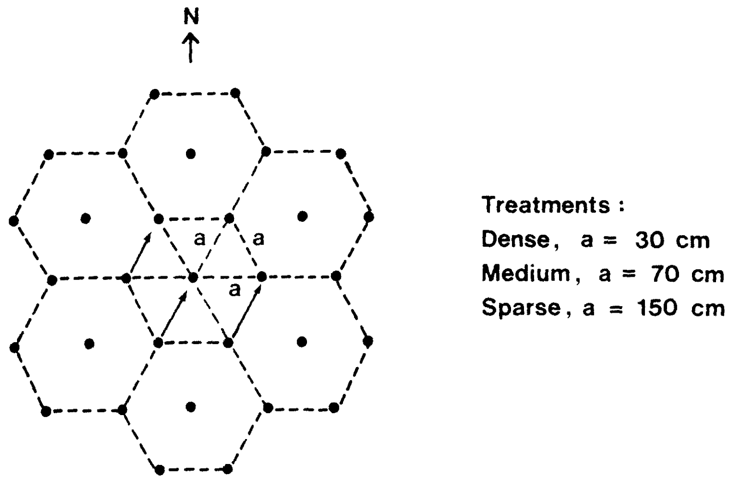
Table 3.3: Description of shelter treatments.

Treatment N°.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Distance between tussocks (cm)	30	70	70	70	150	150	150	150	150	-
Tussocks/m^2	7.8	2.2	2.2	2.2	0.5	0.5	0.5	0.5	0.5	0
% area covered by tussocks	4.9	1.3	1.3	1.3	0.3	0.3	0.3	0.3	0.3	0

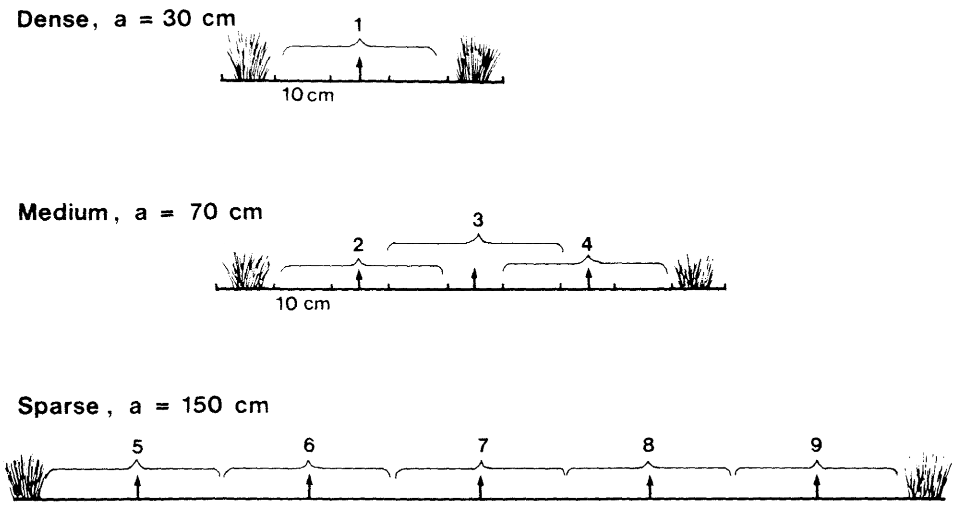
3.4.4.5 Shelter coefficient

Shelter, within the original treatments, is a discrete, nominal variable (levels are not ordered). To improve the analysis, it was proposed to transform these treatments into ordinal (still discrete, but ordered and numeric) or even into continuous, effects. To do this it was necessary to re-define the ten shelter positions through an equation which considered:

- % of canopy coverage,
- exposure to predominant wind,
- distance to the nearest tussock.



a) Basic pattern for dense, medium and sparse planting configurations.



b) Shelter treatments within each spacing configuration.

Figure 3.3: Description of spacing treatments in the tussock shelter experiment at Lincoln Plant Science Department Field Station.

Canopy coverage % (CC%) was determined through canopy photography as detailed in Section 3.4.4.9. The effect of shelter from the SW, (SWCC%) from cool and frequent south-westerlies, was given an estimated weight of two; weight was also given to distance to the nearest tussock (D), assuming that shelter effects are inversely proportional to it as:

$$\text{Shelter coefficient} = [(\text{Total CC\%}) + (2 * \text{SWCC\%})] / D$$

Shelter values for each shelter class will be presented in the Results section, with further comments on calculations.

3.4.4.6 Measurements on pasture

a) Dry matter yield (DM)

Dry matter was determined in 0.1 m^2 quadrats at each of the 10 shelter positions at one week intervals during February, March, April, September and October of 1984. Periodic grazing was programmed every three to four weeks to prevent rank growth; nevertheless, sheep site selection was observed (see Results Section). To avoid non-random animal effects, clippings were done manually.

Successful non-destructive DM measurements with a capacitance probe (Vickery, Bennett and Nicol, 1980) encouraged the use of relative growth rates as the basic parameter to ensure a uniform basis of comparison between treatments. The instantaneous relative growth rate (R) for a period is the slope of the plot of the logs of DM versus time (Hunt, 1981). Values were calculated for each treatment and each regrowth period (roughly, once a month). The advantages of this functional approach are discussed by Hunt (1981).

b) Botanical composition

At the onset of the experimental period (spring of 1983) inter-tussock pasture was 100% ryegrass. Nevertheless, one year later other species, mainly white clover, had appeared. To examine the distribution of this emerging species in relation to shelter, five quadrats 0.1 m^2 were clipped to ground level at each shelter treatment on one occasion in all blocks. Ryegrass, white clover, other grasses, other species and litter were manually separated from subsamples, dried and weighed.

In addition, one composite ground 'plug', also totalling 0.1 m^2, was taken at each shelter treatment in all replications to determine tiller densities. Samples were washed and green grass tillers, dry grass tillers and white clover shoots were counted.

3.4.4.7 Measurements on microclimate

a) Introduction

Interactions between climatic parameters are very complex, because factors are never constant. Interpretative difficulties especially exist for field experiments. To explain thoroughly variations in relative growth rates attributable to shelter, continuous measurements would have been required at each sampling position. Even in that case a functional response could not be expected. Therefore, microclimatic measurements in this case must be understood as periodic observations to improve insight rather than to lead to a model or to produce information elaborated with predictive purpose.

b) Temperature

Thermographs with probes were used to measure air temperature at a height of 10 cm horizontally oriented east-west covered with a white plastic shield. This was done for all densities (dense, medium, sparse and control). Soil temperatures were measured with probes buried to a depth of 7 cm below ground, but only on dense and control treatments.

Series of spot measurements for both densities and shelter treatments within densities were obtained using an infra-red thermometer for leaf temperatures and a tele-thermometer for air and soil temperatures.

c) Wind speed

Sample windspeeds were measured at 5 heights: 10; 20; 30; 50; and 180 cm, equidistant from tussocks at all densities, in one block. Ten one minute series were recorded during three days with different windiness.

d) Radiation

Direct measurements of photosynthetically active radiation were taken with a radiometer under overcast sky conditions. Many series of quick readings were taken at all treatments and at the central point of all densities.

3.4.4.8 Miscellaneous measurements

a) Sheep site selection

Periodic grazing with sheep had been programmed to clean out inter-tussock herbage. However, observation of the first grazing period in November 1983 indicated a possible animal interaction with the treatments. Photos were taken to indicate sheep distribution and dung was collected by hand from all plots, air dried in the sun for two days and weighed.

b) Soil moisture

Continuous soil moisture measurements at treatments had not been planned because they are destructive. During autumn 1985 there was a severe drought period, when it was considered differences should have been at their greatest. Before the drought was broken with late autumn rains, soil samples to 15 cm depth were collected for all treatment sampling points, over-dried and weighed.

c) Tussock height

There was a non-planned effect of tussock plant densities on tussocks themselves. In February 1985, at the end of the experimental period, the height of 300 plants was measured (25 tussocks x 3 densities x 4 reps).

3.4.4.9 Measurement techniques

a) Canopy photography

Estimates of incoming radiation as well as of canopy structure were obtained through hemispherical photography at each shelter treatment (Anderson, 1971). A camera with a 180° auxiliary lens ('fish eye') and yellow filter was buried so as to place the lens at ground level at each sampling point. Coverage and distribution of the canopy were quantified with an appropriate grid (Plate 1; and Figure 3.4). Further calculations to estimate light penetration at the areas of interest under overcast day conditions were obtained calculating solar positions for the specific dates and site of the experiment. The method is explained by Evans and Coombe, 1959; Anderson, 1971; and Jones, 1983.

b) Single probe capacitance meter

Capacitance meters provide a non-destructive means to measure pasture on offer. An early model was first tested in 1949; history and development of the device until 1973 are described by Neal and Neal (1973). Literature on these earlier models has been reviewed by Edge (1979). Boswell *et al.* (1979) summarise the disadvantages of those models which were not well suited to work on steep slopes, uneven grazing, uneven swards, lodged long pastures, or under showery conditions.

A later model developed by Vickery, Bennett and Nicol (1980) overcomes most of the initial drawbacks of the system. The new instrument has only one probe, instead of several, is responsive to the surface area of leaves and it is less sensitive to the succulence of the plant than was formerly the case.

Plate 1: Percentage of canopy coverage from canopy photography at 10 shelter positions within dense, medium and sparse tussock densities.

Positions

1: Dense 59.2%

2: Medium shady 19.2%

3: Medium central 18.3%

4: Medium sunny 22.4%

5: Sparse shady 9.9%

6: Sparse apart 5.1%

7: Sparse central 4.7%

8: Sparse apart 5.4%

9: Sparse sunny 7.5%

10: Control 0%

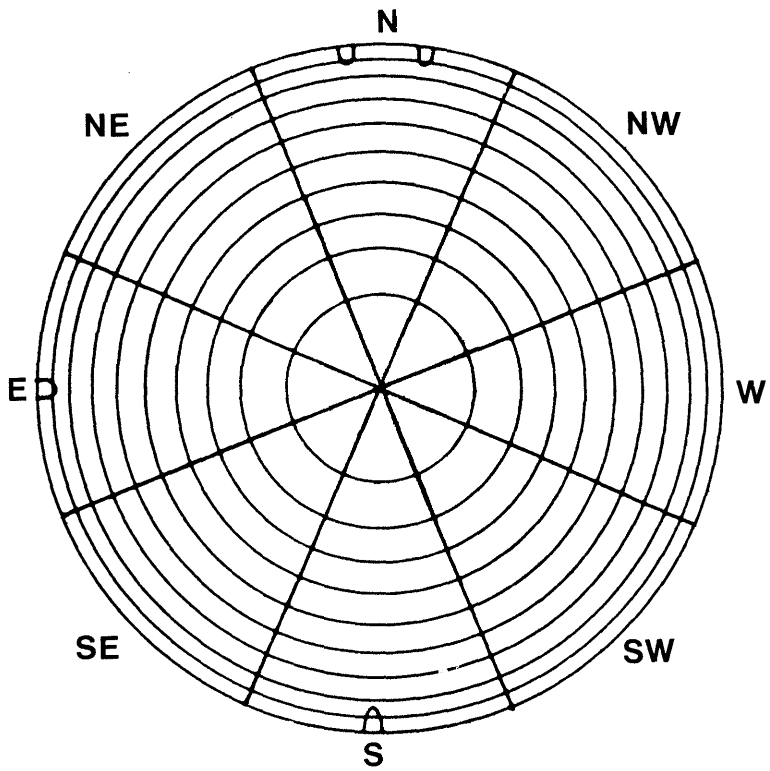


Figure 3.4: Equal area grid for calculation of canopy coverage from canopy photography (after Brown, 1962). Each band delineated by concentric circles represents 10% of the sky hemisphere. The compartments delineated by radial lines represent 1.25% of the hemisphere. Canopy coverage is estimated for each component. Radii of the equal area circles above are:

Equal-area circle (5)		Radius (mm)	
10	60	12.3	34.5
20	70	18.2	37.8
30	80	22.9	40.8
40	90	27.0	42.9
50	100	31.0	44.8

Michell and Large (1983) compared a rising plate with the single probe capacitance meter, finding that the latter was significantly superior to determine dry matter. Correlation coefficients were always above 0.9, but neither the meter nor the plate were accurate when senescent material was abundant. Stockdale and Kelly (1984) confirmed good results, warning against trampled herbage.

In this work the model produced by Design Electronics (Palmerston North, New Zealand; Anon) was used: 'Manufacturers Notes' for calibration are extended by Mansell and Musgrove (1984).

Vickery and Nicol (1982) found that the Mitscherlich function ($Y = a\text{-}b^{-cX}$)provided the best fit for calibration between probe reading and dry matter of herbage mass. Roberts, Cartledge and Stern (1984) considered that the best correlation was obtained with a linear regression if the pasture was a mixture of clover and annual ryegrass. In this case it was preferred to force the calibration curve thrugh a known x-intercept (lowest possible reading) and asymptotic to a known y-intercept (highest reading from experience). The resulting curve, which allows for the unclipped residue, is of the type of an exponential decay to a straight line, as in equation below:

$$DM = b(\text{Probe-k}) + a(1\text{-exp}^{(-c(\text{Probe-k}))})$$

where

k = x-intercept
a = y-intercept of the asymptote
b = slope of the asymptote
c = curve constant for exponential decay

According to the manufacturer, the probe is sensitive to plant material within approximately 4 cm. The calibration procedure, at all sampling dates, consisted of clipping to ground level twenty 30 cm diameter quadrats, where five probe readings had been taken. The average, by difference with the mean of five pre/and post/air-readings produced the final, corrected values. Weights of over-dried collected material were related to corrected readings through the equation above. Correlation coefficents always exceeded 0.9.

Readings were taken weekly at each treatment. The mean of 10 readings per quadrat were taken at each of three fixed shelter treatment positions per replication. This resulted in 120 weekly readings per treatment.

The projection of quadrats for T2; T3; and T4 (Figure 3.3.b) overlapped slightly, but the readings were independent.

3.4.4.10 Statistical analysis

Months were grouped into their corresponding seasons: summer, autumn and spring. The analysis of relative growth rate data was planned as a split-plot design applied on a randomised complete-block arrangement, where treatments (shelter), were the main plot effects and seasons the sub-plot effects (Table 3.4). Class comparisons through orthogonal contrasts and response trends through orthogonal polynomials were considered. Additionally, regression analysis was done on transformed treatment levels (as in Section 3.4.4.5).

Table 3.4: ANOVA table for a split-plot from randomised complete block design of tussock density experiment.

Source of Variation	df
Rep	4
Main Plot	
Shelter (Sh)	9
error (a)	36
Sub-plot	
Season (Se)	2
Se x Sh	18
Error (b)	72

Other measurements were analysed through ANOVA for randomised complete block designs, as indicated when appropriate in the Results section. All tables are in Appendix 2.

3.4.5 Results

3.4.5.1 Effects of tussock shelter on relative growth rates

a) Shelter classes

Mean relative growth rates (RGR) across seasons for each shelter class within tussocks suggest that growth was enhanced on areas not too close, but presumably still under the influence of a tussock (Figure 3.5). This is particularly clear within the sparse density, where a sunny area, close but not contiguous to a tussock (T6) presented an RGR significantly higher than in the open (T10) or completely sheltered ones (T1).

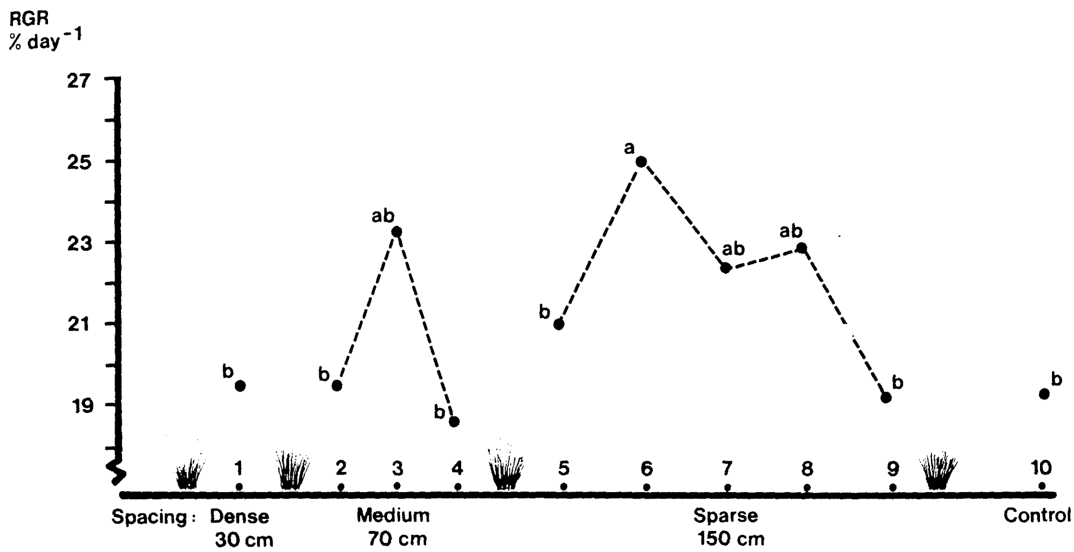


Figure 3.5: Mean relative growth rates of pasture (% day^{-1}) across summer, autumn and spring for shelter treatments within a control and dense, medium and sparse tussock densities. Minimum Significant Difference = 4.89. Means with the same letter are not significantly different according to Waller-Duncan K-ratio t Test.

It could be inferred that sunny aspects (T4 and T9) represent lower RGR values than shady aspects (T2 and T5), but the difference is not significant (p = 0.4). Nonetheless, the contrast between areas close to (T4, T5 and T9) versus away from the tussocks (T3, T6, T7 and T8) was highly significant in favour of positions away from tussocks (p = 0.001). Furthermore, these were also significantly higher than those in the open (T10, p = 0.002). On the other hand, this control treatment (T10) was not statistically different from either aspect or completely sheltered areas (Appendix 2).

All these observations suggest that the differences between treatments may follow a trend, where the response in terms of relative growth rate at each position was determined by intensity of shelter, RGR tending to be higher away from tussocks, but within 'protected' areas.

Table 3.5: Canopy coverage, distance to nearest tussock and shelter coefficients for shelter treatments.

