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Permanent Summer Forage: Development of Chicory to Fill the Feed Gap

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Executive Summary

Chicory (*Cichorium intybus* L.) is a perennial herb and member of the family *Asteraceae*. It is considered native to the mediterranean region, though it had spread throughout much of Europe and into central Asia before being used by man. The release of the New Zealand cultivar Puna in 1984 spurred considerable interest in using this species as a pasture herb. Initial results suggested it was capable of high rates of forage and livestock production. Early work in Australia supported that view and suggested chicory was also productive under dry seasonal conditions. Chicory could fill a very useful role in providing greater quantities of quality forage over summer when most other species have limited growth.

The aim of this project was to develop the agronomic practices to use chicory to fill the summer feed gap in the high rainfall zone of temperate Australia. The specific objectives were to:

i) Compare chicory and lucerne for elite lamb production.

ii) Determine the grazing management practices for chicory pastures to ensure optimal persistence and productivity.

iii) Determine the appropriate mixtures for chicory pastures for optimal productivity and weed management.

iv) Determine suitable herbicides for early post-emergent use, optimal sowing rate, response to nitrogen fertiliser and other management factors to complete a management package for chicory.

The ability of chicory to finish elite lambs was compared with lucerne in an experiment at Cowra over two years. Four groups of lambs were used. Lamb growth rates of 200-300 g d^{-1} were recorded. Lambs grew as well or better on chicory as lucerne and most met market specifications. The differences between pasture species were greater with cryptorchid than ewe lambs. Semi-winter active lucerne cultivars though can have a longer growing season. There could be problems with feed standards as chicory samples showed lower (apparent) values for ME, protein and digestibility than were measured for lucerne in contrast to that expected from the animal performance data. There was evidence that intake rates were initially higher on chicory than lucerne, but the average intake rate for a group of lambs was similar for both species. The role of differences in mineral content is unknown.

The use of chicory for lamb production will depend upon the region involved and the pasture alternatives available. From the Cowra study we concluded that where lucerne can be grown well, it is still one of the better options for finishing lambs, as chicory offered no extra production. However, where lucerne starts to become marginal, yet soils still have some depth and rainfall is above 600 mm, chicory is a very viable option. We suspect from earlier work that chicory will retain green leaf longer during dry summers than lucerne, but we have not been able to collect adequate data on that during this project. Chicory does require some summer rainfall and, or irrigation, plus moderate moisture stored at depth to be productive. Chicory management and adaptability is likely to be more flexible than is the case for lucerne. Special purpose chicory pastures would be better for finishing lambs than most perennial grass based pastures in central NSW as they would produce larger quantities of nutritious green leaf over summer. Chicory would fit within those zones already defined as suitable for elite lamb production over summer.

A long-term experiment investigated the grazing management of chicory. Treatments ranged from continuous grazing to combinations of short grazings with long rest periods. After five years there was effectively no chicory left in the continuously grazed treatment. Chicory persisted best in treatments with the longer rest periods. In general, chicory appears more sensitive to the frequency of grazing than the intensity. Chicory is thought to be more tolerant to grazing tactics than lucerne. A controlled environment comparison of the response to defoliation showed that young chicory plants were more tolerant than lucerne, but not as tolerant as perennial ryegrass.

From these results we recommend that chicory be rotationally grazed in a four paddock system where two rules would apply most of the time and a third in special circumstances:

1. First, livestock grazing periods on any given area of chicory should not exceed two weeks. At each grazing, chicory can be defoliated to remove the green leaf, but some residual stubble *e.g.* 50+mm must remain to minimise damage to the crowns.
2. Second, once the 'new' area of chicory (*i.e.* the next paddock to be grazed in the rotation) reaches 300-500 mm in height, stock should be moved onto that area even if the paddock they are in hasn't been fully utilised.

In a four-paddock system, the application of these rules would mean that when chicory is growing fast and stocking rates are appropriate, animals would be moved at least once a week and a three-week rest would apply. When growth rates are slow, animals would only move once a fortnight to extend the rest period to six weeks. The optimal stocking rates will vary with seasonal conditions and between districts.

3. The third rule would apply only when a decline in plant density is noted. If the chicory plant density dropped to 20 plants m^{-2} then a combination of longer rest intervals (*e.g.* six weeks) and short, less intense grazing intervals (< one week), should be imposed to enable seed set and for some recruitment to occur. In dry years, little recruitment is likely to occur, but reduced grazing pressure would still be important to enhance the survival of chicory. In wetter years where the available forage often exceeds livestock requirements, it may be azing management'. The conclusion was that chicory might be of most

An experiment over four years investigated the interactions, competitive relations and response to plant density of chicory, white clover and perennial ryegrass. This showed that maximum productivity of chicory mixtures was achieved at densities of 50-60 plants m^{-2}. This often requires a high sowing rate *i.e.* 3-4 kg ha^{-1}. Lower sowing rates are likely to result in reduced pasture and livestock productivity, especially over the first two summers. White clover is a very suitable species to sow with chicory as both species behave in a consistently complementary fashion. There was very little evidence that chicory and white clover were competitive. An initial low sowing rate of white clover (*e.g.* up to 1 kg ha^{-1}) would help maximise establishment of chicory. Additional white clover could be sown later if necessary. White clover survived dry summers better in mixtures with chicory than in monoculture.

Chicory is more competitive with grasses than legumes. Perennial ryegrass did not establish very well when sown with chicory. However, there may not be any need to sow grasses as annual grass species voluntarily invade the sward, providing some additional forage over winter. If additional competition was expected from broadleaf species some grass could be included in the mixture, but it may be better to insure good weed control and maintain a high sowing rate of chicory.

If chicory is being sown to provide some additional forage in the early years of a pasture with the intention that it is replaced with perennial grass species then a lower sowing rate of chicory would be appropriate. This use of chicory was not tested in this project, but observations of commercial pastures indicate it is possible to do this. In such cases perennial grasses would be included in the original mixture. Legumes could be left out of such mixtures and sown later to avoid reducing the establishment of grasses and chicory. However, such mixtures may not be as productive as a special purpose chicory pasture.

A short-term study over one summer examined the early growth of chicory when sown with white or subterranean clover or lucerne along with the effect of supplementary nitrogen. Plots were sown in early spring. White clover was the more productive legume, being less effected by chicory competition than the other species. There was only a limited response to applied nitrogen and this was attributed to the high levels of available soil nitrogen at the site. These experiments were not able to resolve how best to use nitrogen in the long-term management of chicory pastures. In general the productivity of chicory will depend upon the supply of nitrogen and there is the suspicion that it is able to utilise more nitrogen at depth in the soil than other pasture species. Once this is used then additional nitrogen will be required to sustain production.

Additional studies investigated a range of herbicides for broadleaf weed control in chicory. Both seedlings and mature plants were tested. Some herbicides had a small effect on chicory productivity and plant numbers, but several satisfactory chemicals were identified. The better strategy is to remove the risk of weeds before sowing chicory.

This project has significantly advanced our understanding of the productivity, management and utilisation of chicory. Future work with chicory will need to resolve the nitrogen requirements for sustained production, the appropriate analyses and role of minerals in nutritive value, tolerance to pH and salinity, optimal sowing methods and reliable means of regenerating chicory pastures.

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Permanent Summer Forage: Development of Chicory to fill the feed gap

General Introduction

Chicory (*Cichorium intybus* L.) is a perennial herb and member of the family *Asteraceae*. It is considered native to the mediterranean region, but it had spread throughout much of Europe and into central Asia before being domesticated (Mitich, 1993). Its' native 'range' is often considered to include China. It is a large leafed rosette plant with a deep taproot that produces tall stems (1m or more) with blue flowers when flowering. Closely related to endive (*Cichorium endivia* L.) it is used as a salad vegetable ('witloof' is one form where shoots are grown in cellars to reduce the bitter flavour). Chicory has a long history of use by man, often featuring in ancient and medieval herbals and prescribed as a tonic, laxative and diuretic (LeStrange, 1977). The roots are often dried, processed and then used as a coffee substitute (Steiner, 1983), which is still an important use for this species.

Chicory has been a component of pastures in Europe for centuries (Brenchley, 1920) and European farmers have considered chicory hay to be superior to that made from lucerne (Spencer, 1974), though it is difficult to make good hay from this species. The high nutritive and mineral content of chicory has often been noted, as has its ability to remain green long after many temperate grasses have dried off (Davies, 1952; O'Brien, 1955). Chicory has been used in Australia for many years, as a vegetable and to provide a coffee substitute. It is naturalised as a roadside weed in higher rainfall areas and occasionally establishes in pasture areas. Chicory contains the bitter glucoside, chicorin and has been reported as imparting a bitter flavour to milk and butter if eaten in large quantities by dairy cows (Anon, 1942).

In New Zealand, early records note that chicory was often recommended for pasture mixtures (Cockayne, 1915), but its value was questioned possibly because it was only present at a low densities. This opinion was reinforced by trial work done between 1948 and 1950 (O'Brien, 1955) which found variable results across 15 sites sown to chicory. Several of these trials though, 'suffered from severe frosts, dry conditions at sowing and severe grazing management'. The conclusion was that chicory might be of most use in drier areas on lower fertility soils to provide forage when other species do not. Future work was to concentrate upon that class of country, but it seems little was done.

In the 1970's investigations began into the potential use of chicory as a pasture species. Selection work resulted in the release of a cultivar, 'Grasslands Puna', in 1984 (Rumball, 1986). This cultivar was selected for leaf production and better persistence under grazing from a range of lines obtained from New Zealand and elsewhere. A base population was established from the New Zealand material from which the cultivar was formed. The initial studies demonstrated ease of establishment, high summer and nil winter production and the need to use rotational grazing to ensure persistence (Lancashire and Brock, 1983). Very high levels of annual production were recorded (<25 t DM ha^{-1}) and high animal growth rates (Hare *et al*, 1987). The high levels of dry matter production also led to preliminary investigations into the use of chicory as a potential energy source (Douglas and Poll, 1986).

Since the release of Puna chicory, it has been widely sown in eastern Australia, but with little information on its local productivity and management requirements. Initial studies at Orange (Kemp *et al*, 1993) found that chicory was more productive than a wide range of other species, particularly over summer when the quantity and quality of forage normally declines. The greater productivity of chicory was particularly evident during a drought in 1990/91 when chicory yields, in one experiment at Orange were 2-4 times that of lucerne or phalaris. As a perennial, chicory has advantages over most forage crops of not having to be resown each year, while summer productivity recorded at Orange was greater than that found from a range of summer forages tested in earlier studies (Kemp, 1987).

Pastures across the higher rainfall, meat-producing areas of southeastern Australia are generally less than satisfactory (Kemp and Dowling, 1991; Quigley 1992). These pastures often have a low content of desirable perennial species. Specific problems arise over the hotter summer months when the quantity of green forage declines significantly. As a consequence, suboptimal animal growth rates and difficulties in finishing livestock are common problems in central NSW. Early reports clearly demonstrated that animal production over summer is directly related to the amount of green forage available (Willoughby, 1959). Lucerne can be used to improve the quantity of quality forage, but it is restricted to a limited range of soil types and requires good management in order to persist. Better quality pastures are needed to support elite lamb and other meat production systems. Better quality forage over summer will improve animal growth and their reproductive efficiency, allowing more timely marketing of finished animals.

The aim of this project was to develop the agronomic practices to use chicory to fill the summer feed gap. The specific objectives were to:

(i) Compare chicory and lucerne for elite lamb production.

(ii) Determine the grazing management practices for chicory pastures to ensure optimal persistence and productivity.

(iii) Determine the appropriate mixtures for chicory pastures for optimal productivity and weed management.

(iv) Determine suitable herbicides for early post-emergent use, optimal sowing rate, response to nitrogen fertiliser and other management factors to complete a management package for chicory.

This report summarises the main effects resulting from this project and draws conclusions on the use of chicory as permanent forage for livestock. The results are presented in three chapters. The first two chapters deal with objectives (i) and (ii), respectively, and the third chapter with objectives (iii) and (iv).

Elite lamb from Chicory

Introduction

In many regions across southern Australia difficulties arise in producing and finishing large lean 'elite' lambs (*e.g.* Hall & Holst, 1994) due to a limited supply of quality forage over summer (Moore *et al*, 1993). Many pastures do not satisfy the requirements for these production systems. Over many years the techniques used to solve this problem have been to sow forage crops (*eg*. Japanese millet) and, or supplementary feed the livestock (Hall & Holst, 1994). In some districts, lucerne (*Medicago sativa*) can be sown and has been successful at providing suitable quantities of quality forage. However, lucerne is not the perfect solution as it cannot be sown on all soil types and in dry summers it often sheds leaves reducing the available forage supply at critical times. Lucerne also has specific management requirements to insure a productive life as a stand (Peart 1968).

Preliminary evidence has found chicory (*Cichorium intybus*) to be a productive, high quality, forage species (Rumball, 1986; Hare *et al*, 1987; Kemp *et al*, 1987) that is as productive as lucerne over summer and will persist as long in a pasture as lucerne. Experiments in New Zealand have recorded high animal growth rates (Fraser *et al*, 1988; Reid *et al*, 1993; Niezen *et al*, 1993) and suggest that it is intake efficient (Komolong *et al*, 1992; Scales, 1993) and comparable to lucerne in fat deposition.

The aim of the experiment reported here was to compare chicory and lucerne for lamb production over the spring to autumn period during a two-year period in the traditional lamb-producing region of Cowra, NSW. Four groups of lambs were studied. This experiment also sought further understanding of the basis for any differences in animal production between chicory and lucerne. Are differences due to nutritive value, forage intake or some other factor?

Methods

Design

Two adjacent pastures were sown (1-2 cm deep in 18cm rows) during August 1991, and treatments commenced in spring 1992. Chicory (cv Puna) was sown (3 kg ha^{-1}) with subterranean clover (*Trifolium subterraneum* cvs. Junee and Dalkeith at 3 kg ha^{-1} each) in one area and lucerne (cv Aurora sown at 4 kg ha^{-1}) in the other. Each pasture received light opportunistic grazing during the establishment phase and was fertilised annually with 150 kg superphosphate ha^{-1}. The chicory was supplemented with 50 kg nitrogen ha^{-1} (as ammonium nitrate) in late July 1992 and 1993 to promote early spring growth.

Both chicory and lucerne require rotational grazing to persist and be productive. Each pasture was split into four replicates and then each (0.5ha) replicate into four subplots (0.125 ha). Lambs were rotationally grazed around the four subplots. In the second year it was decided that the four-paddock rotation was unnecessary as plots were conservatively stocked. Instead a two-paddock (subplots of 0.25 ha) system was used in each of the four replicates.

Four groups of lambs were studied on the experiment. In each case, weaned, four-month-old second cross (Poll Dorset * (Border Leicester * Merino)), cryptorchid and female lambs were allocated to each treatment plot and stratified for liveweight and sex. Ewes were mated in a sequence to provide successive groups of lambs during each summer. In group four only cryptorchid lambs were used. In the first and fourth groups, eight lambs were allocated to each replicate and nine lambs in groups two and three. Stocking rates (*i.e.* 16-18 lambs ha^{-1}) were based on what lucerne would be expected to carry at that time of the year. A conservative stocking policy was used to allow maximum expression of the livestock response to the nutritive value of the forage. Any animals that died were to be replaced with others of similar weight, age and condition to the remainder of the flock, but that was unnecessary. Animals were slaughtered when they reached elite lamb specifications (carcase weight 18+ kg and fat score 2-3).

