RESPONSE OF CHICORY (*Cichorium intybus* L.) TO DEFOLIATION

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ABSTRACT

Chicory (*Cichorium intybus* L.) is a perennial herb which has long been used as a forage crop. However, only recently has this species been re-evaluated in terms of its agronomy and animal performance. The objectives of this research were to study the persistence and the seasonal patterns of herbage mass accumulation and morphological development of forage chicory under defoliation. A series of field and glasshouse experiments were conducted at the Pasture and Crop Research Unit (PCRU), the Deer Research Unit (DRU) and the Plant Growth Unit (PGU), Massey University, Palmerston North, New Zealand (latitude 40°23'S) from 1993 to 1996. 'Grasslands Puna' chicory was used in all experiments except for one of the glasshouse experiments (Chapters 6 and 7) where two contrasting cultivars, 'PG90' and 'Orchies', were also included.

Under grazing, Puna chicory accumulated herbage masses of 8.5, 9.4 and 4.6 t dry matter (DM)/ha from November to April, with average plant densities of 66, 69 and 24 plants/m^2 and plant sizes of 2.9, 2.7 and 6.7 shoots/plant, for 1, 2 and 4 year old stands, respectively (Chapters 3, 4 and 5). It was concluded that the characteristics of a grazed chicory crop that had deteriorated to the point of not being able to accumulate half of its maximum herbage mass were 25 plants/m^2, six or more shoots/plant, or less than 150 shoots/m^2.

Defoliation stimulated the development of secondary shoots, but suppressed the growth of the primary shoot. Axillary shoots, however, developed fully regardless of whether or not plants were defoliated. The main source of feed from chicory for livestock was primary leaves during spring, and secondary and axillary leaves during summer and autumn (Chapters 4, 6 and 7). Results from both field and glasshouse experiments suggested that Puna chicory was more sensitive to defoliation frequency than intensity. It was concluded that defoliation at 50-100 mm in height at 3 week intervals in spring, and at 100-150 mm at 5 week intervals in summer and autumn, maximised the leaf formation and minimised the stem development of chicory.

Grazing decreased the plant density of chicory regardless of grazing intensity or frequency, with the significant decrease in late spring and early summer when primary shoots were controlled (Chapters 3 and 4). Autumn grazing, especially hard grazing, was detrimental to plant persistence (Chapters 4). It was concluded that less grazing pressure through the growing season cannot be used to improve persistence without compromising leaf growth rate, but that avoidance of grazing in late autumn will improve the persistence of chicory.

In a comparison of three cultivars, Orchies was the most persistent cultivar but had the slowest growth rate, and PG90 was the least persistent but with the highest growth rate, whereas the performance of Puna was intermediate, due to their contrasting root sizes and different root carbohydrate reserves. It was suggested that to improve the persistence and enhance the leaf production of Puna by plant breeding the emphasis should be on increasing taproot size without unduly prejudicing herbage mass accumulation.

Keywords: biomass, fructans, grazing intensity, grazing frequency, herbage production, morphology, persistence, plant density, regrowth, taproot.

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STRUCTURE OF THESIS

The thesis is based on a series of papers. All chapters, including three appendices, except Chapters One (General Introduction), Two (Review of Literature) and Eight (General Discussion), have been published or accepted/submitted for publication. The paper in Chapter Three has been slightly modified in a few sections, whereas papers in Chapters Four to Seven are presented as scientific papers but in thesis format. The references relevant to individual chapters are at the end of each chapter, except for Chapter One where the references are merged into those in Chapter Two and placed at the end of Chapter Two. The results are discussed in detail in each experimental chapter and integrated into a general discussion in Chapter Eight. The main findings from the research in this thesis are also summarised at the end of Chapter Eight.

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1. GENERAL INTRODUCTION

PERENNIAL HERBS can play an important role in farming systems due to their deep-rooting and mineral-richness (Foster, 1988). Their roots break up and aerate the subsoil (Clapham *et al.*, 1962) and bring minerals into the above-ground parts of the plants, which may enrich the diet of grazing animals (Niezen *et al.*, 1993a; Hoskin *et al.*, 1995), and enrich the humus and subsequently the upper layers of the soil (Elliot, 1908, cited by Foster, 1988). Drought resistance is also a particular reason why farmers include herbs into their farming systems (Lancashire and Brock, 1983; Foster, 1988).

Chicory, a perennial herb, has high yield potential (Lancashire, 1978; Hare *et al.*, 1987), high feed quality (Clark *et al.*, 1990a; Hoskin *et al.*, 1995), and results in excellent animal performance (Fraser *et al.*, 1988; Niezen *et al.*, 1993a; Hopkins *et al.*, 1995), in addition to the above common characteristics of perennial herbs. Chicory has been adopted world-wide (Jones and Haggar, 1994; Hopkins *et al.*, 1995; Jones, 1995; Jung *et al.*, 1996) as well as in New Zealand since it was released in 1985 (Rumball, 1986). Annual herbage production of 15-18 t dry matter (DM)/ha, and up to 25 t DM /ha, with daily herbage growth rates of 150 kg DM/ha, has been documented in New Zealand (Lancashire, 1978; Hare *et al.*, 1987; Matthews *et al.*, 1990). Lamb liveweight gains of 290 g/day and calf liveweight gains of 900 g/day have also been recorded for pure chicory crops in New Zealand (Hare *et al.*, 1987; Fraser *et al.*, 1988), which are better than for conventional perennial ryegrass (*Lolium perenne* L.)/white clover (*Trifolium repens* L.) pastures in New Zealand (Fraser *et al.*, 1988; Niezen *et al.*, 1993a; Hoskin *et al.*, 1995; Kusmartono *et al.*, 1996a, b), and similar to those on some pure legume pastures, such as white clover, red clover (*Trifolium pratense* L.) and lucerne (*Medicago sativa* L.) (Hare *et al.*, 1987; Brown, 1990; Niezen *et al.*, 1993a; Scales, 1993; Scales *et al.*, 1994; Hopkins *et al.*, 1995).

However, rapid reproductive stem growth (Hare *et al.*, 1987; Clark *et al.,* 1990b) makes Puna chicory hard to manage, and poor persistence (Lancashire and Brock, 1983; Hume *et al.*, 1995) has limited its adoption. Winter dormancy (Rumball, 1986) results in difficulty in selecting companion species (Hare *et al.*, 1987) and balancing feed supply all year round (Hume *et al.*, 1995). Grazing has proved to be one of the effective ways to control stem development (Hare *et al.*, 1987; Clark *et al.,* 1990b; Komolong *et al.*, 1992; Moloney and Milne, 1993; Hume *et al.*, 1995), however, hard grazing might be detrimental to persistence (Hume *et al.*, 1995). Hare *et al.* (1987) and Clark *et al.* (1990b) suggested that rotational grazing to 30-50 mm above ground level at 4-5 week intervals appeared to be the best management to achieve the desirable proportion of leaf (70%) and stem (30%), whereas Moloney and Milne (1993) suggested that two hard grazings to ground level in spring, 20-26 days apart, were required to control primary stem growth. However, no firm conclusions have been drawn from the previous research.

The herbage mass of chicory is formed from leaf and stem accumulation. The seasonal dynamics of morphological development determine the seasonal distribution of herbage mass. Researchers have shown that defoliation intensity and frequency affect morphological development, and thereby affect the productivity and persistence of several tap-rooted perennial plants, such as lucerne, red clover and birdsfoot trefoil (*Lotus corniculatus* L.) (Nelson and Smith, 1968; Leach, 1969, 1979a; Volenec *et al.,* 1987; Bowley *et al.,* 1988). Root carbohydrate reserves play an important role in the regrowth after defoliation for the tap-rooted perennial plants (Fankhauser *et al.,* 1989; Ernst *et al.*, 1996; Van den Ende *et al.*, 1996). However, there is little information available in the literature on the morphological development and the dynamics of root carbohydrate reserves in forage chicory and their effects on productivity and persistence.

Therefore, the general objectives of this thesis are to:

i) study the seasonal patterns of herbage mass production and morphological development of forage chicory under defoliation.

ii) examine the persistence of forage chicory under grazing management.

2. REVIEW OF THE LITERATURE

2.1 INTRODUCTION

CHICORY (*Cichorium intybus* L.) is a perennial herb of the family Asteraceae, native to Europe, many parts of Asia, Africa and America (Clapham *et al.,* 1962). Chicory is grown as a leaf vegetable 'witloof' in Europe (George, 1985; Schoofs and Langhe, 1988), or a fructose crop in many parts of the world (Chubey and Dorrell, 1977; Pollock and Chatterton, 1988; Meijer and Mathijssen, 1992), and its roots are used as a coffee substitute or supplement (Taylor, 1981), particularly in India (Arya and Saini, 1984) and South Africa, where more than 90% of all coffee consumed contains chicory (Anonymous, 1978). It has been widely used as a fodder crop for animal feed since the world's first forage cultivar 'Grasslands Puna' was released in New Zealand in 1985 (Rumball, 1986). A number of experiments have evaluated various aspects of this cultivar, such as seed production (Hare, 1986; Hare *et al.*, 1987; Hare *et al.*, 1990), herbage production (Matthews *et al.*, 1990; Hume *et al.*, 1995), feed quality (Clark *et al.*, 1990a; Niezen *et al.*, 1993a) and animal performance (Fraser *et al.*, 1988; Hoskin *et al.*, 1995; Kusmartono *et al.*, 1996a, b).

This chapter will overview the published research on the agronomic characteristics, animal performance, utilisation and management work of Puna chicory. More detailed reviews precede each chapter.

2.2 HISTORY AND BREEDING

The pioneer for using chicory in pasture in the United Kingdom (UK) was Elliot (1902, cited by Foster, 1988), but the first person to introduce chicory into Britain was Arthur Young in 1785 from France. However, it was Elliot who did some scientific work on chicory (Foster, 1988). In New Zealand, chicory was first recorded in 1867 (Hooker, 1867) and was commonly found on roadsides and waste lands of both Islands (Cheeseman, 1906). It was often included in grass-seed mixtures (Anonymous, 1918), but the growth of chicory was insufficient to make a significant contribution to pasture productivity and the plant soon ran to seed (Cockayne, 1915). Cockayne (1915) classed chicory as a weed in pasture. O'Brien (1955) also concluded that chicory did not persist for any length of time, and had little value as a forage plant, but had a good growth potential on low fertility soil which dried out in summer (O'Brien, 1955).

Chicory was re-evaluated as a potential forage species in the mid-1970s in New Zealand. After over 10 year's selection, a cultivar 'Grasslands Puna' was approved in 1984 as the world's first forage cultivar of chicory (Rumball, 1986). Since 1985, Puna chicory has been widely adopted throughout New Zealand and exported to Australia, UK and the United States of America (USA). In 1996/1997, the estimated sales were 50 t in New Zealand, 60 t in Australia and 15 t elsewhere. The estimated production in 1996/1997 was 91 t in New Zealand, 72 t in Australia and 25 t elsewhere (B. Atiken, personal communication).

2.3 AGRONOMIC CHARACTERISTICS

2.3.1 Growth and development

Puna chicory is active in spring, summer and autumn, but dormant in winter (Lancashire and Brock, 1983). It is a rosette plant with broad prostrate leaves in winter and erect leaves in warm seasons. Chicory will not produce seed heads until it is vernalised by a certain period of cold temperature (George, 1985; Hare *et al.,* 1987). With warm temperature in spring, it rapidly produces large numbers of leaves from the crown and starts to elongate very quickly in late spring. The thick, hollow reproductive stems bearing inflorescences which can reach over 2 m if left ungrazed. Chicory in New Zealand starts to flower in early December and continues until February, with a peak in late December (Hare and Rolston, 1987). It is cross-pollinated largely by honey bees. Seeds mature 20 days after pollination (Hare, 1986). The 1000-seed weight is 1.3-1.7 g (Hare, 1986; Rumball, 1986) and seed yield ranges from 200 to 500 kg/ha (Hare *et al.*, 1990).

Chicory can be sown all year round except in winter. But spring sown crops will not produce seed heads until the next summer (Hare *et al.*, 1987). The sowing rate should be in the range 1.5-3 kg/ha for pure stands and less than 1.5 kg/ha for binary and complex mixtures with white clover or winter-active grasses (Arias-Carbajal, 1994). However, farmers prefer higher sowing rates up to 5 kg/ha in practice.

Chicory has a deep, thick taproot, which can be exposed and damaged by overgrazing and treading (Rumball, 1986). During its first growing season, chicory usually has one intact crown, which will split into multi-crowns from its second growing season (Hume *et al.*, 1995), similar to some tap-rooted legumes, such as lucerne (Nelson and Smith, 1968; Leach, 1979a, b). Chicory stores fructans, up to 80% of root dry weight, as its carbohydrate reserves (Chubey and Dorrell, 1977; Pollock and Chatterton, 1988; Van den Ende *et al.*, 1996).

2.3.2 Soil requirements and fertilisers

Chicory grows best on well-drained soils with medium to high fertility (Hare and Rolston, 1987). Standard nutrient requirements of Puna chicory are as follows: Olsen phosphorus (P) 20-30 µg/g, potassium (K) >8 µg/g and sulphur (S) >10 µg/g (Moloney and Milne, 1993). Puna chicory can tolerate a wide range of pH, but performs best in the range pH 5.6-6.0 (Crush and Evans, 1990). However, increasing soil pH significantly decreased the concentrations of zinc (Zn), boron (B), copper (Cu), manganese (Mn), sulphur and potassium in chicory and increased calcium (Ca) (Crush and Evans, 1990). Nitrogen (N) is an important nutrient, particularly at seedling development. In August, N, P, K and S fertilisers are required as a maintenance application, supplying 35 kg N/ha, 35 kg P and K/ha, and 20-30 kg S/ha. By early December, a second application of nitrogen (eg. urea) should be applied, providing 20-25 kg N/ha (Moloney and Milne, 1993). Clark *et al.* (1990b) showed that spring response to 1 kg of nitrogen was 10.6 kg DM/ha (rates up to 50 kg/ha), similar to that of ryegrass and white clover pasture, however, 60% of the response was in stem production.

2.3.3 Herbage production

Chicory can grow at a rate in excess of 150 kg DM/ha/day in favourable conditions (Matthews *et al.*, 1990; Hare and Rolston, 1987). In most regions in New Zealand, Puna chicory is capable of producing 15-18 t DM/ha annually

(Lancashire, 1978, Matthews *et al.*, 1990, Hare *et al.*, 1987). An annual yield of 25 t DM/ha was recorded on pure stands grown in 150 mm rows for seed production from mid-December to mid-May on well drained soils of medium to high fertility in the Manawatu, New Zealand (Hare and Rolston, 1987). Under grazing conditions in Oklahoma, chicory produced 7.9 t DM/ha under moderate (27 days rest periods) and slow (38 days rest periods) rotational grazing, and 6.6 t DM/ha under the fast (13 days rest periods) rotational grazing (Volesky, 1996).

Chicory yields well in mixed pastures. When mixed with 'Pennlate' orchardgrass (*Dactylis glomerata* L.), the total yields of forage averaged 9.4 t DM/ha for chicory and 7.9 t DM/ha for orchardgrass over 2 years (Jung *et al.*, 1996), whereas in five chicory-based mixed pastures, chicory averaged 8.7 t DM/ha over 4 years with seasonal distribution of 32, 49, 14 and 5% for spring, summer, autumn and winter, respectively (Hume *et al.*, 1995).

Chicory normally dominates in newly sown pastures. Hume *et al.* (1995) reported that chicory contributed 34, 80, 85 and 57% to the green DM yield for years 1-4, respectively, in mixed pastures, whereas Lancashire *et al.* (1984, cited by Hume *et al.*, 1995) found that chicory contributed 14, 61, 48 and 18% of the total yield for years 1-4, respectively, in a long term grazing experiment in the Manawatu, New Zealand. Fraser *et al.* (1988) also stated that the relative yields remained similar averaging 30, 40 and 40% of annual production over three years in Southland, New Zealand. In contrast, chicory yields and contents in pastures in other experiments have been considerably less and chicory plants not as persistent. For example, Lancashire and Brock (1983) reported that chicory contributed 35% of total yield in the summer of year 1 and only about 10% in the summer of year 3 in a pasture under rotational grazing, whereas Moloney (1992) recorded maximum contents of 6% in summer (3-4% of annual yield) from farm sowings.

2.3.4 Feed quality

2.3.4.1 Mineral content

Chicory is rich in minerals and is easily digested. Chicory has been reported high in potassium, sodium, calcium, sulphur, boron, manganese, molybdenum and zinc, but low in nitrogen and silicon compared with perennial ryegrass/white clover pasture (Rumball, 1986; Crush and Evans, 1990). The ash content of chicory (188 g/kg DM) is substantially higher than that found in most perennial forages (90-110 g/kg DM, Hoskin *et al.,* 1995). Scales *et al.* (1994) also reported that the mineral contents of chicory and lucerne were similar and generally higher than those of grasses. Zinc levels in chicory ranged from 31 to 385 mg/kg in the field and 12 to 102 mg/kg in the glasshouse (Crush and Evans, 1990), exceeding normal values in perennial ryegrass/white clover pasture. Zinc has been found to be effective against facial eczema (Munday *et al.*, 1986). Low levels of silicon in chicory make it more readily digested than plants in which silicon is deposited, as silicon can alter the mechanical properties of herbage (Crush and Evans, 1990, Hoskin *et al.*, 1995).

However, a recent study on Cu concentration in lamb liver showed that lambs grazing chicory had higher liver Cu concentrations (3608 µmol/kg) than those grazing pasture (2453 µmol/kg), due to higher Cu concentration in chicory. This may impair market access for sheep products overseas (Clark, 1995).