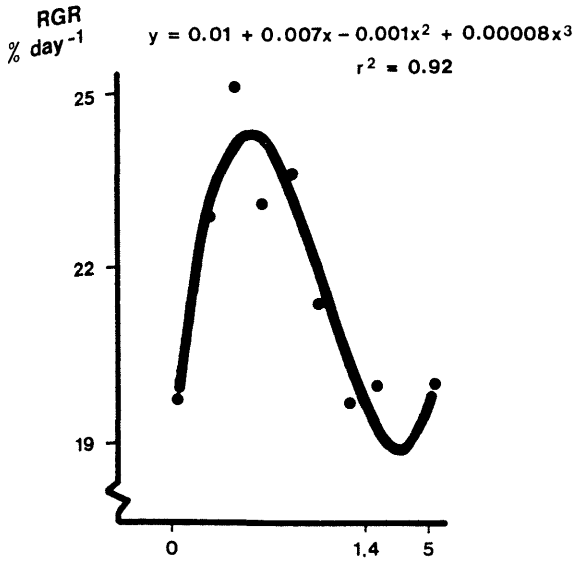
	Shelter positions									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Distance to nearest tussock (cm)	15	15	35	15	15	45	75	45	15	-
% canopy coverage from:										
N	5.0	1.9	2.0	1.0	0.4	0.0	0.3	0.2	0.2	0.0
NW	7.8	1.8	1.7	0.9	0.3	0.4	0.3	0.3	0.3	0.0
W	6.0	1.1	1.9	3.8	0.1	0.2	0.1	0.6	0.8	0.0
SW	8.4	1.9	4.0	8.9	0.8	1.3	1.8	2.5	5.2	0.0
SE	6.2	2.0	2.3	2.3	0.0	0.5	0.2	0.3	0.1	0.0
E	9.8	2.1	1.0	0.9	0.3	0.3	0.3	0.2	0.0	0.0
NE	7.9	7.3	4.6	2.9	7.5	2.4	1.6	1.3	0.6	0.0
Total	59.2	19.2	18.2	22.4	9.9	5.1	4.6	5.4	7.5	0.0
Shelter coefficient	4.5	1.4	0.6	2.1	0.7	0.1	0.1	0.2	0.8	-

b) Shelter levels

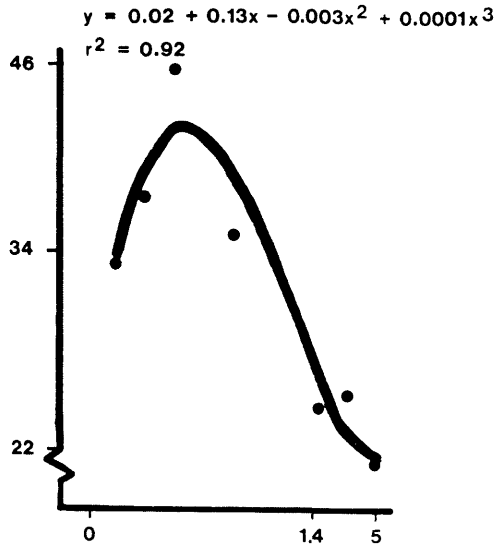
Shelter classes were transformed into shelter levels as detailed in previous sections. Canopy photographies with corresponding percentage of coverage are in Plate 1. New shelter co-efficients are in Table 3.5. These have the advantage of ordering treatments on a gradient which is consistent with Figure 3.5. The least shelter is at T7, at the centre of the sparse density, and at the contiguous T6, with values very close to T8, the other 'central-space' treatment within the sparse density. These are followed by T3, equidistant to tussocks at medium density; then by T5 and T9, this is shady and sunny aspects in the sparse density, where shelter comes mainly from one tussock. Shelter values keep increasing at T2 and T4, now shady and sunny aspects in the medium density, where shelter comes from surrounding tussocks. The higher value belongs to T1, the dense treatment.

These 'upgraded' data allow a second approach, where treatments are ordinated assuming equal 'spacing' between levels. Under such assumption, if results are generalised for all measurements as in Figure 3.6.a, data fit a third degree polynomial function (R^2 = 0.92), whose meaning is basically maintained if decomposed by seasons.

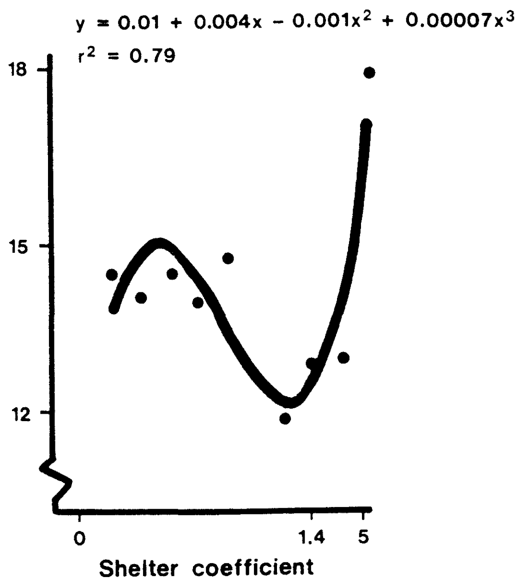
The interpretation of this curve is a sharp increase of RGR values from a non-sheltered to a low-shelter situation until an optimum shelter value is met; and then a decrease with intermediate values, down to a point where seasons determine the effects of extreme shelter.



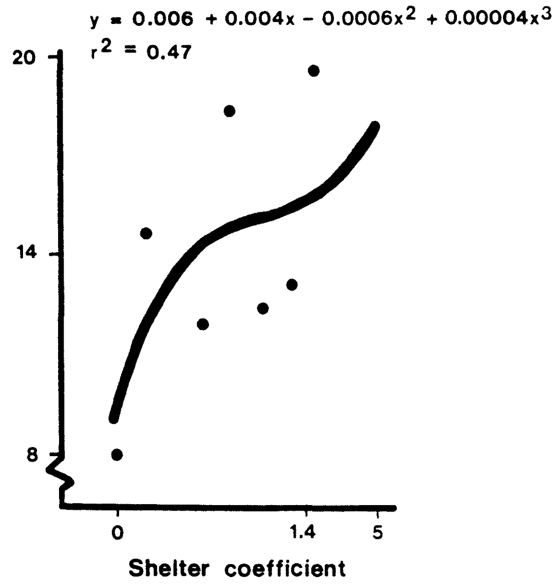
a) Means for all measurements



b) Spring



c) Summer



d) Autumn

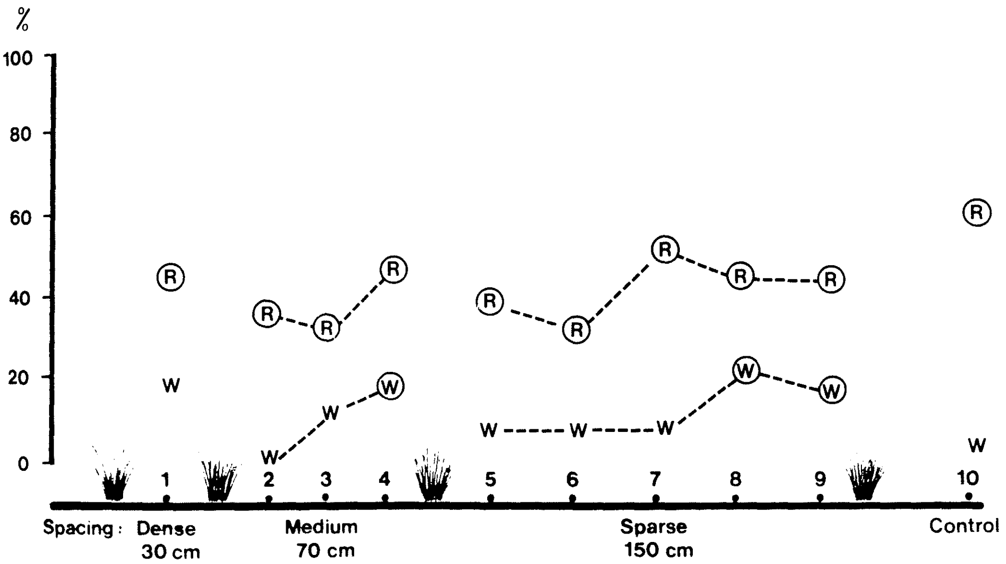
Figure 3.6: Mean relative growth rates of pasture(% day^{-1}) for shelter treatments ordinated assuming equal 'spacing' between shelter levels.

Further 'upgrading' of data could be attempted accepting actual numerical values from transformation. Unfortunately, there is too much difference between the value for dense shelter (T1 and T2) and the rest; points therefore become crowded at the extremes, and a significant linear trend becomes dominant (p=0.003), with RGR decreasing as shelter increases at all seasons. The previous approach seems more appropriate because visual inspection of actual points, significance of contrasts (Appendix 2) and biological meaning are in good agreement.

3.4.5.2 Botanical composition

Green ryegrass was the most important component of total dry matter (43%), followed by litter (31%), other grasses (14%) and white clover (12%). The amount of other species was negligible. Figure 3.7 shows the distribution of white clover and ryegrass at each shelter treatment. White clover grew more at sunny rather than shady sites (p = 0.05). Litter, on the contrary, was more abundant at shady areas. Other effects were not significant.

Tiller numbers decreased linearly with increasing shelter for both white clover and ryegrass (p = 0.00) and tiller density was higher away from rather than close to tussocks (p = 0.00).



igure 3.7: Percentage contribution to total dry matter of white clover (w) and green ryegrass at each shelter treatment. Standard Error LS means = 7.1. Means in circle are significantly different from 0 at $p<0.05$ (H_0 = LS mean = 0).

3.4.5.3 Radiation

a) Light interception

Canopy photography for each treatment (Plate 1) shows that in T1 (centre of high density of tussocks) canopy coverage was 59.2% in contrast to 0.0% at the control (no tussocks). Canopy coverage for treatments within the sparse density was below 10%, whereas at the medium density it ranged between 19 - 23%. Further description is in Table 3.5.

The effects of canopy coverage on incoming radiation will depend on sky conditions and season. Examination of the solar chart for the site (Figure 3.8) shows that maximum inclination of the sun is:

- 69.8° in mid-summer (greatest light penetration),
- 46.7° at autumn and spring equinox,
- 22.9° in winter (least light penetration).

Accordingly penetration of light into treatments will have important seasonal fluctuations. For instance, the track for winter solstice (line I), if superimposed on T1 (high density) reveals an 'opening' of about 12%, whereas for summer, the same 'opening' increases to 50%.

Light penetration calculated as above does not include scattered radiation, but average photosynthetically active radiation is little scattered (Anderson, 1971).

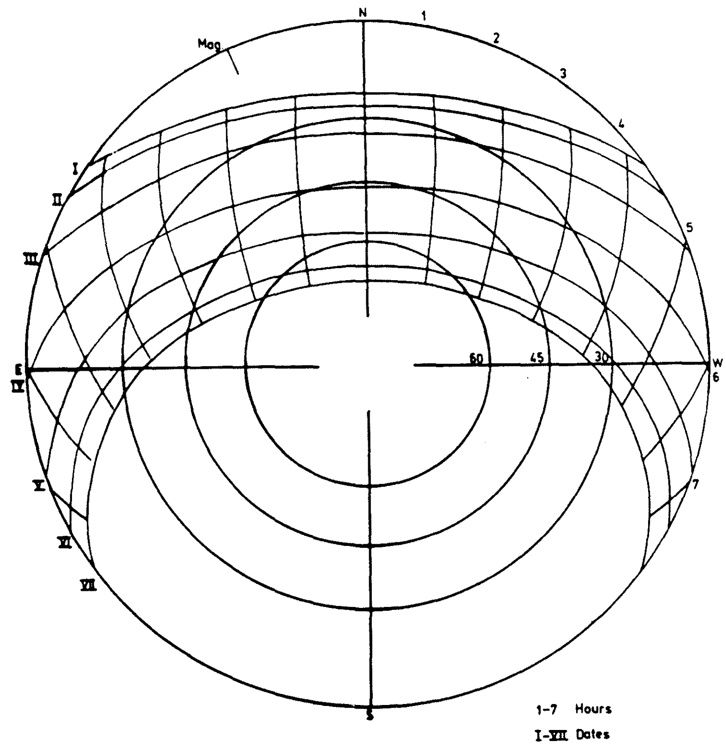


Figure 3.8: Standard solar tracks for Lincoln College, latitude: 43° 39' (calculation according to Evans and Coombe, 1959, pp. 111-113). Numbers right of apparent North represent hours after noon; numbers to the left of apparent North represent hours before noon. I is winter solstice; IV are the equinoxes and VII is the summer solstice.

From another point of view, considering the shadow cast by any individual tussock, noon projections of shade on top of the pasture canopy will cover 0.17 m^2 in mid-winter; 0.09 m^2 in spring-autumn; and 0.05 m^2 in summer (standard procedures for calculation of Ab and Ap, Monteith, 1973; pp.39-43).

From considerations above, there are significant differences in incoming radiation between treatments, T1 intercepting the least; T2, T3 and T4 with intermediate interception; and T5 - T9 receiving a significantly higher amount of light.

b) Photosynthetically active radiation

Means of direct measurements taken hourly (9 AM to 5PM) during three days at all treatments are in Figure 3.9. Shady aspects (T1, T2 and T5) are significantly lower than the rest ($p = 0.05$).

An accurate estimate of radiation income requires complex measurements beyond the objectives of this work. Suffice to conclude that radiation measured with a single radiometer supports descriptions done with canopy photography, in that over-all daily quantum means are lower ($p = 0.05$) within dense tussocks and on shady aspects of tussocks.

3.4.5.4 Wind speed

a) Introduction

The concepts and procedures to develop the wind profile that follows have been extracted from Monteith (1973) and Jones (1983).

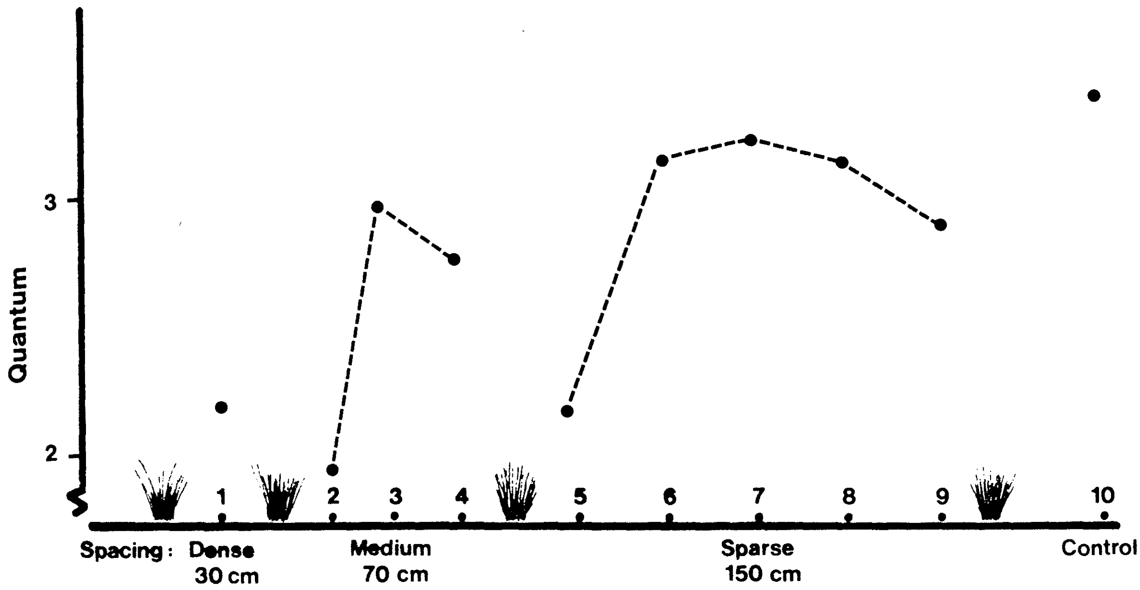


Figure 3.9: Mean radiation at each shelter treatment (LSD = 0.44) (quantum = microeinsteins m^{-2} sec^{-1}).

The ground exerts a drag force which decreases wind speed down to an assumed zero value at the surface. This force, and forces moving the air may 'break' into 'packets' called eddies. The rate at which horizontal momentum is transferred to the surface, or in other words, the drag force per unit area, is often called friction velocity or eddy velocity (u^*). Eddies form a turbulent boundary layer in which the wind speed increases linearly with the log of the height, and eddy velocity can be calculated multiplying the slope of that regression by a constant 'k' (Karman's constant = 0.41).

Irregular or 'rough' surfaces, such as crops, will generate continuous turbulence, which results in the lifting of the apparent soil surface up to a distance 'd', called zero plane displacement. In practice, this distance is about 0.63 of the height of the pasture or crop.

From the shape of a wind profile it is possible to estimate the vertical position above the surface where the mean speed of the wind ('u') will be zero. Such position is called roughness length or z_0. Because in crops the apparent soil surface has a 'd' value, z_o must be added to it to find the true height of wind extinction. From the authors above, the calculation of roughness length is through equation:

$$Zo = e^{-(1/u^*)} m$$

where

z_o = roughness length
u^* = eddy velocity
k = 0.41
m = height in metres

b) Wind profile

Friction velocity and roughness length were calculated for dense, medium, sparse and control tussock densities. Assuming a constant 'd' value for ryegrass, from Table 3.6 it is apparent that the drag force or friction velocity is much higher among dense tussocks, which leads to a roughness length value of 23 cm. This means that inter-growing ryegrass in practice does not suffer the effects of horizontal wind speed.

Table 3.6: Wind profile for spacing treatments.

Treatment	Slope	Intercept	r^2(%)	u* (ms^{-1})	20 (cm)
Dense	1.29	-3.09	95.5	0.53	23.0
Medium	0.59	-0.15	96.1	0.24	2.3
Sparse	0.45	0.22	98.6	0.19	0.6
Control	0.62	0.57	99.7	0.25	2.7

From a practical point of view, differences between other densities are negligible, with z_o values about 3.0 cm. Within the sparse density, however, z_o is only 0.6 cm.

It will be noted that z_o for T1 would fit a value calculated for a closed canopy (0.63 x 35 cm height of tussocks). Other treatments present lower values. Such calculations have only an illustrative value, since wind affects the architecture of vegetation and therefore both (d) and (z_o) will vary with varying wind speed. Furthermore, the ideal ratio between distance of traverse across the surface (fetch) and height of the airflow is 200:1, this is, 200m across is required to achieve a constant layer 1 m deep (Monteith, 1973).

A more general description is obtained plotting wind speed for each density at four heights (10; 20; 30 and 50 cm) expressed as percentage of a standard at 1.8 m (Figure 3.10). This graph shows that within 10 cm from the ground wind speed decreases to less than 10% for dense tussocks, whereas wind speed reduction for other densities is only 50%. Above 30 cm differences tend to disappear. At any rate, differences maintained the expected order: wind speed is higher in the open, decreasing within the sparse, medium and dense planting configurations.

3.4.5.5 Temperature

a) Week records

As shown in Table 3.7, during spring the medium density was the warmer, with 58.1% of the time above 10°C, and 24.2% of the time above 20°C. Other treatments were 44 to 45% of the time above 10°C. In summer, warmer temperatures were recorded at the sparse density, with 91.5% of the time above 10°C, and 8.6% above 31°C. This situation changed again in autumn, when higher temperatures occurred at the control (no tussocks), with 50.2% of the time above 10°C.

Likewise, dense tussock was coolest in spring; medium density was coolest in summer and sparse density in autumn.