The initial aim was to 'finish' at least two groups of lambs each year. In the first year pasture and animal growth exceeded expectations and three groups of lambs were finished on the experiment. When the third group was being studied, evidence of charcoal rot appeared in the chicory. It was then decided to remove the lambs to allow the chicory to recover, set seed and provide the opportunity for recruitment of new plants following the autumn break. During this eight-week rest the chicory recovered and lambs were returned to the plots and finished. This break in the study did mean though that the data obtained was of limited value for evaluating chicory performance and only the first part was used. Chicory plots only received one light grazing during the winter of 1993 to reduce competition and encourage recruitment of new plants. This was observed to occur and chicory density increased prior to the studies during spring 1993. The fourth group of lambs was then studied on the experiment in spring 1993. Three weeks prior to introducing lambs in spring 1993, all plots were slashed to a height of approximately 100mm to remove any stems.

All the animals in groups one, two and three were compared over the same growth intervals. In group four a subgroup was removed from the plots on 18 October when they had reached the minimum required weight (approximately 40 kg liveweight). The balance remained on the plots until 30th November when they reached the maximum target weight (approximately 50 kg liveweight). The initial design had planned to evaluate six groups of lambs. However the results proved so consistent and due to uncertainty about the charcoal rot infection, it was decided to terminate the study after four groups of lambs.

Site

The experiment was done at NSW Agriculture's Cowra Research Station. This is in a region where elite lambs are produced, though pasture growth rates are inadequate to achieve elite lamb specifications in a majority of years (Moore *et al*, 1993). Annual rainfall is 600 mm. The experiment was sown on a eutrophic red chromosol soil (Isbell, 1993), degraded by cropping (B. Murphy, *pers. comm.*). Climate data was recorded at the site.

Management

Each group of lambs was rotationally grazed around the four subplots in each replicate. Lambs were moved based on criteria for minimising overgrazing in the 'grazed' plot and also to limit any excessive stem or flowering development in the plot that had the longest rest from grazing *i.e.* the next plot to be grazed. In part, these decisions were based upon management requirements for lucerne, which is better understood than chicory. Stock were moved when forage yields on lucerne declined to around 1 t DM ha^{-1}. Movements aimed to provide a 30 day rest to each subplot. The optimal time for grazing lucerne is at 10% flowering. Rotations were managed to achieve this. For chicory, the aim was to move stock when the pasture was grazed down to 50-100 mm in height and recommence grazing when it reached 250-300 mm high. On occasion chicory growth rates were higher than expected which meant animals were moved more frequently than planned and on a few occasions a subplot was skipped. Any skipped subplots were slashed to remove stem growth. No specific weed control was implemented during the experiment, as it was desirable to assess how effective each pasture type was at reducing weed invasion.

Measurements

Each subplot of chicory and lucerne was measured for standing biomass and composition were measured using Botanal (Tothill *et al*, 1992) procedures on fixed transects in each treatment sub-plot. Transects were initially chosen at random. A rising plate meter (Earle and McGowan, 1979) was used to estimate biomass. Composition and yield estimates and calibration cuts (separated into green leaf and stem of the principal species and dried at 60°C for 16 h) were taken on 0.1 m^2 square quadrats. Measurements were taken as lambs were moved onto a subplot and as they left that plot.

Cages (approximately 1m^2) were used to measure growth during the period lambs were grazed on the sub-plot. The cage and pasture data were combined to estimate pasture intake. However, it was found that this data was highly variable for the first three groups of lambs, and the number of cages was increased substantially to 20 per plot for the fourth group. Both chromic dioxide and alkane techniques (Dove and Mayes, 1991) were also used with the fourth group of lambs to provide additional estimates of intake.

Pasture samples were processed to estimate forage quality *i.e.* digestibility, protein and metabolisable energy (ME). This was done using standard techniques, based on well-established relationships for grasses and clovers. This led to some uncertainty as to whether this would apply to herbs such as chicory. Some supplementary work was initiated with Dr G. Robards at the University of NSW to analyse in more detail the nutritive value of chicory *in vivo* and *in vitro* systems. This work commenced a study of seasonal trends in the nutritive value of chicory.

Lambs were weighed and body fat scored (Russel *et al*, 1969) every three weeks or earlier, if associated with a change in plots. A fasted weight was taken prior to going onto the plots and preslaughter. At slaughter hot carcase weights and the tissue depth at the GR site (11cm from spinal midline on 12th rib) were measured within 2 hours. Meat quality estimates were made (Holst & Hall, 1994).

Results

Pasture growth

The 1992/93 season was a productive year, with feed available in excess of animal requirements. Total forage yields for lucerne were greater than chicory in early spring, before introduction of the lambs and this continued during spring. However, green leaf yields were similar for both lucerne and chicory. Average pre-grazing green herbage mass exceeded 1.7 t DM ha^{-1} for each subplot during the rotations. This was unlikely to limit animal intake. Pasture growth rates were closely monitored, especially during spring 1993, and averaged 71 and 74 kg DM ha^{-1} d^{-1} for chicory and lucerne, respectively. Chicory growth rates in spring were initially higher than for lucerne, while the reverse applied in autumn. This could reflect differences in flowering patterns.

Nutritive value

Analyses of forage samples during spring and summer of 1992/93 showed that the nitrogen content of chicory ranged from 2.6 to 3.8% and 3.1 to 5.1% for lucerne. Digestible dry matter estimates were 62 to 79% for chicory and 66 to 80% for lucerne. Metabolisable energy estimates varied from 9.3 to 11.8 MJ kg^{-1} DM for chicory and 10.4 to 12 MJ kg^{-1} DM for lucerne. The higher values tended to occur in early spring whereas the lower values in part reflected the amount of stem present in samples in late autumn.

In spring 1993, several techniques were used to estimate consumption rates. Chromic dioxide capsules unfortunately deteriorated and the data proved unreliable, alkane procedures were also unsatisfactory as chicory has few alkanes present at sufficient concentrations for use. Up to 20 pasture cages per subplot were used to provide general estimates of apparent consumption rates during each of the grazing periods.

Estimated animal consumption rates were similar on chicory and lucerne, averaging 1.7 kg (total DM) hd^{-1} d^{-1} for each species over all grazing periods. However, these estimates from cages were subject to considerable variation and arguably represent an overestimate of consumption as allowance for wastage while grazing (*eg.* trampling *etc.*) has not been taken into account. Nevertheless, different trends in consumption patterns were evident between treatments (Figure 1). During the initial grazing period, apparent consumption rates were higher for chicory, but declined with time as the amount of stem increased. The reverse was observed for lucerne with reluctance for animals to consume lucerne when lambs were first put into the sub-plots, but with an increase in consumption with time. This may be due in part to the observations often reported by producers of poor acceptability of lucerne to sheep when alternative forages are available. This was also observed in this study with the lambs readily consuming chicory, but taking some time to utilise lucerne. In all grazing periods, the apparent consumption rates exceeded 1.1 kg hd^{-1} d^{-1}, a level adequate for maximum lamb growth provided the forage consumed is composed largely of green leaf.

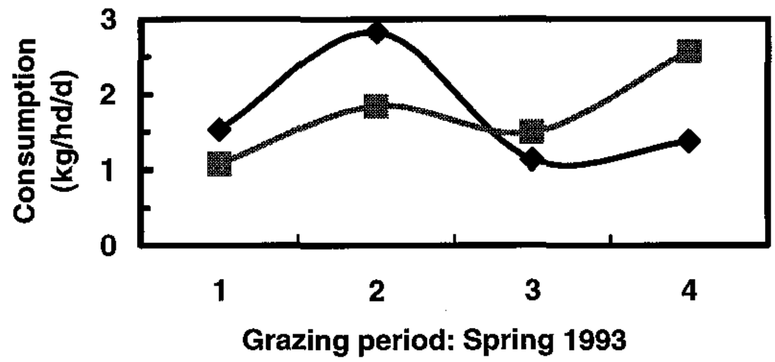

Figure 1: Estimated consumption rates of chicory (diamonds) and lucerne (squares) by elite lambs during spring 1993. Data derived from pasture cages.

Animal growth

The stocking rates used with the initial groups of lambs were conservative, partly due to the season and also to allow full expression of the responses by animals to the different forages. During the summer of 1992/93 three groups of lambs were grown on the chicory and lucerne plots. There were some differences in the starting weights of the three groups: the first group had the heaviest starting weight (range 32 to 35 kg hd^{-1}) while the second group were 1 to 2 kg hd^{-1} lighter and the third were lighter still (25 to 28 kg hd^{-1}). In each case the cryptorchid lambs were heavier than the ewes ($P<0.05$). At the end of the grazing period, Group 1 had reached a weight of 43-50 kg while Group 2 was 1-2 kg lighter. In contrast, Group 3 only reached 32-38 kg hd^{-1} when grazing ceased.

Irrespective of the starting weight, the results showed that lambs grazing chicory grew at significantly ($P<0.05$) faster rates (Table 1). In no group was lucerne better than chicory, though the individual differences were not always significant. All animals in each group were removed from the plots when the average estimated carcass weight approached a marketable size. Final carcase weights were similar for lambs from chicory and lucerne, which may have been due to the slightly higher fat depth on lambs grazing chicory, especially for Group 1. There were no significant interactions between sex and pasture type for animal parameters.

Table 1: Lamb liveweight gain (g hd^{-1} d^{-1}), final carcase weight (kg) & fat depth (mm) (& score) at the GR site (corrected to average carcass weight), for five groups of lambs on the experiment at Cowra comparing chicory and lucerne.

Group	Chicory			Lucerne		
	Gain	Carcase	FD (Sc)	Gain	Carcase	FD
Group I : 15/9/92-4/11/92						
Cryptorchids	312	25.0	14.5 (2)	248	23.2	12.0 (2)
Ewes	194	22.2	16.2 (3)	183	21.9	14.9 (2)
Group II : 6/11/92-3/1/93						
Cryptorchids	243	22.0	12.6 (2)	233	21.8	12.3 (2)
Ewes	190	19.7	13.4 (2)	180	20.2	13.6 (2)
Group III : 7/1/93-11/2/93 [1]						
Cryptorchids	289	-	-	188	-	-
Ewes	224	-	-	172	-	-
Group IVa : 19/9/93-18/10/93						
Cryptorchids	304	18.5	8.7	287	18.1	8.7
Group IVb : 18/10/93-30/11/93						
Cryptorchids	262	22.0	12.4	247	21.6	13.0

[1] Lambs removed from plots early due to disease incidence and hence other measurements were not taken.

The initial plan was to evaluate only two groups of lambs each year, but the excellent spring conditions allowed the evaluation of a third group of lambs to begin during summer in the first year. However, these lambs were removed from the plots before reaching the required average slaughter weight, due to the disease problems encountered in the chicory (see below), and the onset of generally adverse climatic conditions contributing to poor pasture growth. The lambs were returned to the chicory plots a few weeks later and were successfully finished to the specifications required (18+ kg carcase, 2-3 fat score). Lambs continued on the lucerne and reached the required weight on 17 February 1993. Due to the broken period, the growth rate data from this third group is not as useful for comparing lucerne and chicory, although it still demonstrated the ability of a chicory pasture to produce large lean lambs.

In spring 1993, it was decided to run the fourth group of lambs as the pastures had recovered and were productive. This group was put on the plots on 8 September 1993. Again, lambs on both chicory and lucerne met elite lamb specifications within a grazing period acceptable to producers.

Taste tests were done at Rutherglen on the lambs slaughtered from the second group. The objective meat tests conducted showed no significant differences between lambs from chicory or lucerne (D. Hopkins, *pers. comm.*).

Charcoal rot

During the summer of 1992/93, chicory became infected with charcoal rot, a disease caused by the fungus *Macrophomina phaseolina* (Goodacre and Nikandrow, 1993). The disease appeared during the time the second group of lambs was on the plots. Charcoal rot had not previously been recorded on chicory, but had been seen on various broadleaf crops, including cowpeas and also on many weed species when stressed under hot, dry conditions. At the start of the summer chicory density was around 46 plants m^{-2}, but by May 1993, this had declined by 40% to around 27 plants m^{-2}. Over the same period, the density of lucerne remained constant at 46 plants m^{-2}. Many of the chicory plants were easily pulled from the soil. Once the disease was identified animals were removed from the plots for a couple of weeks to allow the remaining plants time to recover and set some seed from which it is hoped that the stand will recover. The third group of lambs were then put back onto the plots and finished. The plots were then rested to allow seed to mature, and during the winter many seedlings emerged and established as a result of this strategy.

Discussion

This experiment demonstrated on four occasions that chicory and lucerne have similar abilities to produce elite lambs, at growth rates in excess of those normally expected. Growth rates between 200 and 300 g d^{-1} were often recorded. The higher growth rates depend upon having animals with high potential growth rates such as cryptorchids. No difficulties were encountered in conditioning lambs to the chicory. In fact, the reverse applied with lambs taking longer to start eating lucerne. No animal health or other problems relating to chicory were encountered. This work showed that it is possible to overcome the normal deficiencies in forage supply in this region (Moore *et al*, 1993).

These plots were stocked conservatively to allow full expression of animal responses to each species. Often the herbage mass exceeded that required to maximise intake. Higher stocking rates could be supported on both species to finish lambs. For more effective management of lambs on these species, rules need to be developed to estimate carrying capacity and the level of forage-on-offer required to maintain optimum pasture production and persistence.

More detailed studies of the nutritive value of chicory are required as the data obtained here suggested it was an inferior forage to lucerne, which clearly conflicts with the animal production data. Resolving this conflict for chicory is necessary as it could have important implications, not only for this species but also for other herbs that occur in pastures. Adequate estimates of carrying capacity would require better knowledge of intake rates and forage quality. The apparent contradiction between estimates of forage quality and animal performance may not simply be due to characters such as greater intake for chicory (not fully resolved in this study), but other nutritional factors could be involved. For example, Crush and Evans (1990) reported that chicory might supply grazing animals with a relatively high concentration of some minerals, possibly leading to improved animal nutrition. Komolong *et al* (1992), however, concluded that the superior performance of chicory might be due to an improved supply of non-ammonia nitrogen relative to the energy intake. These issues are unresolved.

The results obtained support the view that chicory has a high nutritive value. The basis of this is poorly understood, nor do we know much about seasonal trends in nutritive value. We consider that the common digestibility and ME standards may not be appropriate for chicory. These standards have been derived mainly for grasses and legumes and not herbs. Dr G. Robards at the University of NSW has commenced studies into the nutritive value of chicory *in vivo* and *in vitro*.

The better intake data obtained suggested that initially, lambs on chicory had a higher intake, but over time lucerne intake rates increased and then exceeded those on chicory. This suggests that lamb growth rates could follow a similar pattern given the small differences in (apparent) forage quality. In consequence it may be expected that animals with a high potential for growth and a short period required to reach target weights, would perform better on chicory than lucerne. Groups of slower growing animals however, may perform as well on lucerne as on chicory. The results from cryptorchid and ewe lambs support this view.

Meat quality tests showed that the lambs grown on chicory could readily meet elite lamb specifications. Unfortunately the taste tests done were not very satisfactory due to delays at Rutherglen in doing those tests. They reported no 'taste' problems. There has been some concern in New Zealand about a 'taste' in meat and milk from animals grazing chicory dominant pastures, but we were not able to comment on these reports. Such a problem may not prove to be a major constraint on the use of chicory, as it is understood that a 'taint' free variety has now been selected (D. Clark, *pers. comm.*) and will be tested with animals in the near future. This could readily replace the current cultivar.