2.3.4.2 Crude protein

Chicory had variable crude protein levels of 13.4-24.4% from nine locations throughout New Zealand (Crush and Evans, 1990), and an average crude protein of 18.3% was obtained from pre-grazed chicory in Oklahoma (Volesky, 1996). Low nitrogen contents in chicory have also been observed when it was grazed by calves (Fraser *et al.*, 1988; Clark *et al.*, 1990a), or fed indoors to sheep (Komolong *et al.*, 1992) and to deer (Niezen *et al.*, 1993a; Hoskin *et al.*, 1995).

Low levels of total condensed tannin (4.2 g/kg DM) in chicory can protect protein from degradation in the rumen (Terrill *et al.*, 1992), and this may be partly responsible for the higher growth rates of ruminants fed chicory compared with those fed perennial ryegrass/white clover pasture (Hoskin *et al.*, 1995; Kusmartono *et al.*, 1996a, b). Komolong *et al.* (1992) found that no plant protein was lost as ammonia absorbed from the rumen in lambs fed chicory, whilst 39% of the protein was lost as ammonia in those fed Wana cocksfoot (*Dactylis glomerata* L.). Consequently, the amount of protein reaching the duodenum per kg digestible organic matter intake (DOMI) in lambs fed chicory was higher (44 g/kg DOMI) than those fed Wana cocksfoot (32 g/kg DOMI). Kusmartono (1996c) also found that the action of condensed tannin reduced rumen ammonia concentration in deer fed chicory, but did not affect protein solubility. However, Deaker *et al.* (1994) reported that chicory does not contain useful amounts of tannin to protect protein from rumen degradation because chicory only contains trace amount of extractable tannin (1.36 g/kg DM) as measured by the butanol/HCl method of Terrill *et al.* (1992). Jackson *et al.* (1996) also suggested that the minimum level of condensed tannin in grazed forages to prevent bloat in cattle and to increase wool growth is approximately 5 g/kg DM.

However, the use of chicory will reduce the effects of parasitism in grazing lambs relative to either perennial ryegrass, cocksfoot or tall fescue (*Festuca arundinacea* L.) (Scales *et al.*, 1994), as low condensed tannin in chicory has been shown to offer animals some protection from internal parasitism (Niezen *et al.*, 1993b), and the tall growth habit of chicory also offers some protection.

2.3.4.3 Digestibility

Chicory had higher DM and organic matter (OM), but lower fibre apparent digestibility values than perennial ryegrass/white clover pasture (Hoskin *et al.*, 1995; Kusmartono *et al.*, 1996a, b). Chicory flowers (81.0%) and live leaves (77.0%) had higher dry matter digestibility (DMD) values than the main stem (46.2%) (Clark *et al.*, 1990a).

The higher DM and OM digestibility values of chicory were due to a higher readily fermentable carbohydrate (RFC) : structural carbohydrate (SC) ratio (1.15) compared with perennial ryegrass/white clover pasture (1.00) (Hoskin *et al.* 1995; Kusmartono *et al.*, 1996a, b). This was confirmed by Ulyatt and MacRae (1974) who concluded that a higher apparent digestibility value of white clover to perennial ryegrass was due to higher RFC : SC ratio (1.17 vs 1.00). Kusmartono (1996c) also found that chicory had a higher relative ME value than perennial ryegrass/white clover pasture, and even red clover and white clover during summer and autumn. The low rumen pH found in deer grazing chicory may explain the low fibre digestibility of this forage (Kusmartono, 1996c).

2.4 ANIMAL PERFORMANCE

Puna chicory has a great potential for finishing lambs, deer and cattle. Firstly, the seasonal growth pattern of chicory coincidentally fits the feed requirements of animals. For temperate pasture species, the general pattern for all plants is high in both yield and quality in spring associated with vegetative stages of growth, but poor in feed quality and low in yield over summer due to approaching plant maturity (Waghorn and Barry, 1987) and moisture stress (Adam, 1988). However, animal feed requirements during summer are usually high. For example, red deer in New Zealand calve between November-December and are at peak lactation over summer, and lambs are usually at post weaning capable of fast growth in summer. Thus, inadequate feed supply relative to animal requirement is an inherent limitation of seasonality in pasture feed supply to animal production (Christian, 1987), resulting in animal growth being below maximum genetic potential (Komolong *et al.*, 1992; Niezen *et al.*, 1993a). Puna chicory with its deep root system is drought resistant and can fill this feed gap by supplying high quality feed continuously over summer. Secondly, chicory has a high feeding value and is highly preferred by many farm animal species. In a series of grazing preference trials undertaken in New Zealand, red deer preferred red clover and chicory to most other pasture plant species (Hunt and Hay, 1989).

2.4.1 Voluntary feed intake

Chicory had higher organic matter digestibility (OMD) and voluntary feed intake (VFI) than perennial ryegrass/white clover pasture during spring, summer and autumn (Niezen *et al.*, 1993a; Kusmartono *et al.*, 1996a, b), resulting in greater animal production in terms of live-weight gain (LWG) (Niezen *et al.*, 1993a; Hoskin *et al.*, 1995; Scales *et al.*, 1994) carcass weight, and velvet antler production (Kusmartono *et al.*, 1996a). The higher OMD is associated with the higher ratio of RFC : SC of chicory compared with perennial ryegrass/white clover pasture as discussed in Section 2.3.4, whilst higher VFI is closely related to faster particle breakdown in the rumen and faster digesta clearance from the rumen compared with perennial ryegrass/white clover pastures (Kusmartono *et al.*, 1996b).

Particle comminution is achieved by chewing during eating and rumination (Ulyatt *et al.*, 1986). A higher chewing rate during eating (97.4 v. 81.0 chews/min) and a greater number of chews/g DM eaten (36.2 v. 31.5) made the feed particles smaller for deer fed chicory compared with those fed perennial ryegrass/white clover (Kusmartono *et al.*, 1996b). Some deer (60%) could break down swallowed chicory to below the critical particle size (< 1 mm, Domingue *et al.*, 1991) without ruminating at all (Kusmartono *et al.*, 1996b). However, Dryden *et al.* (1995) suggested that the main effect of chewing during eating appeared to be the release of cell contents, rather than the comminution of the cell wall for red deer fed fresh chicory, birdsfoot trefoil and perennial ryegrass, and long lucerne hay.

Behaviour observations, during both indoor feeding (Hoskin *et al.*, 1995) and grazing (Kusmartono *et al.*, 1996a), showed that red deer fed chicory spent a similar time eating (361 v. 379 min/24h), but considerably less time ruminating (33 v. 270 min/24h) compared to those fed perennial ryegrass based pasture.

As eating time was similar for deer grazing either chicory or perennial ryegrass/white clover, the higher VFI for animals grazing chicory resulted from greater bite weight compared with those grazing perennial ryegrass/white clover pasture (Kusmartono *et al.*, 1996a). McCoy *et al.* (1997) found that biting rates of mature beef cows grazing vegetative chicory swards were not affected by increased allowance but herbage DM intake per bite doubled when herbage allowance increased from 1.7 to 3.5 kg/cow/hour.

Shorter ruminating time in deer fed chicory suggested that particles of this feed can be broken down to the critical particle size and passed out of the rumen faster than perennial ryegrass (Hoskin *et al.*, 1995; Kusmartono *et al.*, 1996a, b). Further research showed that the fractional degradation of large particles to small particles and the fractional disappearance of DM from the rumen were both approximately twice as fast for deer fed chicory as for those fed perennial ryegrass (Kusmartono *et al.*, 1996b; Kusmartono, 1996c). This provide a faster clearance of DM from the rumen and hence opportunity for increased VFI, as digesta clearance from the reticula-rumen has long been recognised as a major process determining intake and nutritive value of forage (Black *et al.*, 1982).

2.4.2 Liveweight gain

Liveweight gain is one of most important indices for evaluating feeding value of a forage. The feeding value of chicory for deer was higher than that of red clover in autumn (157 v. 126), similar in spring (115 v. 114), but lower in summer (114 v. 124), when all data for deer were expressed relative to liveweight gain on perennial ryegrass/white clover pasture being 100 (Kusmartono, 1996c). For example, red deer hinds grazing on chicory had higher growth rates for their fawns during lactation (16%, Niezen *et al.*, 1993a) and a higher weight for their fawns at weaning (15%, Hunt, 1993) in both autumn and spring than those grazing perennial ryegrass/white clover pasture.

Fraser *et al.* (1988) reported that animal growth rates were 290 g/day for lambs and 900 g/day for calves with *ad lib.* feeding on pure Puna chicory. Cruickshank

(1986) found that spring lamb growth rates on Puna chicory, white clover and ryegrass were 290, 320 and 227 g/day, respectively. Hopkins *et al.* (1995) found growth rates for lambs grazing lucerne and chicory were similar (233 v. 243 g/day).

Komolong *et al.* (1992) reported that lamb growth over 6 weeks was higher on chicory (268 g/day) than Wana cocksfoot (205 g/day). Although DOMI and nitrogen intake (NI) were lower in Puna chicory (16.10 and 0.71 g/kg LW/day for DOMI and NI, respectively) than Wana cocksfoot (26.69 and 1.39 g/kg LW/day), non-ammonia nitrogen (NAN) flow at the duodenum was similar [0.70 v. 0.85 g/kg live-weight (LW)/day] mainly due to variable N loss as ammonia across the rumen wall. None of the N consumed by lambs grazing chicory was lost as ammonia, whilst 39% of the N consumed by those grazing Wana cocksfoot was lost as ammonia from the rumen. Komolong *et al.* (1992) argued that the disparity in LWG of lambs grazing Puna and Wana may be related to differences in the balance of nutrients rather than the quantity intake or supply of any one nutrient. This was shown in the ratio of duodenal NAN : DOMI which for Puna (43.5) was similar to legumes, but the ratio for Wana (31.9) was lower than for other grasses. They concluded that the nutritive value of Puna and Wana for lamb growth is best described by NAN : DOMI ratio.

2.4.3 Carcass weight and meat quality

Red deer and hybrid stags grazing chicory had higher carcass weight (63.2 and 73.0 kg) than those grazing perennial ryegrass/white clover pasture (56.6 and 57.0 kg) by one year of age, and the dressing out percentage of deer fed chicory was significantly higher than for those fed perennial ryegrass/white clover pasture (Kusmartono *et al.*, 1996a). Hopkins *et al.* (1995) reported that lambs grazing chicory or lucerne exhibited similar carcass compositions in terms of fatness, weight, pH (< 5.6), meat colour value, tenderness and flavour. Young *et al.* (1994) also found no difference between samples from lambs fed chicory or lucerne in terms of flavour and overall acceptability. Hopkins *et al.* (1995) concluded that finishing lambs on chicory will produce meat that is as acceptable as that from lambs fed lucerne, based on both objective and subjective criteria. Scales (1993) reported that there was no effect of forage type on leanness of lambs grown at 200 g/day, nor was there any effect of forage type and liveweight on meat quality when Dorset, Suffolk cross, or Coopworth lambs weighing about 30 kg in January were offered a range of forages including high-endophyte Nui ryegrass-dominant pasture, white clover-dominant pasture, Moata or Concord ryegrass, lucerne, rape, or chicory.

2.4.4 Velvet antler production

Grazing one year old red deer on chicory advanced the mean date of the first cut of velvet antler by 28 days, and increased total velvet antler weight by increasing the length of time for total velvet growth compared to deer grazing perennial ryegrass/white clover pasture (Kusmartono *et al.*, 1996a). In contrast, Semiadi *et al.* (1993) found no difference in velvet antler weight of young stags grazing either red clover or perennial ryegrass/white clover pasture, even though liveweight gain responses were higher for deer grazing red clover. This indicated that the high feeding value of chicory not only increased the body growth rates of deer, but also increased the antler production in one year old stags. However, there appeared to be no effect on the velvet antler growth of adult stags (Cosgrove *et al.*, 1995).

2.5 UTILISATION AND MANAGEMENT

2.5.1 Problems in utilisation

2.5.1.1 Reproductive stem development

Fast growth rate of chicory in the late spring and early summer results in rapid development of reproductive stems. The chicory stands will mature quickly and produce a hollow primary stem in mid-October which will thicken and harden substantially from a height of approximately 60 cm and continue to grow over 2 m tall if reproductive growth is not controlled (Rumball, 1986; Hare *et al.*, 1987). Matthews *et al.* (1990) reported that the treatments not grazed in October and lax grazed until early December developed more than 80% of stem in the total yield. For chicory crops used for seed production, most of the yield consists of reproductive stems although high herbage mass is accumulated (up to 25 t DM/ha, Hare *et al.*, 1987). For maximum seed production, it is not possible to utilise the high herbage growth rates from October onwards as grazing after October will seriously decrease seed yield (Hare and Rolston, 1987). Stem is usually of low quality as discussed in Section 2.3.4.3 and animals clearly avoided grazing matured stems (McCoy *et al.*, 1997). Therefore, the reproductive stems should be properly controlled if high quality feed required.

2.5.1.2 Persistence

Chicory usually persists for 3-4 years under grazing conditions. Although a diminishing soil N supply and pathogens, such as *Sclerotinia* spp., probably contribute to the poor persistence of chicory in some cases (Hare *et al.*, 1987; Moloney and Milne, 1993; Arias-Carbajal, 1994), improper management such as prolonged and heavy set stocking, or grazing at high stocking rates during periods of heavy rain are likely to be the major cause of reduced persistence. Lancashire and Brock (1983) found that chicory disappeared by the end of the first summer under set stocking and persisted well under rotational grazing. Thus, proper management would prolong the life span of chicory. However, chicory should be kept well grazed to prevent the formation of flowering stems.

In mixed pasture, although chicory dominated the swards during the first 3 years, its yields were declining by year 4. Plant numbers, however, declined from 46 plants/m^2 in the establishment year to 15 plant/m^2 by year 4 (Hume *et al.*, 1995). Fraser *et al.* (1988) also observed that plant density of chicory declined over time in pastures although relative yields remained similar over three years. This decline in plant density is common in chicory (Lancashire and Brock, 1983; Fraser *et al.*, 1988). However, the increased plant size due to splitting of the crown and development of more shoots per plant compensated for the continual decline in plant numbers, resulting in relatively constant yields at least over the initial years (Hume *et al.*, 1995).

2.5.2 Grazing management

Chicory will produce excellent forage in terms of herbage yield and feed quality provided it is managed properly. Chicory cannot be used as a crop to accumulate large quantities of herbage to overcome feed shortages (Matthews *et al.*, 1990). Although 8-week cutting intervals maximised DM yield, they produced a large amount of stem (Clark *et al.*, 1990b). Leaf yield rather than total yield should be optimised at each cutting or grazing as stem is low in digestibility and poor in palatability as discussed in Section 2.3.4.3. Therefore, it may be preferable to sacrifice some DM production and keep the swards in a vegetative state by more frequent, severe grazing.

A number of experiments have been carried out on the grazing management of Puna in which the key issue was to maximum leaf growth and minimise stem development (Hare *et al.*, 1987; Clark *et al.*, 1990b; Moloney and Milne, 1993; Hume *et al.*, 1995). Hare *et al.* (1987) suggested that rotational grazing with 4-5 week intervals to 30-50 mm above ground level appeared to be the best management, and Clark *et al.* (1990b) also suggested that grazing intervals of 4-5 weeks would allow close to maximum leaf yield without large amounts of stem (70% leaf : 30% stem), whereas Moloney and Milne (1993) reported that two quick, hard grazings to ground level in October/November with a 3-4 week interval were effective in minimising stem development. Less frequent grazing (5 week intervals) was recommended by Matthews *et al.* (1990) to prevent reproductive stem becoming mature. Moloney and Milne (1993) suggested that making silage in late spring or mechanical topping in summer is another option to control the primary stem growth if the first grazing is missed.

In spite of good spring control of primary stem, a finer more branched secondary stem may develop in early autumn. Often this is in response to an early or sudden drop in soil temperature and good rain. However, it is not seen as a major problem limiting either quality or grazing control (Moloney and Milne, 1993).

Chicory can be eaten to the ground level at each grazing as it will regenerate new shoots from the basal crown (Rumball, 1986). However, frequent cutting or grazing might be detrimental to the persistence of chicory. Clark *et al.* (1990b) found that two 4-weekly cuts to ground-level produced nearly maximum levels of leaf with no effect on plant density or regrowth, whereas four 2-weekly cuts to ground level were sufficient to decrease plant density and affect subsequent regrowth through severe root carbohydrate drain and reduced photosynthesis. In contrast, Volesky (1996) reported that, during the establishment year, plant density was not affected by grazing frequencies, and Hume *et al.* (1995) also reported grazing frequency had no significant effect on plant populations for chicory in pastures, but frequent grazing (3-4 week) significantly decreased DM yields (-19%) and total green herbage (-11%) compared with infrequent grazing (4-6 week). Volesky (1996) concluded that rotational grazing with a rest period of at least 24 days appeared to be the strategy that optimised leaf production while maintaining low numbers of bolting plants.

The decline in plant density in chicory appears to be inevitable under grazing, as discussed in Section 2.5.1.2. Seedling regeneration within established stands is uncommon in chicory as it is for lucerne (Lodge 1991), although Volesky (1996) implied that seed recruitment would be possible in the less dense canopy, and so the persistence of chicory in a stand depends mainly on the survival of the original plants. Therefore, it is essential to maintain enough plant numbers in the sward to ensure high yield although increased plant size over time will compensate the declined plant density for the first 2-3 years (Hume *et al.*, 1995). Volesky (1996) suggested that a density of 43-48 plants/m^2 appeared to be the maximum for established chicory swards from the second growing season, whereas Moloney and Milne (1993) recommended that a target plant density for mature stands was 18-24 plants/m^2.