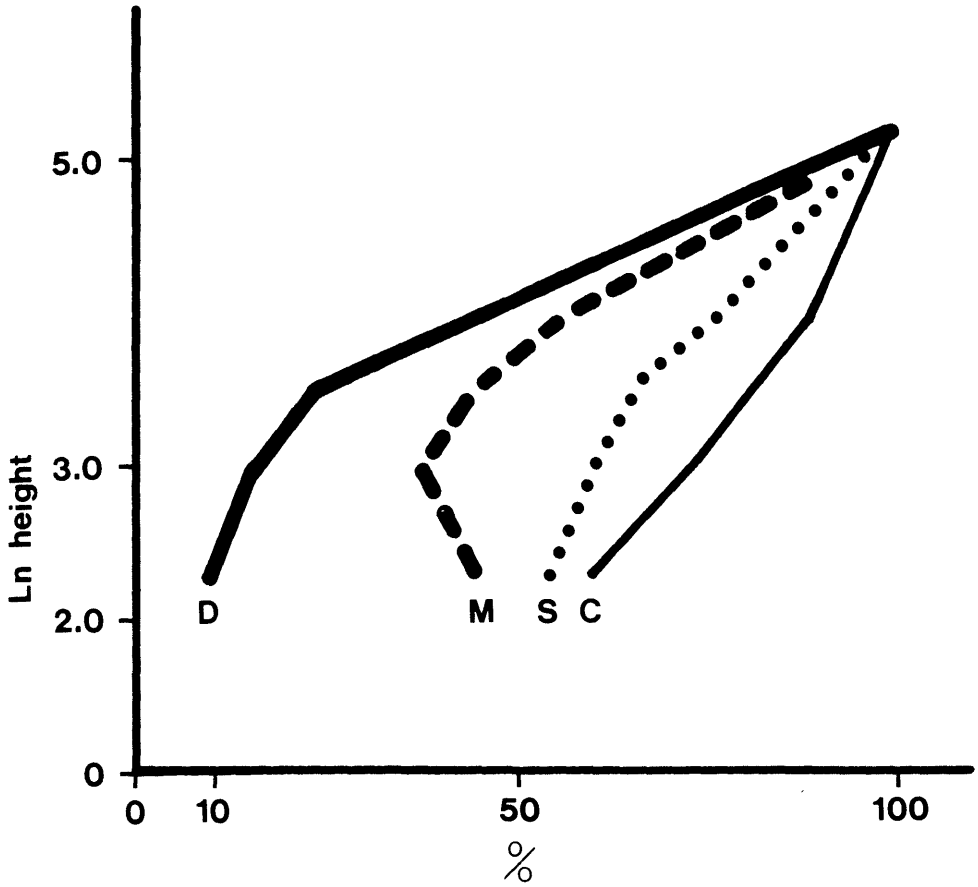


Figure 3.10: Wind speed at four heights below tussock canopy as percentage of speed above canopy (180 cm).

Tussock densities:
D = dense
M = medium
S = sparse
C = control

A closer examination of possible variations due to the presence of tussocks was attempted by taking simultaneous records for air at 10 cm height and soil at 7.5 cm depth. This was done for contrasting shady and sunny aspects within each density on a sunny spring day. Differences between aspects were significant, sunny areas being warmer in all cases (p=0.00; Table 3.9). Mean air temperatures were higher without tussocks and lower at medium density. Soil temperatures were also higher without tussocks, but lower at dense and sparse tussocks.

Table 3.9: Multiple comparison of the mean air and soil temperature of sunny and shady areas within each spacing treatment (Waller-Duncan).

Tussock Density	Air °C	Soil °C
Dense	31.1 b	24.4 c
Medium	28.4 c	25.9 c
Sparse	30.9 b	24.7 c
Nil	32.6 a	26.6 a

Means with the same letter are not significantly different LSD air = 1.2; LSD soil = 0.6.

c) Leaf temperatures

Leaf temperatures related to ordered shelter levels (T1-T10) through a curvilinear relation (R^2 = 0.80) where temperatures were highest without shelter, decreasing towards mid-shelter situations represented by T3, T5 and T9, and increasing again as shelter values approximated higher tussock densities (Figure 3.11).

d) Temperature profile

Within all densities ten sets of simultaneous measurements at 10, 20, 35 and 180 cm height were recorded at two minute intervals during a hot summer day.

Extreme shelter situations presented profiles with opposite trends: among dense tussocks air temperature increased with height; whereas in the open (control) temperature decreased with height (Figure 3.12). At intermediate densities temperatures varied less, tending to be fairly constant at the sparse and more like the control within the medium. Lower temperatures were between 20 and 35 cm, this is, about tussocks height.

3.4.5.6 Miscellaneous observations

a) Sheep site selection

Grazing sheep showed preference to concentrate in between tussocks, both to graze and to rest (Plate 2). An indirect estimate of this reference would be shown by dung accumulation, which was significantly higher ($p = 0.03$) on tussock planted plots when contrasted with non-planted ones.

b) Soil moisture

Under severe drought conditions soil moisture was measured at all shelter treatments. Highly significant differences were recorded for the contrast between tussock densities as compared with the effect of aspect ($p = 0.00$).

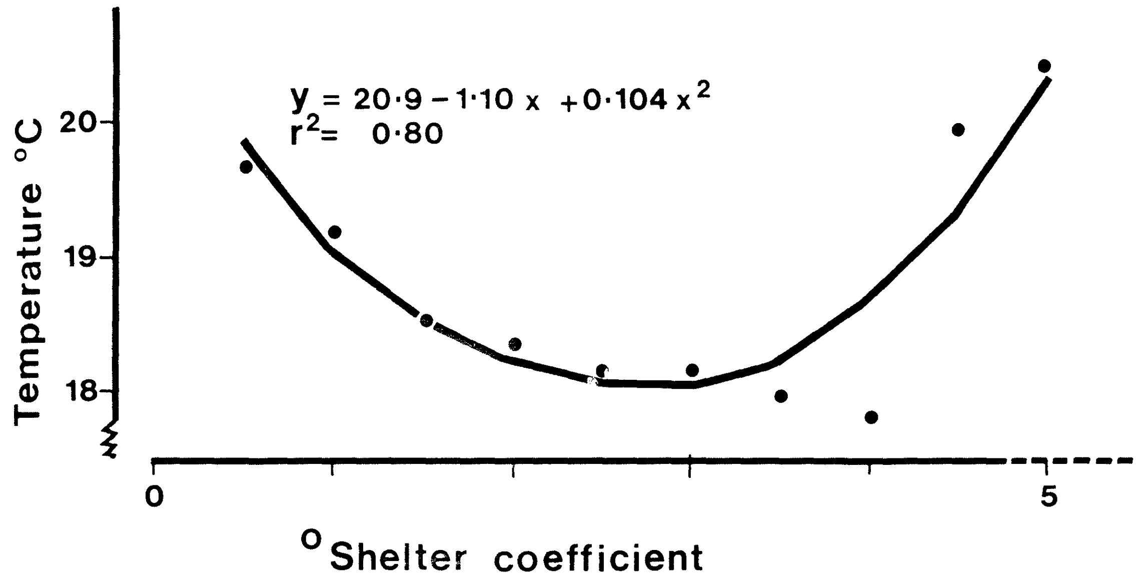


Figure 3.11: Leaf temperature (°C) for shelter treatments ordinated assuming equal 'spacing' between shelter levels.

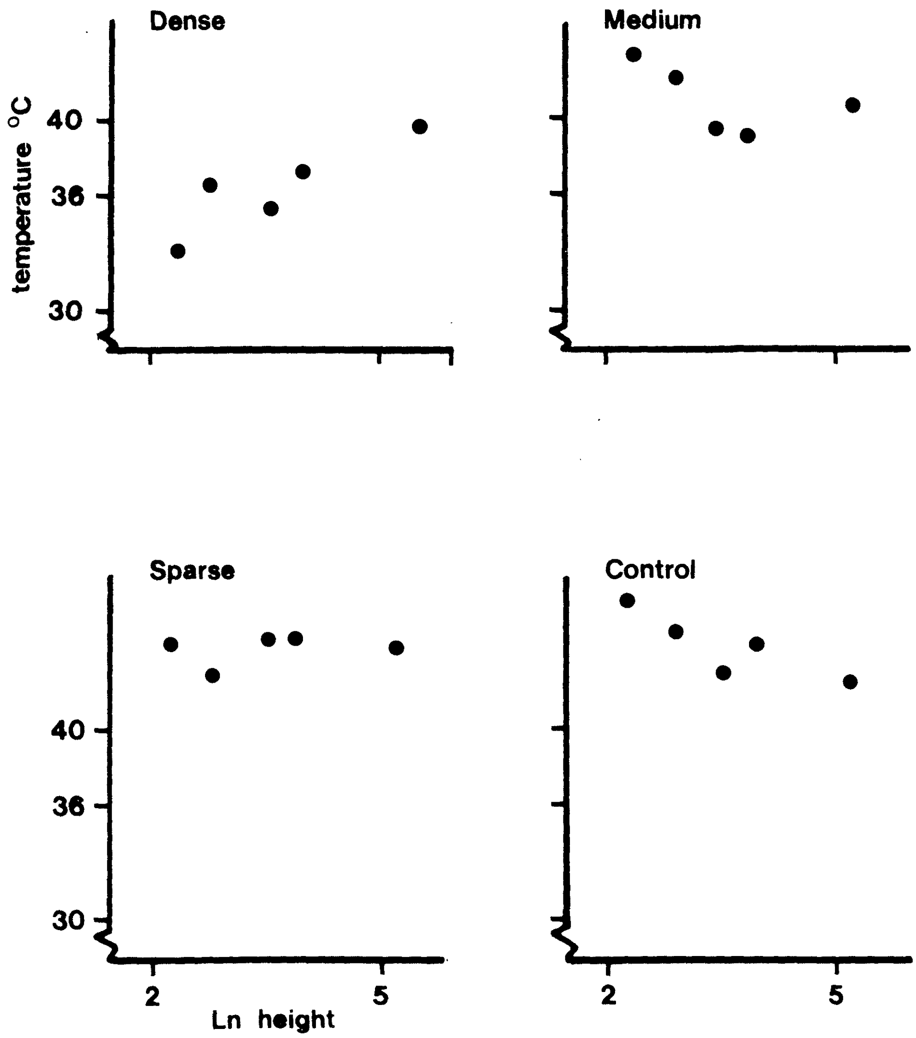


Figure 3.12: Temperature profiles from spot measurements for the central area of each planting configuration (dense, medium, sparse and control).

Plate 2: Hoggets grazing and resting the tussock shelter trial at Lincoln University.

c) Tussocks height

By the end of the experimental period it had become apparent that dense tussocks were taller than the rest. In fact, the sparse tussock density plants were 6.9 cm shorter (L.S.D. = 2.7 cm) than dense and medium spacings (46.4 cm, versus 53.3 cm respectively). In other words, whereas all plants were 30 cm tall at the start, sparse plants grew about 21% less.

3.4.6 Discussion

The basic questions that this experiment attempted to answer were: do tussocks affect the growth rates of an established pasture? If so, could the response of such pasture be related to tussock densities?

Overall results indicate that tussocks, in general, increased the growth rate of an inter-growing established ryegrass pasture. If Figure 3.5 is simplified, and mean relative growth rates for each density are compared with control as base, then growth rates among dense tussocks were 1.4% higher, among medium density tussocks RGR 6.3% higher, and among the sparse density tussocks RGR was 15% higher than in the open.

A second, more quantitative approach, suggests that relative growth rate is increased by low shelter values, but only to an optimum which in this case corresponds to a tussock canopy coverage of 4.7% in an area 30 cm away from the shady aspect of a tussock, yielding protection from cool south-westerlies, within a planting configuration with plants 150 cm apart (T8). Lower relative growth rate values (and clover grass and clover tiller densities) were recorded for intermediate shelter levels equivalent to a canopy coverage of about 20%, corresponding to areas close to tussocks, regardless of aspect, within a spacing with tussocks 70 cm apart (T2 and T4). High shelter effects depended on seasons.

The superiority of the sparse density may be enhanced by the fact that in field conditions, tussocks may have a basal area perhaps larger than the experimental one. More land potentially in improved pasture will be occupied with high densities i.e. if plants occurred 30 cm apart, then the area covered by tussocks may be in excess of 20%, instead of 5% as in the trial. Furthermore, high field tussock densities would imply unrestricted below ground competition which was reduced in this experiment. Such an effect is likely to be more important under drier conditions.

The chosen sampling design may have emphasized shelter effects because it gave preferential importance to aspects and protection from predominant wind direction, and did not cover the entire inter-tussock areas. Planting configurations conformed to geometric patterns which were experimentally convenient, but which may not occur in nature.

To quantify shelter somewhat arbitrary decisions were necessary. In this case, those decisions refer to the proposition of a coefficient, where preferential weight was given to protection against cool (but not dominant) south-westerly winds, on the grounds that this would be more restrictive to growth. It was also assumed that canopy coverage would integrate well the notions of height, porosity and light interception from tussocks and that distance to the sampling areas was inversely proportional to the shelter they provide. This definition of shelter found empirical support in that the resulting functions relating shelter with relative growth rate could be explained satisfactorily in biological terms.

Increasing shelter from zero to low values results in higher relative growth rates than occurred from intermediate shelter levels. This tendency may be related to some extent to temperature interactions, because data collected indicated a trend for leaf temperatures to decrease from extreme towards intermediate shelter. The suggestion is that relatively high temperatures stimulate growth. However, the initial increase from nil to low shelter is not present here, although continuous recording showed lower air temperatures at the unsheltered compared with the range of shelter levels within sparse and medium densities. Additional spot measurements indicate that sunny areas are warmer than shady ones, but these measurements were not taken for all shelter levels.

During spring, accelerated growth could be limited by nutrient availability, light interception and cold winds. This restriction may be greatest among dense tussocks because light penetration is 30% below optimum (summer) and temperatures are also comparatively cooler than other treatments at this time of the year, with a lower percentage of time above 10°C. Protection from wind may have been offset by such factors during spring. In fact, disruption of turbulence and cold might combine to increase the risk of frost (Geiger, 1965). Accumulation of carbon dioxide on calm nights could also be detrimental to photosymbolic ratio (Rosenberg, 1974). Such conditions are, however, infrequent in Canterbury.

During summer and autumn relative growth rates were higher when shelter values were very high. The main probable climatic restrictions to growth at this time are soil moisture and wind, because incoming radiation and temperature will be at their maximum. Soil moisture under extremely dry conditions was in effect higher on shady rather than sunny areas (low and high shelter values respectively) and the reduction of wind speed is greater with high shelter values respectively) and the reduction of wind speed is greater with high shelter values, as seen in the wind profile.

Complex interactions between temperature and light intensity may magnify seasonal effects. Perennial ryegrass has produced higher yields at intermediate intensities of light (medium to high shelter) if temperature was about 30°C; but if temperature was about 20°C higher yields were produced with the highest intensity of light (Dale and Milthorpe, 1983).

This experiment considered tussocks only as a structural component of vegetation. This might have been true early in the experimental period, but tussocks responded positively to increasing density, their bulk becoming larger. Some competition effects cannot be disregarded in explaining the negative effects of increasing shelter levels. On the other hand, animals selected tussock planted areas. This could result in a greater grazing pressure, particularly if white clover were present.

Summarising, recorded relative growth rate trends are supported by a free interpretation of spot microclimatic measurements and have the attractiveness of their seeming logical.

An important comment is in relation to the type of the inter-growing pasture, since this results refer to a grass of lower stature than tussocks. The success of legumes in the Lake Tekapo experiment do not suggest that fescue tussocks of local size could there affect the performance of established, legume-dominated pastures. Rather, their relative importance is greatly reduced.

3.5 SUMMARY

The ecological strategy for tussocks appears to be oriented to stress-tolerance. This enables them to withstand environmental restrictions, but they appear not so tolerant of highly productive conditions with related intensification of grazing management.

In Lake Tekapo, five soil growth potentials, three stocking rates and two grazing management combined showed that persistence of fescue tussocks was better under moderately low levels of intensification (lax stock grazing plus about 100 kg of fertiliser ha^{-1} yr^{-1}). Nonetheless, introduced legume species became dominant and tussocks ranked very low. Interactions with grazing selectivity are very likely.

The presence of tussocks in an established, shorter ryegrass pasture produced a favourable shelter effect if tussock density was low (plants at least 120 cm apart).

Increasing tussock densities may produce the opposite effect, particularly in spring, when growth rates of in-between pasture may actually become lower than in the open.

On the other hand, very dense tussocks may favour growth during the warm season. This might be offset by a larger area occupied by tussocks. These empirical observations find some support in soil moisture contents and interactions between light penetration and temperature.

Chapter 4

GRAZING SELECTIVITY IN SHEEP

4.1 Introduction

It comes from practical knowledge that animals do not graze at random, although controversy has been raised about possible mechanisms regulating this process. Selective grazing has received particular attention in three fields:

- animal ecology, to determine the use an animal makes of its environment,
- plant ecology, with reference to effects of both wild and domestic animals under extensive grazing conditions on plant survival,
- animal production, essentially concerning forage intake.

It could be expected that the great deal of information on this subject would be synthesised and put into practice through specific forage allocation programs. However, the applicability of preference indexes to specific grazing programs in practice has been limited (Wallace, 1984).

Still, knowledge of grazing preferences is useful if the purpose is to diagnose the condition of extensive or semi-extensively grazed vegetation. Here systems are conceivable where knowledge on species distribution and seasonal variations in acceptability for different types of stock could be used for better management decisions. At present, those decisions do not seem to be of paramount importance.

For the specific case of South Island high country, a general ranking of the acceptability of most naturally occurring and a few introduced species is known, either empirically or from the scarce literature on the subject. Yet they cover only the contrasting situations of developed and undeveloped range, under extensive or semi-extensive grazing. If preferences are relative, as they most probably are, a closer definition is desirable within the context of different mixtures and environments.

The aim of this section was to study the relative sheep preferences for the most important species in the species introduction trial at Lake Tekapo. It is hoped that this information will be a useful complement to determine their future utilisation.

4.2 REVIEW OF LITERATURE

4.2.1 Introduction

Forage intake has been reported to be a world-wide major limiting factor to production from grazing animals (Hodgson, 1982). Consequently, there is much information on grazing preferences which have been thoroughly reviewed and discussed in recent times by several authors. Basic to the present work have been critical reviews by Pyke *et al.* (1977) dealing with ecological theory; Arnold and Dudzinski (1978) in relation with animal ethology; Hodgson (1982) referring to intensive or semi-intensive grazing systems; Skiles (1984) covering research in the American range; Wallace (1984) discussing the practical utility of knowledge on this field; and Hughes (1975), Stevens (1977) and Harris and O'Connor (1980) for relevant studies in different conditions of the high country in South Island.

4.2.2 Definition of terms

Preference (Stoddart *et al.* 1975) is merely the selection of plants by animals. In the more general context of resources (Johnson, 1980), 'preference' is the likelihood of a component being chosen if offered on an equal basis with others. Complementary to this are the notions of *abundance,* or quantity of a component in the environment and *availability*, or accessibility of the component to the consumer. Usage would be selective if components were used disproportionatly to their availability.

Palatability (Skiles, 1984) is the attractiveness of the plant, not its actual selection. According to this author it is incorrect to use 'preference' and 'palatability' interchangeably.

Diet selection (Hodgson, 1982) is a function of **preferences** which would occur if **choice** were unlimited, modified by the degree to which the characteristics of the vegetation canopy influence the **opportunity** for selection.

Diet preference (Ellis *et al.* 1976; quoted by Skiles, *op.cit.*) is a function of forage size, forage novelty, temperature and humidity (as affecting plant appearance), forage quality, and physiological and reproductive state of the animal.