This study recorded the first incidence of charcoal rot (*Macrophomina phaseolina*) on chicory in Australia. We also know from New Zealand work that cold, wet conditions can lead to infections with *Sclerotinia*, causing death of the taproots. Occasional infections with *Sclerotinia* have been found at Orange, but incidence has been low (<1%). Both instances seem to support the hypothesis that when chicory is under stress and plant growth rates are being limited by climatic conditions, it is susceptible to infection (this could occur in winter, A. Nikandrow, *pers. comm.*). Full expression of that infection may not occur until some time later when suitable conditions occur. This suggests that management during the initial stress / infection periods may be as critical as during the expression of disease. Fortunately it was possible to withdraw the livestock, allow seed set and then rest the pasture to encourage recruitment of new plants. This was achieved and suggests that management can help the pasture to recover from such problems. Plant breeders (D. Marshall, *pers. comm.*) have suggested that selection for resistance to charcoal rot would be easily done. This may also occur under natural selection in commercial paddocks as some resistance develops by allowing recruitment from surviving plants.

From the production view point, this study has shown that chicory has the potential to very successfully finish lambs to elite specifications. While the use of chicory for this purpose will depend upon the suitability of chicory for the locality and season, it provides an alternative to lucerne. This may be particularly important in locations with rainfall exceeding 550 mm where soil conditions *e.g.* acidity, limits lucerne persistence and performance. While the Al and Mn tolerance of chicory is yet to be determined, other members of the *Asteraceae* (*eg.* capeweed) are highly tolerant of low base cation levels and high Al saturation.

The merits of chicory *versus* lucerne depend upon locality. In this experiment, lucerne usually produced the greater biomass and, therefore, potentially had the greater carrying capacity. However, a simple comparison of biomass does not provide the complete answer, as green leaf yields from both species were similar. Nevertheless, the preliminary evaluation of the results indicates that at this site and for the seasons encountered, lucerne could probably have carried more lambs than chicory. Semi-winter active lucernes would probably have a longer growing season than chicory.

In the Cowra environment, the climate and 'normal' pastures are marginal for the production of elite lambs, often due to the absence of green leaf or to plants shedding green leaf during summer. It is known that lucerne will often drop leaves during dry summers and while the same phenomena has been observed with chicory we do not know if the conditions for this to occur, are the same for both species. Observations at other sites (*eg*. Orange), suggest that chicory may retain its leaves for longer (Davies, 1952; O'Brien, 1955). More experience with chicory in the Cowra environment will be needed to establish where and when it could be used to replace lucerne for finishing lambs. Observations on sown paddocks in hotter climates in the region during the summer of 1992/93 found that many chicory plants had dropped their leaves during hot weather. This would limit the value of chicory as forage in such climates. Lucerne had also dropped its leaves in those areas. At this stage, we recommend that where lucerne can be grown well, then it should be used. On paddocks where lucerne is marginal, chicory would be an alternative worthy of trial. In other regions (*eg*. the Tablelands and Upper Slopes), chicory has been more productive than lucerne and is now being widely sown as a valuable pasture plant.

Where lucerne becomes marginal and where soils have some depth and rainfall is above 550 mm, chicory is a very viable option. Chicory does require some summer rainfall or irrigation, to maintain moderate moisture stored at depth to be productive. Chicory management and adaptability is likely to be more flexible than the rotational systems required for lucerne persistence. Special purpose chicory pastures would be better for finishing lambs than most perennial grass based pastures in central NSW as they would produce larger quantities of nutritious green leaf over summer.

The results from this experiment clearly show that the high nutritive value of chicory can be converted efficiently into animal product. This supported other evidence from New Zealand. Depending upon summer rainfall, up to three groups of lambs could be finished off over a single summer. To achieve this chicory needs to be a major component in the pasture and grazed rotationally as discussed later in this report. Chicory would fit within those zones already defined as suitable for elite lamb production over summer.

Grazing management of chicory

Introduction

Chicory is a perennial plant useful for providing high quality forage for livestock production systems. However, its ability to persist does depend upon its tolerance to grazing. Experience in New Zealand has been that chicory requires rotational grazing to persist (Hare *et al.*, 1987). Initial observations at Orange suggested that chicory might not be as sensitive as lucerne to grazing management. The field experiment reported here aimed to establish how robust chicory is to grazing. Alternative grazing management practices were evaluated for their effect on the productivity and persistence of a chicory pasture.

A supplementary experiment was completed in a controlled environment to compare the growth and regrowth after repeated defoliation of chicory with lucerne and perennial ryegrass. Perennial ryegrass is regarded as very tolerant of grazing whereas lucerne is very sensitive. The early growth of plants was measured as it was considered this would better reflect the innate response of these species to defoliation.

Methods

Design

The field experiment investigated a gradient in management practices from continuous grazing through short grazing to long rest treatments. The median treatment was based on the then current recommendations in New Zealand. An *open communal grazing* design was used (Kemp and Dowling, 1998) similar to that employed within the Meat Research Corporation Temperate Pasture Sustainability Key Program. Small plots were set out within a larger paddock arranged in contiguous blocks. In this design, all plots are grazed communally with one mob of sheep with plots opened and closed to grazing as required for individual treatments. An advantage of this design is that changes in the area available to grazing are small relative to the total area of grazed pasture. This removes the need to continually adjust stocking rates. The aim was to screen options for management to maintain a productive pasture and not obtain data on animal responses. The treatments studied were:

1. Continuous grazing.
2. Rotationally graze - 3 weeks on, 3 weeks off.
3. Rotationally graze - 1 week on when 250-300 mm high (including seed heads).
4. Rotationally graze - 1 week on, 5 weeks off.
5. Rotationally graze - as per 3, but no grazing over winter.

These treatments were replicated four times and located within a 0.5 ha paddock that was stocked at a minimum of 10 DSE ha^{-1} with merino wethers. In periods of peak growth the stocking rate was increased to 15 DSE ha^{-1}. Each plot was 7.5 * 15 m. With this design there can be a perceived problem of stock not grazing newly opened plots when required when the forage available in the paddock is large, or if the forage on the plot is 'rank'. However, no problems were experienced in this experiment. Whenever replicates were opened, stock readily moved in and consumed the available forage down to the same level as the remainder of the grazed area within a short time – usually less than the week some treatments allowed. Animals were monitored for body weight and condition every three months. Normal animal health procedures were followed as per local farm practice.

The controlled environment study included chicory, perennial ryegrass (*Lolium perenne* cv Kangaroo Valley) and lucerne. These species were sown in 30 cm pots using a soil mix provided with non-limiting nutrients and grown in a controlled temperature glasshouse at approximately 20°C for six weeks. During that period some pots remained uncut, while others were cut at ten-day intervals.

Site

The field experiment was sown in late August 1991 at the Orange Agricultural Institute with a mixture of chicory (cv Puna), white clover (cv Haifa) and subterranean clover (cv Leura). Soil type was derived from basalt and had been used for cropping and pastures over many years. The site was heavily infested with Paterson's curse, which necessitated some spot spraying of weeds during establishment. The pasture was intermittently grazed during the first year prior to laying out the experimental plots and commencing the experiment in spring 1992.

Measurements

In the field experiment, all continuously grazed plots were measured for composition and standing biomass every six weekly intervals using dry weight ranks 'Botanal' procedures (Tothill, 1992) and a rising plate meter (Earle and McGowan, 1979). Other treatments were measured prior to and after periods of grazing. Ten sample points were spaced at 3 m intervals along a fixed, diagonal transect in each plot that was initially chosen at random. During the grazing periods, cages (1 m^2) were used to monitor pasture growth rates. In the continuously grazed plots, however, cages were measured and moved every three weeks. Yield estimates were calibrated using four harvested 30*30 cm quadrats per plot. Plant densities were recorded at approximately annual intervals in each plot. From the second year these counts were done on fixed quadrats.

Results

Plant density

Chicory densities declined under moderate continuous grazing, especially after the third year (Table 2). Under the rotational grazing treatments densities initially increased as plants were able to flower and set seed. The longer the rest period, the more density increased (*eg*. see Treatment 4). The five-week rest between grazings resulted in very little decline in plant densities over five years. Treatments with more moderate rest periods showed a decline after three years.

Table 2: Changes in density of chicory plants in response to management treatments.

	Chicory Density - plants m^{-2}				
Treatments	April 1993	June 1994	January 1995	July 1996	July 1997
1. Continuous grazing	20.0	11.3	17.0	5	1
2. 3 weeks on / 3 weeks off	17.5	16.0	26.8	12	13
3. 1 week on when 250 mm high	15.0	19.0	27.8	18	14
4. 1 week on / 5 weeks off	15.5	23.8	36.2	35	30
5. treatment 3 / no winter grazing	15.5	21.0	25.0	19	17
$lsd_{0.05}$ (all combinations)			7.1		

Forage yields

The very good growing conditions during 1992 resulted in the pasture containing 80% legume when grazing treatments commenced in late August 1992. However, legume content declined during the year and remained lower throughout the five years of this experiment. The proportion of chicory increased to two-thirds of the pasture by autumn 1993. None of the management treatments had any significant effect on the proportion of chicory in the first two years. Herbage mass (pre-grazing) was significantly greater in treatments that provided a longer rest from grazing.

After the second year, chicory productivity declined under continuous grazing and produced very little forage after three years (Figure 2). All other treatments retained productive chicory plants for five years. The longer the rest periods, the more chicory herbage mass was present in year five.

Chicory leaf yields were consistently greater with longer rests between grazing as was stem growth. There were no consistent significant differences between treatments three and five and hence only the data for treatment three are presented.

Where chicory herbage mass declined weeds invaded the pasture. The main weeds were *Vulpia* spp. and Paterson's curse (*Echium plantagineum*). The continuously grazed treatment had a significant weed component from the second year, whereas the five-week rest treatment did not until year four. Across the treatments, Paterson's curse appeared to invade the plots before vulpia species (Figure 2). This may have been due to the heavy infestation of Paterson's curse that was present in the paddock before the chicory was sown.

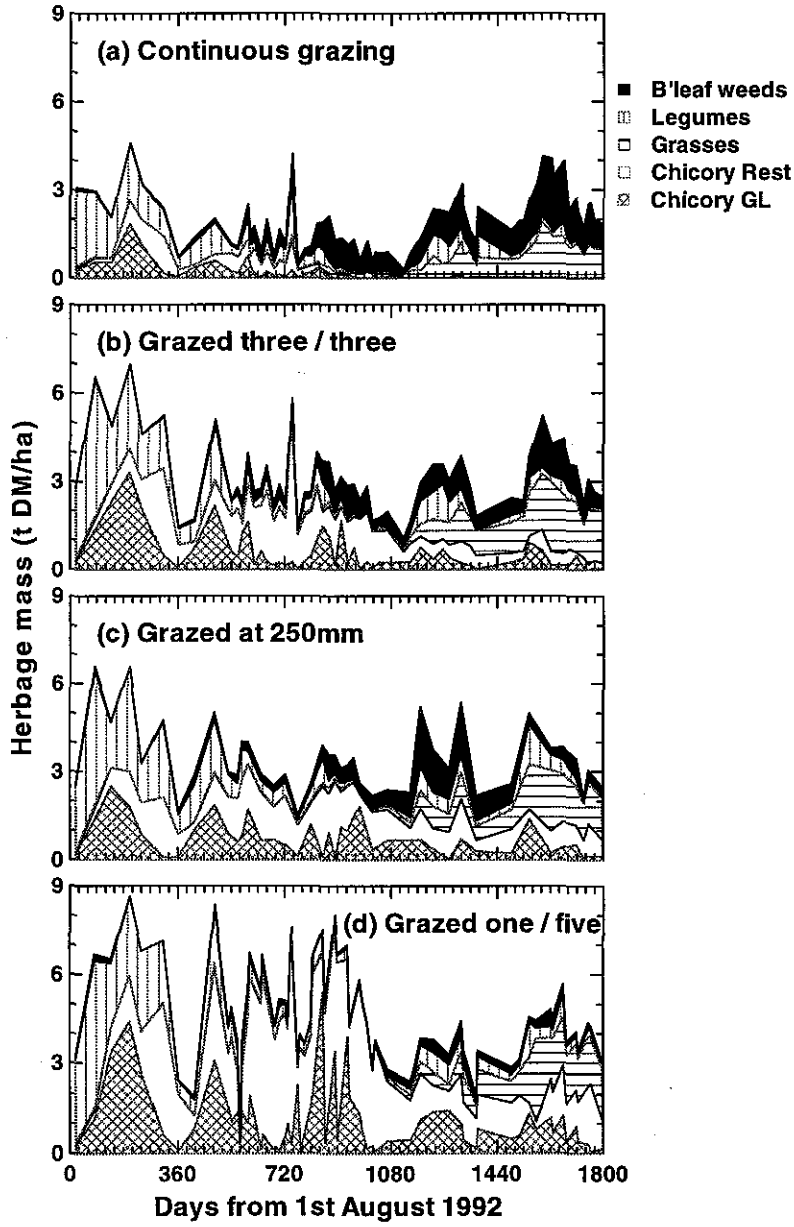

Figure 2: Composition of chicory pastures (a) continuously grazed, (b) grazed three weeks in six and (c) grazed for one week when chicory was 250mm high and (d) grazed one week in six over five years from August 1992. Data show the herbage mass (pre-grazing) for chicory green leaf and remainder, legumes (predominantly white clover) volunteer grasses (mostly *Vulpia* spp.) and broadleaf weeds (mostly Paterson's curse). Yields were measured to ground level, while stocking rates were managed to moderate grazing pressures.

Species interactions

To investigate the overall interactions between species a principal components analysis was done using the data on percent composition of chicory, legumes, grasses (mostly annuals) and broadleaf weeds. Data from all harvests and treatments were combined for a biplot analysis (Figure 3) using a method described by Wilkinson (1997).

The first principal component was significantly influenced by the interaction between chicory and the annual grasses and broadleaf weeds. Most of the data for the one week on / five off treatment were associated with the focus for chicory, whereas by the end of the experiment the continuously grazed and three weeks on / off treatments were dominated by annual grasses and broadleaf weeds. Other treatments were intermediate.

The first two principal components accounted for most of the variation in the data. The third component (not shown) separated the annual grasses and broadleaf weeds. This analysis suggests that the annual grasses and broadleaf weeds acting as a group had the most influence on the proportion of chicory in the pasture. Then within that group the annual grasses and broadleaf weeds were competing for similar resources.

Legumes were the major influence on the second principal component. The legume content was poorly correlated with the other components *i.e.* largely independent of the trends in chicory and other species. Legume contents were highest in the first year and most of the data points associated with the legume focus were from the early harvests.