2.6 CONCLUSIONS

Chicory has been evaluated on its agronomic properties and feeding value in a number of experiments since it was released in 1985. The high herbage growth rate, feed quality and animal performance have been well documented in the literature. Control of rapid reproductive stem development has been attempted by various management approaches, such as cutting or grazing intensity and frequency, however, no firm conclusions have been drawn from the previous research. Poor persistence is another drawback of chicory that has been addressed in several studies, however, the causes have not been clearly identified. Root carbohydrate reserves and residual leaf areas have been used to explain the mechanisms of regrowth after defoliation of tap-rooted plants, such as lucerne, red clover and birdsfoot trefoil (Kendall, 1958; Smith, 1962; Smith and Nelson, 1967; Nelson and Smith, 1968; Greub and Wedin, 1971; Wolf, 1978; Fankhauser and Volenec, 1989; Boyce and Volenec, 1992), however, the research on these aspects of forage chicory is limited.

The above-mentioned limitations in the literature on forage chicory provide the focus for this thesis.

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3. CONTROL OF REPRODUCTIVE GROWTH IN PUNA CHICORY BY GRAZING MANAGEMENT[†]

[†] This chapter has been published in *Proceedings of the New Zealand Grassland Association* **56**, 213-217 (Li *et al.*, 1994).

3.1 ABSTRACT

The effect of reproductive stem removal on the growth and development of Grasslands Puna chicory (*Cichorium intybus* L.) was studied on the Deer Research Unit (DRU) and the Pasture and Crop Research Unit (PCRU) at Massey University in 1993-1994. The chicory was in its second and fourth years on the DRU and PCRU, respectively. A medium grazing intensity with deer was used on the DRU and four grazing intensities were applied with sheep on the PCRU. Chicory accumulated 10,007 kg DM/ha herbage mass over 6 months from November to May on the DRU and accumulated 4,904 kg DM/ha herbage mass on the PCRU over the same period. The growth of primary reproductive stems was suppressed by grazing intensities that left less than 100 mm of stem stubble. None of the grazing intensities prevented the growth of secondary and reproductive axillary stems. Leaf mass accumulation over the season was greatest under very hard grazing (0-50 mm), whereas the total herbage (leaf and stem) mass was greatest under lax grazing (150-200 mm). The primary stems produced in spring were utilised by sheep and deer, but secondary stems produced in summer were poorly grazed. Medium grazing (100-150 mm stem stubble) of chicory gave a reasonable compromise between total production and feed quality. There was a large decrease in plant density in November-December, which was unrelated to grazing intensity, that requires further study.

Keywords: *Cichorium intybus*, grazing intensity, growth rate, plant density, Puna chicory, reproductive growth.

3.2 INTRODUCTION

CHICORY (*Cichorium intybus* L. cv Grasslands Puna) has been widely adopted as a specialist forage crop in recent years. A major attribute of Puna chicory is its high growth rate in late spring and summer (Lancashire and Brock, 1983; Hare *et al.*, 1987). Puna chicory has been reported to have high daily growth rates in excess of 150 kg DM/ha per day and total forage yields up to 25 t DM/ha from December to May in favourable conditions (Matthews *et al.*, 1990; Hare *et al.*, 1987). These high growth rates are driven by reproductive growth that culminates in the production of stems up to 2 m tall unless the crop is grazed (Matthews *et al.*, 1990; Rumball, 1986). Chicory cannot be used as a crop to accumulate large quantities of herbage to overcome feed shortages (Matthews *et al.*, 1990). A difficulty with the grazing management of Puna chicory is maintaining a balance between control of the reproductive stems, which have poor digestibility (Clark *et al.*, 1990b), and maximising leaf production without prejudicing the persistency of the crop. Clark *et al.* (1990a) suggested that grazing Puna chicory to 30-50 mm at 4 to 5 week intervals would produce the optimal leaf to stem ratio of 70%:30%. In contrast, Moloney and Milne (1993) recommended that two quick and hard grazings to ground level, the first in mid spring (i.e. mid to late October) and the second in November, 20-26 days later, was the easiest way to minimise stem development. However, there is a poor understanding of the effect of reproductive stem removal on plant growth and development. The objective of this research was to examine the influence of the height of stem remaining after grazing on subsequent leaf and stem growth, and on plant survival.

3.3 MATERIALS AND METHODS

3.3.1 Experimental sites

Two field experiments were carried out on the Deer Research Unit (DRU) and the Pasture and Crop Research Unit (PCRU), Massey University, Palmerston North, New Zealand from November 1993 to May 1994. The soil type is a deep Manawatu silt loam soil (Hewitt, 1992). Chicory was in its second and fourth growing season on the DRU and PCRU, respectively. During early spring, herbicide, Gramoxone at 3 l/ha, was used to kill all the grass on the PCRU. Nitrogen fertiliser, as urea, was applied at 37 kg N/ha in early spring, late spring and early autumn, respectively, on the DRU, whereas only one nitrogen application of 20 kg N/ha was made in spring on the PCRU. The animals used for grazing were red and hybrid (0.25 elk : 0.75 red) deer, and mature age ewes on the DRU and PCRU, respectively.

3.3.2 Experimental design

A Latin square design was used with four grazing intensities and four replicates on the PCRU. The treatments were very hard (stem grazed to ground level 0-50 mm), hard (50-100 mm stem stubble), medium (100-150 mm) and lax (150-200 mm). The grazing frequency was 3 week intervals up to January, and 5 week intervals from January onwards. The experimental unit was 288 m^2. On the DRU, a medium grazing intensity (down to 100-150 mm stem stubble) was used with about 5 week intervals between grazings before January and 7.5 week intervals thereafter. Eight 0.5 ha plots were used in this rotational grazing regime.

3.3.3 Grazing management

The first grazing was when the reproductive stem began to elongate, which was in October on the DRU and in November on the PCRU. The phenological development of chicory on the DRU was about one month earlier than on the PCRU because of the different ages of the plants. On the DRU, 23 deer, equivalent to 46 deer/ha, rotationally grazed each plot, and the duration of grazing was between 3-5 days, depending on the growth rate of chicory. On the PCRU, about 15-20 sheep, equivalent to 520-695 sheep/ha, were used in each plot for 1-2 days, depending on the grazing intensity. The grazing intensities were controlled by adjusting the grazing time. Once the desired height was reached, the sheep were moved out of the plot. Grazing finished on 27 May 1994 on the DRU and on 4 May 1994 on the PCRU.

On the DRU, all the plots were mowed to 80-100 mm to remove the old stubble in early February. In contrast, on the PCRU, all the plots were also trimmed to clear the inedible stubble and *Rumex* spp. in January, but to different heights according to the treatments. The mowing heights were 30, 70, 120 and 170 mm for the very hard, hard, medium and lax grazing treatments, respectively.

3.3.4 Measurements

On the DRU, leaf and stem masses were measured on an individual plant basis. Leaf and stem masses were further separated into primary, secondary and axillary leaf and stem. Twenty plants inside and outside the exclusion cages (1 × 2 m) were dug out after each grazing in each plot as pre- and post-grazed plants, respectively. All plant parts were oven-dried at 80°C for 48 h. On the PCRU, pre- and post grazed herbage masses were measured by cutting to the ground level using 500 × 500 mm quadrats with four replicates as sub-samples in each plot. Herbage mass was dissected into leaf, stem, dead materials and weeds by taking botanical samples during each measurement. All samples were washed free of soil and oven-dried at 80°C for 48 h.

Shoot density was counted by using a 500 × 500 mm quadrat, with 20 samplings in each plot on the DRU and four samplings in each plot on the PCRU. Plant size (shoots/plant) was measured by digging plants out, 20 plants on the DRU and 10 plants on the PCRU. Plant density was derived from shoot density divided by plant size.

3.3.5 Statistical analysis

All the data were analysed using the SAS GLM procedure (SAS Institute, 1990). Herbage masses were analysed by using the model of repeated measures for the DRU and using a model of Latin square design for the PCRU. Plant density and plant size were analysed by using the model of repeated measures for both sites.

3.4 RESULTS

3.4.1 Herbage accumulation

The weather during 1993-1994 was very dry, especially in summer. The total rainfall from October 1993 to April 1994 was 375 mm, which was 67% of the

10-year mean. The rainfall in January and in February was only 33% and 19%, respectively, of the 10-year mean (26 v. 79 mm and 13 v. 67 mm).

The very hard grazing accumulated the highest leaf mass, 3,967 kg DM/ha, and the least stem mass, 420 kg DM/ha, over the 181 days from 5 November to 5 May on the PCRU (Table 3-1). The lax grazing gave the highest stem accumulation (2,114 kg DM/ha), which was significantly higher than for any of the other grazing treatments ($P < 0.01$). There was a significant difference in leaf accumulation between very hard and hard grazing treatments ($P < 0.01$), but there were no significant differences among very hard, medium and lax grazing treatments.

In contrast, Puna chicory on the DRU accumulated 5,665 and 4,342 kg DM/ha for leaf and stem mass, respectively, during the same period. The total herbage accumulation on the DRU was 10,007 kg DM/ha, which was twice as much as that on the PCRU under a similar grazing intensity (Table 3-1).

Table 3-1 Herbage accumulation of leaf and stem dry matter (kg DM/ha) over 181 days from 5 November to 5 May

Grazing intensity	Leaf	Stem
	PCRU	
Very hard (0-50 mm)	3967	420
Hard (50-100 mm)	2802	627
Medium (100-150 mm)	3546	1358
Lax (150-200 mm)	3221	2114
s.e.m.	± 238	± 200
$LSD_{0.05}$	674	567
	DRU	
Medium (100-150 mm)	5665	4342
s.e.m.	± 282	± 537
$LSD_{0.05}$	429	

3.4.2 Growth rate

Growth rates of leaf and stem were significantly influenced by grazing intensities before early January ($P < 0.01$), but after this time there were no significant responses to grazing intensity except for leaf growth rate under lax grazing ($P < 0.05$) (Figure 3-1). The very hard grazing gave the highest leaf growth rate and the least stem growth rate before early January compared with the other grazing treatments. The lax grazing had the highest leaf growth rate after early January. During spring, lax grazing greatly suppressed the stem growth rate, whereas the very hard and hard grazing intensities totally controlled primary reproductive stem growth. Stem growth rate under lax grazing decreased from 67.4 kg DM/ha in mid November to 16.7 kg DM/ha in early January. Stem growth rates under very hard and hard grazing were less than 1.0 kg DM/ha through the rest of the season.

3.4.3 Growth pattern of different plant parts (DRU)

Grazing sharply decreased the growth rates of the primary leaf and stem during early spring (Figure 3-2). Growth rate of primary leaf decreased from 29.7 kg DM/ha in October to 0.6 kg DM/ha in December, while growth rate of stem decreased from 46.5 to 2.3 kg DM/ha during the same period. After December, the growth rates of primary leaf and stem were never over 5.0 kg DM/ha. However, secondary and axillary leaves and stems started to grow after grazing stopped primary leaf and stem growth. After reaching their peaks in December, secondary leaf growth rate remained relatively constant throughout the rest of the season, but secondary stem growth rate quickly declined. The decline in secondary stem growth rate in January-February was at least partly due to mowing (80-100 mm) after grazing.

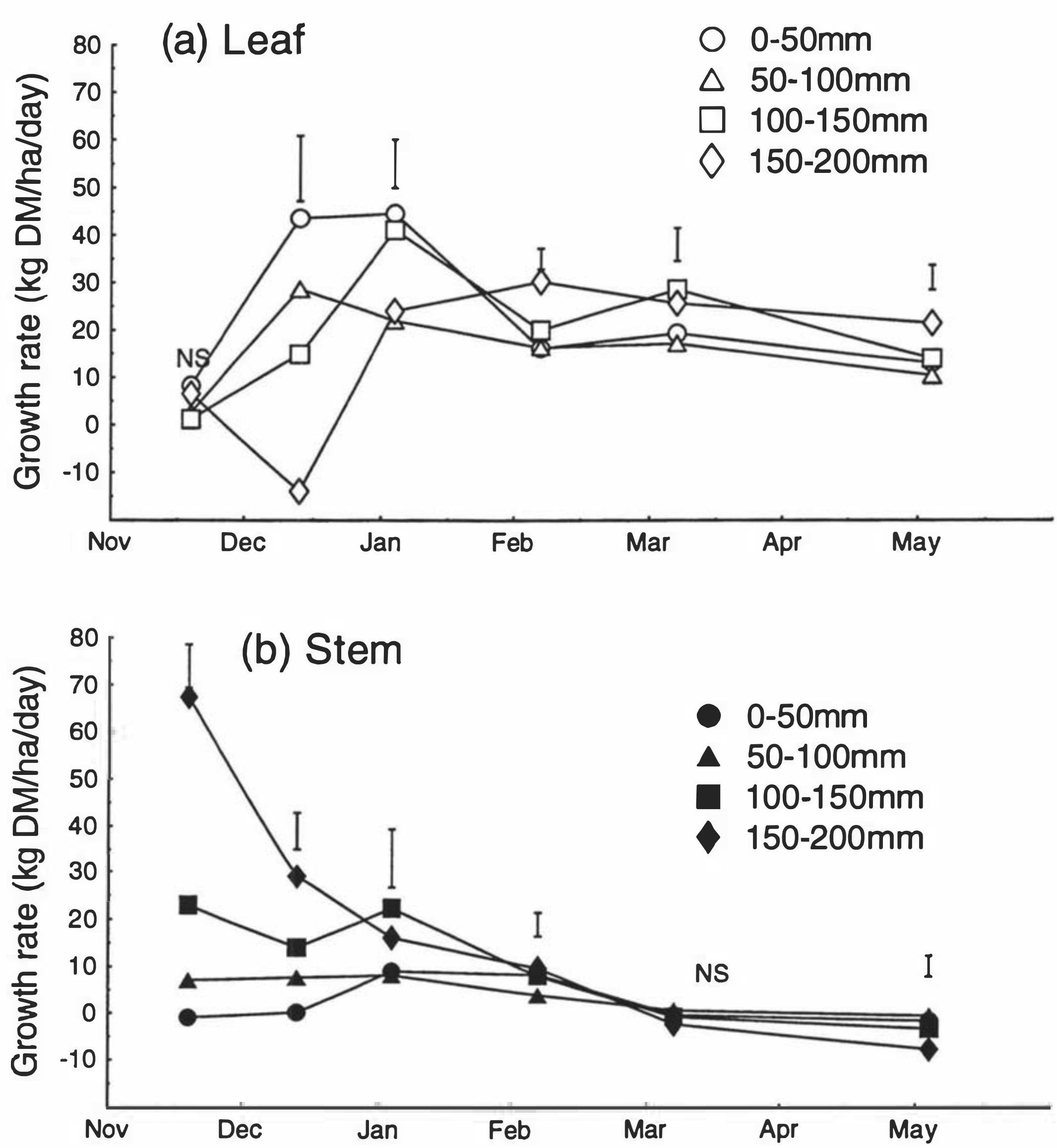

Figure 3-1 Leaf and stem growth rates of Puna chicory over the season on the Pasture and Crop Research Unit. Vertical bars represent $LSD_{0.05}$; NS, not significant.

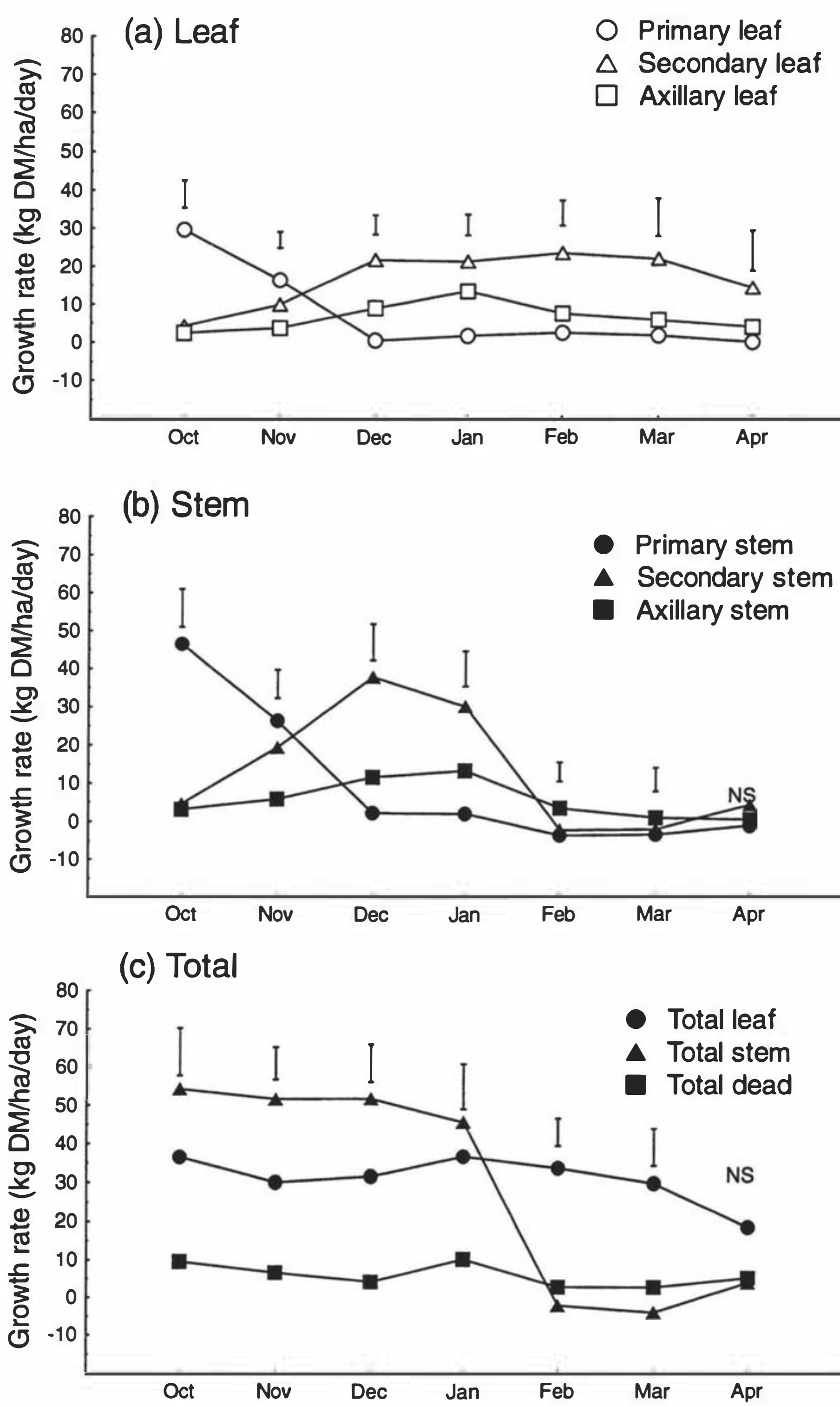

Figure 3-2 Leaf and stem growth rates of Puna chicory over the season on the Deer Research Unit. Vertical bars represent $LSD_{0.05}$; NS, not significant.