Site selection and **bite selection** (Milne *et al.* 1979; quoted by Hodgson, *op.cit.*) introduce the component of sward structure and give a new perspective to an earlier definition by Arnold (1964), where grazing occurred as movement in a horizontal plane, whereas selection was movement on a vertical plane.

In this work the terms **selectivity** and **acceptability** are used reciprocally for animal and plant, corresponding to **preferences** as defined above.

4.2.3 Ranking of food preferences

Whether consideration is given to elements which determine the ecological success of different pasture species, or to the ultimate utilisation of pasture for stock feed, then preferences that stock exercise for different species have been historically considered an important factor. Skiles (1984), from 137 entries for specific dietary preferences for diverse ungulates, concluded that such preferences depend on season; past history and physiological state of both plants and animals; local patchiness of environment; herbivore interactions and competition etc. However, he warns that "...they are speculations, and though they seem intuitively correct, based on our human experience, the reasons for animal preference remain obscure".

Diet selection may result in a ranking of animal food preferences, which has been proposed as a function of food value and time. Although for ruminants most plants are edible, different parts of the plant will present different ratios of food value to handling time. Therefore, the ability to exert bite selection is an important adaptation of the grazer (Coley *et al.*, 1985). Early works by Cook and Stoddart (1953) demonstrating a selectivity of 75% for leaf tissue versus 25% for entire plants, have been followed by many others.

Within this concept, an animal may optimise its diet without being attracted by any particular species. Grazing specialisation will occur, but in vegetationally rich and stable environments, where the specialised grazer develops adaptations to break through the defences of a relatively abundant species-prey (Pyke *et al.*, 1977). However, as environments become poorer and fluctuating, then grazing animals will have to be less selective between species and more able to exert a higher bite selection within plants. In this harsh environment successful grazers in need will find few truly inedible species.

4.2.4 Species preference

In accord with the previous section, a ranking of food preferences will exist, but the items need not to be entire plants, nor a given part of plants and therefore, strictly, the ranking needs not to refer to species as such.

Nevertheless, a ranking for species preferences is a convenient way to summarise animal selectivity in practice. The accuracy of such ranking will be related to the structure of the canopy of the vegetation. If the canopy is closed and thick, such as within improved temperate grasslands, then bite opportunity may be reduced. Here species may not differ much in their acceptability, and the important selectivity factor may be the vertical structure of the vegetation, where the depth of the grazed horizon may be related to the distribution of pseudostems more than to any other component. In the same line of thought, within an open canopy such as in tussock grassland, the opportunity for bite selection will be greater and the acceptability between species will vary due to their different structure; this may result in some species appearing as preferentially grazed. In even more extensive systems the opportunity for site selection may be more obvious.

In New Zealand, Cockayne (1919, 1920, 1926) assembled many identified records on grazed plants compiled by keen observation. He pioneered this type of study world-wide (Milton, 1933). However, variation in acceptability from one site or period to another seemed to frustrate him. In fact, few words on this specific subject have been published in New Zealand since. Hughes (1975) comments that only J.M. and B.H. Hercus did further research attempting to quantify sheep grazing preference. His own thesis work is one of the more comprehensive studies on sheep's grazing preferences done in the high country (Hughes, *op.cit.*). He reported the preference order as changes in mean ranks from availability to selection for 20 species. The first 10 in preference order were: perennial ryegrass; cocksfoot; browntop; catsear; white clover; *Hieracium praealtum*; storksbill; hawksbeard; *Rytidosperma spp*; and red clover. Well down the scale of preference were alsike clover and Yorkshire fog and last was mouse-ear hawkweed. Availability and stage of maturity altered the order. He also concluded that sheep appeared to react in a predictable way to plant appearance. Spiny species such as *Discaria toumatou* and *Hymenanthera alpina* were avoided or rejected, as well as strongly fibrous grasses such as *Festuca rubra*, *F. novae-zealandiae* and *Chionochloa rigida*. Appearance was not infallible because *Hypochaeris radiata* and *Hieracium praealtum* species were among the highly preferred in spite of being apparently physically unattractive.

In summary, from concepts above it may be proposed that:

- sheep will graze according to a ranking of preferences,
- as available dry matter decreases, less preferred items will be incorporated to the diet, and
- the preference ranking may be expressed as a species ranking, particularly in reference to an open canopy.

4.3 MATERIAL AND METHODS

4.3.1 Introduction

The mob-stock treatments of the experiment as described in Chapter 2.3 is considered here. The designation of treatments will be as before:

- **(F1)** no fertiliser application;
- **(F2)** P + S = 4.5 + 10 kg/ha;
- **(F3)** P + S = 9 + 20;
- **(F4)** P + S = 25 + 27;
- **(F5)** P + S = 50 + 55 kg/ha plus irrigation;
- **(SR2)** 'ideal' stocking rate;
- **(SR1)** 'light' stocking rate (50% fewer sheep);
- **(SR3)** 'hard' grazing (50% more sheep).

The number of observations varied because plant growth varied, the minimum number of observation sets was four on SR1 at F1. The highest was 31 on SR1 at F5.

Out of this Lake Tekapo experiment only the more abundant species were analysed. Of these, the general preference for white, alsike and red clovers, as well as of the resident species have been described to some extent in literature cited. Russell lupin has not previously been reported as a pasture species and its relationship in preference to other better known species would be desirable.

4.3.2 Development of technique

4.3.2.1 Background

The determination of forage preferences by herbivores has been attempted in a variety of ways, ranging from simple direct observation to more sophisticated analysis of actual ingesta. Methods have been reviewed by Martin (1970); Hughes (1975); Holecheck, Vavra and Pieper (1982); and Skiles (1984). The conclusion from these readings is that the most used basic methods are:

- direct observation,
- determination of utilisation of available herbage,
- fistula sampling, and
- faecal cuticle analysis.

They are not mutually exclusive.

Laycock, Buchanan and Krueger (1972) compared oesophageal fistulae, paired plots (caged and open) and ocular utilisation estimates. They concluded that ocular estimates by plot were the best compromise to determine both diet and utilisation in a large scale operation. Milton (1933) had determined preferences successfully through changes in visual ranking of vegetation; Pechanec and Pickford (1937) described a technique which inspired many other papers. Methods of this kind have been improved periodically (Carande and Jameson, 1986).

In New Zealand ranking has been used by Hughes (1975) to relate the abundance of components ranked in the field and in the diet (as determined by faecal cuticle analysis); previously Scott and Maunsell (1974) had applied differences in relative rankings to determine seasonal variations in the availability of herbage species in the high country. This method is quick; differences between classes are easy to establish and these are mutually exclusive.

Stevens (1977) in New Zealand has compared analyses of samples from oesophageally fistulated animals with analyses of cuticle fragments in faeces, and also with direct observations of eaten swards as outlined by Cockayne. Stevens also attempted to compare these methods under conditions of varying total herbage supply by examining diet contents at different stages of the grazing of a sward.

4.3.2.2 Rationale

The following concepts were developed to determine whether there were selection preferences within the experiment. If selective grazing occurred, it should alter the initial relative abundance of species in a sward and hence the ranking of species within a pasture. However since the rank classes are relative and exclusive, it only requires differential selection of one species to re-order the ranking of all species. Therefore even if alternation in rank conveys a relation with animal selection suggesting rejection, preference or indifference by rank change, it would be desirable to relate this back to actual specific and total dry matter variations.

A description of selectivity should have at least two components - the process of selection and the effect of the selection on pasture components. The first component, hereafter referred to as **intensity of selection,** reflects the amount of animal 'effort' required to 'find' the preferred species. Quantitatively this could be determined by whether the rate of reduction of a particular species is greater or less than the rate of general reduction in herbage from grazing. The measure is relative and independent of whether a common or rare species is being considered. The formula developed will be given later.

The second component, hereafter referred to as **importance of selection,** differentiates between common and rare species in the relative importance in absolute herbage removal from the pasture. Quantitatively, this could be determined by the ratio of dry matter (dm) reduction of a particular species relative to the total dry matter (DM) reduction. As both components are involved in selection and both can be expressed in relative terms, a **combined selection index** was used as the product of the two.

4.3.2.3 Procedure

The available data were capacitance probe measurements of total vegetation and rank scorings of species before grazing and after 4-5 days grazing of the mob-stocked treatments in the last year of the trial as reported here.

These pairs of data for each grazing were used for each of three stocking rates by five fertiliser combinations. As mentioned earlier the total number of grazings providing 'before and after' data pairs varied considerably, from 31 for the F5 treatment to four for the F1 treatment.

The general selection response for each species was assessed from the change of frequency in rank scorings before and after grazing. In addition to this assessment a series of indices were derived. The mean total dry matter (DM) present before and after grazing were determined from the capacitance probe measurements. The corresponding estimates of the dry matter (dm) of each species were derived from the product of mean rank of each species, the percentage equivalence for ranks given in Section 2.3.3.3 and the total DM. From these, the following indices were calculated.

4.3.2.4 Indices

(1) Proportional decrease of total herbage dry matter relative to initial herbage dry matter (PDM):

$$PDM = (DM_1 - DM_2)/DM_1$$

where DM_1 = total initial herbage dry matter

DM_2 = total final herbage dry matter

(2) Percentage decrease of particular species herbage relative to initial (pdm):

$$pdm = 100 * (dm_1 - dm_2)/dm_1$$

where dm_1 = estimated species initial dry matter

dm_2 = estimated species final dry matter

(3) The relative intensity of selection of a species (Ii):

$$Ii = pdm/PDM$$

This index represents the percentage dry matter variation of a species relative to total variation. It is an indicator of animal 'effort' to select a species. It follows that:

- if Ii is greater than 100 then the indication is that a species was preferentially grazed,
- if Ii is close to 100 that the species was accepted but the selection indifferent, and
- if Ii is less than 100, then the species was not preferred.
- because of the continual growth of non-preferred species, the value of dm_2 could be greater than dm_1 and hence negative values of Ii were possible, indicating a high degree of rejection.

(4) The relative importance of selection of a species (Im):

$$Im = (dm_1 - dm_2)/(DM_1 - DM_2)$$

This index gives an estimate of the magnitude of dry matter extraction or removal for that species.

(5) Combined selection index (Si):

$$Si = Ii \times Im$$

The intensity and importance indices may vary independently. The combined selection index should allow relative assessment of species under different conditions where wide differences in initial abundance are accounting for actual animal use. High values in Si indicate both high selection and actual intake.

4.3.3 Analysis of results

4.3.3.1 Introduction

The analysis of grazing preferences has met with difficulties which have led some authors to suggest that analysis need not involve the use of mathematical formulae, nor the extensive manipulation of data (Skiles, 1984).

For assessment of general response in relation to initial species availabilities, contingency tables are used in which treatments and sampling periods are combined. For the graphic presentation of treatment effects, information on initial availabilities is sacrificed to a pooled mean for each stocking rate and soil fertility combination.

For data in the present experiment, categorical analysis is appropriate, but it can only be applied within a general context, due to the low number of measurements and the variable number of measurements within each response level and also to a high frequency of values in the lower range of the scale of measurements. On the other hand, a functional approach is precluded both by the complexity of the variables and the nature of data. Therefore, intensity of selection and effective selection indices will be presented and interpreted graphically.

4.3.3.2 General response of individual species

Pairs of ranks (range 1 to 6) corresponding to before and after grazing assessments for each species can be arranged in 6 x 6 frequency tables. These can be further condensed to give estimates of these kinds of response for each initial rank class value:

- **selected,** for where a given initial rank, the after-grazing rank, value was greater than the initial, the species therefore becoming less abundant (possible positive selection),
- **neutral,** where after-grazing rank value did not vary from the initial (possible grazing indifference), and
- **declined,** where after-grazing rank value was lower than the initial, the species therefore becoming relatively more abundant (possible animal rejection).

For each initial rank class value, all events may be assigned as a percentage to these three response classes.

A total of 183 pairs rank were considered for each species with five observations per cell being required for partial Chi-square values to be valid. The changes in frequency of a particular rank after grazing were tested by Chi-square with a single degree of freedom against the null hypothesis that frequency had not changed or that the expected frequency would be similar in three classes ('selected', 'neutral' or 'declined') using the analysis described by Lehmann and D'Abrera (1975).

4.3.3.3 Indices of individual response of species

Variations in intensity of selection (Ii) and combined selection index (Si) through the five soil growth potentials F1 - F5 and under three stocking rates SR1-SR3 (as described in Section 2.3.2.2) are presented graphically for each species. Intensity indices are interpreted as a percentage greater than 100 (positive selection), equal to 100 (indifferent grazing), or less than 100 (non-selective grazing); or negative (total rejection). On the other hand, the combined selection index is expressed in units on a scale 1-100, allowing the importance of selection to be incorporated in this index of actual utilisation of the species. When either component is negative, there is difficulty in interpreting the combined selection index.

4.3.3.4 Comparisons between species

These will be presented graphically for each stocking rate, assuming that they represent high, moderate and restricted selection opportunities at SR1, SR2 and SR3 respectively. Bar graphs are used to represent the relative variation of the six species in percentage decrease (pdm) and combined selection index, in relation to total dry matter disappearance (apparent grazing) for each soil fertility treatment.

4.4 RESULTS

4.4.1 General response of individual species

4.4.1.1 Russell lupin

4.4.1.1.a General response

Lupin was dominant in most plots of the experiment. Fifty-one per cent and 13 per cent of the records before grazing ranked it as the most abundant and second in relative importance respectively (Table 4.1). The comparison of ranks before and after all grazings over all treatments (183 data pairs) shows significant acceptance (no rank variation) in more than two-thirds of all occurrences, particularly when lupin was initially dominant. It should be observed, as indicated in Table 4.1, that this form of analysis precludes the detection of rejection at Rank 1, just as it precludes the detection of selection at Rank 6. There were too few observations of intermediate ranks to detect significant trend in selection of Russell lupin.

Table 4.1: Change in rank frequency of Russell lupin (*Lupinus polyphyllus*) with grazing.

	Change with grazing			
Initial rank	Selected	Neutral	Declined	Significance of trend
1	21	72	-	-
2	4	14	6	
3	2	4	6	
4	9	1	3	
5	4	2	0	
6	-	32	3	-

This initial analysis suggests a trend for sheep indifference in grazing lupin. There is no evidence here for species rejection.

4.4.1.1.b Intensity of selection

Figure 4.1a describes variations in grazing intensity of Russell lupin relative to total apparent grazing. As indicated earlier in Section 4.3.2.4, values over 100% signify a reduction in Russell lupin mass larger than the rate of total dry matter reduction. Grazing directly proportional to initial availability might signify indifference. Values clearly below 100% suggest non-preferential grazing. Negative values would indicate rejection.

Nearly all values for intensity of animal selection in Figure 4.1a lie at or above 100%, indicating that Russell lupin was not rejected and, at worst, grazed indifferently. At F1, it appears to have been actively selected, especially at the lowest stocking rate. It is also evident that Russell lupin has been preferentially grazed at higher stocking rates at the F4 level where it was highly productive.

4.4.1.1.c Importance index

Russell lupin was dominant at all but the highest soil fertility level and therefore was potentially a major component of animal feed. Values for importance index over the treatments F1 - F4 range from 69 to 125 at the medium stocking rate; between 40 and 80 at the low stocking rate; and between 26 and 76 at the high stocking rate. Various factors might be advanced to account for the higher range of importance values at SR_2.

Importance index was low, however, for lupins at all stocking rates at F5, where they contributed relatively little to the total herbage mass.

4.4.1.1.d Combined selection index

The combined selection indices for Russell lupin are shown in Figure 4.1b. At the low stocking rate the index showed a value higher than 100 at F1.

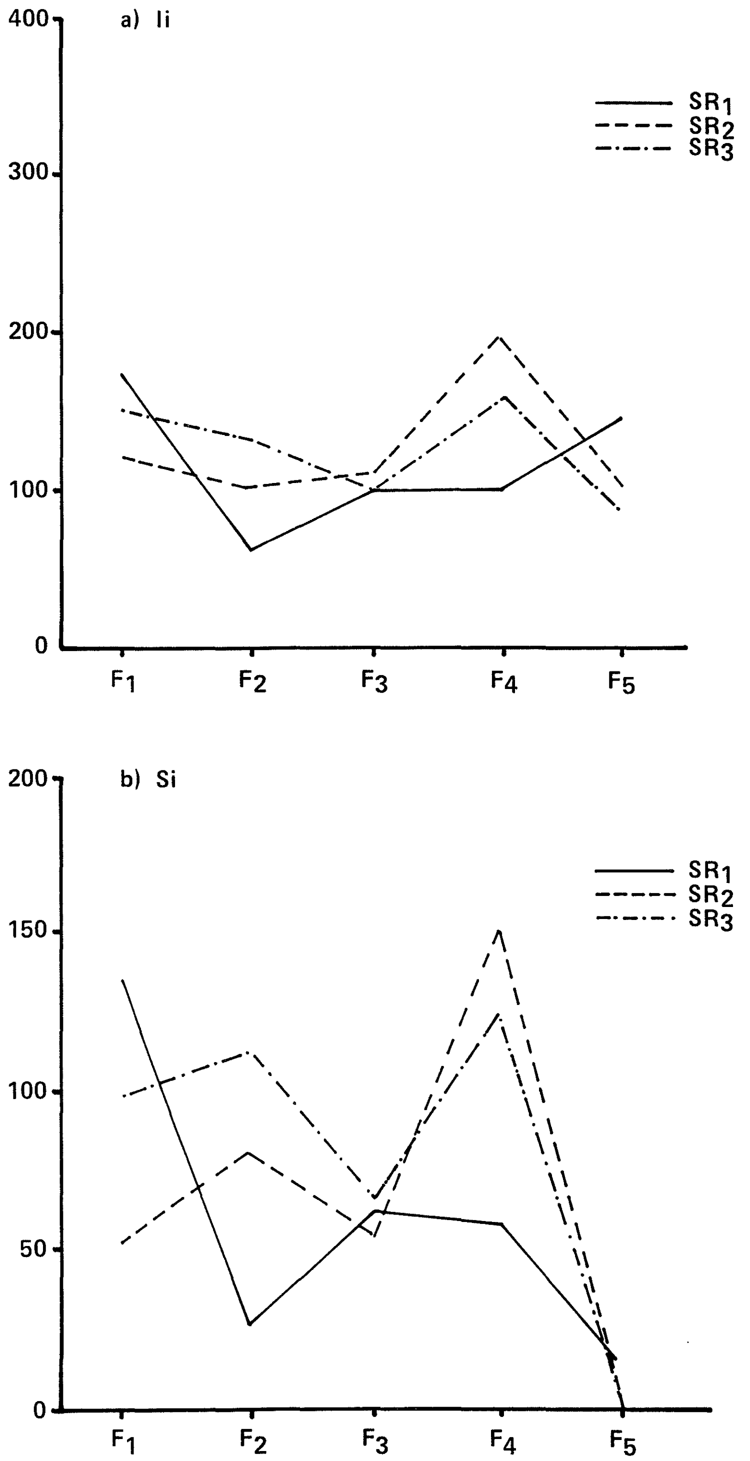


Figure 4.1: Intensity of animal selection (Ii) and selection index (Si) for Russell lupin under five soil growth potentials (F1-F5) and three stocking rates.