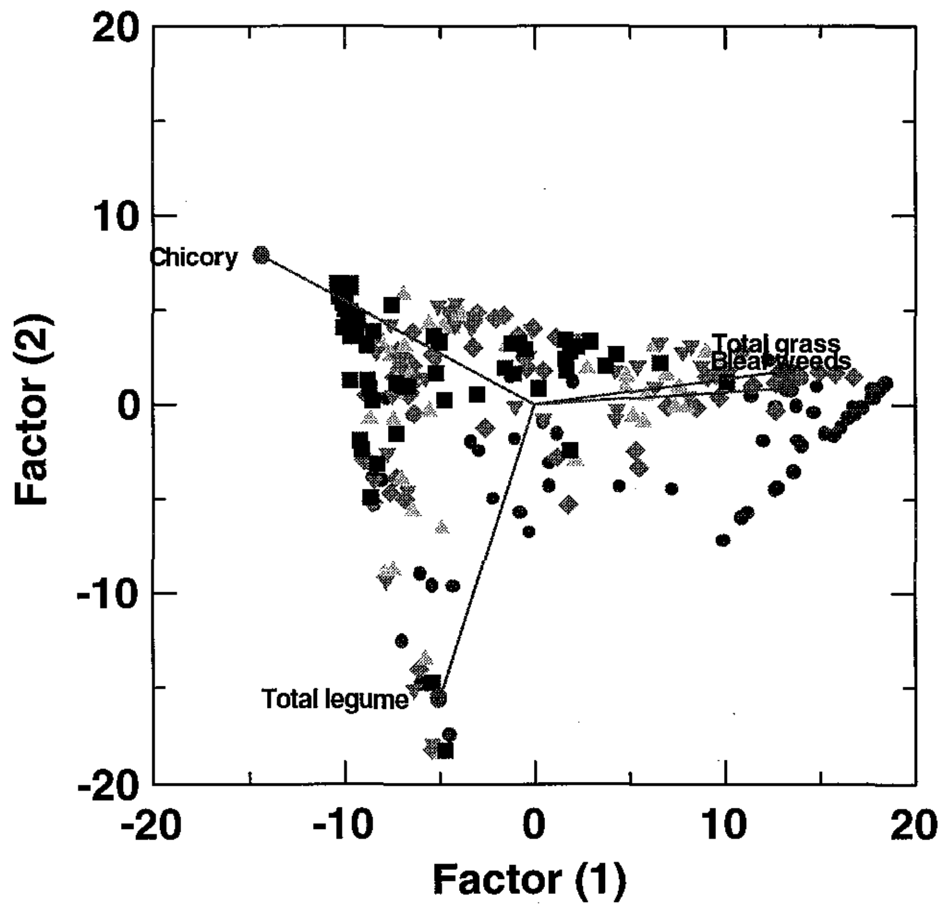

Figure 3: Principal components analysis presented in a biplot, for data on percent composition of chicory, legumes, annual grasses and broadleaf weeds in the herbage mass, for all treatments and harvests over five years. Data are for treatment means. The treatments were; continuous grazing (●), three weeks on / off (◆), one week at 250 mm (▲, with winter rest▼), one week on / five off (■).

Disease

In December 1994, plots were surveyed to establish the number of plants that were infected with charcoal rot. The one week on / five weeks off treatment had significantly more infection than any other treatments. However, the level of infection across treatments was very low, ranging from 0% in the control to 0.9% in the one week on / five weeks off treatment. Plants in that treatment had been slashed the previous June to remove dead stems. This may have resulted in some damage, enabling limited infection. The incidence of *Sclerotinia* infections was also monitored and rarely exceeded 1%.

Controlled environment comparisons

The controlled environment study provided considerable data for growth analysis of chicory, perennial ryegrass and lucerne. Only a summary of the results is presented here. Alemseged (1998) gives a complete discussion. The total yield of young plants cut every ten days over six weeks was compared with the yield of uncut plants over the same period (Figure 4). These results showed that perennial ryegrass was the most tolerant of cutting and lucerne was the least. Chicory was much closer to perennial ryegrass than to lucerne in response to cutting. Chicory leaf area responded better to cutting than did lucerne.

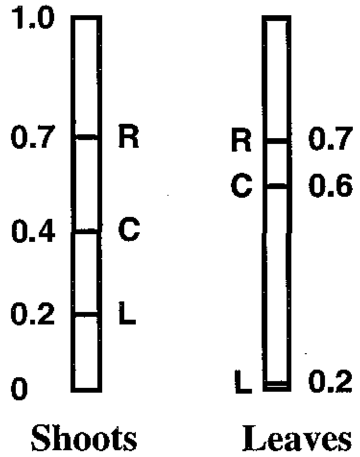

Figure 4: Relative growth response of shoots and leaf area for perennial ryegrass (R), chicory (C) and lucerne (L) to cutting at ten day intervals. Responses are relative to the uncut controls for each species.

Discussion

Chicory was known to be sensitive to continuous grazing and that was confirmed in this experiment. Like lucerne, chicory requires rotational grazing to persist and be productive. However, chicory appears to be more tolerant of grazing than lucerne as was evident with the results that it took several years for the differences in these treatments to emerge. Another study (Alemseged, 1998) showed that chicory regrowth under cutting was greater than from lucerne. The better treatments still have a high proportion of chicory and may still persist for many years, unlike lucerne where the productive life of most stands rarely exceeds four to five years. In general, the longer the rest interval the greater was the productivity and plant density of chicory. This supports the view that chicory is more sensitive to the frequency rather than the intensity of grazing (Li *et al.*, 1997). Chicory regrows from the crown with new leaves after grazing and not from residual stems or leaves.

Up to three years, there seemed few differences between the three weeks on / off and one week at 250 mm treatments. However, over the next two years, chicory declined in the three weeks on / off treatment and was replaced by grasses and broadleaf weeds. This may have been due to the period of grazing being longer than desirable which provided the opportunity for plants to be grazed early in their regrowth cycles. The five week rest treatment did maintain a high population of productive chicory plants. This suggests that the optimal rest interval is between three and five weeks, depending upon conditions for growth. Future work should aim to refine these rest periods to a plant-based criterion. The results indicate that a height > 250 mm may be optimal as the one week grazing when the chicory reached a height of 250 mm, plants were not as productive or persistent as those in the five week rest. We suggest the optimal height to commence grazing of chicory pastures would be in the range of 300-500 mm. In addition, sheep should not graze a chicory pasture longer than one to two weeks.

Recent studies in New Zealand found that overgrazing of chicory can increase the incidence of disease. Plants should be grazed to leave stubble of 50-100 mm (Li and P. Kemp, *pers. comm.*). This work also found an optimal interval between each grazing with sheep or deer of 3-4 weeks which is in close agreement with the results reported here. The New Zealand research was conducted under high rainfall conditions at Palmerston North where growth rates were high. Nevertheless, around 30% of plants died each year (in late spring) even under the better grazing tactics, but remained healthy and persistent in ungrazed plots. The results presented here suggest that longer rest periods may have been required in those studies to enhance persistence, particularly when summer rainfall is variable.

The five-week rest treatment did result in significant amounts of stem growth. The initial impressions were that this depressed leaf production as leaf size was reduced the further up the stem they grew. However, the data show that total leaf mass available on this treatment was as great, or greater than from others suggesting that extra stem growth may not be as problematically for management it was initially considered. There is, however, a perceived aesthetic problem with stem growth. Once producers are aware that it arguably does not depress animal production, they should adjust to the differences from some more traditional pastures. Chicory pastures are never going to look as neat as newly mown lucerne or ryegrass / clover pastures. During this experiment, it was considered that slashing chicory pastures was necessary to remove the dry stalks and allow stock easier access to the forage. To this end, the experiment was slashed during winter 1993. Stock did not remove all the seed heads and stalks at each grazing as evident in Figure 2. However, animals did remove all the leaf and we now consider that stem growth is not a problem for access. It has also been suggested that slashing stems could provide a site for fungii to invade the plant (A. Nikandrow, *pers. comm.*). Chicory stems are hollow and water is often observed to pool in the cut stems. This could become a problem in winter when chicory is not actively growing and hence less capable of overcoming infections through rapid growth rate. Disease problems in this pasture were minor, though disease attacks have been significant in other experiments. The lack of a difference between Treatments 3 and 5 suggests that grazing during winter has so far had no major detrimental effects on plant persistence. This may also be due in part, to the general favourable management given to chicory in those treatments. The influence of grazing in winter when chicory is grazed more frequently the rest of the year is unknown.

There was an initial increase in chicory densities on the rotationally grazed treatments presumably due to seed set and recruitment of new plants. The increase in density by January 1995 could not be linked with late germinating sown seed as observations suggest chicory has limited dormancy and this was 3.5 years after the paddock had been sown. Measurements of plant density were taken on fixed quadrats from June 1994 onward. The decline in plant densities after three years occurred on most treatments. It is unlikely that recruitment occurred in all years. Undoubtedly, the maintenance of desirable densities will require a specific management strategy that enables recruitment to occur when the density has declined to a suboptimal level *eg.* 20 plants m^{-2}. These results suggest that at least a five-week rest period is needed to ensure some seed set and recruitment. Future work is needed to define more precisely the conditions under which recruitment can be maximised and the density threshold at which special management strategies need to be activated.

Weeds invaded these treatments from around the third year on and chicory and legumes declined. This was not a reflection of climatic conditions, as the total herbage mass available still remained high. Fertiliser applications were suspended after the third year as the soil was very high in available phosphorous (>20 mg kg^{-1}, Bray No 1 test). However, this change in composition of the more desirable components may have been influenced by the limited fertiliser applications. The experiment will be continued and fertiliser applied to establish if this has influenced the desirable components.

The principal components analysis strongly supported the results from a competition study (see later section on Chicory Agronomy). In that study, it was evident that chicory and legumes did not compete but rather behaved in a complementary way such that the productivity of the mixture often exceeded the combined total of yields for each species growing in monoculture. However, chicory did compete with the companion grasses and broadleaf weeds (as was also found in the competition study). This probably reflects that chicory grows over the warmer months and restricts the growth of these other species to the winter period when they are more competitive and can gain an advantage at that time. As the grasses and broadleaf weeds were restricted to growing in winter, they were then more competitive with each other. This situation does not always apply in other pastures as broadleaf species such as Paterson's curse can establish over summer and the competitive interactions become more complex (Kemp, *unpublished data*).

The controlled environment study showed that young chicory plants are more sensitive to defoliation than perennial ryegrass, but significantly more tolerant than lucerne. That response reinforces the results from the grazing management study where continuous grazing killed most of the chicory plants over a few years. General experience with lucerne is that it would disappear from a continuously grazed pasture within two years (Peart 1968).

The flexibility with which chicory can be managed is uncertain. This experiment provides a continuing opportunity to explore tactics to rehabilitate a degraded pasture. We propose to fence off some additional plots within the paddock, where the chicory has declined under continuous grazing and then use periods of exclusion over summer to enable maximise plant size and seed set and then for seedlings to establish. In addition the continuously grazed and one week on / five weeks off treatments will be reversed to explore rehabilitation tactics. These results will test if a moderately lax rotation is enough to rehabilitate a degraded pasture and how tolerant a good pasture then is to being continuously grazed.

In summary, we recommend that chicory be rotationally grazed in (ideally) a four-paddock system where two rules should apply most of the time and a third in special circumstances. First, livestock should not be allowed to graze any given area of chicory for more than a two-week period. At each grazing, chicory can be grazed down to remove the green leaf, but retain some stubble (50-100 mm) and to minimise damage to the crowns. Second, once the 'new' area of chicory (*i.e.* the next paddock to be grazed), reaches 300-500 mm in height, stock should be moved onto that area even if the paddock they are currently grazing has not be fully utilised according to rule 1. In a four-paddock system, the application of these rules would mean that when chicory is growing fast and stocking rates are appropriate, animals would be moved at least once a week and a three-week rest would apply. When growth rates are slow, animals would only move once a fortnight and the rest period would then extend to six weeks. The optimal stocking rates will vary with site potential, seasonal conditions and between districts. The third rule would apply if plant density significantly declined. If the chicory plant density dropped to 20 plants m^{-2} then longer rest intervals *e.g.* six weeks and short, less intense grazing intervals (< one week), should be imposed to enable seed set and for some recruitment to occur. In dry years, little recruitment is likely to occur but reduced grazing pressure would still be important to enhance the survival of chicory. In wetter years where the available forage is often in excess of requirements, it may be possible to defer paddocks for longer from a rotation to encourage recruitment.

Chicory pasture agronomy

The successful use of a species in agriculture requires considerable information not only on its productivity, but also on the details of management. Which species is it compatible with, what sowing rates are suitable, can herbicides be used for weed control and other related techniques? Several separate experiments reported here were undertaken to provide additional information on the agronomy of chicory.

Competition, sowing rates & mixtures

Introduction

Chicory is a very new pasture species and little is known about the optimum sowing rates and mixtures to ensure productive pastures. Despite the commercial promotion of chicory as a pasture species, the competitive relations between chicory and other pasture species (such as legumes) are still poorly understood. Mixed chicory pastures containing legumes are likely to be preferred to single species swards, which would require supplementary nitrogen. Legumes are needed to fix nitrogen, while winter active grasses and legumes can help to provide forage when the chicory is dormant, thereby extending the period of productive pasture. Early observations on chicory pastures suggested that it is a very competitive species. Phalaris failed to establish when sown with chicory (Kemp *et al*, 1993) and few other species were observed in well established chicory pastures. This experiment aimed to examine the competitive relationships between chicory (cv. Puna), white clover (cv. Haifa) and perennial ryegrass (cv. Kangaroo Valley) when sown at a range of densities.

Methods

Design & management

The experiment was sown, during May 1993, to evaluate the productivity of chicory (4 densities) * white clover (4 densities) * ryegrass (2 densities) mixtures. The experiment used a bivariate factorial additive design (Snaydon and Satorre, 1989; Snaydon, 1991) with combinations of chicory and white clover as the main plots, which were then split with or without perennial ryegrass. There were two replicates of the 32 treatments. Plots were hand sown into a seedbed prepared with a rotary hoe. The soil was cultivated on several occasions prior to sowing to remove weeds. The subplots were 2 * 2 m with a 20 cm buffer between them which was sprayed with herbicide (glyphosate) at intervals to limit plant spread between plots. Volunteer white clover and other plants were hand weeded when required.

The experiment was sown on a soil of moderate fertility, derived from basalts and similar igneous rocks. The A1 (0-10cm) horizon is a dark reddish-brown sandy loam overlaying a red-brown earthy loam A2 (15-25cm thick). The B horizon grades from an earthy, red-brown clay loam at 15-30cm to dark red-brown medium clay at depth. The profile is slightly acidic throughout (pH (C_aCl_2) 4.8-5.5) and is well drained.

Establishment was slow due to the dry autumn and supplementary irrigation was used to establish the plots. The dry season limited the growth of legumes and ryegrass considerably. During periods when rainfall was significantly below average (1994/95) irrigation was used at the end of each month to bring water inputs up to the average rainfall.

Measurements

Establishment measurements were not taken until spring 1993 due to the dry year and the slow establishment of plots. Regular sampling of plots started in January 1994, and then continued at six weekly intervals. At each harvest, dry weight ranks, dry matter yields and percent green data were collected using Botanal techniques (Tothill *et al*, 1992) using five (30 * 30 cm) quadrats per plot. On each occasion after rating each quadrat, one quadrat was harvested close to ground level (without cutting into the crown of plants) with electric hand shears to provide data for calibrations. These quadrats were sorted into species and the chicory into leaf and stem components, dried at 60°C for 24 hrs and then weighed. Plots were then mown off to sample heights using a self-propelled sickle bar mower.

White clover densities were difficult to determine after the initial count due to stolon development. Instead percent ground cover was measured each winter in a fixed 50 * 50 cm quadrat in the centre of each plot. The quadrat was divided into 36 squares and the number of squares where white clover was present were counted and converted to a percentage. The initial densities determined were used to characterise treatments.

The water relations of chicory and white clover were investigated during the summers of 1995/96 and 1996/97. This involved monitoring the soil water content of the surface soil with gravimetric samples and pre-dawn and midday leaf water potentials and relative water contents. Light interception by canopies was also measured.

Data analysis

The slow establishment of this experiment and the resultant variability in plant densities across plots required the development of an alternative approach to data analysis than originally planned. The initial plan was to establish 0, 20, 40 and 60 chicory plants m^{-2}, 0, 15, 30 and 45 white clover plants m^{-2} and 0 and 25 perennial ryegrass plants m^{-2}. Since the actual densities varied considerably within treatments, a regression approach was used to plot yield responses *etc.* in relation to actual chicory densities (range 0, 25-110 plants m^{-2}) as measured in spring 1993.