3.4.4 Leaf and stem consumption

There were no significant differences in the percentages of grazed leaf and stem masses until January (Figure 3-3). The retained primary stems and new secondary stems produced after December were largely ignored by deer. In February, the percentage of stem grazed was only 25%, whereas more than 70% of leaves were grazed. In autumn, both percentages of grazed leaf and stem increased and had no significant differences between them ($P < 0.05$), partly due to mowing which made the newly produced shoots more easily accessible.

3.4.5 Plant density and plant size

Plant density was unaffected by the level of grazing intensity on the PCRU but it decreased at both sites ($P < 0.05$), especially after the primary stem stopped growing in November on the DRU and in December on the PCRU (Figure 3-4). Plant density declined to its lowest point in February both on the DRU and the PCRU. The minimum plant density of 69 and 19 plants per m^2 on the DRU and the PCRU, respectively, represented a 41% and 27% decrease compared with the densities in November. However, the shoot numbers per plant had tripled on the DRU and doubled on the PCRU by autumn compared with in spring. Shoot numbers per plant on the PCRU were three times as many as those on the DRU.

The shoot number per m^2 was similar for the two sites (183 ± 12 shoots per m^2, Figure 3-4a, b). However, shoot number per m^2 increased 67% and 77% from February to April on the DRU and the PCRU, respectively.

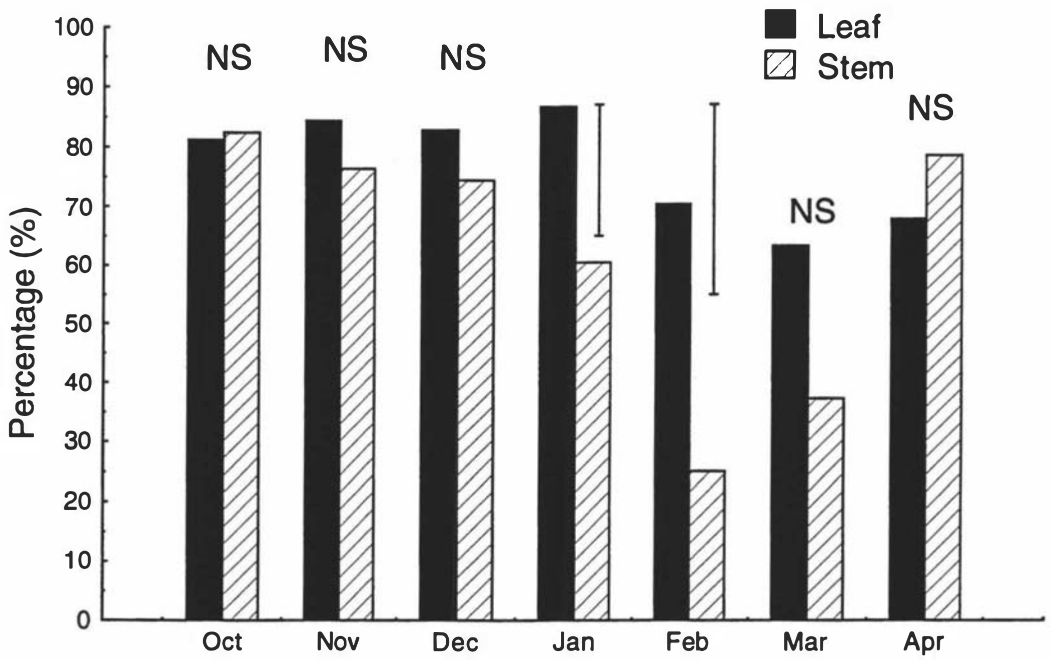

Figure 3-3 Percentage of grazed leaf and stem over the season on the Deer Research Unit. Vertical bars represent $LSD_{0.05}$; NS, not significant.

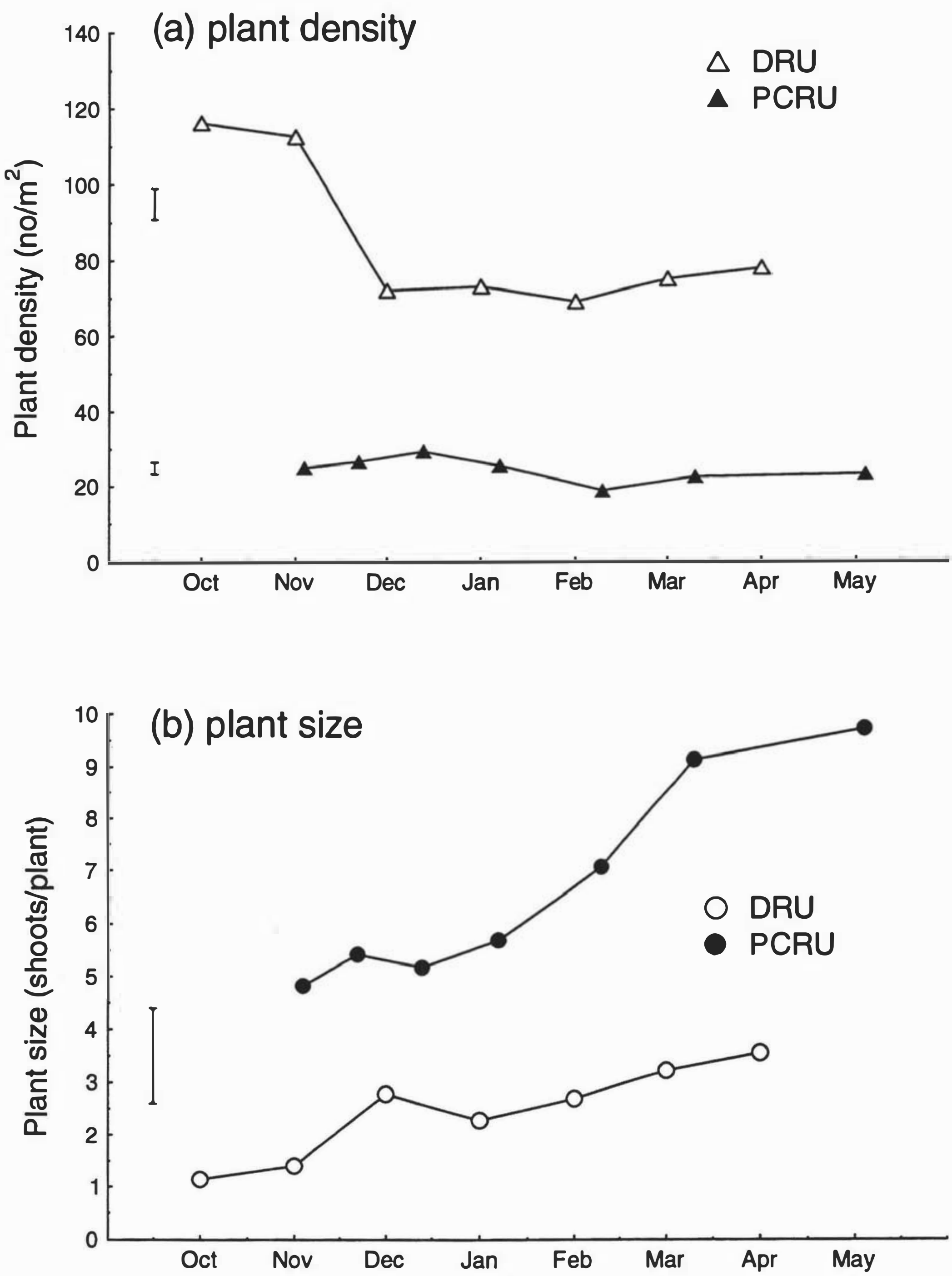

Figure 3-4 Plant densities and plant sizes over the season on the Deer Research Unit and the Pasture and Crop Research Unit. Vertical bars represent $LSD_{0.05}$.

3.5 DISCUSSION

The growth of the primary reproductive stem was greatly suppressed by grazing intensities that left less than 100 mm of stem stubble. Although hard grazing suppressed primary stem growth, it increased leaf growth rate until January. After January leaf growth rate was the greatest under lax grazing due to the greater secondary and axillary shoot growth resulting from the higher primary stem stubble. However, suppression of the primary reproductive stem under hard grazing failed to prevent the production of secondary and axillary reproductive stems. Moloney and Milne (1993) also found that more fine branched secondary stems may develop in early autumn despite good spring control of the primary stems. Although there were less stems on the hard grazed plants all shoots were reproductive until autumn. This suggested that the buds released for growth by removal of the apical dominance effect of the primary stem were all vernalised during winter. That is, grazing management can decrease reproductive stem production but not prevent it.

Utilisation of primary reproductive stem by both deer and sheep was similar to utilisation of leaf, although digestibility of stem is lower than that of leaf (Clark *et al.,* 1990b). The greater stem growth under medium and lax grazing resulted in a greater total herbage accumulation compared with hard and very hard grazing. The utilisation of the secondary and axillary reproductive stems produced in January to March was very low compared with that of leaf. However, Moloney and Milne (1993) implied that the stem developed in autumn might not limit either the feed quality or grazing control. In the current experiments, animals were observed to eat only the soft buds on the stems. Therefore, over the growing season, while leaf production was similar in all treatments total herbage accumulation was greater in the laxer grazed treatments, but the quality of the feed was lower. It is also possible that until they were mowed, the secondary stems hindered stock access to leaves.

Shoot number per plant increased throughout the season. There was a noticeable flush of vegetative shoots in late autumn (April-May), which were highly utilised by stock. Presumably these vegetative shoots develop late in the growing season each year but the timing of the flush was probably determined by the onset of autumn rain after the dry summer. These vegetative shoots require further study, particularly their survival through winter.

Shoot number per plant was greater on the PCRU than the DRU as would be expected due to the lower plant density on the PCRU. Shoot number per unit area was similar on the PCRU and the DRU but herbage mass accumulation was approximately twice as great as on the DRU despite the close proximity of the two sites. This indicated that the younger stand was more productive than the older one. However, the total herbage production was quite low compared with those reported by Hare *et al.* (1987) and Matthews *et al.* (1990). The herbage production on both sites was affected by the dry summer (the total rainfall in January and February was only 39 mm in 1994). Nevertheless, the herbage yields reported for chicory, up to 25 t DM/ha, are also dependent on the degree to which stem growth is controlled (Hare *et al.,* 1987; Matthews *et al.,* 1990). Hare *et al.* (1987) harvested the herbage from a seed production crop while 90% of the maximum herbage yield reported by Matthews *et al.* (1990) was stem.

Plant density decreased over the season on both sites which is not uncommon in chicory (Lancashire and Brock, 1983). However, about 40% of plants lost died in November-December on the DRU. This decrease on the DRU coincided with the cessation of primary stem growth, but there was no effect of grazing intensity on plant density in the PCRU trial. Although the cause of the decline in plant density in early summer was not determined, this decline will shorten the productive life span of the crop and requires further study.

In conclusion, the primary reproductive stem growth of chicory was controlled by grazing, but secondary reproductive stem was not due to its poor palatability. Leaf growth rate was greater early in the season under hard grazing, and late in the season under lax grazing. Overall, medium grazing (100-150 mm stem stubble) represented a reasonable compromise between total herbage production and feed quality.

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4. REGROWTH, MORPHOLOGY AND PERSISTENCE OF GRASSLANDS PUNA CHICORY (*Cichorium intybus* L.) IN RESPONSE TO GRAZING FREQUENCY AND INTENSITY†

† This chapter has been published in *Grass and Forage Science* **51**, 33-41 (Li *et al.*, 1997).

4.1 ABSTRACT

Effects of different grazing frequencies and intensities on herbage production, both on a unit pasture and individual plant basis, and on persistence of chicory (*Cichorium intybus* L. cv. Grasslands Puna), were studied at Palmerston North, New Zealand (latitude 40°23'S) from November 1994 to November 1995. Three experiments were conducted on the same chicory stand, sown on 12 May 1994. The main grazing experiment had two grazing intensities, hard-lax grazing (50-100 mm stem stubble to mid-January, and thereafter 100-150 mm stem stubble) and lax grazing (100-150 mm stem stubble), and three grazing frequencies (1-, 2- or 4-week intervals). A subsidiary plant survival experiment compared the survival of 120 marked plants in ungrazed and grazed treatments. A late autumn grazing experiment examined the effects on plant persistence in the following spring. The greatest herbage mass (leaf + stem) resulted from the 4-week grazing frequency [9 640 ± 874 kg dry matter (DM)/ha], in which stem mass was reasonably low (1 270 ± 410 kg DM/ha), but was significantly higher in the 4-week grazing frequency than 1- and 2-week grazing frequencies ($P < 0.01$). Grazing intensity had no significant effect except on the average stem mass of individual plants where the hard-lax intensity gave a lower stem mass ($P < 0.01$). There were no interactions between grazing frequency and intensity in herbage mass. Plant density declined by 35% over the growing season with the decline unaffected by grazing intensity or frequency during the season. Grazing in late autumn resulted in approximately 27% less plants in the following spring. It was concluded that grazing management through the growing season cannot be used to improve persistence without compromising leaf growth rate, but that avoidance of grazing in late autumn will improve the persistence of chicory.

Keywords: *Cichorium intybus,* digestibility, grazing frequency, grazing intensity, herbage production, persistence, plant density, Puna chicory

4.2 INTRODUCTION

GRASSLANDS PUNA chicory (*Cichorium intybus* L.) was the world's first forage cultivar of chicory when released commercially in New Zealand in 1985 (Rumball, 1986). Chicory is a summer active crop that is dormant in winter, but responds quickly to warm temperature in spring (Lancashire and Brock, 1983). Chicory produces high yields of palatable feed for deer, sheep and cattle in spring, summer and autumn (Hunt and Hay, 1990; Clark *et al.*, 1990a). Feed quality and yield of chicory in summer is superior to that of traditional perennial ryegrass (*Lolium perenne* L.)/white clover (*Trifolium repens* L.) pastures (Moloney and Milne, 1993; Niezen *et al.*, 1993). Animal performance is better than for ryegrass/white clover pastures (Fraser *et al.*, 1988; Niezen *et al.*, 1993; Hoskin *et al.*, 1995) and similar to that on some pure legume species, such as white clover (Hare *et al.*, 1987; Brown, 1990; Scales, 1993). Daily herbage growth rates of 150 kg dry matter (DM)/ha for chicory are not uncommon over summer (Lancashire, 1978; Hare *et al.*, 1987) and lamb liveweight gain of 290 g/day and calf liveweight gain of 900 g/day have been recorded for pure chicory crops in New Zealand (Hare *et al.*, 1987; Fraser *et al.*, 1988). Chicory is regarded as being best suited to rotational grazing systems (Lancashire and Brock, 1983; Hare *et al.*, 1987; Moloney and Milne, 1993).

Chicory has been reported to be capable of averaging 15-18 t DM/ha, and up to 25 t DM/ha, annually in most regions in New Zealand (Lancashire, 1978; Hare *et al.*, 1987; Matthews *et al.*, 1990), but in most cases the total yields were obtained with little control of stem growth, and as a consequence a high proportion of the yields consisted of reproductive stems. Chicory can be up to 90% stem mass and is not a crop that is suited to the accumulation of large quantities of herbage to overcome feed shortages (Matthews *et al.*, 1990), as careful grazing management is needed to control its reproductive stems. Leaf mass rather than total herbage mass is of importance to animals because of its higher palatability and digestibility and better accessibility.

A number of experiments have been carried out on the grazing management of chicory in which the key issue was to maximise leaf growth and minimise stem development (Hare *et al.*, 1987; Clark *et al.*, 1990b; Komolong *et al.*, 1992; Li *et al.*, 1994; Moloney and Milne, 1993; Hume *et al.*, 1995). Hare *et al.* (1987) and Clark *et al.* (1990b) suggested that rotational grazing to 30-50 mm above ground level at 4-5 week intervals appeared to be the best management to achieve the desirable proportion of leaf and stem (70% leaf and 30% stem), whereas Moloney and Milne (1993) suggested that two hard grazings to ground level, 20-26 days apart in spring, were required to control primary stem growth in chicory. Although Moloney and Milne (1993) suggested their management would result in the desirable leaf to stem ratio of 70%:30% (Clark *et al.*, 1990a), they provided no herbage components data, nor did they monitor plant density. Therefore, grazing management that best achieves the desired proportion of leaf in the grazed crop without unnecessarily suppressing growth rate requires further clarification. Also, better understanding of the morphological response of chicory plants to grazing would assist in the development of grazing strategies.

The persistence of chicory has been observed to vary but the dynamics of the plant population under grazing are not fully understood (Lancashire and Brock, 1983; Li *et al.*, 1994; Hume *et al.*, 1995). As the persistence of a forage crop is a major determinant of its profitability any grazing management that lessens the persistence of chicory needs to be identified. Therefore, the objectives of the research were to determine the effect throughout the growing season of grazing intensity and grazing frequency on the herbage production and persistence of chicory on both an area and individual plant basis.

4.3 MATERIALS AND METHODS

Three experiments were undertaken at the Pasture and Crop Research Unit, Massey University, Palmerston North, New Zealand (latitude 40°23'S) from November 1994 to November 1995. The soil type was a deep Manawatu silt loam (Hewitt, 1992), fuventic haplumbrept in US soil taxonomy, with pH 5.8 and Olsen P 22 µg/g. The climate in this area is warm-temperate (Table 4-1), with an annual rainfall of 995 mm and mean soil temperature at 100 mm of 12.8°C (10 year mean).