Under higher stocking rates, selection indices for lupin were at a maximum at F4, with values over 100. Under high fertilisation plus irrigation (F5), combined selection indices approached zero at all stocking rates. Animal selection cannot be advanced therefore as the reason for the low contribution of lupin under these conditions.

In summary Russell lupin tends to be a dominant species under all except the irrigated high fertility conditions and is grazed by animals at least equal to, or proportionately greater than, its contribution to the vegetation.

4.4.1.2 Alsike clover

4.4.1.2.a General response

Alsike clover was the second most abundant species within the experiment: rankings before grazing were 39% at first rank, 34% at second rank and 10% at third rank among total records. Grazing, however, showed a significant persistence of initial rankings in 54% of total cases, indicating neutrality or acceptance. Relative abundance decreased, indicating positive selection, in more than 20% of total cases, principally at Rank 1 and Rank 2. There were some indications of an increase in relative mass of alsike between rankings suggesting some apparent discrimination against alsike, but none could be found to be statistically significant (Table 4.2).

Maintaining the same rationale as for lupin, the initial analysis indicated that alsike clover was an abundant species, normally accepted by stock. Conditions under which it was apparently declined were not clear and may be seasonal.

Table 4.2: Changes in rank frequency of alsike clover (*Trifolium hybridum*) with grazing.

	Change with grazing			
Initial rank	Selected	Neutral	Declined	Significance of trend
1	14	58	-	-
2	23	31	8	
3	6	3	9	
4	2	4	4	
5	2	1	4	
6	-	6	8	-

4.4.1.2.b Intensity of selection

Figure 4.2a illustrates variation in selection intensity of alsike clover relative to total apparent grazing. Animal preference is indicated throughout the range of fertility and stocking rate treatments by the intensity of selection index remaining above 100%.

At the low stocking rate, values for intensity of animal selection were generally higher than at the higher stocking rates. Especially was this true over the F1 to F4 range of fertility treatments.

These observations suggest that alsike was preferentially grazed when animals had high selection opportunity.

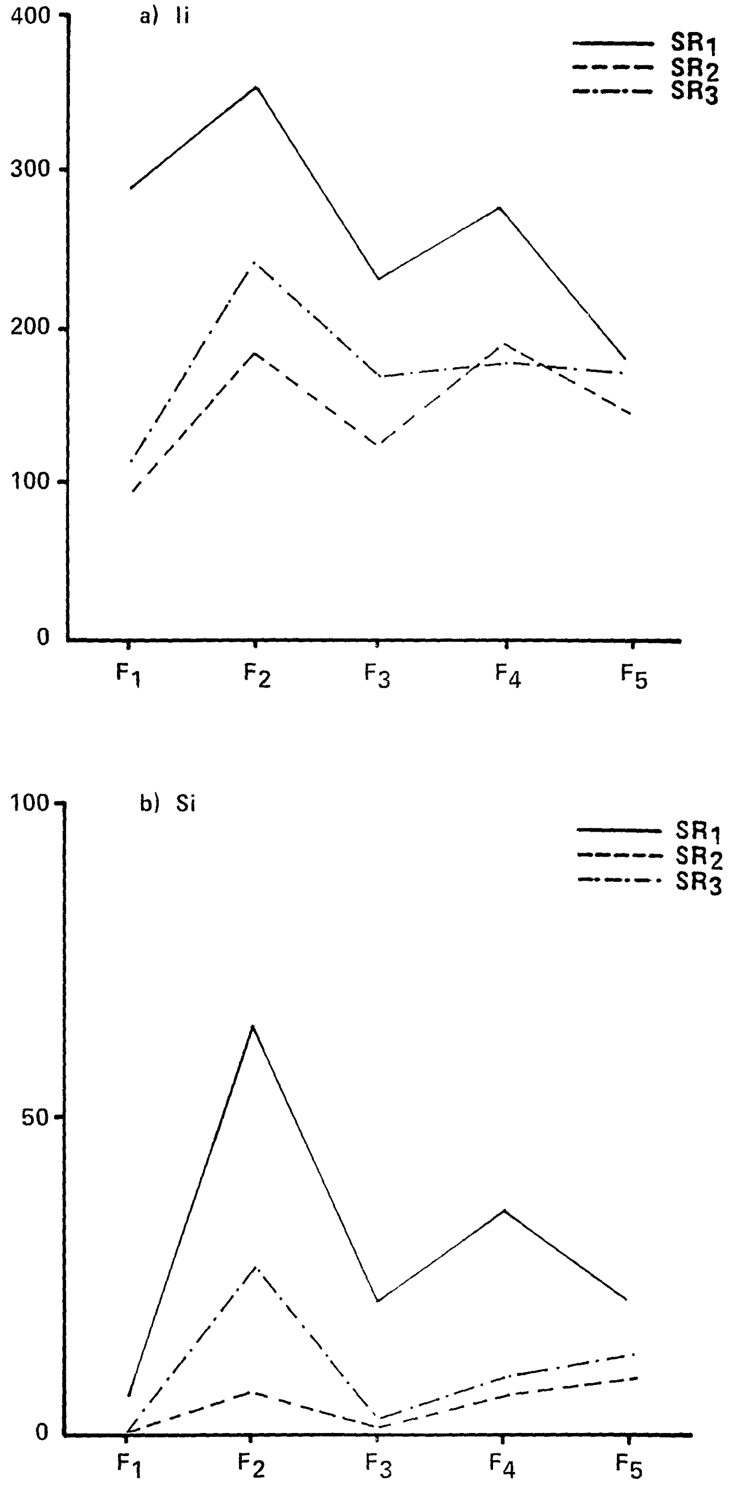


Figure 4.2: Intensity of animal selection (Ii) and selection index (Si) for alsike clover under five soil growth potentials and three stocking rates.

4.4.1.2.c Importance index

Values of importance for alsike clover are generally low, but declining from low to high stocking rates, ranging from two to 19 at SR1, compared with values ranging between one and eight for higher stocking rates. This must be related to a consistently higher initial relative abundance for alsike in SR1 treatments. From another point of view, importance for this species does not appear to be related to fertiliser levels.

4.4.1.2.d Combined selection index

In spite of a comparatively high selection intensity, the low importance indices mean that combined selection index reaches appreciable magnititude only at SR1 (Figure 4.2.b). Under higher stocking rates, the combined selection index describes variations ranging from zero to 17, lower than for SR1 at all fertility levels.

In summary, alsike clover is well accepted by animals under almost all conditions. When it is especially abundant, as at the low stocking rate, it appears to be preferentially grazed.

4.4.1.3 Mouse-ear hawkweed

4.4.1.3.a General response

Mouse-ear hawkweed appears as the absolute dominant in only 6% of total initial observations; however it is present at close to 20% at all other rank classes, which indicates its importance as a prevalent resident species. At initial Rank 1 and Rank 2, there is some evidence for persistence of ranking, indicating acceptance.

An important proportion of all occurrences (54%) show discrimination against hawkweed. At initial Rank 3, Rank 4 and Rank 5, this change was significant, but the determination of significance was restricted by the number of observations per cell (Table 4.3).

Table 4.3: Change in rank frequency of mouse-ear hawkweed (*Hieracium pilosella*) with grazing.

	Change with grazing			
Initial rank	Selected	Neutral	Decline	Significance of trend
1	4	8	-	-
2	2	19	12	
3	3	13	18	*
4	4	9	25	*
5	5	7	21	*
6	-	10	23	-

4.4.1.3.b Selection intensity

The intensity of selection for this species show negative values (Figure 4.3), indicating animal rejection at practically all situations. The exceptions are for SR1 at F1 and F3, with values that could suggest reluctant grazing.

4.4.1.3.c Importance index

Mouse-ear hawkweed was important with no added fertiliser, with values of 10 and 23 at SR1. Other treatments present either negative values implying strong rejection or very low values meaning a very low level of grazing.

4.4.1.3.d Combined selection index

The presence of negative values for importance index and some other component makes calculation of combined indices invalid.

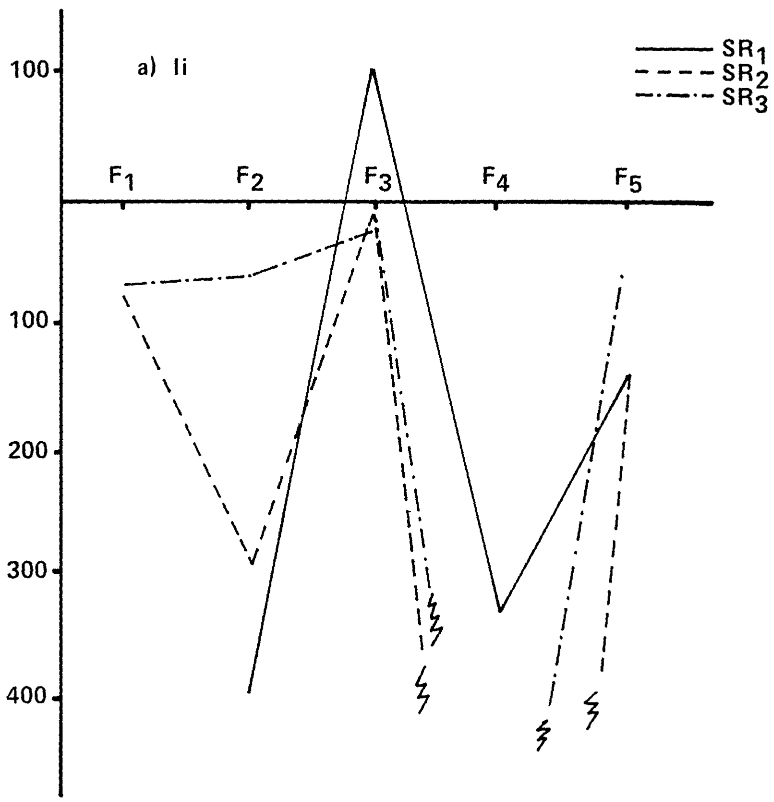


Figure 4.3: Intensity of animal selection (Ii) for mouse-ear hawkweed under five soil growth potentials and three stocking rates.

Mouse-ear hawkweed stands out as a strongly rejected species at almost all situations, at best reluctantly grazed in non-fertilised treatments.

4.4.1.4 Red clover

4.4.1.4.a General response

Red clover appears to be an important companion species, because 52% of data pairs are for initial ranks R2 and R3, with only 3% for R1 (Table 4.4).

Table 4.4: Change in rank frequency of red clover (*Trifolium pratense*) with grazing.

	Change with grazing			
Initial rank	Selected	Neutral	Declined	Significance of trend
1	6	0	-	-
2	26	5	0	*
3	40	17	6	*
4	19	4	8	
5	12	5	8	
6	-	18	9	-

The contingency table shows significant Chi^2 values for selection at R2 and R3. Although not significant at each abundance rank, the relative abundance of red clover decreased as a result of grazing in 56% of all occurrences which suggests a fair selectivity for this species. In contrast only 17% of all occurrences showed any sign of adverse discrimination.

4.4.1.4.b Intensity of selection

Examination of the trends under all three stocking rates (Figure 4.4.a) indicates generally positive selection within the middle range of soil growth potentials (F2 - F4). At F1 and F5, grazing was indifferent to non preferential. Higher stocking rates do not seem to be associated with any marked change in intensity of selection, but at the low stocking rate intensity of selection indices are much less consistent.

4.4.1.4.c Importance index

The importance index for red clover clearly increased with increasing fertiliser levels, ranging from negative or extremely low values at zero up to 66 at the highest fertiliser plus irrigation condition. Trends for stocking rate are not consistent.

4.4.1.4.d Combined selection index

The effect of increased importance index with increasing soil fertility outweighed the decline in intensity of animal selection that occurred at F5. The outcome is shown in Figure 4.4b as a generally constant increase in combined selection index with increasing soil fertility at the medium and high stocking rates. At the low stocking rate, the variation in intensity of selection between fertility levels appears to dominate the combined selection index. In summary, red clover showed a generally high level of acceptance by animals.

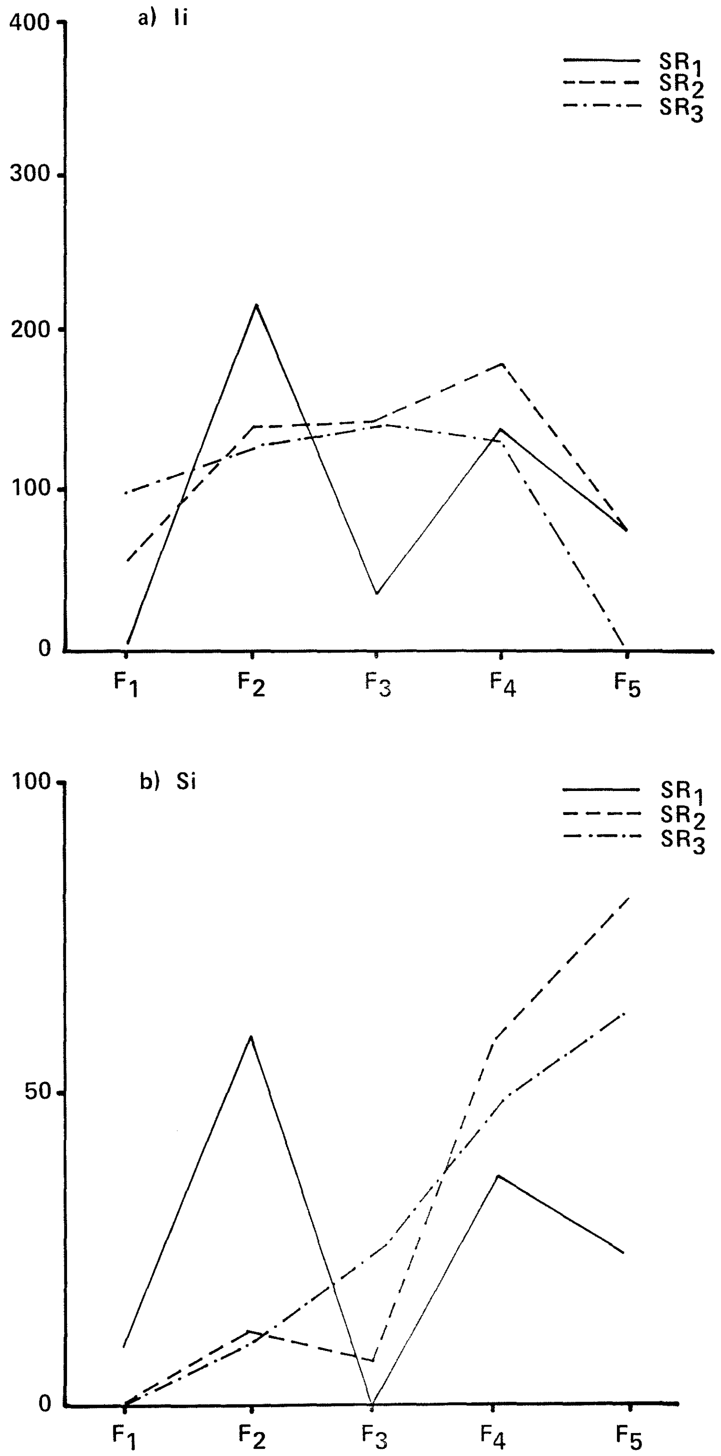


Figure 4.4: Intensity of animal selection (Ii) and selection index (Si) for red clover under five soil growth potentials and three stocking rates.

4.4.1.5 **White clover**

4.4.1.5.a General response

White clover was never the most abundant species within the trial; 59% of the records ranked it last and for only 19% of occurrences was this species second or third in rankings previous to grazing. Yet, in those opportunities the responses to grazing included statistically significant reductions in relative abundance, indicating selection.

Selection at Rank 2, Rank 3 and Rank 5 was significant. In fact, for 33% of all cases positive selection could be inferred, 60% indicate acceptance and only 6% of all occurrences indicate possible adverse discrimination (Table 4.5).

Table 4.5: Change in rank frequency of white clover (*Trifolium repens*) with grazing.

	Change with grazing			
Initial rank	Selected	Neutral	Declined	Significance of trend
1	0	0	-	-
2	14	5	0	*
3	15	1	0	*
4	11	2	3	
5	21	0	3	*
6	-	103	5	-

4.4.1.5.b Intensity of selection

As indicated in Figure 4.5a, at the low stocking rate there is an apparent trend to increase intensity of selection with increasing soil fertility to reach 300% at F5. At higher stocking rates, there is relatively little deviation from the 100% level of indifferent grazing, except perhaps at the F5 soil fertility level.

4.4.1.5.c Importance index

The importance index of white clover emerged only at high fertiliser plus irrigation and even there it reached a value of only 63 for the medium stocking rate, with values of six and three for SR1 and SR3 respectively. Similarly to lupin, the importance of this species appeared to be enhanced at an 'ideal' grazing pressure.

4.4.1.5.d Combined selection index

Regardless of intensity of selection at lower levels of soil fertility, the importance index of animal preference allows the combined selection index to be positive (Figure 4.5b) only at F5, where white clover is relatively abundant.

In summary it appears that white clover is a species highly selected for when there is a high selection opportunity, but the combined selection index recognises the practical importance of this species only at high soil growth potential conditions as found in F5.

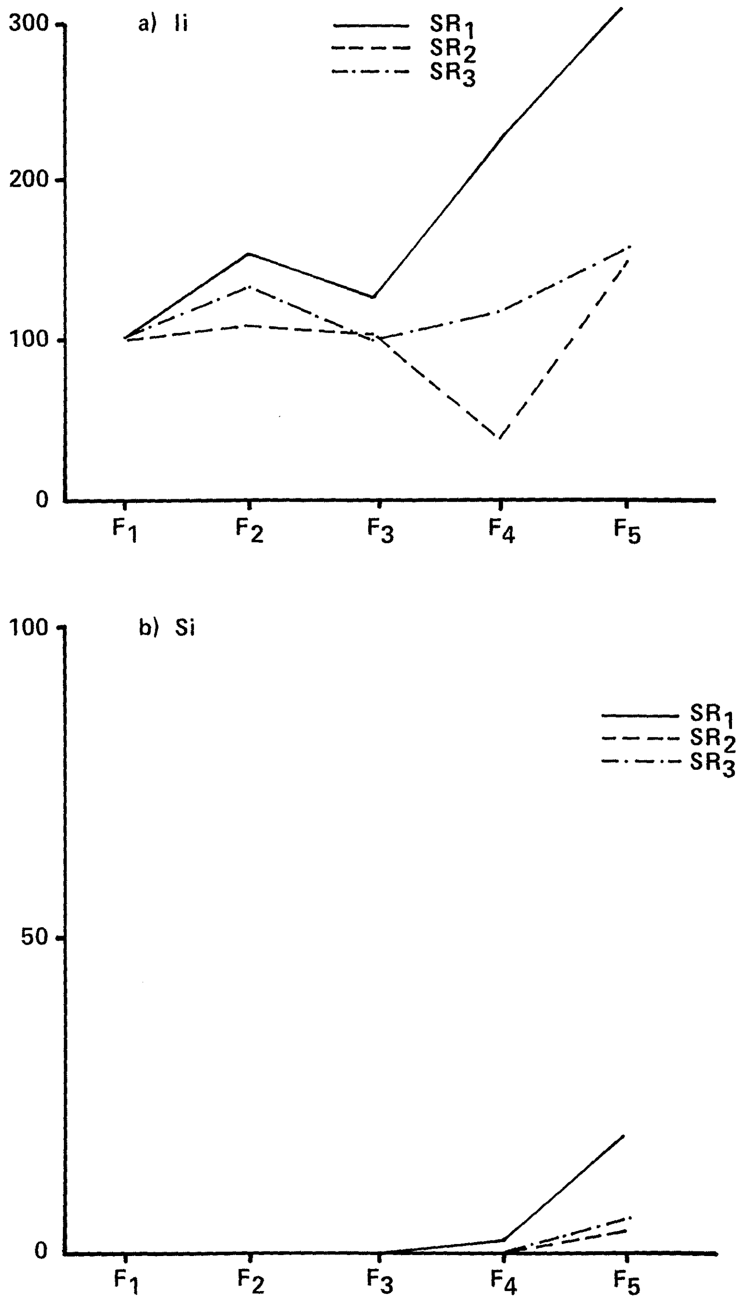


Figure 4.5: Intensity of animal selection (Ii) and selection index (Si) for white clover under five soil growth potential levels (F1-F5) and three stocking rates.