The cover measurements for white clover were used to initially allocate plots to groups with 'nil', 'low' and 'high' levels of white clover. In some cases, there were few differences between the low and high white clover and subsequent analyses then considered only the presence or absence of white clover. Perennial ryegrass establishment was poor and the plots were invaded with other annual grasses (mostly *Bromus* spp.). Because yields were low, grasses were combined with the forb components in those plots and classified as 'weed' yields.

The main emphasis for data analysis was on the interactions between chicory and white clover. Regressions for log yield were then fitted against linear, quadratic and interaction terms to derive equations of best fit using procedures in Genstat. The fitted equations were then used to estimate yields of chicory and white clover (and their standard errors) in monoculture and mixtures, initially removing weed effects. The estimated yields were then used to derive measures of relative yields, resource complementarity and competitive ability (Snaydon, 1991). The relative yield total (RYT) is the sum of the yield of each component in mixture relative to the sum of their yields in monoculture. Additional analyses tested the effect of weed components. Only the main effects are reported here.

Results

Climate

In 1993, the initially dry season limited early growth and delayed establishment. Annual rainfall varied from 700 mm in 1994 to 1040 mm in 1996. The long-term average at the site is approximately 900 mm. Temperatures were close to average.

Dry matter yields and chicory density

Chicory yields increased with density. The fitted equations showed that in most seasons yields were approaching an asymptote at around 50-60 plants m^{-2} (Figure 4). These data also showed that chicory yield response varied little with the presence (mean of low and high cover) or absence of white clover. There was a tendency though for slightly higher overall yields in the presence of white clover. This translated into higher annual yields. Where chicory was grown in monoculture the mean total annual yield from chicory at optimal densities was estimated to be around 11 t DM ha^{-1} and in mixtures with white clover around 15 t DM ha^{-1}. Approximately half the yield of chicory was recorded over summer.

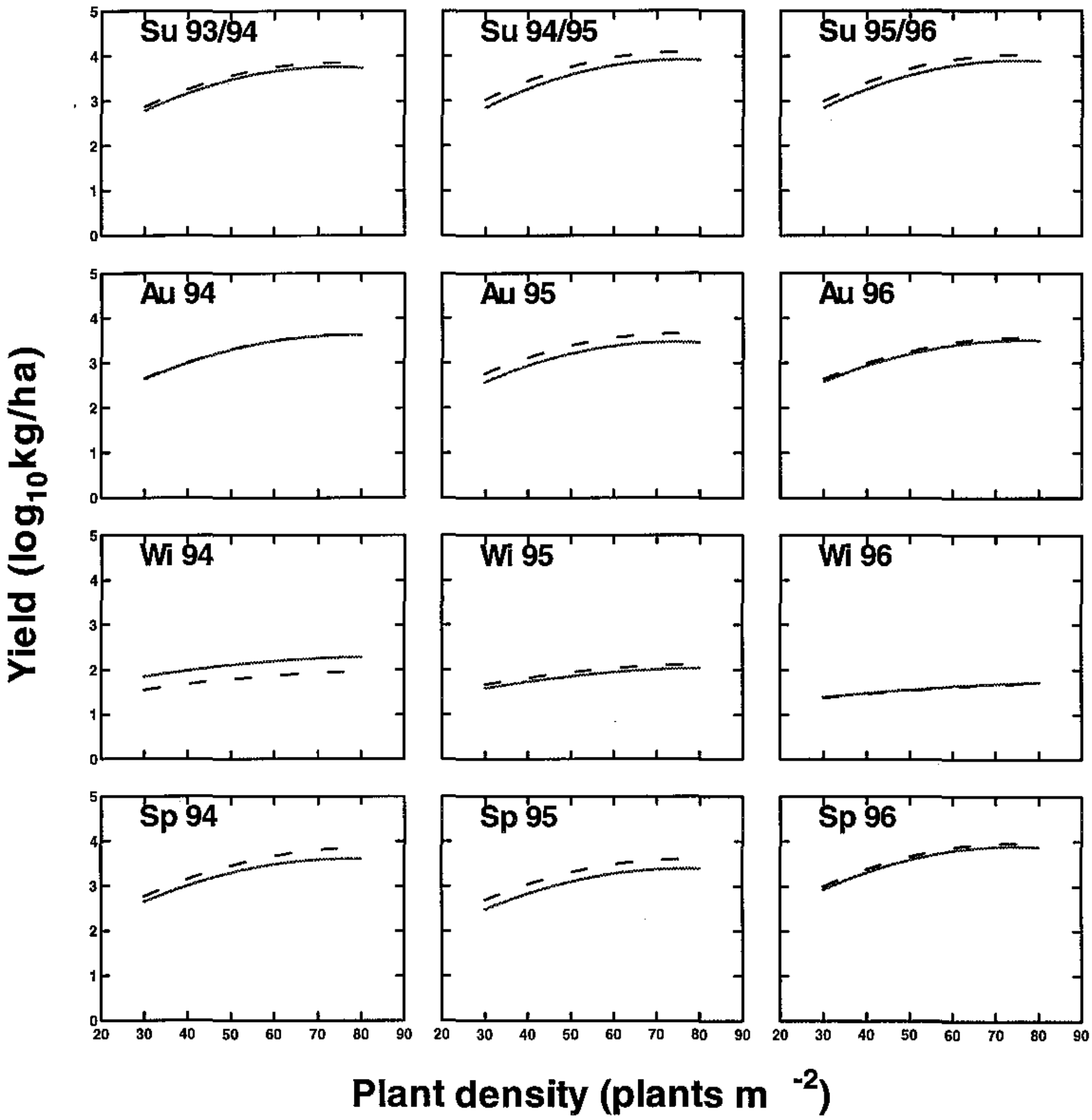

Figure 4: The effect of chicory density on the yield of chicory in monocultures (solid lines) and in mixtures with white clover (dashed lines). Lines shown are regressions of best fit. Data for each season from summer 1993/94 to spring 1996.

The fitted equations were used to derive chicory yields at densities of 25, 45 and 65 plants m^{-2}. From this data the growth rates of chicory with nil, low or high initial levels of white clover (Figure 5) were calculated. Chicory recorded very high growth rates during summer. Chicory growth rates increased with density with a large increase from 25-45 plants m^{-2} and a smaller one from 45-65 plants m^{-2}. At the higher initial levels of white clover (Figure 5) there is some evidence for a small depression in chicory growth rates, but overall this was not significant. The early data (not presented) showed that chicory yields were marginally depressed at the first harvest in the plots with the highest cover from white clover. These results also showed that white clover was able to establish in chicory plots where chicory density was >60 plants m^{-2}. White clover yields did increase with increasing (white clover) plant cover and were greater in spring than other seasons. In this experiment, white clover was the dominant legume and dominated volunteer subterranean clover plants that established in the plots.

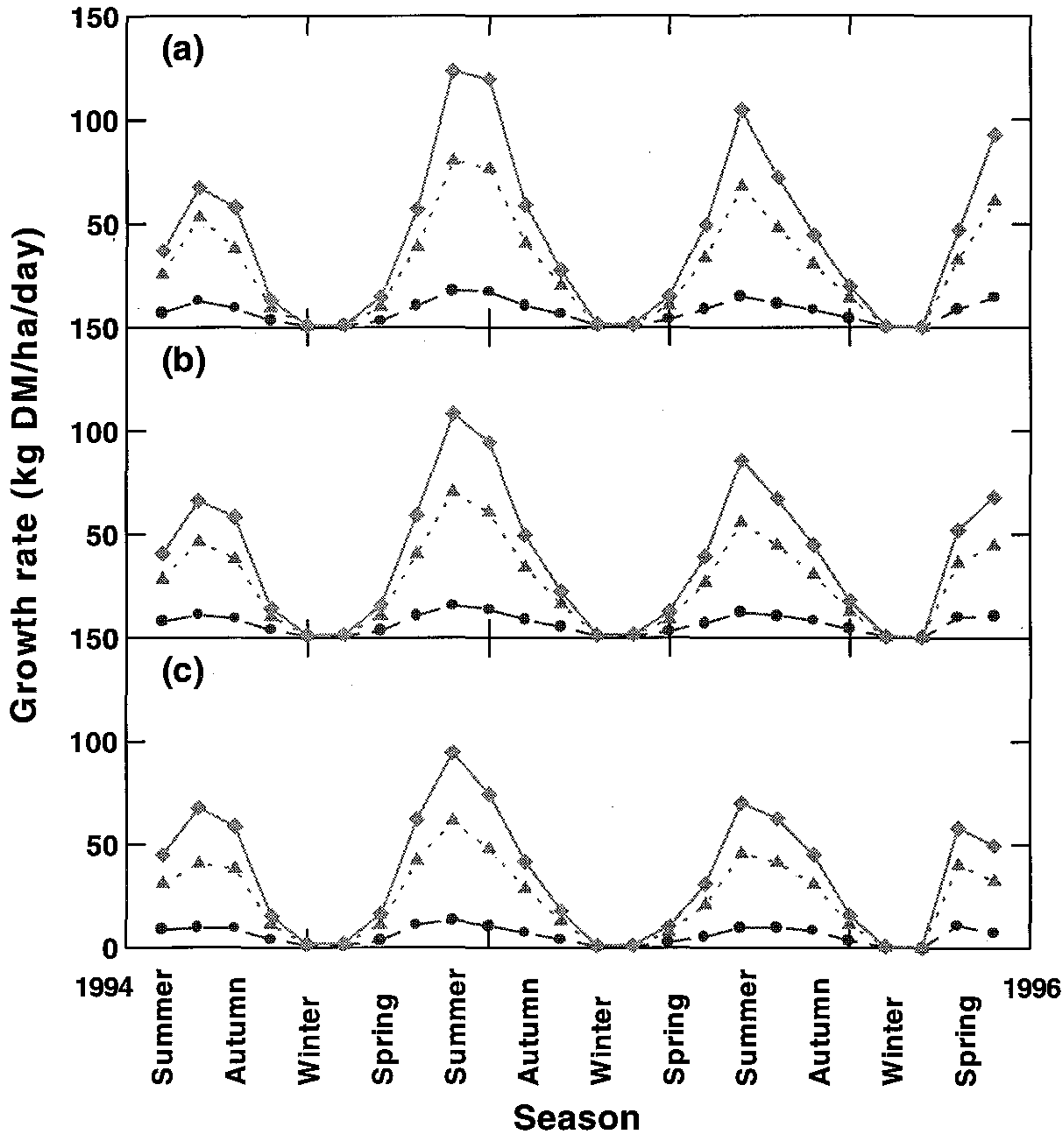

Figure 5: Growth rates of chicory over three years at densities of 25 (●, dashed lines), 45 (▲, dotted lines) and 65 (◆, solid lines) plants m^{-2} for plants growing in monoculture (a) and in mixtures with initial white clover densities that were low (b) or high (c).

Weed yields, including the small amount of perennial ryegrass that established and other volunteer grasses, were limited more by competition from chicory than from white clover. There was no significant impact of the grasses and other weeds on the productivity of chicory. White clover significantly depressed weed yields only in the first winter and spring (1994) after establishment.

The relative yield totals for chicory and white clover growing in mixtures were not significantly different from 2 for most of the three years of measurements (Figure 6). This indicated that there was almost no competition between these species. The relative yield totals were similar at low and high levels of white clover.

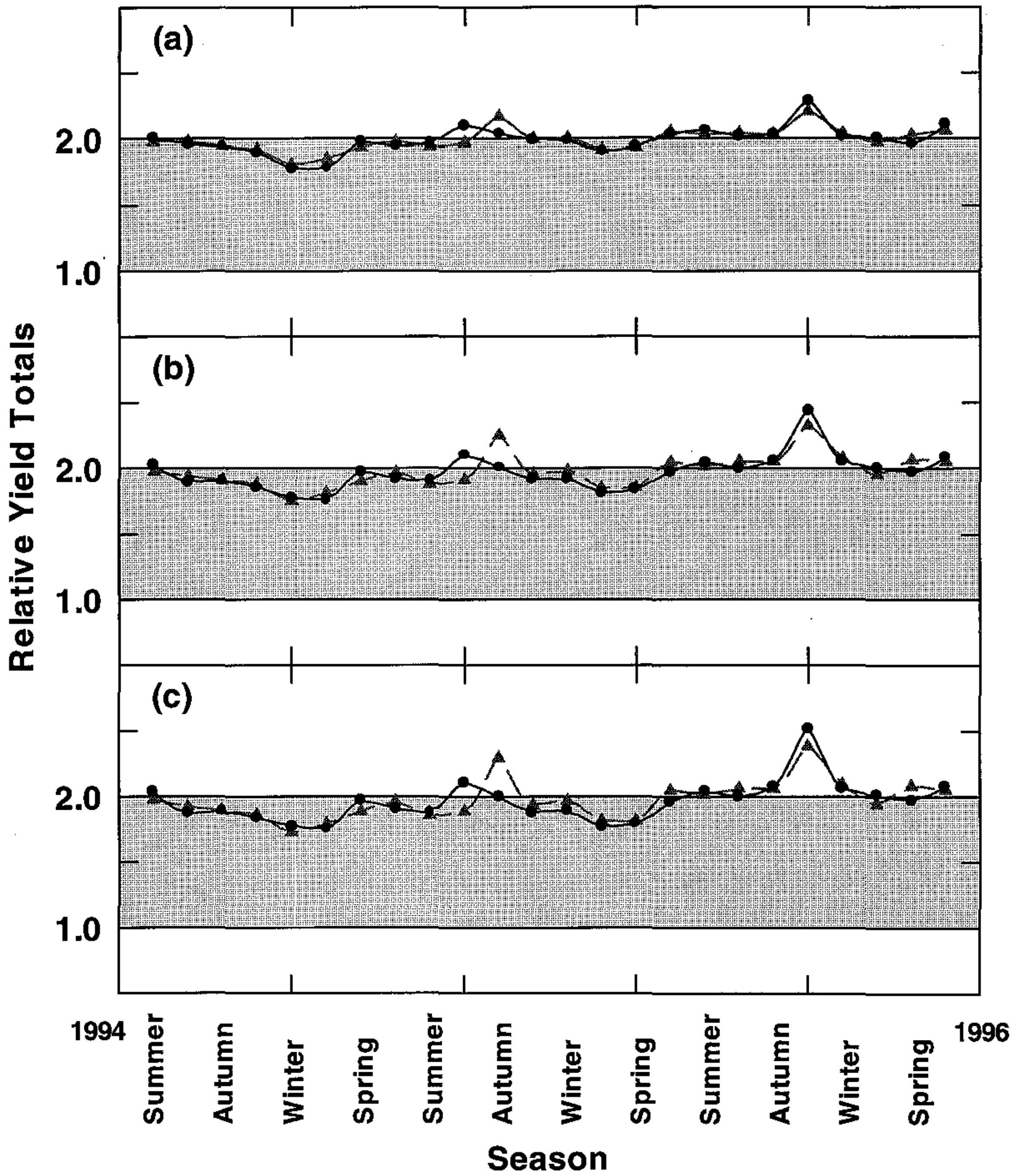

Figure 6: Relative yield totals for chicory, white clover mixtures from harvests every six weeks over three years. Data are for either low (▲, dashed lines) or high (●, solid lines) levels of white clover ground cover and 25 (a), 45 (b) and 65 (c) chicory plants m^{-2}. Relative yield totals <1 indicate a high degree of competition and that species are having an adverse effect on each other, while values >2 indicate no competition and complementary effects.