All three experiments used a stand of chicory that had been sown into a cultivated field at 5 kg/ha on 12 May 1994. Nitrogen, as urea, was applied at 37 and 46 kg N/ha in July and September 1994, respectively. Basagran® at 3.0 l/ha (480 g/l bentazone in the form of a soluble concentrate) was applied to kill annual broadleaf weeds on 1 October 1994. On 7 October 1994 the experimental field was mown to 50 mm, followed by 2 days grazing, to remove the weed stems and improve the uniformity of the chicory.

4.3.1 Expt 1: Grazing trial

The experiment was a 2 × 3 factorial combination of treatments in a randomised complete block design with four replicates. There were two grazing intensities, hard-lax grazing and lax grazing, and three grazing frequencies (1-, 2- or 4-week intervals). Hard-lax grazing was defined as grazing to stem stubble of 50-100 mm until mid January, and thereafter lax grazing to stem stubble of 100-150 mm. Lax grazing was defined as grazing to stem stubble of 100-150 mm at each grazing.

Table 4-1 Monthly rainfall and soil temperature at 100 mm during the growth period for Puna chicory and the 10-year mean.

	Rainfall (mm)		Soil temperature (°C)	
	1994-95	10-year mean	1994-95	10-year mean
November	183	78	14.2	15.1
December	21	94	17.2	17.3
January	72	79	17.4	18.5
February	65	67	18.9	18.1
March	107	69	16.6	16.3
April	111	81	15.4	13.2
May	77	89	11.2	10.1

Plots (300 m^2) were grazed with 15-20 mature aged Romney ewes, equivalent to 500-600 sheep/ha. Grazing intensities were achieved by adjusting grazing time (1-2 days). Once the desirable stem stubble height was reached, the sheep were moved out of the plot. The experiment started on 21 November 1994 and finished on 10 April 1995.

4.3.1.1 Herbage mass, yield components and quality

Pre- and post-grazing herbage mass were measured by cutting to ground level with an electric shearing handpiece in a 500 × 500 mm quadrat in four places in each plot. Botanical samples were taken by cutting a 50 × 500 mm strip beside each quadrat for yield component dissection. Herbage mass samples were washed and then oven-dried at 80°C for dry mass; botanical samples were dissected into leaf, stem, weeds and dead material (including dead mass from leaf, stem and weeds) and also oven-dried. In order to make valid comparison among grazing frequencies, the pre- and post-grazing herbage mass of 1- and 2-week interval treatments were added to 4-week basis before further statistical analysis.

Fresh leaf and stem samples of all treatments were taken from pre-grazing pasture in mid-January for *in vitro* digestibility and nitrogen analysis. Samples were freeze-dried and ground to pass a 1-mm sieve. Total nitrogen concentration was determined using the Kjeldahl method and *in vitro* digestibility was determined using the enzymatic hydrolysis method of Roughan and Holland (1977). However, data presented in Table 4-3 were averaged over all treatments because of no significant difference among treatments.

4.3.1.2 Plant morphology, density and size

Ten plants were dug from each plot every four weeks before grazing. The plants were separated into three categories: primary, secondary and axillary shoots. Within each category the shoots were dissected into leaf, stem and dead material (i.e. dead leaves and stems combined). The initial shoot coming from the crown was defined as 'primary shoot', lateral shoots coming from the crown were defined as 'secondary shoots', and all the shoots coming from axils of primary and secondary shoots above ground were defined as 'axillary shoots'. Dry mass of leaf, stem and dead material in each category was measured.

Shoot density (shoots m^{-2}) and plant size (shoots/plant) were counted every four weeks and plant density was derived by dividing shoot density by plant size. A 500 × 500 mm quadrat was used to count shoot density at four locations in each plot, and plant size was measured by digging out ten whole plants in each plot.

4.3.1.3 Statistical analysis

All data were analysed by using the SAS GLM procedure (SAS Institute, 1990). Accumulated herbage mass and herbage residue data were analysed by using the model for a 2 × 3 factorial combination of treatments in a randomised complete block design. Herbage accumulation rate, plant density and plant size data over the season were analysed by using the model of repeated measures.

4.3.2 Expt 2: Plant survival

Before Expt 1 began, a corner (4.5 m^2) was protected from grazing in each of the four plots of the hard-lax grazing at 2-week interval treatment. Thirty plants were randomly marked in each of these plots in the protected and the grazed areas, using a transect technique (Bircham and Hodgson, 1983), with ten plants in each 2 m transect. All marked plants were monitored once a month and the number of surviving plants recorded.

Data were analysed by the SAS GLM procedure using the model of repeated measures (SAS Institute, 1990).

4.3.3 Expt 3: Effects of autumn grazing on plant persistence

After the final grazing of chicory in Expt 1 in autumn 1995 (10 April), all fences were removed and the field was re-divided into two treatments with approximately equal plant densities. One treatment was left ungrazed until spring whereas the other treatment was grazed on 10 and 23 May 1995 to 50 mm stem stubble. In the following spring (late September), both treatments were grazed to 50-100 mm above ground at 3-week intervals by Romney ewes. Plant density, shoots per plant and the diameter of the top of the taproot were monitored on 20 September and 29 November 1995.

Data were analysed by the SAS GLM procedure using the model for two treatments in a completely randomised design (SAS Institute, 1990).

4.4 RESULTS

4.4.1 Herbage production

4.4.1.1 Leaf and stem residues

There were significant differences between grazing intensities in stem residues throughout the season ($P < 0.05$), and in leaf residues until mid-February ($P < 0.05$). Stem residues increased dramatically in both treatments over the course of the experiment, while leaf residues varied considerably less with season (Figure 4-1). These results reflected the efficacy of the grazing treatments.

4.4.1.2 Accumulated herbage mass and quality

There were significant differences between grazing frequencies in both leaf ($P < 0.01$) and stem mass ($P < 0.05$) accumulated for the 20 weeks of the experiment (Table 4-2), the 4-week interval accumulating the highest leaf and stem mass, and the 1-week interval the lowest. There were no significant differences between grazing intensities in either leaf (mean 6 510 kg DM/ha) or stem mass (460 kg DM/ha). There were no significant interactions ($P > 0.05$) between grazing intensity and frequency.

Accumulation rates of leaf were higher than those of stem throughout the experiment, but generally declined in both cases with time (Figure 4-2).

Chicory leaf had substantially higher *in vitro* digestibility and nitrogen content and lower organic matter than stem (Table 4-3).

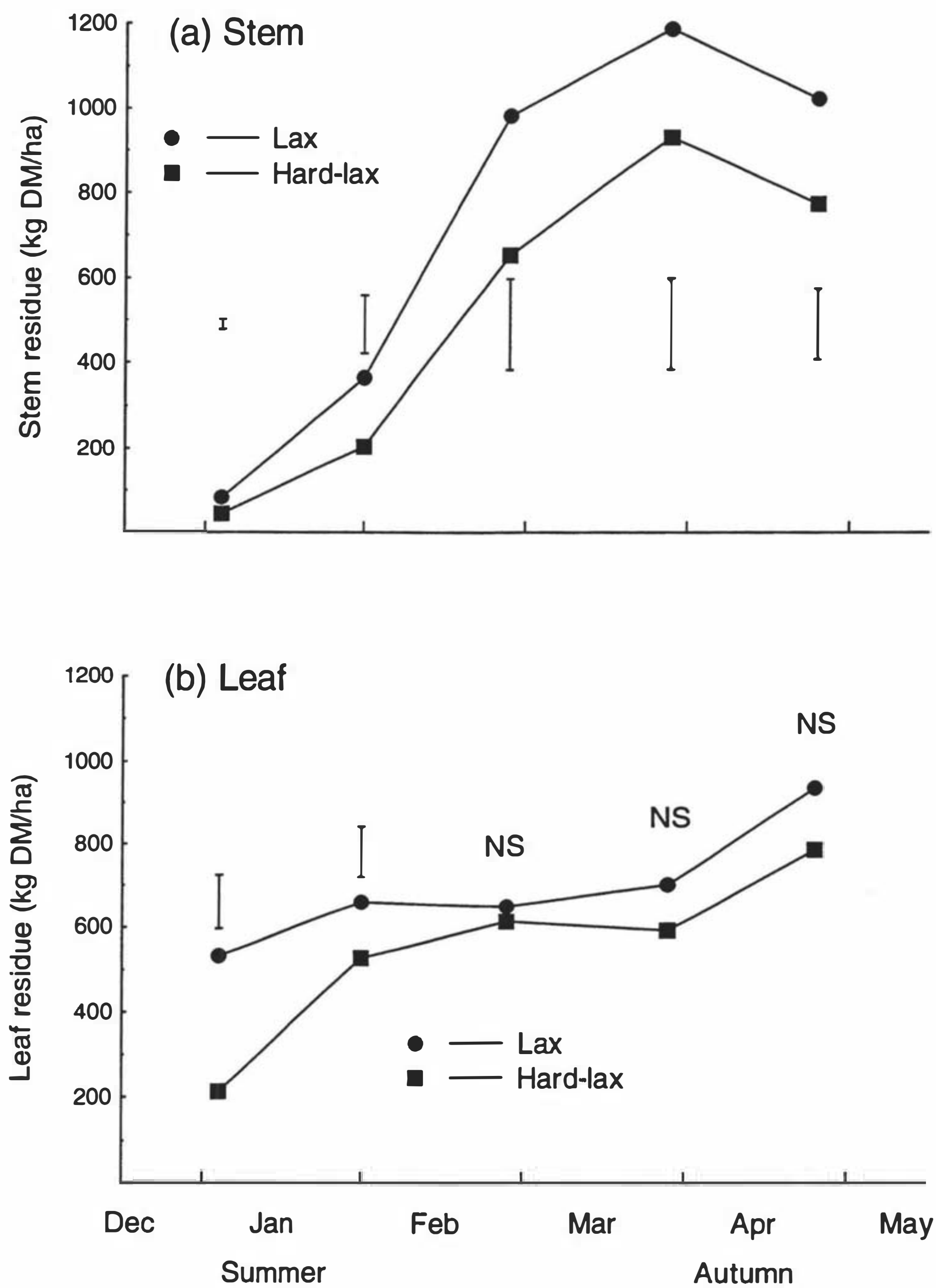

Figure 4-1 Stem and leaf residues after hard-lax and lax grazing every four weeks over the season. Vertical bars represent $LSD_{0.05}$; NS, not significant.

Table 4-2 Effect of grazing management on accumulated herbage mass (kg DM/ha) over 20 weeks from 21 November 1994 to 9 April 1995

Treatments	Leaf	Stem	Total
Grazing intensity			
hard-lax	6770	560	7330
lax	6240	350	6590
s.e.m.	373	286	379
significance	NS	NS	NS
Grazing frequency			
1 week	4850	10	4860
2 weeks	6290	90	6380
4 weeks	8370	1270	9640
s.e.m.	456	350	464
significance	**	*	**

NS, not significant; * $P<0.05$; ** $P<0.01$

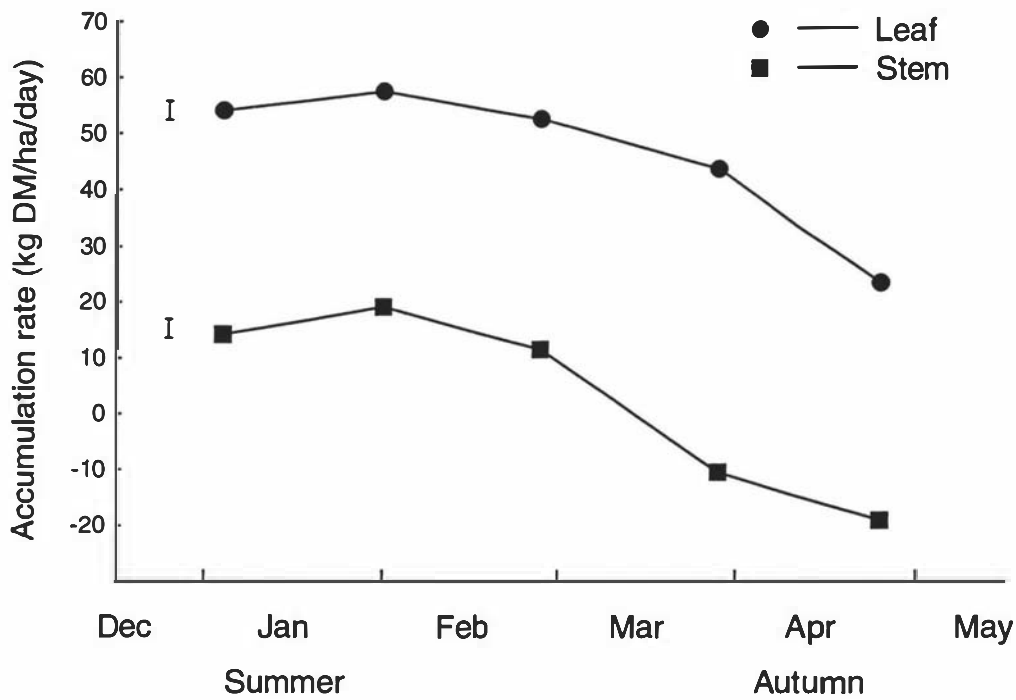

Figure 4-2 Leaf and stem accumulation rates of chicory every four weeks over the season. Vertical bars represent s.e.m.

Table 4-3 Organic matter, nitrogen, digestibility and ash content of chicory, sampled in mid-January 1995. OM, organic matter; N, nitrogen; DMD, dry matter digestibility; OMD, organic matter digestibility; DOMD, digestible organic matter in dry matter; ash, ashes in dry matter

Measurement	Leaf	Stem	s.e.m.	significance
OM (g/kg)	865.6	894.1	3.03	**
N (g/kg)	39.7	15.2	1.44	**
DMD (g/kg)	903.4	669.1	12.92	**
OMD (g/kg)	926.6	679.7	13.14	**
DOMD (g/kg)	789.2	597.3	10.50	**
Ash (g/kg)	147.4	116.5	3.32	**

** $P<0.01$

4.4.2 Individual plant mass distribution

4.4.2.1 Treatment effects

Grazing intensity had no effect on average leaf mass over the season, but affected stem mass ($P < 0.01$) and dead material ($P < 0.05$), whereas grazing frequency had significant effects on leaf mass ($P < 0.01$) and stem mass ($P < 0.01$) but not dead material, as determined from ten pre-grazed plants dug every four weeks. There were no interactions ($P > 0.05$) between grazing intensity and grazing frequency (Table 4-4).

4.4.2.2 Allocation of shoot mass

Leaf of the primary shoot decreased sharply in the first two periods and remained less than 0.1 g DM/plant after mid-January. In the meantime, secondary and axillary shoot grew quickly. Leaf from secondary shoot was the major contributor to leaf mass after mid-December. The components of leaf mass changed from 100% primary leaf in late November to 83% secondary leaf in mid-April. Primary stem remained relatively low in mass, and was less than 0.37 g DM/plant over the season. Secondary and axillary stem contributed more to total stem mass after primary stem was controlled by grazing. By 13 February, chicory produced more axillary stem mass than secondary stem mass, and this continued until the end of the experiment. Dead material increased gradually from 21 November and reached a peak, 1.14 g DM/plant, on 10 April. Most dead material was leaves and stems of secondary shoots (Figure 4-3).

Table 4-4 Mean dry mass of individual plants (g DM/plant) over the season under different treatments

reatments	Leaf	Stem	Total	Dead
Grazing intensity				
hard-lax	1.72	0.79	2.51	0.43
lax	1.67	1.19	2.86	0.56
s.e.m.	0.074	0.070	0.126	0.029
significance	NS	**	NS	*
Grazing frequency				
1 week	1.17	0.75	1.92	0.43
2 weeks	1.45	0.83	2.28	0.49
4 weeks	2.47	1.39	3.86	0.56
s.e.m.	0.091	0.086	0.154	0.036
significance	**	**	**	NS

NS, not significant; * $P<0.05$; ** $P<0.01$

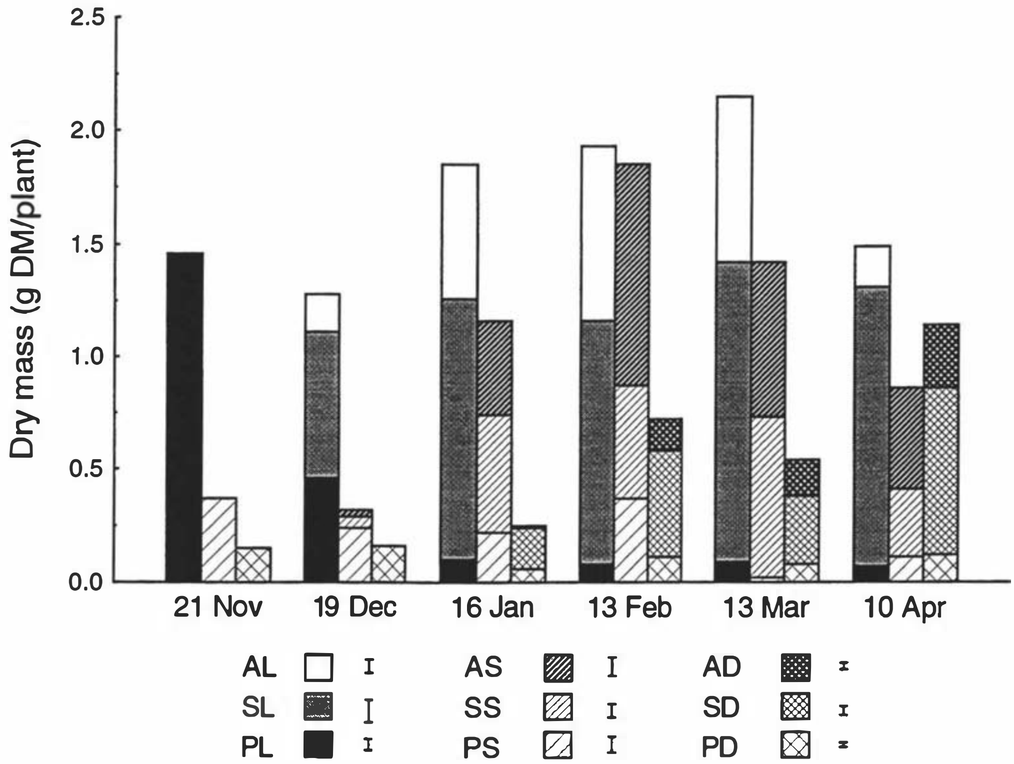

Figure 4-3 Allocation of shoot mass to primary, secondary and axillary leaf, stem and dead material of chicory every four weeks over the season. Means of all grazing treatments. AL, axillary leaf; SL, secondary leaf; PL, primary leaf; AS, axillary stem; SS, secondary stem; PS, primary stem; AD, axillary dead; SD, secondary dead; PD, primary dead. Vertical bars represent overall s.e.m.