4.4.1.6 Fescue tussock

4.4.1.6.a General response

The relative abundance of fescue tussock was low within this experiment. Tussock ranked at between fourth and sixth (i.e. contributing less than 6.5% to total initial availability) in 88% of measurements (Table 4.6). Significance of the responses is not discernible because of very skewed distribution of data. Most of the data refer to Rank 6 where absence of variation in rank after grazing is difficult to interpret. Some rejection might have occurred, as 22% of total observations showed an increase in relative abundance when the species was already at Rank 6 at the beginning of a grazing cycle.

Table 4.6: Change in rank frequency of fescue tussock (*Festuca novae-zelandiae*) with grazing.

	Change with grazing			
Initial rank	Selected	Neutral	Declined	Significance of trend
1	2	0	-	-
2	1	1	3	
3	3	11	1	
4	4	1	4	
5	4	0	4	
6	-	104	40	-

The overall picture emerging from observations at other initial ranks seems to be fairly evenly divided among selection, acceptance and rejection. This form of analysis is clearly not conclusive for fescue tussock.

4.4.1.6.b Intensity of selection

Fescue tussock tended to be grazed non preferentially or to be rejected in absolute terms at all soil fertility levels up to F4. At the highest soil fertility level with irrigation, there was a slight increase in intensity of selection index at all stocking rates, but it never advanced beyond the non-preferential or indifferent (Figure 4.6).

4.4.1.6.c Importance index

In terms of importance as defined here, fescue tussock remained unimportant, with values of zero or one at all treatments except one. At the medium stocking rate at the zero level of fertiliser, importance index reaches a value of 17, emphasising the value of tussocks as a resource under some undeveloped conditions.

4.4.1.6.d Combined selection index

The presence of negative values for components makes calculation of combined selection index invalid for this species.

In summary, this set of observations indicates that fescue tussock is a resident species which tends to be selected against both in relative and absolute terms. It is grazed under some circumstances, which could be when other more palatable species are scarce, or perhaps as a accompaniment to less fibrous herbage.

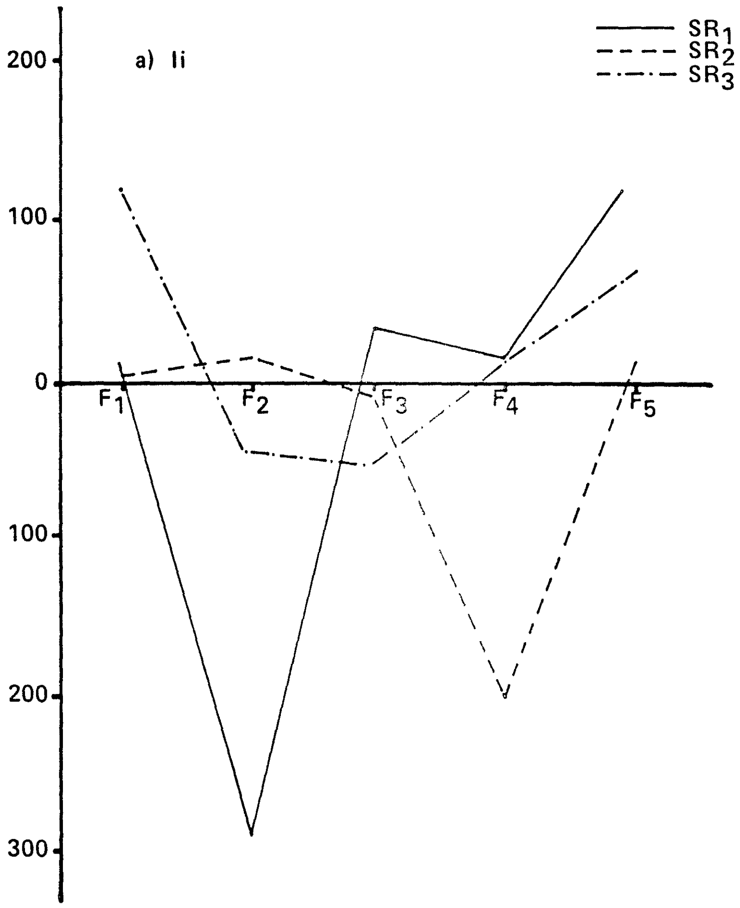


Figure 4.6: Intensity of animal selection (Ii) for fescue tussock under five soil growth potentials and three stocking rates.

4.4.2 Comparisons among species

4.4.2.1 High selection opportunity (SR1)

The variation in each species' abundance from before to after grazing (pdm) is represented within bars with discontinuous lines. The selection index for each species is shown as a dark bar within solid lines. These values are presented in relation to percentage of total apparent grazing (PDM), shown as a broken horizontal line, and to initial rankings, shown as numerals.

These values are all presented in the series of bar graphs corresponding to the five soil fertility treatments (Figure 4.7).

For example, in Figure 4.7, alsike (A) was ranked 4.8 under the zero fertiliser (F1) treatment prior to grazing under the high selection opportunity (SR1). Over the measurement period only 27% of the total available dry matter was removed (PDM) (horizontal broken line). In contrast, 78% of the alsike dry matter had been taken (pdm). In terms of relative intensity of selection index (289%, not shown on this figure) this indicates a high preferential grazing. This is highlighted by the fact that R = 4.8, indicating rather a small contribution to total vegetation mass available before grazing. Under such conditions, the combined selection index (dark bar) shows a low contribution to total dry matter decrease (PDM). In terms of importance it means that only 2% of the grazed material was alsike clover.

By contrast, under the same conditions Russell lupin (L) had an initial rank of 1, indicating that it was abundant and accessible. Of this species 46% was removed (pdm). Although this value was lower than for alsike it is higher than the grazed proportion of the total (PDM = 27%). In this case the apparent preferential grazing may not be significant due to the large associated standard errors. However, this is compensated by a large contribution to total vegetation mass consumed which results in a combined selection index of 120.

A greatly different situation was found for red clover (R) with an initial rank of 5.3. This species apparently was not grazed and proportionally increased during the grazing period. This is evident in the negative values for pdm and Si implying rejection. This situation is found for red clover only at the lowest soil fertility level.

White clover with an initial rank of 6 is removed during grazing at a pdm in proportion to pasture apparent usage PDM = 27%. Fescue tussock with an initial rank of 2.8 was removed at a much lower pdm. Both white clover and fescue tussock have combined selection indices approaching zero. Hawkweed with an initial rank of 2.3 is removed at a pdm similar to the PDM of the whole. Although animals may prefer and actively search alsike clover, the greater abundance of hawkweed is sufficient to ensure a larger contribution to the total diet.

It is apparent that intensity and selection index are not correlated. Alsike clover, for example, is preferentially grazed at all treatments, showing the highest intensity of selection at each soil growth potential level. However, to match the contribution to diet of Russell lupin measured in terms of selection index, the alsike clover index would have to be multiplied by a factor of 22.3 at F1, 3.0 at F3, and 1.6 at F4.

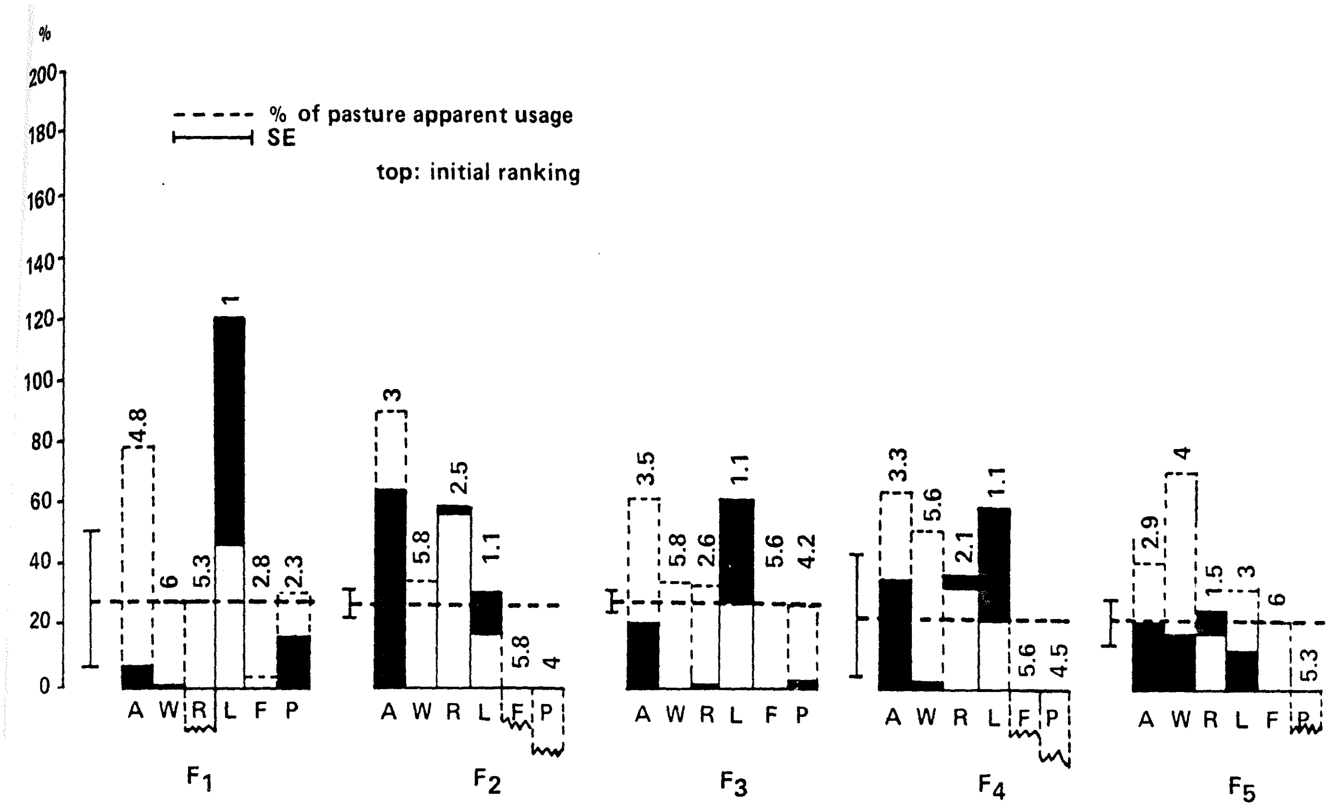


Figure 4.7: Intensity of selection (light bars) and combined index of selection (dark bars) for six species at five soil growth potential levels and at high selection opportunity (SR1). Horizontal broken line indicates PDM for total herbage. Numbers indicate initial rank of species.

A = alsike clover W = white clover R = red clover
L = Russell lupin F = fescue tussock P = mouse-ear hawkweed

Yet, the contribution of alsike clover is higher at F2 and F5 by factors of 2.4 and 1.7 respectively.

In general, the most selected species are the clovers. Alsike is less actively selected than white clover only at F5. White clover is less actively selected than red clover only at F2. Russell lupin is less actively selected than all three clovers at all soil fertility levels except F1 and F5. At F1 it is second only to white clover. At F5, it is third to white clover and alsike clover.

Fescue tussock is apparently rejected at F2 and F4, but grazing is indifferent at F1 and F5, and apparently reluctant at F3. Mouse-ear hawkweed is rejected at all levels except F1 and F3, where it appears to be eaten nearly proportionally to total dry matter disappearance.

The major contributions to diet are made by lupin at F1, secondarily by hawkweed; by alsike and red clover, and secondarily by lupin at F2; by lupin and alsike clover at F3; by lupin, red and alsike clover (at F4) and by red, alsike and white clovers at F5, where a smaller contribution is made by lupin.

Within the environment defined by high fertilisation and irrigation white clover becomes important, with a high intensity of selection corresponding with a comparatively high selection index. Nonetheless, the general observation for this situation is that animal preference seems here less relevant that at lower levels of soil growth potential.

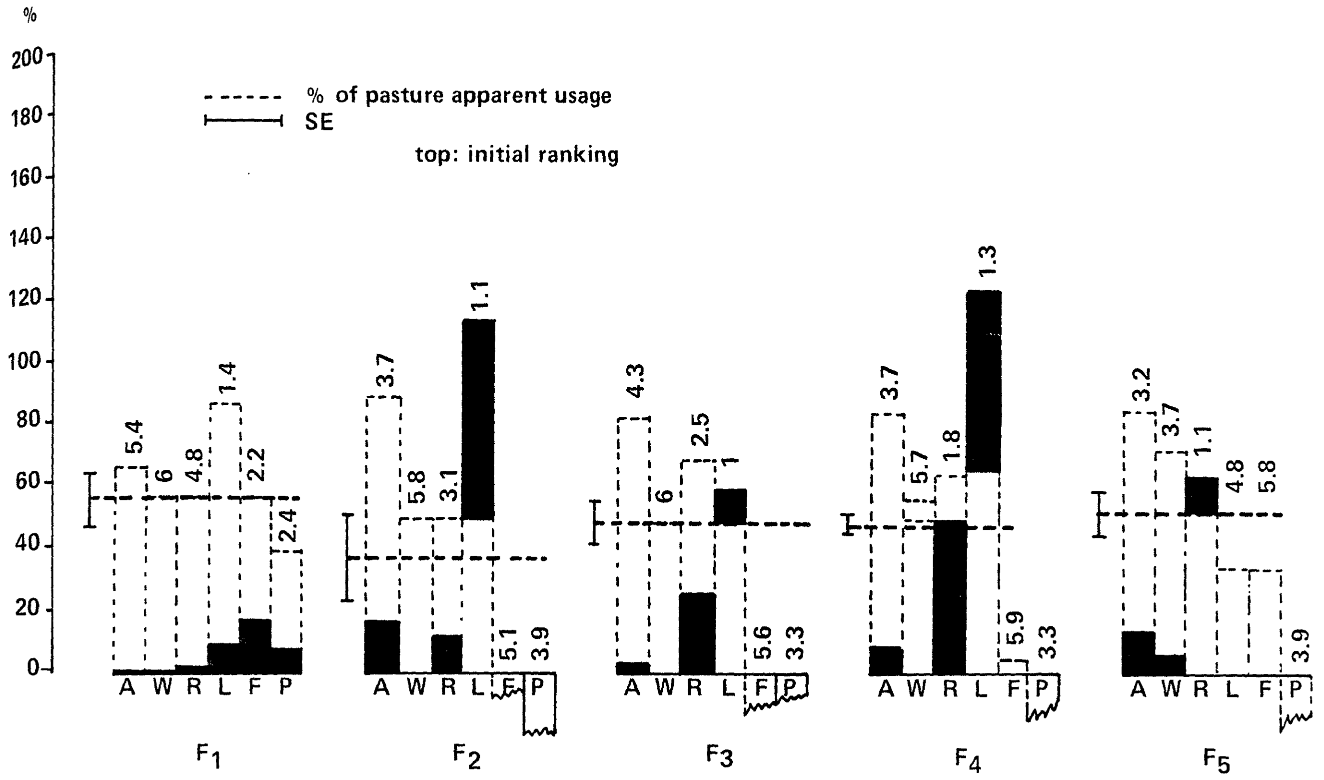


Figure 4.8: Intensity of selection (light bars) and combined index of selection (dark bars) for six species at five soil growth potentials and at moderate selection opportunity (SR2). Horizontal broken line indicates PDM for total herbage. Numbers indicate initial rank of species.

A = alsike clover	W = white clover	R = red clover
L = Russell lupin	F = fescue tussock	P = mouse-ear hawkweed

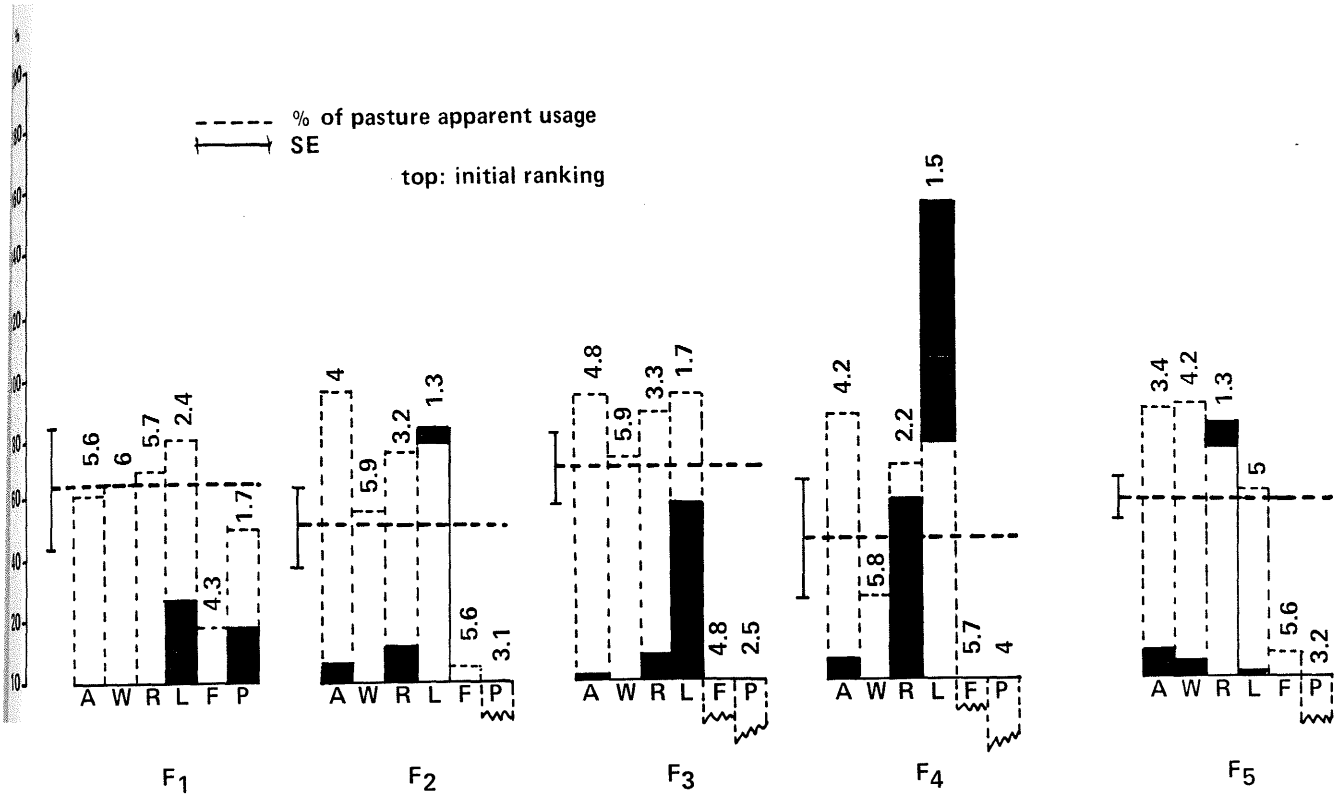


Figure 4.9: Intensity of selection (light bars) and combined index of selection (dark bars) for six species at five soil growth potentials and at reduced selection opportunity (SR3). Horizontal broken line indicates PDM for total herbage. Numbers indicate initial rank of species.