Plant water relations

White clover yields were greater at times when grown in mixtures with chicory than in monoculture. This suggested chicory had a positive effect on the growth of white clover and it appeared that this could be mediated through effects on water relations. The soil surface water content in mid-summer of 1996 and 1997 was 6-7% under white clover monocultures and 9-11% under mixtures with chicory. These differences were significant.

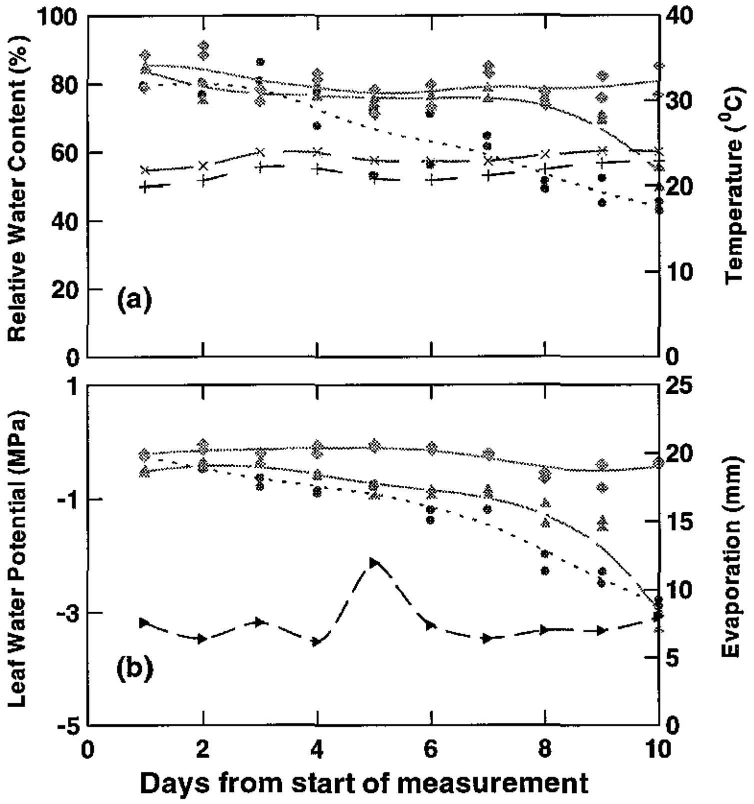

Figure 7: Changes in (a) leaf relative water content and (b) leaf water potentials for chicory (◆, solid lines), white clover in monoculture (●, dotted lines) and white clover in mixtures with chicory (▲, dashed lines). The mean soil temperatures shown in (a) are for under white clover monocultures (x) or under chicory, white clover mixtures (+). The lower dashed line in (b) is the daily evaporation rate.

The leaf water potential and relative water content of white clover declined more during a drying cycle in summer than chicory and this decline was greatest for white clover monocultures (Figure 7). These data show that over the period of measurements, chicory did not appear to suffer any water stress, presumably reflecting its deeper root system. Chicory leaf water potentials rarely declined below -1MPa.

The relative water content of white clover leaves, especially in monoculture, showed an earlier decline than leaf water potentials. The relationship between relative water content and leaf water potentials did differ for white clover between mixtures and monocultures (Figure 8). White clover in monoculture showed a rapid decline in relative water content reaching 50% at a leaf water potential of around -1MPa. In mixtures, the relative water content of white clover did not start to decline until around -2Mpa.

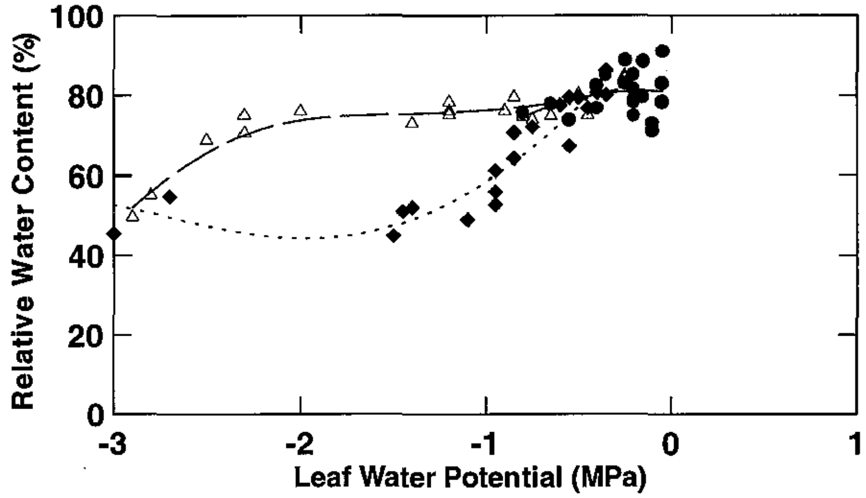

Figure 8: The relationship between relative water content (RWC) and leaf water potential (LWP) for leaves of chicory (●, solid line) and of white clover in monocultures (◆, dotted line) or mixtures with chicory (▲, dashed line). Chicory maintained a higher RWC and LWP throughout the period of the experiment than white clover.

Discussion

Chicory is a very productive species. Total annual yields and pasture growth rates from this experiment exceed those previously found for well-fertilised grass pastures growing under similar conditions (Kemp, 1987). Most of this production occurred in summer, a critical time for green forage supply in central NSW. To achieve these high yields, chicory densities need to be optimised. These results show that densities of 50-60 plants m^{-2} are required. Lower densities may still produce good pastures, but be vulnerable to weed invasion leading to reductions in overall pasture and animal productivity. The grazing management study presented in an earlier chapter showed that lower densities are productive, but weed invasion was clearly evident at suboptimal densities.

Observations across commercial paddocks also suggest that chicory densities are often sub-optimal. This possibly reflects that chicory is being sown as just one component of pastures. As a consequence, over summer pasture productivity will be less than the expected potential. Given the need for careful management of chicory to insure persistence, it would seem preferable to sow chicory at higher densities and manage it as a special purpose pasture as is the case with lucerne. To achieve optimal chicory density, sowing rates of 3-4 kg ha^{-1} are likely to be needed. This estimate is based upon calculations involving seed size and average establishment rates. To date, chicory has been relatively easy to establish in commercial paddocks, but further work on establishment methods is justified to determine if lower sowing rates were viable.

Chicory can be a very competitive species as shown by the low weed content in treatments with optimal densities and by the non-significant effects of weeds on chicory. A very interesting aspect of these results is the almost complete lack of competition between chicory and white clover that appear to act in a complementary fashion. The relative yield totals of 2 or more that were recorded indicate that these species were not competing for any limiting resources and shows full resource complementarity. Part of this could be due to the nitrogen supplied by white clover. No nitrogen was applied to the monoculture chicory treatments. The stoloniferous nature of white clover may also enable positioning of roots to minimise direct root competition between these species.

The very intriguing impact of chicory on white clover water relations explains in part the complementary nature of their relationship. The higher soil water content under chicory compared to white clover monocultures suggests that a higher degree of shading of the soil surface by larger and denser chicory canopy although other mechanisms such as hydraulic lift (Caldwell and Richards 1989) could also be involved. The slower decline in relative water content of white clover leaves in mixtures relative to leaf water potentials indicates that white clover had more time to adjust to water stress than occurred in monocultures. It also may reflect some differences in rooting pattern.

These results suggest that in areas where white clover would normally be marginal, it could survive when sown with chicory. The productivity of chicory and white clover mixtures over several years does show that such mixtures are suitable for long-term pastures. Plots that were sown to low initial white clover densities increased their white clover content reasonably quickly. When sowing chicory pastures, a low sowing rate of white clover would be feasible, especially as this would reduce any risk of white clover limiting the establishment of chicory. White clover could also be oversown effectively at some later stage. The stoloniferous nature of white clover enables it to colonise areas throughout the pasture.

Other legumes may also be sown with chicory and their usefulness is dealt with in a subsequent section. The previous chapters on lamb production and grazing management have shown that subterranean clover can be a very productive component in chicory pastures. Subterranean clover has the advantage that its autumn-spring growing season is almost completely out of phase with chicory. This suggests that competition between these species would be minimal, if at all.

Perennial ryegrass failed to satisfactorily establish within this experiment. This was a direct result of the seasonal conditions that prevailed after sowing. The grazing management study suggested that chicory and grasses (plus broadleaf weeds) were direct competitors. However, the results from this experiment suggest that chicory will dominate that competition. The inclusion of some grass in chicory mixtures could be useful to help reduce any risk of invasion from broadleaf weeds if the chicory density is suboptimal. In many instances, however, annual grasses are likely to voluntarily invade pastures and this may be sufficient to provide some additional forage over winter and limit invasion from more problematic weeds. An earlier study (Kemp *et al.*, 1993) found that phalaris was unable to establish with chicory.

This study has shown that maximum productivity of chicory mixtures is achieved at densities of 50-60 plants m^{-2}. This would require sowing rates of 3-4 kg ha^{-1}. Lower sowing rates are likely to result in reduced pasture and livestock productivity over summer. White clover is a very suitable species to sow with chicory as both species behave in a consistently complementary fashion. An initial low sowing rate of white clover (*e.g.* up to 1 kg ha^{-1}) would help maximise establishment of chicory. Additional white clover could be sown later, if necessary. Chicory is more competitive with grasses than legumes and there may not be any need to sow grasses, as annual grass species are likely to voluntarily invade the sward, providing some additional forage over winter. If additional competition was expected from broadleaf species some grass could be included in the mixture, but it may be better to insure good weed control and maintain a high sowing rate of chicory.

If chicory were being sown to provide some additional forage in the early years of a pasture with the intention that it is replaced with perennial grass species then a lower sowing rate of chicory would be appropriate. This use of chicory was not tested in this project, but observations of commercial sowings indicate that this is a possible option. In such cases, perennial grasses would be included in the original mixture. Such mixtures though would not be as productive as a special purpose chicory pasture.

Legumes and nitrogen

Introduction

One of the major uses for chicory is likely to be as a special purpose, short to medium-term forage crop. Such crops need to produce quality forage as early as possible. Any legume sown with chicory needs to either be highly productive early in the life of the crop and to quickly release nitrogen to the chicory to ensure maximum early pasture growth. In southern Australia, chicory could be sown with subterranean or white clover or lucerne, but no information is available to assess which species is the best companion, or if there are any important differences between their interaction with chicory. The competition study reported earlier showed that chicory and white clover are complementary, but that was once the pasture was established. Limited information was obtained on the early growth and development of these species in a pasture.

Chicory requires nitrogen to realise its potential production. A limitation with chicory is that its spring growth can lag behind other summer growing species like lucerne whereas its autumn growth ceases earlier. This was evident in the elite lamb experiment at Cowra. An increased nitrogen supply may help to alleviate these problems. Nitrogen can be supplied from strategic applications of fertiliser or more economically from companion by legumes, provided they can persist and grow successfully with chicory.

The field experiment reported here evaluated the effects of alternative legumes and alternative nitrogen fertiliser strategies on the productivity and persistence of chicory in the short-term. The objectives of this experiment were to investigate the effects of alternative nitrogen fertiliser strategies on the productivity and early growth of chicory, quantify the nitrogen requirement of chicory and determine how much of this requirement can be supplied from companion legumes.

The legumes used differ in growth characteristics and morphology. They also differ in their ability to fix nitrogen and in patterns of release of fixed nitrogen to companion non-legume species. This experiment was short-term to clarify options during the initial year of a chicory pasture.

Methods

Design

The field experiment involved 13 treatments in a randomised block design with four replicates. Plot sizes were 2 * 2 m. The treatments are shown in the table below. The species used in the study were chicory (*Cichorium intybus* cv Puna), subterranean clover (*Trifolium subterraneum* cv Goulburn), white clover (*Trifolium repens* cv Haifa) and lucerne (*Medicago sativa* cv Aurora). Sowing rates aimed to give initial densities of 60 chicory plants m^{-2}. Legumes were sown at recommended rates. All plots were fertilised with 100 kg P ha^{-1} as single superphosphate (8.8 % P) at the beginning of the experiment. Nitrogen was applied as ammonium nitrate.

Table 3: Treatments combinations for the legumes and nitrogen experiment.

Treatment	Species 1	Species 2	Nitrogen
1- CLON0	Chicory	-	Nil
2- CLON1	Chicory	-	30 kg ha^{-1} yr^{-1} [a]
3- CLON2	Chicory	-	60 kg ha^{-1} yr^{-1} [b]
4- CLON3	Chicory	-	120 kg ha^{-1} yr^{-1} [c]
5- CSN0	Chicory	Sub clover	-
6- CWN0	Chicory	White Clover	-
7- CRN0	Chicory	Lucerne	-
8- CSN1	Chicory	Sub clover	30 kg ha^{-1} yr^{-1} [a]
9- CWN1	Chicory	White Clover	30 kg ha^{-1} yr^{-1} [a]
10- CRN1	Chicory	Lucerne	30 kg ha^{-1} yr^{-1} [a]
11- COSN0	-	Sub clover	-
12- COWN0	-	White Clover	-
13- CORN0	-	Lucerne	-

[a] Applied 30 kg N ha^{-1} in early spring (1st September).
[b] Applied 60 kg N ha^{-1} in early spring (1st September).
[c] Applied 30 kg N ha^{-1} every six weeks from 1st September.

Site

The experiment was sown at the Orange Agricultural Institute on the 19 September 1995 by hand broadcasting and then raking into a well-prepared soil.

Measurements

Each month the composition of each plot in the field experiment was estimated using dry weight ranking procedures (Botanal, Tothill *et al*, 1992). A rising plate meter (Earle and McGowan, 1979) was used to estimate forage yield. Composition was ranked on nine quadrats within each plot. These ranks were calibrated by cutting the herbage from one quadrat/plot and sorting samples into species, which were further divided into dry and green components. Samples were dried at 60°C for 24 hrs. Plant density was recorded at fortnightly intervals using a 30 * 30 cm quadrat, placed in a fixed position within each plot.

The topsoil (0-10 cm) was analysed for nitrate at the beginning and end of the experiment. Five samples were taken from each plot and bulked for analysis on each occasion. Chicory and legume samples from each harvest were analysed for protein content to determine the proportion of nitrogen fixed by the legumes and to determine the efficiency of nitrogen uptake over time.

To investigate the interactions between chicory, legumes and water stress, the soil moisture content (0-10 cm); light interception (using radiometers above and below the canopy); and leaf area index were measured over summer. Leaf area was measured on harvested samples using an electronic planimeter.

Results

Establishment

All species established well. Four weeks after sowing 75% of the viable chicory seeds had germinated, resulting in around 480 plants m^{-2}. By ten weeks this had declined to 68 plants m^{-2}.and a further declined to 40 plants m^{-2} by autumn, six months after sowing. Neither legume species nor nitrogen rates had any significant effects on chicory density. Eight weeks after sowing white clover densities averaged 170 plants m^{-2}, lucerne 80 plants m^{-2} and subterranean clover 45 plants m^{-2} when sown in monoculture. The respective values when sown with chicory were 100, 56 and 19. Nitrogen treatments did not affect legume densities. Volunteer annual grasses invaded all plots and these contributed significantly to forage yields.