4.4.3 Plant persistence

4.4.3.1 Expt 1

There were no significant differences in plant density between grazing intensities, or grazing frequencies nor were interactions between grazing intensity and grazing frequency significant. However, the plant density meaned over all treatments decreased 35% over the course of the experiment with the decrease starting with the onset of grazing and ending in mid February (Figure 4-4). In contrast, shoot numbers per plant tripled between late November 1994 and mid-January 1995 and then remained constant afterwards. The increase in plant density in early autumn was because of the emergence of buried shoots from severely grazed plants during the dry summer with the onset of rain.

4.4.3.2 Expt 2

None of the plants marked in the ungrazed treatments died, but 10% of plants marked in the hard-lax treatment with 2-week grazing intervals died during the season. The greatest death of plants in the grazed treatment was noted in mid December.

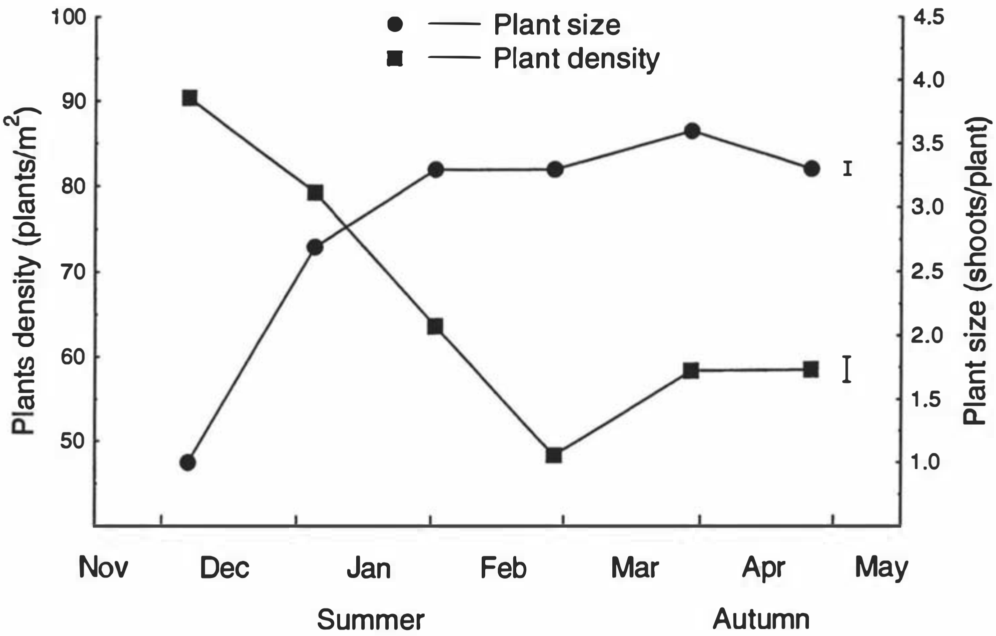

Figure 4-4 Plant density and plant size of chicory every four weeks over the season. Vertical bars represent s.e.m.

4.4.3.3 Expt 3

Late autumn grazing had a significant effect on subsequent plant density but no effects on plant size and taproot diameter (Table 4-5). There were 27% more plants in the late autumn ungrazed treatment than the late autumn grazed treatment in September and November. However, plant densities in both treatments decreased by similar amounts (mean 18%) from September to November.

4.5 DISCUSSION

4.5.1 Herbage production and quality

Although the accumulated herbage mass was lower than a two year old chicory crop (Li *et al.*, 1994), leaf yield was higher in the current experiment. The 93% leaf in the crop was also higher than the ratio of leaf and stem (70%:30%) proposed as desirable by Clark *et al.* (1990a). Stem development was controlled in all grazing treatments, even the 4-week interval treatment, as evidenced by consistently greater accumulation rate for leaf than stem. The greatest total herbage mass of chicory with reasonably low stem yields was obtained in the hard-lax grazing at 4-week interval treatment.

Table 4-5 Effects of late autumn grazing on plant density, plant size and taproot diameter of chicory plants

Treatment	Plant density (plant/m^2)	Plant size (shoots/plant)	Taproot diameter (mm)
		20 September	
Grazed in autumn	55	4.1	14
Ungrazed in autumn	74	3.2	15
s.e.m.	4.6	0.48	1.5
significance	**	NS	NS
		29 November	
Grazed in autumn	44	3.4	16
Ungrazed in autumn	61	3.9	15
s.e.m.	3.9	0.55	1.1
significance	**	NS	NS

NS, not significant; ** $P<0.01$

Negative stem accumulation rate and high percentage of dead material during autumn reflected the high senescence rate of stem, which indicated that mechanical topping in autumn was unnecessary even though the stem residues were high. There was no evidence to show that the inedible stem stubble remaining in the field would be detrimental to stand longevity as suggested by Clark *et al.* (1990a). Chicory seed crops, which consist of a high proportion of stems, have been observed to have greater longevity than grazed chicory (J. G. Hampton, personal communication).

Chicory leaf had a better quality than stem due to its higher digestibility and nitrogen content. The low concentration of condensed tannin (0.42% DM in total herbage) found by Terrill *et al.* (1992) should improve the efficiency of protein degradation (Niezen *et al.*, 1993). High ash content confirmed that chicory is rich in many macro and micro elements (Crush and Evans, 1990), including zinc which is prophylactic for facial eczema (Munday *et al.*, 1986).

4.5.2 Individual plant performance

The detailed study of individual plants showed that grazing intensity had no effect on average leaf mass of individual plants but had a significant effect on stem mass. The lax grazing left more stem residue than hard-lax grazing and the greater stem residue in turn resulted in more stem growth at the next grazing. Grazing frequency, however, had significant effects on average leaf mass and stem mass of individual plants; more frequent grazing resulted in smaller plants. The mass of the individual plants in the 1-week interval treatment was half that of the plants in the 4-week interval treatment. Smaller plants are possibly more susceptible to death after grazing. Leach and Ratcliff (1979) found that lucerne (*Medicago sativa* L.) plants decreased in size prior to their death, with plants that eventually died notably smaller than those that survived. Similarly, Gramshaw *et al.* (1993) reported that increasing cutting frequency from a 5-week interval to 3-week interval substantially depleted root reserves of lucerne.

Primary shoots were successfully controlled by grazing as evidenced by primary leaf and stem mass contributing only 5.4% and 19% to total leaf and stem mass, respectively, after the first eight weeks grazing. Release from apical control of the primary shoot encouraged secondary and axillary shoot development, resulting in high accumulation rates of secondary leaf and stem throughout summer and high accumulation rate of axillary stem in autumn. These results confirmed the conclusions of Li *et al.* (1994) that grazing management can control the primary stem growth but not secondary and axillary stem growth. Moloney and Milne (1993) reported that secondary stem produced in autumn was not seen as limiting either quality or grazing control because of the fine structure of these stems. However, field observation in the current experiment showed that animals largely ignored the secondary and axillary stem except for the flower buds which have high DM digestibility (81%, Clark *et al.*, 1990a). Therefore, control of secondary and axillary stems is still a problem in practice which needs further study. Mowing in summer time would be an option if a high proportion of leaf mass was required.

4.5.3 Plant persistence

All grazing managements regardless of treatments decreased plant density, in agreement with the findings in lucerne that even when soil moisture conditions are suitable and management is conservative, lucerne density declines markedly with time (Lodge, 1991). In contrast, all chicory plants in the ungrazed treatment in Expt 2 survived over the growing season. However, grazing intensity and grazing frequency had no effect on plant density, supporting the results of Li *et al.* (1994) and Hume *et al.* (1995). In Expt 1 the plant density decreased 35% over the season with most of the decrease during late spring and early summer. Expt 2 confirmed that there is a large decrease in late spring and early summer. Similar decreases were observed for two and four year old chicory crops (Li *et al.*, 1994). On the other hand, plant size, in terms of shoot number per plant, tripled over the season, especially during late spring and early summer, which compensated for the decrease in plant density. A similar phenomenon has been observed in many forage species that grow from a tap-rooted crown, for example, lucerne, red clover (*Trifolium pratense* L.), and Sulla (*Hedysarum coronarium* L.) (Chloupek, 1976; Smith *et al.*, 1992; Krishna, 1993).

Chicory was very sensitive to late autumn grazing, in terms of plant density. Avoidance of late autumn grazing would appear to be an important management practice to improve the persistence of chicory. Late autumn grazing, especially hard grazing, presumably depletes carbohydrate reserves (polyfructosan inulin in chicory) at a time of the year when the chicory is unable to grow sufficient leaves to replenish stored carbohydrate (Chubey and Dorrell, 1978). Smith (1972) also found that defoliation of lucerne in autumn reduces the level of root carbohydrate reserves in the plant, the level of winter hardiness and survival, and the number of crown buds available for growth in spring. The death of chicory plants through winter and particularly when grazing re-commenced in spring is a similar pattern to that observed when lucerne is over-grazed in autumn (Smallfield, 1982).

Plant death under grazing management was closely related to the grazing behaviour of animals although grazing intensity and grazing frequency had no effects on plant density in the current research. Sheep, used as grazing animals in the current experiment, graze less evenly than cattle (Clark *et al.*, 1990a). Field observation showed that sheep grazed some plants to crown level and left others to develop flowering stems. Furthermore, during the next grazing, sheep were more likely to graze the younger shoot generated from the crown, while the chicory plants with old stems were again ignored and became older and tougher. Over-grazed plants have to use reserve carbohydrate in the root system for new growth. Plants depleted of reserve carbohydrate, especially small plants, will die of starvation eventually. Chloupek (1976) found that the size of root systems of red clover usually decreased after cutting, and plants depleted of carbohydrate died of starvation (Kendall, 1958). Some marked plants in the ungrazed treatment in Expt 2 were very small and still in the vegetative state when the experiment finished, although they all survived the season. A glasshouse experiment showed that 73% of chicory plants died after 3 severe cuttings at 3 week intervals (all the visible shoots above ground removed) and the root systems of surviving plants were very small, whereas only 4% of plants died under lax cutting (100 mm above ground) with the same time interval (G. D. Li, unpublished data).

Treading damage, especially when the soil is wet, might be another cause of plant death in chicory. Jones and Haggar (1994) found newly sown chicory was severely damaged by treading. Treading would damage the new buds on the crown and the crown itself with the resultant damaged crown more susceptible to diseases. Only isolated plants in the current experiment were observed to be infected with *Fusarium* sp.

In conclusion, hard-lax grazing at 4-week intervals can be recommended as it provided high quantities of herbage mass with high animal feed quality in terms of high leaf to stem ratio and high digestibility. Primary stems were controlled by grazing down to 50 mm, while control of secondary and axillary stems needs further study. Initially, leaf mass consisted mainly of primary leaves on primary stems, but after primary stems were controlled, leaves on the secondary and axillary stems were the major contributors to leaf mass. Grazing killed plants regardless of grazing intensity and grazing frequency. Plant death under grazing management was coincident with the onset of grazing in spring. Despite no plant death with no grazing, grazing management was the only way to maximise leaf mass. Late autumn grazing detrimentally affected future plant density and is not recommended.

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5. HERBAGE PRODUCTION AND PERSISTENCE OF PUNA CHICORY (*Cichorium intybus* L.) UNDER GRAZING MANAGEMENT OVER FOUR YEARS†

† This chapter has been published in *New Zealand Journal of Agricultural Research* **40**, 51-56 (Li *et al*., 1997).

5.1 ABSTRACT

Three grazing experiments were conducted at the Pasture and Crop Research Unit (PCRU) and Deer Research Unit (DRU), Massey University, Palmerston North, New Zealand, from November 1993 to January 1996. Expts 1 and 3 examined effects of grazing frequency and grazing intensity on the herbage production and persistence on year 1 and year 4 chicory stands, respectively. In Expt 2, the plant density and plant size (shoots/plant) were monitored over 3 years starting from the second growing season. Results showed that year 1 and year 2 chicory accumulated 8460 ± 668 and 9360 ± 640 kg DM/ha over 6 months, which was double that of year 4 chicory (4590 ± 343 kg DM/ha). The average plant densities for year 1 and year 2 chicory were 66 ± 2.1 and 68 ± 4.0 plants/m^2, respectively, significantly higher than those for year 3 and year 4 chicory of 49 ± 0.6 and 24 ± 1.3 plants/m^2, respectively. However, plant size increased from 2.9 ± 0.04 and 2.7 ± 0.15 shoots/plant for the first two years to 4.1 ± 0.15 and 6.7 ± 0.21 shoots/plant in year 3 and year 4, respectively. It was concluded that the characteristics of a grazed chicory crop that had deteriorated to the point of not being able to produce half of its maximum herbage mass were 25 plants/m^2, six or more shoots/plant, or less than 150 shoots/m^2. The implications for chicory grazing management are also discussed.

Keywords: *Cichorium intybus* L., grazing management, herbage production, plant density, plant population, plant size, Puna chicory

5.2 INTRODUCTION

GRASSLANDS PUNA chicory (*Cichorium intybus* L.) with its high vegetative growth rate (Lancashire, 1978; Hare *et al.*, 1987), feed value (Clark *et al.*, 1990b; Hoskin *et al.*, 1995; Li *et al.*, 1997) and animal performance (Fraser *et al.*, 1988; Niezen *et al.*, 1993; Hopkins *et al.*, 1995) during late spring and summer has been widely adopted by farmers in New Zealand. Its growth pattern supports high animal feed requirements in summer, whereas conventional perennial ryegrass/white clover pasture often has low growth rates and is of poor quality in summer (Niezen *et al.*, 1993).

Persistence is a key factor that influences farmers' acceptance of perennial forages. Hume *et al.* (1995) reported that chicory dominated the swards in mixed pastures during the first three years, but its yield declined by year 4 and it made no significant contribution to the total yield by year 6. Li *et al.* (1997) found that a pure chicory stand lost about 35% of its population during its first growing season with the largest decline in late spring and summer. A similar seasonal pattern of plant population decline was observed in a pure chicory stand in its fourth growing season (Li *et al.*, 1994). There has been insufficient information published to define the plant population characteristics of stable yielding and deteriorating chicory crops. Three field experiments were examined with the objective of providing this information.

5.3 MATERIALS AND METHODS

5.3.1 Experimental sites

Three grazing experiments were conducted at the Pasture and Crop Research Unit (PCRU) and Deer Research Unit (DRU), Massey University, Palmerston North, New Zealand from November 1993 to January 1996. All chicory crops were initially sown as pure stands at the rate of 5 kg/ha on fully cultivated fields. White clover was a volunteer species after the first growing season. The basic information on all experiments is summarised in Table 5-1. Details of the design of each experiment and information on factors like soil type, fertility level and fertiliser application in each site are given in Li *et al.* (1994; 1997).

Chicory was in its first growing season in Expt 1 (year 1 chicory); and in its second and third growing seasons in Expt 2, but herbage mass data were collected only in the second growing season (year 2 chicory). Chicory in Expt 3 was in its fourth growing season (year 4 chicory).

Table 5-1 Time of sowing and period of monitoring for all experiments.

	site	date sown	measurement period	herbage mass	plant density and plant size
Expt 1	PCRU	May 94	Nov 94-May 95	year 1	year 1
			May 95-Jan 96	-	year 1-year 2
Expt 2	DRU	Oct 92	Oct 93-May 94	year 2	year 2
			Jun 94-Jan 96	-	year 2-year 4
Expt 3	PCRU	Oct 89	Nov 93-May 94	year 4	year 4

5.3.2 Experimental design and grazing management

5.3.2.1 Expt 1: PCRU

Grazing was by mature aged Romney ewes. The grazing began in November 1994 and finished in May 1995 on Frewen section of PCRU. During each grazing, ewes were put in each plot, a stocking density equivalent to 500-600 sheep/ha, for 1-2 days. Two grazing intensities (hard-lax, lax) and three grazing frequencies (1-, 2- 4-week intervals) were applied in this 2 × 3 factorial experiment with four blocks. The treatment effects are not presented here (see Li *et al.*, 1997).

5.3.2.2 Expt 2: DRU

Red deer and hybrid (0.25 elk : 0.75 red) deer were rotationally grazed on eight 0.5 ha plots from early October to mid May each year on Moginie section of DRU (Kusmartono, 1996). The grazing intensity used was medium, 100-150 mm stem stubble, with about 5 week intervals between grazings before January and 7.5 week intervals thereafter. The grazing period in each plot was 3-5 days. In early February all plots were mowed to 80-100 mm to remove old stem stubble.