A = alsike clover W = white clover R = red clover
L = Russell lupin F = fescue tussock P = mouse-ear hawkweed

4.4.2.3 Reduced selection opportunity (SR3)

Under the highest stocking rate, the intensity of selection remains highest for lupin at F1, but the prominence of alsike clover at other soil fertility levels is now subdued (Figure 4.9) in relation to other legumes. Lupin makes the principal contribution to diet at all levels except F5 and the secondary contributions remain similar to SR2.

4.5 DISCUSSION

4.5.1 Introduction

Animal preference was expressed in terms of an index where the relative variation in abundance of a species (associated with intensity of selection) was multiplied by the absolute dry matter variation for that species (associated with the importance of the process). The distinction between process and results implicit in these concepts has enlightened other ecological subjects (Welden and Slauson, 1986).

The intensity of selection affects individual species but need not be related to the same degree with the importance of change in the structure or composition of vegetation. On the other hand, the importance of selection is determined by the degree to which differential grazing affects the vegetation. For example, apparently indifferent grazing or rejection of a dominant species may lead over a number of years to complete change in the physiognomy of a grassland. Such a process has been suggested for the development of the short tussock grasslands in New Zealand (O'Connor, 1986).

A comparison between soil growth potential or fertility levels and stocking rates is not inappropriate because they represent diverse situations of grazing opportunity, in this case mostly determined by animal competition and vegetational composition.

4.5.2 High selection opportunity

Measurements and calculations indicate that when the selection opportunity was high (SR1), alsike clover and lupin were selected and that that selection was important enough to affect composition of the pasture.

Nonetheless, even under conditions of reduced animal competition, the environmental gradient determined vegetations where white and red clovers were very scarce at lower levels of the gradient. Here, grazing of white clover occurred when those scarce plants were randomly found by sheep, their grazing being proportional to total dry matter disappearance. This could otherwise be interpreted as indifference.

Something somewhat similar may have happened to red clover, except that this species was grazed rather reluctantly, which led to an effect of apparent total rejection at that level.

On the other hand, alsike clover appeared to be intensely selected for, which might convey the idea of an active search. More likely, because it was proportionally more abundant, when it was found, sheep stopped to graze as much as possible of it. This discussion does not eliminate the possibility of a genuine gradient in acceptability at low fertility and high opportunity of alsike clover > white clover > red clover.

The importance of lupin is obviously shown by its abundance, which in most cases, but not all, outweighed a comparatively less intense selection.

Fescue tussock varied, suggesting some non-preferential, almost negligible grazing. It is possible that grazing was incidental or reluctant and due in the main to a lack of fodder; but as selection may focus on particular plant parts, selectivity may well have been for young shoots which have different composition.

Hawkweed at low fertility level declined in abundance proportionally to total herbage removal, its apparent reduction being attributable to grazing, destruction by treading, or both.

Environments with better soil growth conditions allowed a better expression of animal preference in that all species became more accessible because they were also more abundant. Clovers were preferred, but lupin still remained the most important plant, because even though it may appear to be reluctantly grazed, it was the most abundant material, offering a good opportunity for selection within the plant. Visual observation showed that seed pods, flowers and young leaves were taken first, while stems could be totally rejected.

Under the best conditions for plant growth at F5, sheep selectivity was still clearly discernible, white clover being highly preferred. Yet, the importance of the results of selectivity was diminished with alsike, white and red clovers presenting very similar combined index values, not much higher than lupin. Furthermore, it was only under this condition that tussocks were grazed indifferently (the highest value of the series), possibly due to an improved palatability, but also to a more conspicuous presence.

This SR1 series is the set of treatments where animal preference should have found its maximum expression. Trying to generalise this response over the series, there were no completely rejected species, because even mouse-ear hawkweed suffered apparent grazing within the non-improved treatment. In fact, some grazing is also apparent, though to a lesser extent, at F3. Yet, these were not important in terms of selection index.

The other resident, fescue tussock, was either rejected or non-preferentially grazed, but unimportantly within the general context.

Animal preference for white clover is a well known fact which was confirmed here. Nevertheless, in terms of contribution to apparent grazing, it became relevant only on fully developed areas, involving high fertilisation and irrigation, where a high intensity of selection compensated for a reduced initial relative availability.

Red clover was accepted wherever soil fertility was raised and it became a strategic component of pasture at all levels. Alsike clover at low to high soil growth potentials demonstrated high animal preference, and wherever soil fertility was raised it became second in importance as well.

Strictly in terms of animal preference, lupin surpassed only red clover among the legumes. Grazing tended to be non-preferential for this species. Yet, because of its abundance it became the most important species at all levels except high fertilisation plus irrigation, where clovers were more important. Oddly perhaps, a relative unwillingness of sheep to graze lupins may prove to be a further advantage for an oversown species within a low investment scheme of management.

Four main conclusions may be drawn from this section:

- animal preferences were measured even at the lower level of total initial dry matter availability (about 600 kg ha^{-1}),
- preference in itself was not always the determinant of total apparent grazing and may be unimportant from a production point of view,
- neither intensity nor importance of selection were directly related to apparent grazing, and
- less preferred species tended to make less contribution to grazing.

4.5.3 Moderate selection opportunity

While the set of treatments under SR1 offered conditions in which true animal selectivity could be better expressed, information from treatments under SR2 may be more relevant to commercial production conditions.

The importance of fescue tussock and mouse-ear hawkweed was increased at F1, but rejection was also more evident at other fertility treatments than under more lenient grazing (at SR1).

The effect of an increased grazing pressure from the higher stocking rate was to reduce differences in intensity of selection among the legumes. Values estimating the intensity of selection for alsike, red and white clover were now closer together despite different initial availabilities. Accordingly, combined selection indices taking account of importance maintained closer relation with initial relative abundances for introduced species. This again emphasises the role of lupin at all treatments but F5.

Russell lupin revealed the same properties shown under SR1, but now moving towards preferential grazing, always with the exception of F5. Red clover became a better resource, comparable to alsike clover which still was the most intensely selected species through all treatments, but with a lower selection index. The importance of selection for white clover was very low, and even at F5 this species was third to alsike and red clovers.

As a general conclusion, under 'normal' grazing pressure animal preferences were clearly discernible, but on the whole the significance of selectivity between lupin and conventional forage species seems to have been determined by initial abundance more than by anything else. From the point of view of plant strategies, it seems only natural that highly preferred species should also be able to tolerate a heavy defoliation, as is the case of white clover under high fertilisation and irrigation; partial avoidance of grazing and the ability to fix nitrogen may contribute to the successful strategy of lupin at lower levels of soil growth potential.

Conclusions from this section are:

- animal preferences under moderate stocking rates were detectable and differed perceptibly for most changes in soil growth potential level,
- the importance of introduced species in terms of contribution to apparent grazing tended to correspond with initial availability,
- soil improvement resulted in rejection of mouse-ear hawkweed.

4.5.4 Reduced selection opportunity

Differences between selection intensities for introduced species are reduced to a minimum, and may be significantly different and lower only for lupin under high fertilisation plus irrigation. Although minor, non-preferential grazing of fescue tussock is sometimes notable, but always unimportant in terms of selection index, hawkweed continued to be rejected at all treatments except F1 where, reluctantly or not, this species was grazed.

On the other hand, the importance of animal preference for species was not as at lower stocking rates, effective selection being more or less proportionally determined by initial availabilities. Russell lupin remained as the species with the highest index of selection through F1 to F4, whereas red clover was much higher at F5.

Animal preferences were measurable, but under hard grazing they appeared less relevant, whether utilisation was unwilling or not. Some inflection point may exist, as indicated by non-preferential grazing switching to rejection, observed for fescue tussock and mouse-ear hawkweed, particularly at good soil conditions.

4.5.5 General

It is suggested that the selection process in these small paddocks does not involve an active, time-investing search for preferred species, but rather that attention is focused on some preferred items as they are encountered. This would not exclude the utilisation of whatever edible material is readily accessible, the involuntary ingestion of some plant parts, and the occasional browsing of otherwise unwanted material. Such a comment does not exclude the possibly of time investment in searching for attractive sites or returning to what are familiar grazing sites in farm scale conditions.

In terms of understanding variations in vegetational composition and structure, the importance of animal selectivity is evident. It may explain, for instance, why fescue tussocks may stand a better chance of persistence under moderate fertilisation than under non-improved conditions. This could also be true for mouse-ear hawkweed, unless they are shaded out by the management regime for the accompanying vegetation.

This series of observations has confirmed the indication of Stevens (1977) that diet composition changes with increasing grazing pressure, and that the animal selectivity influence is diminished as opportunity for its expression is reduced. Such a feature may have greatly affected the conflicting results which Cockayne reported (Cockayne, 1919, 1920, 1926).

As seen within this trial, it is very likely that all introduced forage species will be accepted to some degree, preferences being outweighed by actual contribution to dry matter availability. Thus, under semi-improved conditions in the high country, further knowledge of animal preference in itself seems less interesting than total forage ingestion. In contrast, understanding of animal preference in unimproved conditions may be important for the interpretation of present high country grassland composition. This has been indicated for New Zealand from as early as Cockayne (1927).

Reluctance to graze may be unimportant in the end, but the question remains whether animals suffer weight losses by reduced utilisation or temporary refusal to eat some items at some particular times of the year. Does reluctant grazing lead to increased searching and grazing time and so to increased maintenance and less weight gain? The high proportion of time spent in grazing in the range behaviour study reported by Harris and O'Connor (1980) suggests that the answer may be affirmative.

4.6 SUMMARY

The importance of animal preferences in the composition of apparent grazing under five levels of soil growth potential within South Island high country conditions was estimated for three different situations of selection opportunity. The estimator was an index based on relative and absolute differences in species from rankings before and after grazing, which attempted to compensate the relative initial abundance of a species and animal preference defining rejection, reluctance, indifference and positive grazing selectivity.

Animal preferences resulting in disproportional grazing of species were measurable at all levels. However, the importance of such preferences decreased inversely to the selection opportunity represented by increasing grazing pressures. On the other hand, animal preferences expressed as intensity of selection, decreased with increasing specific grazing pressure for preferred items. Conversely, less preferred species are selected more intensely under a reduced selection opportunity.

For the set of environments under low to moderate soil fertility, lupin, red clover and alsike clover appeared as the most balanced mixture considering both preference and absolute grazing. Animal preference was towards alsike clover, but it ranks third in importance under moderate to hard grazing. Under high fertility plus irrigation, white and alsike clovers are preferred, but red clover is a species becoming more relevant on account of its contribution to apparent grazing.

The main conclusion is that animal preferences are expressed regardless of initial dry matter availability, stocking rate or botanical composition; but that such preferences do not affect apparent utilisation unless grazing is very lax. Otherwise, the utilisation of introduced species is more related to actual availability than to animal preferences as such. It must be noted that these comments refer to the bulk of apparent grazing and not to nutritive value of the ingesta, which was not measured in this trial. Resident fescue tussock and mouse-ear hawkweed were discriminated against under improved conditions, but not so severely at non-improved treatments, where they remain as a resource of some consideration.

Many of the concepts and conclusions derived in this chapter must be regarded as tentative, since the small data base limited quantification and full statistical testing.

Chapter 5

GENERAL DISCUSSION

5.1 INTRODUCTION

The concept of production, so commonly used in agriculture, may be misleading when applied to activities which are basically extractive, such as mining, fisheries, extensive forestry with native trees or extensive grazing of native grasslands. The production process is characterised because it is a human creation involving the multiplication of goods. It is that creative component, which even if present may not be enough to govern the extractive process which frequently runs out of control.

Grassland depletion, weeds and animal pests, erosion and tenancy problems are some current consequences of having 'lost control' of natural grasslands management throughout the world. Such terrains have satisfied economic needs through systems that in the medium term have proved not to be sustainable. The notion of true agricultural development involves a production system which is *prima facie* ecologically and economically sustainable. Therefore, if South Island high country is to be developed, environments must be defined where sustained production is both attainable and profitable.

The contribution attempted by the present work to these general objectives is methodological in that a specific approach to research is proposed, and it is also practical in that different situations of development were analysed to define the success of forage species.

5.2 ENVIRONMENTAL SELECTION OF SPECIES

In a general sense it is normally accepted that any environment will determine whether a species will be able to live within it. In that case, the implicit notion of environment stresses the abiotic components to a point where a logical consequence, for example, was the design of large trials testing forage species in practical isolation.

The concept of environmental selection is more complex because the environment is conceived as the interaction of all of its components, including human manipulation and introduced species themselves. Within this dynamic frame, a species will be able to thrive or not on account of distinctive adaptations together configuring a particular strategy allowing it to survive. Taking this notion to a theoretical extreme, for each environment within a gradient there should be only one dominant species.

Under this conception environmental selection does not refer to the presence of climatic or soil thresholds to species establishment, but to the predominance of species with a suitable, genetically defined strategy involving size, growth potentials, reproduction, adaptations to grazing etc.

If this concept be accepted, introduction trials for oversown species would become easier to carry out and much time would be saved, because work could be done on the basis of multiple mixtures. Furthermore, the persistence of mouse-ear hawkweed on depleted high country; the likely disappearance of tussocks from developed pastures, or the dominance of any species for a particular set of combinations might become theoretically better understood.

5.3 REPLACING THE NATIVES

According to the concept of environmental selection, native grasslands evolved in the absence of grazing mammals over the few centuries since forest destruction could not sustain a grazing industry without some vegetational change. The possibility of bird grazing in some past time does not alter this probability. New dominants would require the ability to withstand grazing, the extreme strategies being avoidance or tolerance.

Grazing tolerance is related to the ability to capture the nutrients and water required for high growth rates. On the other hand, grazing avoidance relies basically on physical and chemical deterrents (size, shape, chemical components etc.) and a slow release of energy. These are theoretical extremes and in practice plants will present mixed characteristics appropriate to a particular environment.

In consequence, grazing over the last one and a half centuries, modified the original vegetation of South Island high country favouring first the dominance of short tussocks (being relatively unpalatable) and later the replacement of intertussock vegetation by hawkweeds (being rejected by stock). Both dominants appear to have elements of stress tolerance. On the basis of the arguments above, there is no reason to suppose that conservative management could alter this situation, or that other more productive species could eventually be introduced without further inputs to the system. At best conservative management might delay the outcome. Alternative outcomes would remain dependent on other inputs to the system.

The experiment showed that tussocks and hawkweeds remain dominant even if a range of exotic forage species is oversown into non-fertilised soils. Resident species tend to be avoided by stock, but they become grazed with increasing grazing pressure, particularly tussocks. Hard grazing, therefore, leads to hawkweed dominance, which sets a threshold to animal production. Within the trial this was 2.9 su ha^{-1} for moderate grazing (as compared with 14 su ha^{-1} for fully developed areas). This margin might be less in practice because of varying specific animal requirements at different times of the year.

Modifications of the environment which improve soil fertility should allow the success of other species which may not be present within the soil seed bank.

5.4 IMPORTANCE OF TUSSOCKS

Development programs will range from low to high investments and an economical optimum might be found within this range. Questions arising from these new conditions include: do native species, such as tussocks, have a productive role to play, particularly at low input development schemes? Should they be kept or protected to some extent?

A resource rich environment under moderate to lenient grazing results not in disappearance, but in a minor increase in relative abundance of tussocks, which at lower fertility rates may even be invigorated, always within the lower range of relative abundance. This is due both to a very lenient defoliation derived from non preferential grazing and to a reduced competition from other species kept down by preferential grazing and moderate to low soil growth potential.

The Lake Tekapo experiment after four years does not suggest that tussocks could play a vegetationally important role where inputs exceed 50 kg of fertiliser per ha per year and with good legume establishment. If anything, tussocks appear favoured by low levels of soil improvement and legume oversowing. This situation is not dissimilar to that described by O'Connor (1966) from Pukaki at lower levels of applied fertiliser and under lax grazing.

The situation may be totally different if the inter-tussock pasture is formed by grasses of lower stature than the tussocks. The experience with ryegrass at Lincoln College showed that tussocks, if sparse (plants at least 120 cm apart) may favour significantly higher grass growth rates, particularly in spring. An important contribution of tussocks to grazing management may be as an emergency fodder during hard, snowy winters. Under low input development programs this is likely to occur naturally.

5.5 SPECIES SUCCESS

5.5.1 Russell lupin (*Lupinus polyphillus*)

Russell lupin was the overall dominant species within the range 50-250 kg fertiliser yr^{-1} ha^{-1} if grazing was moderate or lenient. Tolerance to soil aluminium, a comparatively large size of seeds, slight unpalatability, plus large bulk and rapid growth may explain in part the relative success of this, hitherto unusual pasture species.

Russell lupin is very promising for the high country environment. It establishes at low temperatures, reseeds well, is highly productive under low fertiliser inputs and because of its large bulk, it could, like tussocks provide shelter to animals. It is non-preferentially grazed, but still is one of the most important contributors to apparent grazing. On the other hand, it does not tolerate hard grazing. This should not present a great disadvantage because intensive, hard grazing is not likely to be included within the management options of less developed systems. It may require caution in further breeding development to limit the content of the alkaloid anagyrine (Davis and Stout, 1986).

5.5.2 Alsike clover (*Trifolium hybridum*)

Alsike clover was second only to Russell lupin in general importance, but it was dominant at high fertiliser input plus irrigation. Somewhat in disagreement with common belief, it was shown to be both relatively preferred by animals and tolerant to hard grazing. This may not, however be, true at all seasons. Indeed, this information is relative to the other components of the mixture and their proportions. Alsike clover's preferential grazing was confirmed by decreasing intensity of selection with increasing stocking rates, as pressure is exerted on other species. Conversely, less preferred species, such as Russell lupin, were more selected as dry matter decreased. The situation changes with high fertilisation and irrigation, where red and white clovers are also important.

5.5.3 Mouse-ear hawkweed (*Hieracium pilosella*)

This is a weed of paramount importance in the high country. The experiment showed that sheep in need will graze it, but that in presence of other options it is completely rejected. On the other hand, increasing soil growth potential did not eliminate it during the experimental period. It is interesting to note that during the pregrazing year, mouse-ear hawkweed showed a trend to decrease in relative abundance. Conversely after grazing started, the trend was to persist unless grazing was lenient, where it decreased. Apparently, this species may be shaded out by competitors, but this process is delayed by grazing, particularly if grazing.