Forage yields

Chicory yields were significantly increased by nitrogen applications (Figure 9), as were the volunteer grasses in those treatments. Over the six months from sowing chicory produced around 4 t DM ha^{-1} and the volunteer grasses 2 t DM ha^{-1} from the highest nitrogen applications. The total yield at high nitrogen levels (6 t DM ha^{-1}) was above the 5 t DM ha^{-1} produced from the better chicory and legume mixtures. Without nitrogen, chicory produced a little less than 3 t DM ha^{-1} over six months. The overall response to nitrogen was low. The better response was to 30 kg N ha^{-1} where chicory produced 6 kg DM kg^{-1} N. Soil nitrate levels were 80 kg N ha^{-1} which would have limited any response to applied nitrogen over the short duration of this study. There were no changes in seasonal growth patterns from the different treatments.

Subterranean clover did not produce much herbage from the spring sowing. Lucerne was more productive than subterranean clover, but total herbage mass was low. White clover was the most productive legume, in monoculture or mixtures with chicory, but yielded significantly less in plots fertilised with nitrogen. Chicory yields in mixtures with white clover were the same as in treatments receiving nitrogen applications, whereas with other legumes chicory yielded less in the mixtures. This trend was not significant, but does suggest that within six months white clover may have been providing some nitrogen for chicory.

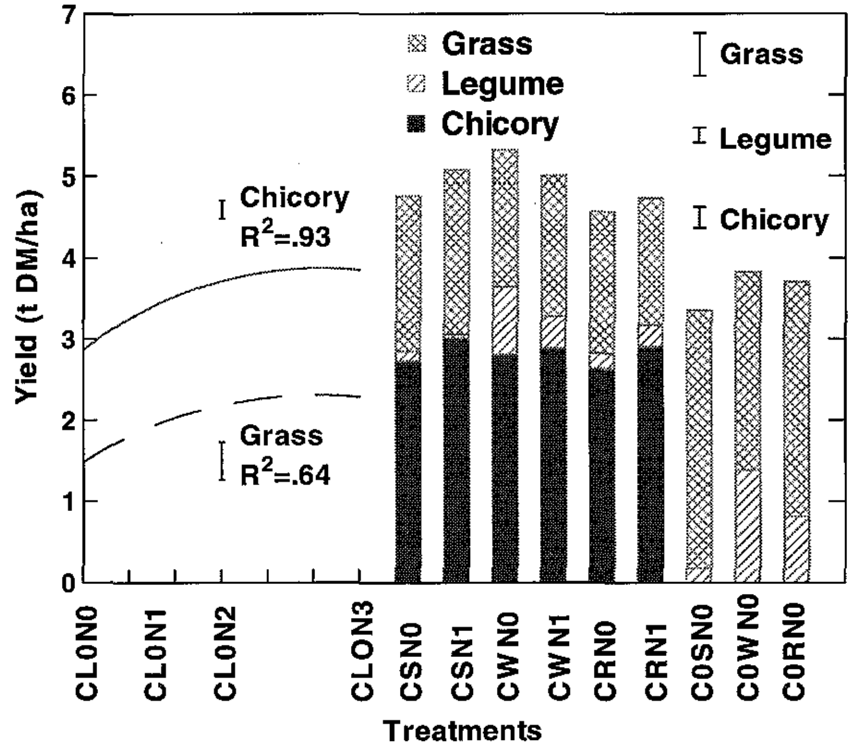

Figure 9: The total yield response of chicory, legumes and grasses to nitrogen fertiliser and pasture mixtures over the first six months from sowing. Treatments are given in the text. Vertical lines are $lsd_{0.05}$.

Discussion

In this short-term study white clover was the more productive legume. It established quickly and sustained chicory yields. This substantiated the results from the competition study that white clover is a very compatible species for chicory. The legume densities established for white clover and lucerne were above those planned, indicating that these species can be successfully sown with chicory in spring. While lucerne plant densities were satisfactory it was not as productive as white clover. In part, this could be due to the differences in plant densities, but it could also indicate that since lucerne takes more time to establish, it might not be able to sustain competition from chicory. White clover yield in mixtures with chicory were approximately half that of white clover in monoculture, whereas lucerne produced only 20% of its monoculture yield when grown with chicory. Subterranean clover densities were low relative to that required for a productive pasture (Blumenthal, 1991). Normally subterranean clover would not be sown in spring and these results show that it would be better to delay sowing subterranean clover until the autumn.

This experiment was used to gain further information on the initial plant populations of chicory. There was a very high population of seedlings, but a rapid decline in density within the first few months. This process was probably driven mostly by self-thinning through intraspecific competition. It did show that under good conditions a very high proportion of the viable seeds can produce seedlings which suggests that lower initial sowing rates could achieve desirable plant populations. However, future research is needed to resolve what seedling mortality to expect for a range of conditions and hence how to optimise sowing rates. The high initial seedling numbers found in this study were above those recorded in other field experiments.

The fertility at this site limited any responses to applied nitrogen. Soil nitrate levels were sufficient to produce yields of at least 3 t DM ha^{-1}. Ammonia levels were not measured, but presumably would have added to the available N pool, while during the experiment further N would have been released from the less available soil pools. At this site, additional N is unlikely to be economic until chicory has extracted much of the available N in the 0-40 cm strata. Nitrogen may still have a key role in the later years of a chicory pasture. The grazing management study did suggest that after three years the legumes were not as productive as in the first years and chicory productivity was declining. This was a period after that monitored in the competition study where white clover productivity was sustained. Legume productivity will also depend upon the seasonal conditions.

These experiments have been unable to resolve if legumes can always provide sufficient nitrogen to sustain highly productive chicory pastures. The low legume content observed throughout much of the grazing management study could be taken to indicate that chicory is 'mining' nitrogen from the soil profile, possibly at depth. That theory receives some support from earlier work (Kemp *et al*, 1993) where chicory productivity in the first few years after sowing greatly exceeded that of phalaris – both sown in monocultures because chicory was able to extract more nitrogen from the soil than phalaris. In practice, this may mean that N applications will be needed at some time to sustain a chicory pasture. On the other hand, if chicory is able to extract more N from the soil than other species, this could also be useful to limit nitrate fluxes to depth, the main cause of soil acidification. The long-term maintenance of chicory pastures will require further research into the role and use of nitrogen.

Herbicides

Introduction

Herbicides are a valuable tool for pasture management, both to reduce weeds during establishment, and to control weed populations during the productive life of a pasture. They are also used to remove pasture species prior to resowing an area with another pasture or crop. Little was known about the sensitivity of chicory to herbicides for these various purposes. The objective of this series of experiments was to test the tolerance of chicory to a range of herbicides at a seedling stage and as mature plants.

The testing of chicory sensitivity to a range of broadleaf herbicides was done in collaboration with Mr Barney Milne (Field Officer (Weeds), Orange Agricultural Institute). The data is confidential at this stage due to the use of some unregistered mixtures and chemicals. Approval to use this information must be obtained from Mr Milne.

Methods

Sites

Experiments were done on seedling pastures at the Orange Agricultural Institute growing on a red basaltic soil and on a one-year-old chicory pasture at Canowindra growing on a red clay loam.

Design

The basic design used in each experiment was to apply herbicides in a spatial analysis design (three replicates in each case) to an area of newly sown or established chicory. Herbicides were applied with a handheld boom spray in water at 100 L ha^{-1}. Each plot was 10 * 3 m.

The first experiment was sown in winter 1992 to evaluate the effects of a range of herbicides on newly sown chicory. That experiment failed to establish satisfactorily, possibly due to the cold weather. Some herbicides were tested on the plants that established, but it was considered that the results were inadequate and are not presented here. A second experiment was sown in September 1993 and herbicides applied to the seedlings six weeks later. The third experiment involved applications of herbicides to a one-year-old chicory pasture in August 1993. This pasture also contained mature plants of subterranean clover, capeweed, saffron thistle and Paterson's curse.

Measurements

Plant counts and forage yields were estimated soon after application of the herbicides. Subsequent measures were undertaken to monitor medium-term responses. This data was supplemented with visual ratings, but these data are not presented here.

Results

Seedlings

Only a few of the herbicides tested had any significant effects on populations of chicory seedlings. All caused an initial reduction in yield, but most treatments recovered satisfactorily (Table 4). At the second harvest there were only two treatments where both plant density and yield were significantly less than the control. In these cases, the plant densities were still larger than those found to be productive in other experiments, although this may reflect the higher sowing rates used in this study.

Table 4: Sensitivity of chicory seedlings to herbicides for broadleaf weed control. Experiment sown 6th September 1993, ARVC, Orange. Sprayed 26th October 1993 when plants had 2-6 leaves.

Treatment (rates ha^{-1})	**Plants m^{-2}**		**Yield kg DM ha^{-1}**	
[CONFIDENTIAL data]	25/11/93	11/1/94	25/11/93	11/1/94
1. Unsprayed control	148	121	1360	2490
2. Bromoxynil (1.4L)	149	103	740*	2380
3. Bromoxynil (2L)	117	116	660*	1810
4. 498 + LI700 (25g+100ml)	139	148	925*	1950
5. 498 + Bromoxynil + LI700 (25g+1.4L+100ml)	120	119	870*	2210
6. EC + Uptake (7g+0.5L)	135	104	990*	2160
7. EC + Bromoxynil (7g+1.4L)	112*	99	560*	1295*
8. Spinnaker + LI700 (200ml+200ml)	140	136	920*	1530*
9. Spinnaker + Bromoxynil (200ml+1.4L)	103*	99	635*	1970
10. Jaguar (0.5L)	125	100	620*	1805
11. Jaguar (1L)	116	95	440*	1530*
12. Gramoxone (1L)	87*	71*	420*	1080*
13. Spinnaker + Simazine + LI700 (200ml+2L+200ml)	149	135	1080*	2080
14. Bromoxynil + Simazine (1.4L+2L)	69*	79*	240*	1510*
lsd $_{.05}$	36	41	280	810

* treatments that were significantly less than the unsprayed control.

Mature plants

A range of herbicides was tested on a one-year old chicory pasture at Canowindra. Herbicides were applied on 5 August 1993. At spraying, the chicory plants ranged from having 2 leaves to being mature plants up to 20 cm across. However, most plants were 10-15 cm in diameter. Plant counts and yield estimates were taken two and five months after spraying (Table 5).

Table 5: Sensitivity of chicory plants to herbicides for broadleaf weed control. Chicory sown in 1992 at Canowindra. Sprayed 5 August 1993.

Treatment (rates ha^{-1})	**Plants m^{-2}**		**Yield kg DM ha^{-1}**	
[CONFIDENTIAL data]	5/10/93	4/1/94	5/10/93	4/1/94
1. Unsprayed control	88	60	780	2040
2. MCPA amine (1L)	29*	34	8*	780*
3. MCPA amine (2L)	35*	49	180*	840*
4. Bromoxynil (2L)	88	89	1675	1970
5. Trifolamine (2L)	59	35	370*	865*
6. MCPA amine + Simazine (1L+1.5L)	63	75	395*	1680
7. AGH7-74 (2L)	76	59	760	2270
8. MCPA amine + Lontrel (1L+50ml)	47*	56	240*	1390
9. Glean + BS1000 (20g+200ml)	63	54	380*	1510
10. Ally + BS1000 (7g+200ml)	24*	4*	100*	120*
11. Exp.498 + Uptake (25g+0.5L)	77	83	1600	1700
12. Exp.498 + MCPA + LI700 (25g+1L+100ml)	63	49	460*	1360
13. Exp.498 + Bromoxynil + LI700 (25g+2L+100ml)	80	45	1710	1900
14. Exp.EC + Uptake (7g+1L)	103	98	920	1940
15. Exp.498 + Trifolamine + LI700 (25g+2L+100ml)	88	59	960	1530
16. Lontrel (200ml)	87	54	770	1550
17. Gramoxone + Diuron (1L+3.5L)	77	88	1590	1930
18. Jaguar (1L)	93	82	1780	1910
$lsd_{.05}$	38	36	320	800

* treatments that were significantly less than the unsprayed control

Discussion

These results show that chicory is tolerant of common herbicides that would be commonly used for weed control. Seedlings were only marginally less tolerant than the one-year-old plants that were tolerant of most herbicides tested. At the second set of measurements taken in January 1994, only one treatment had a significantly lower plant density and forage yield. These data suggest that while some treatments did result in initial reductions in forage yield, in most cases the plants were recovering. The results also show that herbicides are available to kill a chicory pasture should the need arise.

General Discussion

Chicory is a new species for livestock production. The initial results (*e.g.* Kemp *et al*, 1993) suggested that it was capable of higher levels of production than alternative summer forages. The results presented here support that early promise. This project has provided considerable data on the use of chicory in livestock grazing systems, how it should be managed and which other species can be readily sown with it.

Industry Implications

This project has provided extensive information on the establishment, management and use of chicory-based pastures for summer forage. In some situations, chicory is likely to replace lucerne while in others it will challenge the commercial use of special purpose forages such as the brassicas. The more practical outcome is that more productive species like chicory reduce significantly a number of on-farm activities including: the need for hand-feeding, sowing annual forage crops and re-sowing pastures as well as minimising the use of herbicides to control weeds. Better quality forage over summer will improve animal growth and reproductive efficiency, allowing more targeted marketing of finished animals. Chicory can also be used as a general-purpose pasture, provided it is managed appropriately. Chicory could prove to be one of the more productive dry season forages within the perennial pasture zone across southern Australia, particularly it proves to be more tolerant of soil acidity than lucerne. This aspects still needs to be investigated.

Limits for the use of chicory

One major objective of this program was to gain a better understanding the limits for chicory as a forage species. Chicory can be sown in pasture mixtures, provided appropriate companions are selected. Otherwise its density and then its productivity will be reduced over summer. Given the specific needs for management, chicory is arguably better used as a special purpose pasture. The obvious comparison is then with lucerne. Lucerne is more sensitive to management, rarely recruits new plants within a pasture and is more susceptible to weed invasion. However, as shown in the elite lamb study, lucerne is as productive as chicory. Where lucerne can be grown well, *i.e.* on good soils and where producers understand know how to manage it, then there may not be any advantage gained from sowing chicory. But when problems are encountered in growing lucerne (*e.g.* soil types and limitations in management), chicory has a place.

Chicory has a deep taproot, which provides access to soil water. Provided it can access water and nutrients, chicory will grow until frosts and low temperature limit growth. Chicory like most C3 perennial species in use (Kemp & Culvenor, 1994) is unlikely to survive in completely dry soil despite its deep and extensive root system. While chicory does produce good quantities of forage during dry summers, this depends upon soil water reserves. Observations on sown paddocks in hotter climates during the summer of 1992/93 found that many chicory plants dropped their leaves suggesting that chicory had exhausted soil water reserves. This would limit the value of chicory as forage in such climates. Lucerne also drops its leaves under similar circumstances and possibly earlier than chicory does.

Chicory is of more use in climates where effective summer rain occurs and, or soils normally store some available water. Chicory would be of no benefit in climates where the soil profile is dry over summer. These considerations mean that the productivity of chicory would increase with soil depth. Being a new species there is only limited information on where chicory has proved of value to producers. At this stage, it is recommended where annual rainfall exceeds 600 mm and on soils where roots can go down at least a metre. The soil should not be too acid, although chicory appears more tolerant than lucerne to low pH. Its aluminium tolerance is yet to be determined.

Chicory is affected by disease that may limit its use in some cases. New Zealand work has shown that cold, wet conditions can lead to infections with *Sclerotinia*, causing death of the taproot. The occurrence of charcoal rot at Cowra indicated other diseases might also appear and limit its use. Both instances seem to support the hypothesis that when chicory is under stress and plant growth rates are limited by climatic conditions, it is susceptible to infection. For both diseases, winter seems to provide condition conductive to infection. Full expression of that infection may not occur until some time later when other stress conditions occur. As more chicory is sown an increase in the incidence of disease could be expected.