5.3.2.3 Expt 3: PCRU

The grazing period was from November 1993 to May 1994. The grazing animals were mature aged Romney ewes on Moginie section of PCRU. High numbers of sheep, equivalent to 500-600/ha, were grazed in each plot for 1-2 days each grazing. A Latin square design with four grazing intensities was used. The grazing frequency was 3 weeks before January and 5 weeks afterwards. Further details of experimental design and results of treatment effects were reported in Li *et al.* (1994). Mechanical topping at the desired treatment heights of 20, 70, 120 and 170 mm, was used to remove old stem stubble and *Rumex* spp. in mid January.

5.3.3 Measurements

Pre- and post-grazed herbage masses were measured by cutting to ground level using 500 × 500 mm quadrats in Expts 1 and 3, four replicates randomly located in each plot each time. Yield component data were obtained by taking botanical subsamples. In Expt 2, leaf and stem masses were measured on an individual plant basis. Twenty plants inside and outside of an enclosure cage were dug out after each grazing in each plot as pre- and post-grazed plants. All plants were dissected into leaves and stems in a laboratory, then oven-dried at 80°C for 48 hours.

Shoot density was counted by using a 500 × 500 mm quadrat in all experiments, four replicates in each plot in Expts 1 and 3, 20 replicates in each plot in Expt 2, all randomly placed each time. Plant sizes were measured by digging 10 plants from each plot in Expts 1 and 3, and 20 plants from each plot in Expt 2. Plant density was derived from shoot density divided by plant size.

5.3.4 Statistical analysis

All data presented in this paper were averaged over all treatment effects in each experiment and were analysed by the SAS GLM procedure (SAS Institute, 1990). Annual accumulated herbage mass, overall plant density and plant size, shoot density and shoot size among experiments were compared using a model for an unbalanced completely randomised design. Monthly accumulated leaf and stem masses in each year were analysed by using a model for a balanced completely randomised design. The relationships between plant density and plant age (month unit), plant size and plant age (month unit), and plant size and plant density were analysed using a linear regression model. The plant density and plant size data of year 1 chicory were not included due to the large variation associated with establishing plants.

5.4 RESULTS

5.4.1 Climate conditions during the experimental period

November was very wet, especially in 1994-95. Summer in 1993-94 was particularly dry, whereas rainfall in the 1994-95 summer was average, except December 1994 in which rainfall was only 22% of the 10-year mean. Soil temperatures for both years were similar to each other and to the 10-year mean (Table 5-2).

Table 5-2 Monthly rainfall and soil temperature at 100 mm during the growth period for chicory and the 10-year mean.

	rainfall (mm)			soil temperature (°C)		
	1993-94	1994-95	10-year mean	1993-94	1994-95	10-year mean
October	57	70	88	12.7	11.5	12.5
November	114	183	78	13.6	14.2	15.1
December	62	21	94	16.6	17.2	17.3
January	26	72	79	18.4	17.4	18.5
February	13	65	67	19.0	18.9	18.1
March	62	107	69	14.8	16.6	16.3
April	41	111	81	13.0	15.4	13.2
May	98	77	89	11.1	11.2	10.1

5.4.2 Accumulated herbage mass

The greatest herbage mass of chicory accumulated during late spring and summer (Figure 5-1) in these experiments. Year 1 and year 2 chicory had higher leaf mass accumulations than year 4 chicory during this period, but year 2 chicory had higher stem mass accumulation because of less frequent grazing. Leaf mass accumulation in autumn was similar for chicory of all ages. The decrease in stem mass accumulation after January in year 2 and year 4 chicory was due to mowing. In contrast, the negative change in stem mass accumulation from February onwards in year 1 chicory was because of its senescence.

Overall, the leaf mass accumulation over six months from November to April was higher in year 1 and year 2 chicory than in year 4 chicory ($P < 0.05$), whereas year 2 chicory accumulated the highest stem mass. The total accumulated herbage mass was significantly greater for year 1 and year 2 than for year 4 chicory ($P < 0.05$, Table 5-3).

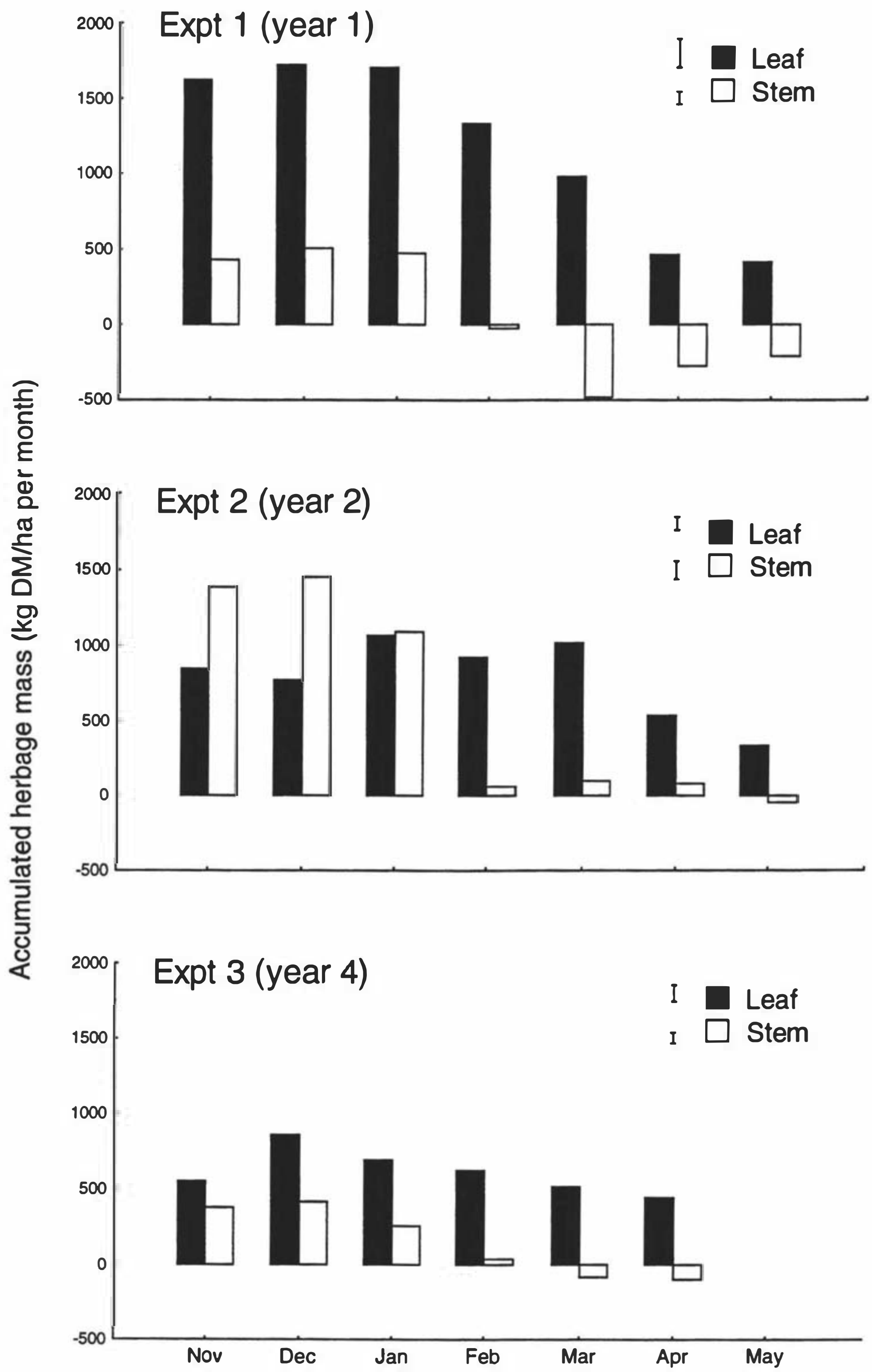

Figure 5-1 Leaf and stem mass accumulation for chicory each month. Vertical bars represent s.e.m.

Table 5-3 Accumulated herbage mass (mean ± SE, kg DM/ha) over six months from November to April on each site.

	Expt 1 (year 1) (n = 24)	Expt 2 (year 2) (n = 20)	Expt 3 (year 4) (n = 16)	$LSD_{0.05}$
leaf	7830 ± 477	5180 ± 249	3670 ± 299	1110
stem	630 ± 307	4170 ± 470	920 ± 206	1028
total	8460 ± 668	9360 ± 640	4590 ± 343	1764

5.4.3 Plant density and plant size

The average plant densities for year 1 and year 2 chicory were significantly higher than those for year 3 and year 4 chicory ($P < 0.05$, Table 5-4). Plant sizes were greater than double in year 4 compared to those in the first two years (Table 5-4). Plant density decreased with plant age from its second growing season (Figure 5-2a), while plant size increased with plant age from the second growing season (Figure 5-2b). The predicted dates of 50% and 75% losses of original plant population were at the end of the third and fourth growing seasons, 18 June and 6 May, respectively (Figure 5-2a). The seasonal patterns of plant density and plant size of year 1 and year 4 chicory were discussed in Li *et al.* (1994; 1997). Plant size increased as plant density declined (Figure 5-2c). Shoot density remained over 177 shoots/m^2 during the first 3 years, but declined to 157 shoot/m^2 in year 4 despite an increase in plant size as plant density decreased. Furthermore, shoot size in year 4 chicory was significantly smaller than in year 1 and year 2 chicory (Table 5-4).

Table 5-4 Average plant density, plant size, shoot density and shoot size for chicory over 6 months from November to April each year (mean ± SE).

	year 1 (n = 24)	year 2 (n = 20)	year 3 (n = 10)	year 4 (n = 16)	$LSD_{0.05}$
plant density (plants/m^2)	66 ± 2.1	68 ± 4.0	49 ± 0.6	24 ± 1.3	6.4
plant size (shoots/plant)	2.9 ± 0.04	2.7 ± 0.15	4.1 ± 0.15	6.7 ± 0.21	0.36
shoot density (shoots/m^2)	189 ± 5.6	178 ± 8.6	204 ± 8.8	158 ± 6.3	16.7
shoot size (g DM/shoot)	1.7 ± 0.09	1.7 ± 0.11	-	1.1 ± 0.11	0.27

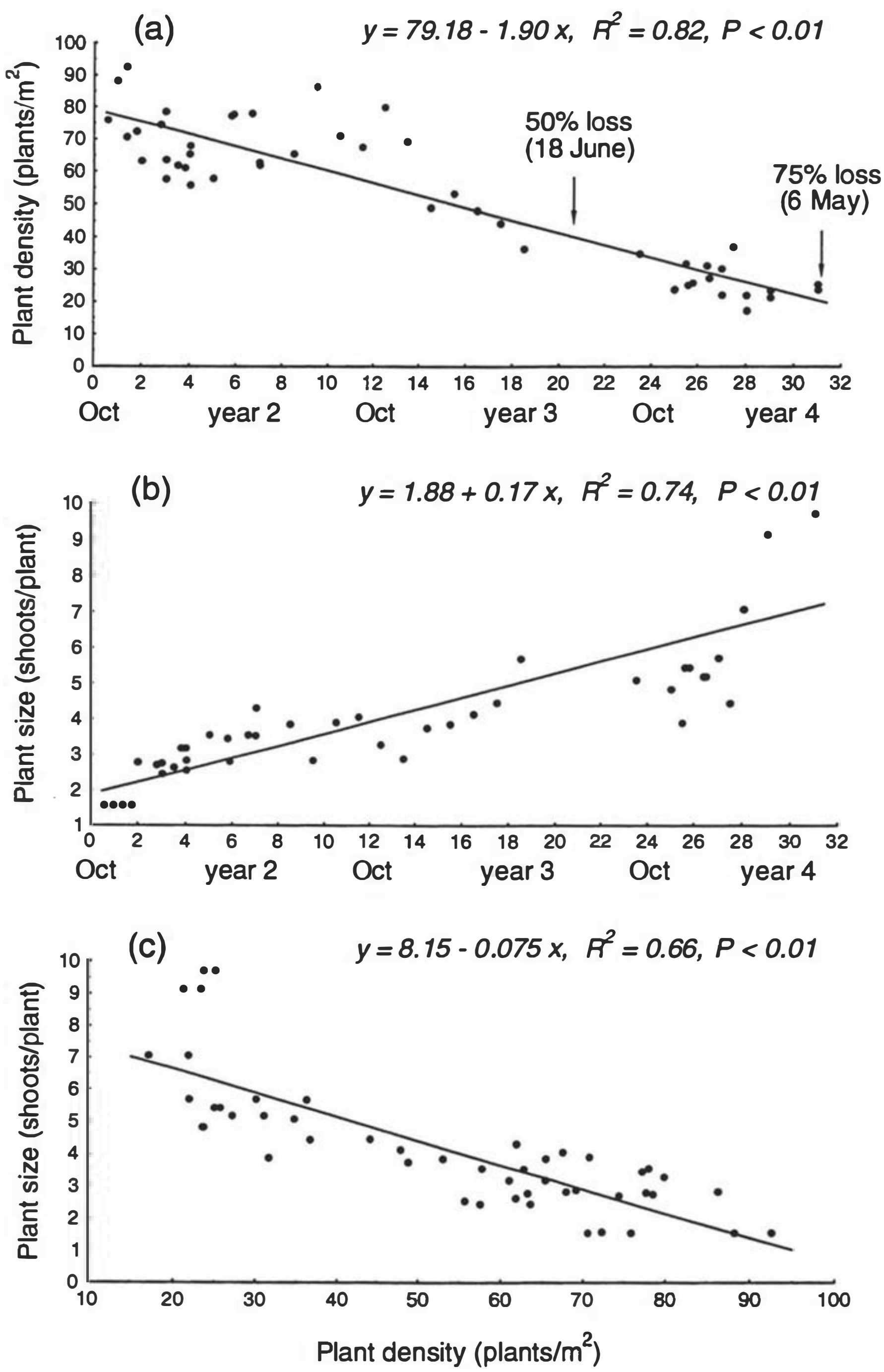

Figure 5-2 Plant density and plant size dynamics for chicory over three years. (a) plant density versus plant age (month unit), arrows show predicted month for 50% and 75% plant losses; (b) plant size versus plant age (month unit); and (c) plant size versus plant density.

5.5 DISCUSSION

The total accumulated herbage mass over 6 months from November to April decreased with increasing stand age. Year 4 chicory accumulated only half of the herbage mass of year 1 and year 2 chicory. Similarly, Hume *et al.* (1995) reported that chicory dominated the swards in mixed pastures during the first 3 years, but its yield was reduced by year 4. Although individual plants produced more shoots as the stand aged, this was not sufficient to compensate for the continual decline in plant density after year 3, hence yield decreased significantly in year 4. A similar pattern of stand deterioration occurs in lucerne and red clover (Singh and Winch, 1974; Bowley *et al.*, 1988). Severe decline in lucerne plant population may occur before significant yield reduction because of compensation between plant density and plant size (Sheaffer *et al.*, 1988), which is common in taproot crops such as lucerne and red clover (Volenec *et al.*, 1987; Bowley *et al.*, 1988; Kephart *et al.*, 1992). Regrowth yield per unit area of lucerne was maintained by compensatory increase in yield per plant even though density has been reported to decline from an initial 50 plants/m^2 to about 30 plants/m^2 over the first 3 years, but subsequent losses of plants led to decreased yields per unit area (Leach, 1979).

The annual herbage mass accumulation of chicory remained stable until the plant density decreased to less than half of the original plant density and then deteriorated. Shoot density remained at 170-200 shoots/m^2 in the first 3 years and declined by year 4 due to the inability of remaining plants to compensate for the decreased plant density. Therefore, a chicory crop that has deteriorated to producing half of its maximum herbage mass is characterised by approximately 25 plants/m^2 or less, six or more shoots/plant, or less than 150 shoots/m^2. In comparison, Tesar and Marble (1988) and Nelson *et al.* (1986, cited by Smith Jr and Bouton, 1993) stated that 40-60 plants/m^2 and 32 plants/m^2, respectively, were required to maintain the maximum yield of pure lucerne stands.

Seedling regeneration within established stands is uncommon in chicory, as it is for lucerne (Lodge, 1991), and so the persistence of chicory in a stand depends mainly on the survival of the original plants. Two unsuccessful oversowing attempts in year 2 and year 3 chicory on the DRU confirmed the difficulty of establishing chicory seedlings in competition with mature plants (Li, unpublished data). Bowley *et al.* (1988) suggested that in both red clover and lucerne stands of high plant density with small plant size would produce more herbage than lower density stands with larger plant size. Results in the current study confirmed that chicory stands of over 50 plants/m^2 with 2-4 shoots/plant yielded more than 25 plants/m^2 with 6-7 shoots/plant. Therefore, maintaining an adequate plant population is a prerequisite for high yields. However, a decrease in plant density under grazing management appears to be inevitable, although avoidance of hard grazing in late autumn lessens the decline in plant density (Li *et al.*, 1997).

For year 1 and year 4 chicory, frequent grazing (average 2.3 weeks and 3 week intervals, respectively, Li *et al.*, 1994; 1997) during late spring and summer controlled the reproductive stems (mainly primary stems). Thus more leaves than stems (78% vs. 22% and 66% vs. 34%) were produced, whereas for year 2 chicory, less frequent grazing (about 5 week intervals) gave poorer control of primary reproductive stems and resulted in greater secondary and axillary stem development. Consequently, more stem mass (59%) than leaf mass (41%) was accumulated in year 2 chicory. Clark *et al.* (1990a) suggested the desirable proportion of leaf and stem under the best management should be 70% leaf and 30% stem. Leaves have a higher *in vitro* digestibility than stems (Clark *et al.*, 1990b; Li *et al.*, 1997). Therefore, in order to get high quality feed, chicory should be grazed frequently enough (less than 4 weeks) to produce a high proportion of leaves, especially in late spring and early summer. However, if optimal grazing control is missed in spring, mechanical topping appears to be the only way to remove old stem stubble and control secondary and axillary stem development in summer.

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6. BIOMASS ALLOCATION, REGROWTH AND ROOT CARBOHYDRATE RESERVES OF CHICORY IN RESPONSE TO DEFOLIATION IN GLASSHOUSE CONDITIONS[†]

[†] This chapter has been accepted for publication in *The Journal of Agricultural Research, Cambridge* (Li *et al*., 1997).