5.5.4 Red clover (*Trifolium pratense*)

In spite of its recognised resistance to drought, red clover did better under high fertility plus irrigation, being below Russell lupin and alsike clover at all the other treatments, although showing little seasonal variations.

Red clover was common, though not dominant, within all treatments. Under productive management systems it did not show acceptability problems. Indeed it is not a very palatable species, but a moderate grazing pressure was enough to obtain a good standard of utilisation at all treatments but high fertility plus irrigation. Here grazing must be more intensive to prevent rank growth. Animals will not reject red clover. The species may become very important within the bulk of apparent grazing.

5.5.5 White clover (*Trifolium repens*)

White clover relative ranking and selection index point to the fact that moisture sets a threshold to its importance at Lake Tekapo. Under high fertilisation plus irrigation it revealed all the well known attributes of this species under intensive grazing management. Although it was not the most abundant species initially, it showed a clear trend to increase, particularly as a result of hard grazing. The strategy favouring white clover under these circumstances is based on prostrate growth and rapid regrowth from little aftermath. Lenient grazing seems detrimental to this species which is highly preferred by sheep, resulting in over-grazing and shading by more erect, less grazed, aggressive growers (red and alsike clover, Russell lupin).

5.5.6 Other species

Other sown species were not important during the experimental period. This does not mean they cannot become important in the future since this part of the experiment basically covers the establishment period. Legumes presumably are releasing nitrogen to the soil and grasses should benefit, probably browntop, cocksfoot and ryegrass, as soil growth potential increases.

Red clover may eventually disappear, leaving space for Caucasian clover, which seems to share a related environmental startegy. Birdsfoot trefoil, lucerne and Maku lotus may have a chance as well, although this seems less likely.

At the moment, the ideal mixture should include Russell lupin, alsike and red clover for treatments without irrigation, whereas under high fertiliser input plus irrigation, white clover should replace lupin.

5.6 REVIEW OF METHODS

5.6.1 Visual ranking

This technique offers the advantage of being quick and easy to apply. In fact, a similar version is being used through **Botanal** with good practical results in many research works. Indeed, the underlying interaction of this technique with a theory involving the notion of constancy in pasture composition has not been sufficiently conceptualised in the literature. It does, however, remain as an empirical observation which has been confirmed for pastures in Australia, New Zealand and southern South American countries.

Ecological laws, or rather, general principles, have been proposed for a variety of subjects. They are seldom applied to intensive agriculture probably because those environments are more amenable to manipulation. Within extensive grazing management science, a fruitful area of research still remains in the formulation of general principles of ecology, including the relationship of abundance rank to composition of standing biomass.

5.6.2 Capacitance probe

This device offers sufficient accuracy and represents a great advantage over quadrat clipping. This becomes particularly relevant at large (and distant) grazing trials, where collecting and transporting of samples may be a great inconvenience and source inaccuracy. Yet, from this point of view it may compare unfavourably with visual estimates, so long as the latter are applied always by the same person. Careful calibration of the capacitance probe leads to confirmation of its objective values enhancing the fact this is a non-destructive, repeatable method of measurement.

5.7 CONCLUSIONS

Species introduction from multi-species mixtures at Lake Tekapo resulted in absolute dominance of legumes over grasses during the establishment phase of the first three years.

The most important legume from zero to 250 kg fertiliser ha^{-1} yr^{-1} was Russell lupin (*Lupinus polyphyllus*), unreported hitherto as a pasture species.

The second most important species was alsike clover, followed by red and white clovers, the latter only under irrigation and high fertilisation.

The most important experimental factor affecting the relative ranking of species during the experimental period was fertiliser input; secondly stocking rate and last grazing methods.

Introduced and resident species showed affinity with environmental situations that can be synthesised through the concepts of disturbance and stress as follows:

- Russell lupin at moderate to moderately low levels of soil growth potential and grazing intensity,
- alsike clover at moderately high to highly developed conditions,
- tussocks, mouse-ear hawkweed and adventive grasses related to unimproved conditions.

Hawkweeds did not disappear as a consequence of soil improvement and grazing and may be favoured by hard grazing.

Fescue tussock within dense legume swards does not seem to play any role of importance; if the canopy is open they become more conspicuous, but always at the lower range of relative abundance.

Shelter provided by such short tussocks to shorter inter-growing grasses results in increased relative growth rates. Tussock density must be rather sparse (plants 120 cm apart) for this benefit to occur.

Sheep grazing preferences were detected at all situations, but actual utilisation of pasture did not present important differences between introduced species. True rejection only occurred for mouse-ear hawkweed in soil improved treatments.

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APPENDIX 1: COMPARATIVE ANALYSIS OF SPECIES RANK DATA

1 Introduction

Variables can be classified according to their nature as **qualitative** or **categorical** (no definable relationship between classes), **ordinal** (related classes) and **continuous** or **quantitative.** This classification is extended by some authors (Scott, 1969; Fienberg, 1978; McCullagh and Nelder, 1983).

The most appropriate form of statistical analysis for a particular data set is determined by the nature of each variable, their classification as dependent or independent variables, and the assumed nature of the random variation.

For example, simple ANOVA is appropriate when the dependent variable is quantitative and the independent variable is qualitative; multiple regression when both dependent and independent variables are quantitative etc.

In the present study, the main dependent variables are relative rank values of pasture species, corresponding to six ordinal classes. Independent or explanatory variables (treatments) were either quantitative (fertiliser level, stocking rate) or qualitative (stocking method, season). A variable which is quantitative can also be treated as ordinal, or qualitative, but not *vice-versa* e.g. the fertiliser levels can be treated either as five levels of a continuous variable (as in linear regression); as five ordered classes, or as five unrelated treatment levels (as in simple ANOVA).

Because a conversion of relative ranks to percentage values is possible by means of geometric series equivalences, ordinal dependent variables (ranks) could be transformed and treated as quantitative.

2 Statistical procedures

In the recent decade, there has been a rapid development of methods (linear logistic models) suited to data where the dependent variable is only ordinal or qualitative values, whereas the independent variables are quantitative or qualitative. The difference between these newer models and the quantitative dependent variable model of regression is that rather than directly estimating the value of the dependent variable, they estimate the probability that the dependent variable is greater or less than a certain reference value e.g. that there is a 0.34 probability that white clover will be a rank two or greater.

Linear logistic models, including a version specially adapted to ordinal series are available in recent versions of some statistical packages, particularly in the SAS procedures entitled PROC CATMOD and PROC LOGIST (SAS 1985). An obvious advantage of these models is that they are the most appropriate to the nature of the kind of data in this thesis and still offer a good analogy with the more common ANOVA or regression models. There are also disadvantages derived from their unfamiliarity to most agriculturalists and their somewhat experimental nature.

For example, in the specific case of SAS PROC CATMOD, zero entries pose computational problems and must be replaced by small quantities, which has unknown effects in the levels of significance for the hypothesis under test. Furthermore, a convenient measure of the predictive power of this model, namely the proportion of variation accounted for (r^2) is not available, and the question of goodness fit is not easily answered.

3 Account of variation

A comparison was carried out to inspect goodness of fit and significance of effects using rank data in various forms, under the assumptions of the procedures GLM (ANOVA in a general linear model context), CATMOD (categorical analysis on the basis of least squares and maximum likelihood with logit function) and LOGIST (alternative specifically designed for linear logistic models), as specified in SAS manuals.

The first comparison required is the proportion of variation accounted for by the different analysis (r^2). According to McCullagh and Nelder (1983) the problem of model fitting is basically one of measuring discrepancies between a set of data values 'y' and the set of fitted values 'U' derived from the proposed model. This measure of discrepancy, or goodness of fit, in classical least squares theory is $(y-Y)^2$ (as in PROC GLM).

Other approaches, depending on the author, have used maximum likelihood, minimum modified Chi-square or minimum discrimination information.

Dealing with categorical analysis, the likelihood ratio criterion is preferred by most authors to the more usual Pearson's chi square. This way, where:

Chi^2 = $(\text{observed-expected})^2$, alternatively we have

Likelihood Ratio = 2 observed x log observed/expected

The notation for this statistic is not generalised as yet, and may be found as XL in Everitt (1977); GSQ in Fienberg (1983) and G in Sokal and Rohlf (1969). Both estimates, XSQ and GSQ, approximately follow the Chi-square distribution and are asymptotically equivalent.

Estimates based on maximum likelihood are more convenient as a measure of association, because generally they are additive, whereas Pearson's is not (both are produced by PROC CATMOD).

A direct comparison of these measures derived from different models is not possible, since they are not in the same range of values, and the models themselves are actually explaining different aspects of the relationships between the variables.

For instance, many computer outputs offer ANOVA-like tables derived from contingency tables. Fienberg (1983) explains that, whereas true ANOVA models determine effects of independent variables on dependent ones partitioning the over-all variability, contingency tables only describe structural relationships among variables in the table. However, the same author goes on suggesting that in linear logistic models where the logit function and a clear distinction between response and explanatory variables is possible (as in LOGIST) the parallel with true ANOVA may be more acceptable.

For all these reasons, a comparison of methods as follows is, strictly, wrong. It is only a rough way to check for wide differences. If they should occur it would be an antecedent to consider other approaches.

In the light of these comments, an attempt was made to homogenise estimates of predictive value to a common scale in the range zero to one. The same calculations originating r^2 in GLM was applied on the ANOVA like tables derived from CATMOD. PROC LOGIST produces several statistics of which Somer's **d** was chosen for this presentation.

4 Data

The data used for comparisons was taken independently by four observers for six species in the samplings of October 1985. The species considered were two of the abundant sown legumes (lupin and alsike clover); two spasmodic sown species (white and caucasian clover) and two of the resident species (mouse-ear hawkweed and fescue tussock).

The six rank values for each species were treated as either ordinal classes (LOGIST); six unrelated classes (CATMOD); or directly as quantitative values (GLM). Also, using the geometric series conversion to percentage contribution, they were treated as quantitative values using either the mean estimate of first ranked species versus the whole data set (mean R1); or the mean ratio of fifth to first rankings versus the whole data set (R5/R1); or using the individual estimate of first ranked species for each observation.

The explanatory independent variables were treated as either continuous (except observers) or as unrelated categories. A summary of the resulting 17 different analyses for each species is in the following tables.

5 Comparison

Goodness of fit for PROC LOGIST procedure expressed as **d** value is consistently higher for all cases if values are considered categorical (**d** ranging from 0.69 to 0.90). The second best fit is for CATMOD under the assumption of dependent continuous variables, except for white clover ($r^2 = 0.001$), otherwise with r^2 values ranging from 0.33 to 0.95. As for options tested under PROC GLM, rank classes as such show a better fit for expected-observed values (r^2 between 0.25 to 0.79) than ranks considered continuous (r^2 between 0.14 to 0.68). Using the parameters above, PROC LOGIST stands as the more adequate model.

Nevertheless, the significance of the sources of variation analysed either through GLM or LOGIST remain in good agreement, showing a very high significance for the effects of Fertility, Stocking Rate and Replication, with a maximum difference of 0.0017 for p values in the case of lupin replication.

Some contradiction occurs with Grazing Methods, which show a very significant effect for lupin and alsike clover (p = 0.00) or mouse-ear hawkweed (p = 0.007), whereas analysis under PROC GLM produces p values 0.014 for lupin; 0.15 for alsike clover and 0.158 for hawkweed. Coincidence of least-square and maximum likelihood estimators occurs when random variables are normally distributed; in this case the probability density function is not known, which is an argument in favour of GLM results. On account of the additional practical advantages of the GLM procedure, it was preferred for the main analysis.

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Appendix Table 1: Comparison of statistical methods for Russell lupin.

a) assuming a quantitative dependent variable using several linear models (GLM), using either rank values directly (Rank), or conversion to percentage contribution using mean estimate for 1st ranked species (mean R1), or mean ratio of 5th to 1st ranked species (mean R5/R1), mean 5th ranked species (MR5), or ratio 5th to 1st for each observation (R5/R1), or percentage contribution of 1st species in each observation (%R1), or 5th species for each observation (%R5);

b) assuming ordinal dependent variable with logistic regression (LOGIST) as rank values (Rank);

c) assuming categorical dependent variable (CATMOD) as rank values (Rank).

		R-square and sources of variation											
		r2		FERT		GM		SR		REP		PBS	
		Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat
PROC	VAR												
GLM	Rank	0.52	0.62	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.02		0.16
	meanR1	0.45	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.09		0.05
	mR5/R1	0.46	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.07		0.07
	mR5	0.45	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02		0.00
	R5/R1	0.48	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03		0.00
	%R1	0.48	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00		0.00
	%R5	0.52	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02		0.00
LOGIST	Rank	0.68	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05		0.02
CATMOD	Rank	0.63	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.01		0.23

Appendix Table 2: Comparison of statistical methods for Alsike clover.

Assumptions for Appendix Table 1.

		R-square and sources of variation											
		r^2		FERT		GM		SR		REP		PBS	
		Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat
PROC	VAR												
GLM	Rank	0.05	0.81	0.00	0.01	0.16	0.00	0.00	0.00	0.03	0.00		0.66
	meanR1	0.64	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.43
	mR5/R1	0.63	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.39
	mR5	0.63	0.69	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00		0.22
	R5/R1	0.61	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.21
	%R1	0.61	0.72	0.00	0.00	0.08	0.06	0.00	0.00	0.00	0.00		0.72
	%R5	0.57	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.29
LOGIST	Rank	0.72	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00		0.07
CATMOD	Rank	0.95	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.03

Appendix Table 3: Comparison of statistical methods for white clover.

Assumptions as for Appendix Table 1.

		R-square and sources of variation											
		r^2		FERT		GM		SR		REP		PBS	
		Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat
PROC	VAR												
GLM	Rank	0.69	0.80	0.00	0.00	0.07	0.10	0.00	0.00	0.00	0.38		0.00
	meanR1	0.47	0.58	0.00	0.00	0.53	0.29	0.00	0.02	0.01	0.01		0.00
	mR5/R1	0.51	0.63	0.00	0.00	0.74	0.44	0.00	0.01	0.00	0.02		0.00
	mR5	0.57	0.71	0.00	0.00	0.87	0.84	0.00	0.00	0.00	0.00		0.00
	R5/R1	0.56	0.69	0.00	0.00	0.71	0.42	0.00	0.00	0.00	0.00		0.00
	%R1	0.63	0.77	0.00	0.00	0.38	0.58	0.00	0.00	0.00	0.00		0.00
	%R5	0.67	0.80	0.00	0.00	0.75	0.93	0.00	0.00	0.00	0.00		0.00
LOGIST	Rank	0.87	0.91	0.00	0.00	0.22	0.04	0.00	0.00	0.27	0.15		0.01
CATMOD	Rank	0.00	0.46	0.00	1.00	0.04	0.04	0.00	0.13	0.30	0.16		0.07

Appendix Table 4: Comparison of statistical methods for Mouse-ear hawkweed.

Assumptions as for Appendix Table 1.

		R-square and sources of variation											
		r^2		FERT		GM		SR		REP		PBS	
		Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat
PROC	VAR												
GLM	Rank	0.54	0.68	0.00	0.00	0.16	0.17	0.00	0.00	0.00	0.00		0.00
	meanR1	0.04	0.59	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00		0.00
	mR5/R1	0.04	0.62	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00		0.00
	mR5	0.34	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00		0.00
	R5/R1	0.32	0.56	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00		0.00
	%R1	0.35	0.64	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00		0.00
	%R5	0.36	0.59	0.00	0.00	0.06	0.05	0.00	0.00	0.00	0.00		0.00
LOGIST	Rank	0.65	0.76	0.00	0.00	0.01	0.06	0.00	0.00	0.00	0.00		0.00
CATMOD	Rank	0.66	0.45	0.00	0.10	0.06	0.02	0.00	0.00	0.00	0.00		0.00

Appendix Table 5: Comparison of statistical methods for Caucasian clover.

Assumptions as for Appendix Table 1.

		R-square and sources of variation											
		r^2		FERT		GM		SR		REP		PBS	
		Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat
PROC	VAR												
GLM	Rank	0.14	0.25	0.01	0.00	0.16	0.27	0.00	0.00	0.00	0.00		0.00
	meanR1	0.13	0.20	0.00	0.01	0.30	0.43	0.00	0.00	0.00	0.00		0.00
	mR5/R1	0.13	0.20	0.00	0.00	0.35	0.40	0.00	0.00	0.00	0.00		0.03
	mR5	0.18	0.29	0.00	0.00	0.64	0.62	0.89	0.98	0.00	0.00		0.00
	R5/R1	0.20	0.26	0.00	0.00	0.30	0.37	0.03	0.04	0.00	0.00		0.03
	%R1	0.19	0.32	0.00	0.00	0.92	0.93	0.33	0.55	0.00	0.00		0.00
	%R5	0.24		0.00		0.21		0.16		0.00			
LOGIST	Rank	0.50	0.69	0.02	0.02	0.16	0.25	0.00	0.00	0.00	0.00		0.00
CATMOD	Rank	0.33	0.65	0.05	0.03	0.48	0.44	0.00	0.02	0.23	0.13		0.27

Appendix Table 6: Comparison of statistical methods for Fescue tussock.

Assumptions as for Appendix Table 1.

		R-square and sources of variation											
		r^2		FERT		GM		SR		REP		PBS	
		Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat	Cont	Cat
PROC	VAR												
GLM	Rank	0.30	0.54	0.00	0.00	0.22	0.20	0.00	0.00	0.41	0.37		0.00
	meanR1	0.18	0.38	0.00	0.00	0.22	0.21	0.00	0.00	0.63	0.59		0.00
	mR5/R1	0.20	0.41	0.00	0.00	0.23	0.21	0.00	0.00	0.59	0.56		0.00
	mR5	0.09	0.34	0.00	00.00	0.48	0.44	0.00	0.00	0.82	0.85		0.30
	R5/R1	0.12	0.00	0.00	.00	0.16	0.16	0.00	0.00	0.97	0.93		0.07
	%R1	0.04	0.33	0.05	0.00	0.49	0.41	0.03	0.01	0.43	0.41		0.44
	%R5	0.11	0.32	0.02	0.00	0.16	0.14	0.00	0.00	0.81	0.81		0.14
LOGIST	Rank	0.76	0.90	0.00	0.00	0.16	0.10	0.00	0.00	0.24	0.05		0.00
CATMOD	Rank	0.78	0.45	0.00	0.02	0.43	0.24	0.00	0.00	0.17	0.13		0.45

APPENDIX 2

ANOVA table for Relative Growth Rates of inter-tussock pasture over 3 seasons from a Split-Plot design.

a) Summary

Source	df	SS	p	r^2
Model	77	142.0	0.0	0.48
Residual	1182	154.0		
Corrected Total	1259	296.0		

b) Main effects and interactions

Source	df	SS	p F
Rep (r)	4	2.0	0.003
Shelter (S)	9	4.8	0.000
r x S	36	7.7	0.010
Season (SS)	2	93.6	0.000
r x SS	8	6.4	0.000
n	12	25.7	0.000

Class comparisons : Orthogonal Contrasts

a) Shelter

Contrast	df	SS	p F
Near v far	1	2.74	0.001
Control v far	1	2.44	0.002
Control v near	1	0.01	0.785
Aspects	1	0.17	0.368
Control v dense	1	0.00	0.836