Sowing rates and times

Early recommendations advocated spring sowing at 2 kg ha^{-1} as the most reliable means of establishing chicory (Hare *et al*, 1987). This rate is probably appropriate for mixed swards where chicory dominance is not required. In some instances, it would produce a dense chicory sward, but that may not always apply. Higher sowing rates are likely to be needed where a special purpose chicory pasture is required. The competition experiment reported here indicated that to achieve highly productive swards, plant densities of 50-60 plants m^{-2} are needed. At current establishment rates this would require sowing rates of 3-4 kg ha^{-1}. To justify this expense, producers would need to pay attention to seed bed preparation and would need to use appropriate grazing tactics to ensure the longevity of the pasture.

Seed should not be buried to deeply (*e.g.* sow at < 2 cm). Experience in NSW has found that chicory has established very easily at most times of the year, provided moisture conditions were adequate. Problems arose in winter when germination rates were low, frosts occurred or dry conditions were encountered. Autumn sowings were more successful, especially if undertaken in March or April, before the onset of cold weather. The rapid early growth of chicory also meant that sowing from late winter (August) on was successful, as pastures could be (lightly) grazed 8-12 weeks from sowing. Further work should be done to resolve the issue of sowing rates and times for chicory as it may be that spring sowings into weed free seedbeds will result in high establishment rates.

Species mixtures

This work demonstrated that subterranean and white clovers were compatible with chicory and in fact there seemed very little competition between them. This means that minimal problems should be encountered in using legumes to provide nitrogen for chicory pastures.

Recommendations of suitable grasses for use with chicory are less well resolved. Grasses could fill a useful role to occupy space and utilise N not used by chicory. Over summer, chicory would be expected to be very competitive and this may limit the ability of some grass species *e.g.* perennial ryegrass, to survive. In winter, chicory is dormant which allows grasses to compete with legumes to fill the gaps between the chicory plants and provide valuable forage along with legumes. For these reasons, annual grasses may be more appropriate than perennials in chicory pastures. Annual grasses are ubiquitous and will invade most swards. As well most annual grasses are palatable to stock during winter, although they lose quality rapidly when their seedheads emerge. Sowing species such as annual ryegrass would only be necessary if there was a desire to improve the quality of forage from grasses during winter and, or reduce the incidence of some less desirable annuals (*e.g.* vulpia or barley grass). Winter active, biennial grasses are recommended for chicory pastures in New Zealand (Rumball, 1986).

In some instances chicory is seen as a species to use for the first few years of a pasture. The longer-term aim is to then establish a suitable perennial grass under the chicory to become the 'base' for the long-term. Some work needs to be done in this area. In the original studies at Orange, chicory was undersown with phalaris (cv Sirosa). Little phalaris was seen in the chicory plots for several years, but it did establish and ultimately produced a productive pasture. Tall fescue has been sown with chicory in paddocks in central NSW and as the chicory has declined (usually from inappropriate grazing practices and possibly disease) the fescue has become dominant and formed a productive pasture. This suggests that temperate perennial grasses known to have some drought tolerance can successfully establish under chicory. However little is known of the optimal mixture to sow for this purpose and the better management practices to adopt to ensure good establishment of the perennial grass. Other paddocks seen in central NSW have only a low density of perennial grass after the chicory has disappeared from the pasture. An alternative approach may be to sod seed chicory into degrading lucerne pastures. Provided there were sufficient lucerne plants present, the chicory / lucerne combination may provide reasonable pasture and extend the life of the sward by 3 to 5 years.

Extension

Use of chicory is still in its infancy. In most cases in the central tablelands, chicory has been sown as part of a general mixture. This may not be the most effective way to use this species, as it would limit its productivity and persistence over summer. To maximise the benefits from chicory extension work should give more emphasis to its use as a special purpose pasture, managed correctly for higher value livestock. At present, a conservative approach to recommendations should be adopted. Establishment should follow best practice for pasture establishment with attention given to seedbed preparation and weed control. Grazing should aim for a four-paddock rotation, managed as outlined in this report.

Experience from producers should be collated to fill in some of the gaps in knowledge on its agronomy, adaptability to soil types, combinations with other species and fertiliser needs. This report considers these issues, but not all could be covered in depth in this project.

Future work

Limited information is available for the range in soil types and pH that suit chicory. Initial studies showed that chicory was tolerant of soil pH from 4 to 6 (presumably determined in water) (Crush and Evans, 1990). No reports are known that establish its tolerance to aluminium or manganese, though one encouraging piece of evidence was that aluminium concentrations in chicory were not influenced by pH (Crush and Evans, 1990). That work also showed the high concentrations of magnesium, potassium, sodium, calcium, sulphur, boron, manganese, zinc and phosphorous that were accumulated in chicory, often above that commonly found in ryegrass or white clover. Of interest were the increasing concentrations of zinc, boron, copper, sulphur, manganese and potassium as pH declined and the generally low level of silicon. This may have implications for better mineral nutrition of livestock on lower pH soils. Ultimately this may also suggest that more use of herbs in pastures will help sustain livestock production.

Nitrogen use in chicory swards needs further study for the reasons outlined in earlier sections. Chicory had limited response to nitrogen in the first year, but this may reflect its ability to 'mine' nitrogen at depth. Older stands do not appear to be as productive as they were initially. This could be due to a run down in nutrient supply. The ability of chicory to utilise more soil nitrogen particularly over summer is being investigated as part of a Meat Research Corporation funded Sustainable Grazing Systems study in central NSW. If chicory can utilise more soil nitrate than alternative species, this could reduce the rates of soil acidification.

Further work is needed to refine sowing methods and rates for chicory. In the experiments reported in this project the percent of viable seed that emerged as seedlings varied from 5-75%. This makes it very difficult to decide on an ideal sowing rate. The recommendations in this report are to use 3-4 kg seed ha^{-1}, but lower rates should be possible using current best practice sowing methods. Sodseeding of chicory into existing areas needs exploration, as should preparing those sites by grazing versus herbicides.

What are the best ways to encourage recruitment of chicory when stands thin? The grazing management study showed that recruitment was possible, but it did not occur every year. The conditions under which adequate seed set and recruitment of new plants can occur need to be defined. The grazing management work has suggested a strategy producers can adopt to enhance recruitment, but that has not been comprehensively tested.

Tolerance of chicory and lucerne to dry conditions warrants closer study to define the regional limits for both species. Chicory does seem to retain green leaf longer than lucerne, but there is little objective data.

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Publications

Alemseged, Y., Kemp, D.R., Michalk, D.L., and Millar, G.D. (1995). Chicory based pastures for the central tablelands of NSW. In (D.L. Michalk) (Ed.) *Latest Developments in Pasture Species.* The Grassland Society of NSW, pp 24-25.

Goodacre, M., and Kemp, D.R. (1991). Chicory: A new forage herb for the New South Wales central tablelands and slopes. *Proceedings Sixth Annual Conference Grassland Society NSW.* **6**: 93.

Goodacre, M. and Kemp. D.R. (1991). Chicory, A new forage herb for the NSW Central Tablelands and Slopes. *Forage Facts*, Wright Stephenson & Co., Australia, pp 2.

Goodacre, M., and Kemp, D.R. (1993). Chicory: Dan.070. *MRC Meat Profit Day Notes* (October 21st 1993). pp 1.

Goodacre, M., and Nikandrow, A. (1993). Charcoal rot in Grasslands Puna Chicory. *Pasture Notes, NSW Agriculture,* **3(10)**: 4.

Holst, P.J., Kemp, D.R., Goodacre, M., and Hall, D.G. (1998). Summer lamb production from Puna chicory (*Chicorium intybus*) and lucerne (*Medicago sativa*). *Proceedings Australian Society of Animal Production* (in press).

Michalk, D.L., Kemp, D.R. and Alemseged, Y. (1994). Improving livestock production: Is chicory the ideal forage. *Grassland Society of NSW Newsletter.* **3**: 16-19.

References

Alemseged, Y. (1998). *PhD Thesis, University of New South Wales* (in preparation).

Anon. (1942). *Poison Plants of NSW.* p 406.

Blumenthal, M. (1991). Persistence and Productivity of Subclover and Murex Medic in the Central-West of New South Wales. *PhD. Thesis University of Sydney.*

Brenchley, W.E. (1920). *Weeds of Farm Land.* Longmans, Green & Co., London.

Caldwell, M.M., and Richards, J.H. (1989). Hydraulic lift: water efflux from upper roots improves effectiveness of water uptake by deep roots. *Oecologia* **79**: 1-5.

Cockayne, A.H. (1915). Chicory. *New Zealand Journal of Agriculture* **11**: 468.

Crush, J.R., and Evans, J.P.M. (1990). Shoot growth and herbage element concentrations of 'Grasslands Puna' chicory (*Cichorium intybus* L.) under varying soil pH. *Proceedings of the New Zealand Grassland Association* **51**: 163-166.

Davies, W. (1952). *The Grass Crop.*

Douglas, J.A., and Poll, J.T.K. (1986). A preliminary assessment of chicory (*Cichorium intybus*) as an energy crop. *New Zealand Journal of Experimental Agriculture* **4**: 223-225.

Dove, H., and Mayes, R.W. (1991). The use of plant alkanes as marker substances in studies of the nutrition of herbivores: a review. *Australian Journal of Agricultural Research* **42**: 913-52.

Earle, D.F. and McGowan, A.A. (1979). Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* **19**: 337-43.

Fraser, T.J., Cosgrove, G.P., Thomas, W.J., Stevens, D.R., and Hickey, M.J. (1988). Performance of Grasslands Puna chicory. *Proceedings of the New Zealand Grassland Association* **49**: 193-196.

Gilmour, A.R. (1988). REG – A generalised linear models program. *NSW Agriculture, Biometrics Bulletin* (Agdex 962).

Hall, D.G., and Holst, P.J. (1992). Production systems for elite lambs. *Proceedings Australian Society of Animal Production* **19**: 176-180.

Hall, D.G., and Holst, P.J. (1994). *Practical, cost effective production systems for elite lamb in New South Wales.* Report to Meat Research Corporation on Project DAN.052.

Hare, M.D., Rolston, M.P., Crush, J.R., and Fraser, T.J. (1987). Puna chicory – a perennial herb for New Zealand pastures. *Proceedings Agronomy Society of New Zealand* **17**: 45-49.

Isbell, R.F. (1993). A classification system for Australian soils – 3rd approximation. *CSIRO Division of Soils Technical Report* 2/1993.

Kemp, D.R. (1987). The improvement of pasture productivity on the Central Tablelands of New South Wales. *Report to Australian Meat and Livestock Research and Development Corporation, Project DAN 25S*, pp 83.

Kemp, D.R., and Culvenor, R.A. (1994). Improving grazing and drought tolerance of temperate perennial grasses. *New Zealand Journal of Agricultural Research*, **37**: 365-78.

Kemp, D.R., and Dowling, P.M. (1991). Species distribution within improved pastures over Central NSW in relation to rainfall and altitude. *Australian Journal of Agricultural Research*, **42**: 647-659.

Kemp, D.R., and Dowling, P.M. (1998). Sustainable temperate perennial pastures. *Australian Journal of Experimental Agriculture* (in press).

Kemp, D.R., Dowling, P.M., and Michalk, D.L. (1993). *Management and legume performance: Developing new guidelines for NSW tableland pastures.* Final report to Wool Research & Development Corporation. pp 64.

Komolong, M., Nicol, A., Poppi, D.P., Fraser, T.J., and Kirsopp, S.(1992). Nutrient supply for lamb growth from grasslands Puna chicory (*Cichorium intybus*) and Wana Cocksfoot (*Dactylis glomerata*). *Proceedings of the New Zealand Society of Animal Production* **52:** 85-87.

Lancashire, J.A., and Brock, J.L. (1983). Management of new cultivars for dryland. *Proceedings of the New Zealand Grassland Association* **44**: 61-73.

LeStrange, R. (1977). *A History of Herbal Plants.* Angus & Robertson, London.

Li, G.D. (1997). Response of Chicory (*Cichorium intybus* L.) to defoliation. *PhD Thesis, Massey University.*

Li, G.D., Kemp, P.D., and Hodgson, J. (1997). Regrowth, morphology and persistence of Grasslands Puna chicory (*Cichorium intybus* L.) in response to grazing frequency and intensity. *Grass and Forage Science* **52**: 33-41.

Michalk, D.L, Kemp, D.R., Read, J.W., and Robards, G.E. (1993). *New Zealand grazing systems and species: Are they relevant to NSW?* Travel Report to MRC. pp 17.

Mitich, L.W. (1993). Chicory. *Weed Technology* **7**: 274-277.

Moore, A.D., Donnelly, J.R., and Freer, M. (1993). Report to the Meat Research Corporation on Project CS.149.

Niezen, J.H., Barry, T.N., Hodgson, J., Wilson, P.R., Ataja, A.M., Parker, W.J., and Holmes, C.W. (1993). Growth responses in red deer calves and hinds grazing red clover, chicory or perennial ryegrass / white clover swards during lactation. *Journal of Agricultural Science* **121**: 255-263.

O'Brien, A.B. (1955). Chicory. *New Zealand Journal of Agriculture* **91**: 494.

Peart, G. (1968). A comparison of rotational grazing and set stocking of dryland lucerne. *Proceedings Australian Society of Animal Production* **7**: 110-13.

Quigley, P.E., Ward, G.N., and Morgan, T. 1992: Botanical composition of pasture in south-western Victoria. *Proceedings of the Sixth Australian Agronomy Conference 6*: 533.

Rees, S.B., and Harborne, J.B. (1985). The role of sesquiterpene lactones and phenolics in the chemical defence of the chicory plant. *Phytochemistry* **24:** 2225-2231.

Reid, R.L., Jung, G.A., Picoli, J.R., and Poland, F.K. (1993). Chicory pastures for sheep: composition and quality. *Journal of Animal Science* **71** *Supplement* **1:**

Rumball, W. (1986). 'Grasslands Puna' chicory (*Cichorium intybus* L.). *New Zealand Journal of Experimental Agriculture* **14**: 105-107.

Russel, A.J.F., Doney, J.M., and Gunn, R.G. (1969). Subjective assessment of body fat in live sheep. *Journal of Agricultural Science* **72:** 451-454.

Scales, G.H. (1993). Carcass fatness in lambs grazing various forages at different rates of liveweight gain. *New Zealand Journal of Agricultural Research* **36:** 243-251.

Snaydon, R.W. (1991). Replacement or additive designs for competition studies? *Journal of Applied Ecology* **28**: 930-46.

Snaydon, R.W., and Satorre, E.H. (1989). Bivariate diagrams for plant competition data: modifications and interpretation. *Journal of Applied Ecology* **26**: 1043-57.

Spencer, E.R. (1974). *All about Weeds.* Dover Publications, New York.

Steiner, E. (1983). The blue sailor: weed of many uses. *The Michigan Botanist* **22**: 63-67.

Tothill, J.C., Hargreaves, J.N.G., Jones, R.M., and McDonald, C.K. (1992). BOTANAL – A comprehensive sampling and computing procedure for estimating pasture yield and composition. *CSIRO Tropical Agronomy Technical Memorandum* **78**.

Wilkinson, L. (1997). Systat 7: graphics manual. *SPSS, Chicago, USA.*

Willoughby, W.M. (1959). Limitations to animal production imposed by seasonal fluctuations in pasture and by management procedures. *Australian Journal of Agricultural Research* **10**: 248-68.