6.1 ABSTRACT

Three glasshouse experiments were conducted between 14 September 1993 and 9 January 1996 at the Plant Growth Unit, Massey University, Palmerston North, New Zealand. Experiment 1 studied the effects of cutting height on the regrowth and biomass allocation of chicory (*Cichorium intybus* L. cv. Grasslands Puna), Expt 2 investigated the biomass allocation and root carbohydrate reserves of three chicory cultivars (Puna, PG90 and Orchies) in response to defoliation, and Expt 3 studied the morphological characteristics and persistence of Puna under extreme defoliation. Cutting height had no significant effect on accumulated secondary leaf and stem masses in Expt 2, but affected secondary leaf mass in Expt 1. However, cutting height significantly reduced root size after two cuttings in both Expts 1 and 2. Three severe cuttings (removing all shoots including visible buds > 5 mm on crown) killed 73% of plants, whereas 96% plants survived under lax cutting (100 mm) in Expt 3. Orchies had the highest total reducing sugar concentration in its taproot (56.6%), whereas PG90 had the lowest (32.1%). Therefore, Orchies was the most persistent but had the slowest growth rate, and PG90 the least persistent with the highest growth rate. The performance of Puna was intermediate. It is concluded that the persistency of Puna would be more sensitive to cutting frequency than cutting intensity due to its medium level of root carbohydrate reserves. In contrast, PG90 could be defoliated frequently, but not closely. However, Orchies with its thick taproot was insensitive to cutting intensity and would also be insensitive to cutting frequency due to its larger root carbohydrate reserves. It is suggested that to improve the persistence and enhance the leaf production of Puna by plant breeding the emphasis should be on increasing taproot size without unduly prejudicing herbage production.

Keywords: Biomass, carbohydrate reserves, defoliation, fructan, persistence, regrowth.

6.2 INTRODUCTION

FORAGE CHICORY (*Cichorium intybus* L.) cultivar Grasslands Puna released in 1985 (Rumball, 1986), has been widely used as a specialist summer feed for animals throughout the world including the UK (Jones, 1990; Jones and Haggar, 1994), Australia (Hopkins *et al.*, 1995), and the USA (Jung *et al.*, 1996) as well as in New Zealand (Clark *et al.*, 1990a; Niezen *et al.*, 1993; Hume *et al.*, 1995). Its productivity (Lancashire and Brock, 1983; Hare *et al.*, 1987), persistence (Hume *et al.*, 1995; Li *et al.*, 1997a, b), feed value (Clark *et al.*, 1990a; Li *et al.*, 1997b) and animal performance (Fraser *et al.*, 1988; Clark *et al.*, 1990a; Niezen *et al.*, 1993; Hoskin *et al.*, 1995) under grazing conditions are well documented.

Chicory is a perennial herb of the family Asteraceae. It is a rosette plant with broad leaves and a long, thick taproot (Rumball, 1986). The cultivar Puna has proven to be a high quality feed capable of producing high liveweight gains in sheep, deer and cattle (Fraser *et al.*, 1988; Clark *et al.*, 1990a; Komolong *et al.*, 1992; Niezen *et al.*, 1993), but it has three main shortcomings. The reproductive stems need to be controlled to enhance leaf mass (Clark *et al.*, 1990b, Li *et al.*, 1997a); the plant is dormant in winter (Rumball, 1986); and it is susceptible to damage from grazing and treading (Jones, 1995; Li *et al.*, 1997a). Grazing (< 150 mm stubble) at 3-4 week intervals effectively controlled the primary stem development in spring, but failed to prevent secondary and axillary stem growth in summer (Moloney and Milne, 1993; Li *et al.*, 1994, 1997a, b), whereas hard grazing (< 50 mm stubble) was detrimental to plant persistence, especially in late autumn (Li *et al.*, 1997b). Grazing chicory, regardless of intensity and frequency, decreased plant density (Li *et al.*, 1997b). However, there has been little research on biomass allocation and carbohydrate reserves in forage chicory although some predictions can be made by analogy with tap-rooted forage legumes.

Nearly all reported grazing research on chicory has been on one cultivar, Grasslands Puna. In this study, the cultivars Orchies and PG90 were compared with Puna in terms of persistence and herbage production. Orchies is a root-type cultivar bred in France for the extraction of the reducing sugar inulin, and PG90 is a selection from the Italian leaf vegetable type Spadona (A. V. Stewart, personal communication). Carbohydrate reserves in perennial forage plants are important in forage management, as they are the source of energy necessary for winter survival and initiation of growth in spring. They may also serve as an important source of energy used to support shoot growth immediately after defoliation (Fankhauser *et al.*, 1989). Witloof chicory contains the polyfructosan inulin (Chubey and Dorrell, 1978; Pollock and Chatterton, 1988) as its long-term reserve with up to 20% on a fresh weight basis and up to 80% on a dry weight basis in its taproots (Van den Ende *et al.*, 1996); it can be used as a fructose crop (Chubey and Dorrell, 1978). Plants like Orchies, with a large taproot, were assumed to have more root carbohydrate reserves (Wolf, 1978), and therefore to have better persistence.

The mobilisation of total non-structural carbohydrates (TNC) after defoliation has been investigated for several perennial legumes such as lucerne (*Medicago sativa* L.), red clover (*Trifolium pratense* L.) and birdsfoot trefoil (*Lotus corniculatus* L.) (Kendall, 1958; Nelson and Smith, 1968; Wolf, 1978; Fankhauser and Volenec, 1989; Boyce and Volenec, 1992). Smith (1962) found that root TNC levels in mature lucerne and red clover decreased after defoliation, then increased before the next defoliation. In contrast, birdsfoot trefoil maintained lower root TNC levels throughout the season and did not exhibit a strong cyclic trend of TNC depletion and replenishment following herbage defoliation as did lucerne or red clover. Birdsfoot trefoil relies on current photosynthate production for regrowth and needs a greater residual leaf area following defoliation than lucerne and red clover, which rely on stored carbohydrates for initial regrowth (Smith, 1962; Smith and Nelson, 1967; Greub and Wedin, 1971).

The objectives of the research were to study the effects of defoliation intensity on the biomass allocation and regrowth of Puna, and to compare persistence and herbage production of three chicory cultivars with contrasting root sizes and root carbohydrate reserves.

6.3 MATERIALS AND METHODS

Three glasshouse experiments were conducted in the Plant Growth Unit, Massey University, Palmerston North, New Zealand (latitude 40°23' S).

6.3.1 Expt 1: Effect of cutting height on regrowth and biomass allocation in Puna chicory

6.3.1.1 Plant establishment

The experiment was carried out from 14 September 1993 to 15 March 1994. Seeds of Puna were germinated in trays (300 × 400 mm) of sand under mist in a glasshouse. Air temperature was maintained between 15 and 25°C. Seed germinated in a week, then seedlings were moved to a cool room (4-5°C) at night and returned to the glasshouse (25°C) during daylight for 2 weeks to induce vernalisation. When the first true leaf appeared, the seedlings were transplanted to plug trays (40 mm diameter, 50 mm depth), one seedling per plug, and underwent another 2 weeks of vernalisation. When the fifth true leaf appeared, the seedlings were transplanted to pots (plastic bags, 280 mm diameter, 300 mm depth), with six plants per pot initially, thinned to three plants per pot 3 weeks later. Automatic irrigation watered individual pots to field capacity twice a day. A standard long-term medium was used, made up of peat and pumice (3:2 by volume) amended with lime (1.0 kg/m^3), dolomite (3.0 kg/m^3), and Osmocote® (long term 8-9 months, 2.0 kg/m^3, and short term 3-4 months, 1.0 kg/m^3) as a base starter fertiliser. Air temperatures were maintained at 10-15°C/25 -30°C (night/day) by heating or ventilating until late November. After that the glasshouse was unheated but well-ventilated. The average minimum and maximum daily air temperatures were 16.7 and 39.1°C, respectively, over the whole cutting period from 21 December 1993 to 15 March 1994. When the treatments were started 2 months after transplanting, liquid nutrients (1 g/l) were supplied through the irrigation system twice daily (5 min each time) to meet the high nutrient requirement of chicory. The liquid fertiliser used was Peters® Professional water soluble NPK fertiliser (27 + 6.5 + 10) plus trace nutrients (Mg, B, Cu, Fe, Mn, Mo, Zn).

6.3.1.2 Experimental design

A completely randomised design (CRD) was used, with five cutting heights (0, 50, 100, 150 and 200 mm above media level) and four replications. For the 0 mm cutting treatment, buds on the crown were uninjured. The cutting intervals were 3 weeks, with five cuttings in total. At each cutting, 20 pots were destructively harvested and the remaining pots were cut to the treatment heights.

6.3.1.3 Measurements

Herbage masses above and below the cutting height at each cutting were dissected into leaf, stem and dead material. Leaf and stem were further partitioned into primary, secondary and axillary leaf and stem, respectively. The initial shoots coming from the crown were defined as primary shoots, lateral shoots coming from the crown as secondary shoots, and all the shoots coming from axils of primary and secondary shoots as axillary shoots. Leaves and stems generated from primary, secondary and axillary shoots were named accordingly. The definitions were applied to all experiments. Morphological characteristics such as leaf number and shoot length were also recorded at each cutting (data not presented). The root mass was measured after washing off media manually at each cutting. All roots were collected except the fine roots (< 1 mm diameter). All mass data are presented on a dry weight basis, oven-dried at 80°C for 48 h.

Total leaf area was measured on one plant per pot selected at random. A LI-Cor LI-3100 Leaf Area Meter (Lambda Instruments Co, Lincoln, NE, USA) was used.

6.3.1.4 Statistical analysis

All data were analysed using the SAS GLM procedure (SAS Institute, 1990). Accumulated leaf and stem masses over the whole experimental period (12 weeks), and shoot and root masses at each cutting were analysed using a CRD model. The mean relative growth rates (RGR) of the shoot and whole plant, on an individual plant basis, between two consecutive cuttings were calculated using the classic growth analysis method (interval approach, Hunt, 1978) and a CRD model was used to perform the ANOVA for each growth period. Basic allometric relationships such as leaf area ratio (LAR), specific leaf area (SLA), leaf weight ratio (LWR) and root weight ratio (RWR) were also calculated at each cutting (Hunt, 1978).

6.3.2 Expt 2: Biomass allocation and root carbohydrate reserves in response to defoliation of three chicory cultivars

6.3.2.1 Plant establishment

The experiment was conducted from 10 March 1995 to 9 January 1996. Three chicory cultivars, Puna, PG90 and Orchies, were used in this experiment.

Seeds of Puna, PG90 and Orchies chicory were sown directly into pots (same size as in Expt 1) on 10 March 1995 and misted during germination in a glasshouse. The media and base starter fertiliser were the same as in Expt 1. After seed germinated, seedlings were thinned to six per pot, then to three per pot when well-established on 31 March 1995. Air temperatures in the glasshouse were 15/25°C (night/day) until 20 April 1995 when plants were moved out of the glasshouse for vernalisation during winter. All plants were cut to 50 mm in height before being returned to the glasshouse on 10 August 1995. Air temperatures in the glasshouse were maintained at 10-15°C/25-30°C (night/day) by heating or ventilating until early November, then the glasshouse was unheated but well-ventilated. The average minimum and maximum daily air temperatures were 14.9 and 31.6°C, respectively, in the glasshouse over the whole cutting period from 25 September 1995 to 9 January 1996. Watering and nutrient supply arrangements were the same as in Expt 1.

6.3.2.2 Pesticide and fungicide applications

When pots were moved back to the glasshouse, Mesurol® pellets (20 g/kg carbamate) at 10 g/m^2 were applied to kill slugs, and fungicides, Saprol® (190 g/l piperidine) at 1 ml/l and Benlate® (500 g/kg benzimidazole) at 0.5 g/l, were sprayed to control root and leaf fungi, respectively. Bactericides, Agrimycin® (170 g/kg as the sulphate salt) at 0.6 g/l and Copper Oxychloride (500 g/kg copper as copper oxychloride) at 5 g/l, were applied alternatively to suppress the infection of *Pseudomonas* spp. When the cutting treatments began, only Agrimycin® was applied after each cutting until the experiment finished.

6.3.2.3 Experimental design

A 3 × 2 factorial combination of treatments in a randomised complete block design (RCB) with four blocks was used. The two main factors were cultivars, Puna, PG90 and Orchies, and cutting heights, 20 and 100 mm cutting above media level. Five cuttings at 3 week intervals were accomplished in total. Because of the slower phenological development of Orchies, cuttings of it began and finished 3 weeks later than for Puna and PG90. At each cutting, four replicates in each treatment combination were destructively harvested and the remaining pots were cut to the designated treatment heights.

6.3.2.4 Measurements

Herbage masses above and below the cutting height were dissected and weighed at each cutting as in Expt 1. The total leaf area was also measured as in Expt 1. The root mass was washed free of media at each cutting, but only taproots (> 2 mm thick) were collected. All mass data were on a dry weight basis, oven-dried at 80°C for 48 h. Fresh root samples were taken for total reducing sugars (Nelson, 1944; Chubey and Dorrell, 1974) and glucose analysis (Bergmeyer, 1974; Caraway, 1976) at the time when plants were moved back to the glasshouse after vernalisation, and at weeks 0, 6 and 12. Concentration of fructose was calculated by subtracting the concentration of glucose from that of total reducing sugars as the relationship between fructose and glucose concentrations was found to be inverse (Chubey and Dorrell, 1974, 1977, 1978). Fresh root samples were put in deep refrigeration (-75°C) immediately after being washed, then freeze-dried and ground to pass a 1 mm sieve for analyses.

6.3.2.5 Statistical analysis

All data were analysed using the SAS GLM procedure (SAS Institute, 1990). Four pots in the Puna 100 mm cutting height treatment were accidentally destroyed early in the experiment, therefore, type III sums of squares (each effect is adjusted for all other effects) were used for the F-test whenever missing data were involved (SAS Institute, 1990). Accumulated leaf and stem masses, and shoot and root masses at each cutting were analysed using the model of 3 × 2 factorial treatment combination in a RCB design. The main effects for accumulated leaf and stem masses, and shoot mass at each cutting are not reported because of significant interactions between the two main factors; whereas the significant main effects for root mass at each cutting are reported, as interactions between the two main factors were not significant. Basic allometric relationships, LAR, SLA, LWR and RWR, were analysed at each cutting for cultivar comparison as in Expt 1, using the data from the 100 mm cutting height treatment only because of plant death in the 20 mm cutting treatment of PG90 from week 9 onwards and of Puna at week 12. The mean RGR was calculated as in Expt 1. Total reducing sugar yields of the three cultivars were calculated as the product of root mass and total reducing sugar concentration (100 mm cutting treatment data only).

6.3.3 Expt 3: Morphological characteristics and persistence of Puna chicory under extreme defoliation

6.3.3.1 Plant materials

The experiment was conducted from 8 August 1995 to 20 December 1995 in the same glasshouse as Expt 2. Early in spring (early August) before chicory started to grow, Puna chicory sods were dug out *in situ* from the field (see Li *et al.*, 1997b for details) to fit pots of 315 mm in diameter and 400 mm in depth, 7-9 plants/pot, and moved into the glasshouse. Puna in the field was at the beginning of its second growing season. All pots were watered automatically twice daily.

6.3.3.2 Experimental design and measurements

Eight pots were prepared and arranged randomly, with two treatments, severe and lax cutting, and four replicates. The severe cutting treatment removed all shoots including visible buds > 5 mm on the crown; lax cutting treatment cut all material from 100 mm above soil level. The cutting started on 17 October 1995 at 3-week intervals. After three cuttings, all pots were destructively harvested to examine the number of live and dead plants. Herbage mass above cutting height was measured at each cutting, and herbage mass below cutting height was measured at the last defoliation only. Leaf and shoot numbers per pot were also recorded at each cutting.

6.3.3.3 Statistical analysis

Leaf and shoot numbers between treatments were compared using a model for a completely randomised design with the SAS GLM procedure (SAS Institute, 1990). Plant size (g DW/plant) and the percentage of live plants were compared at the third cutting.

6.4 RESULTS

6.4.1 Accumulated shoot mass

In Expt 1, cutting height had no effect on total accumulated leaf mass, but had a significant effect on total accumulated stem mass (Table 6-1). There were significant differences in the secondary and axillary leaf masses at different cutting heights, but no significant difference in secondary stem mass. In Expt 2, there were significant differences in total accumulated leaf and stem masses among treatment combinations, but there were no significant differences in either secondary leaf or stem (Table 6-2). Puna and PG90 under the 100 mm cutting treatment accumulated more stem mass than that under the 20 mm cutting treatment. In contrast, cutting height had no significant effect on stem mass accumulation in Orchies. PG90 accumulated the highest leaf and stem masses with 100 mm cutting, but the least with 20 mm cutting (Table 6-2). The 20 mm cutting treatment resulted in PG90 plants dying.

Table 6-1 Accumulated leaf and stem masses (g DW/plant) of Puna chicory for a range of cutting heights over 12 weeks (Expt 1)

Cutting height	0 mm	50 mm	100 mm	150 mm	200 mm	s.e.m.(d.f.)
Leaf						
Primary	13.6	17.4	17.4	18.9	23.4	3.25 (15)
Secondary	56.6	28.1	28.3	38.3	40.0	6.74 (15)
Axillary	0.2	15.7	15.2	11.7	11.7	1.91 (15)
Total	70.3	61.2	61.0	68.9	75.1	6.22 (15)
Stem						
Primary	0.3	2.5	4.5	5.9	5.5	1.14 (15)
Secondary	1.0	1.1	2.1	2.3	3.5	0.77 (15)
Axillary	0.0	3.6	7.3	10.6	11.2	2.18 (15)
Total	1.3	7.2	13.9	18.8	20.2	2.35 (15)

Table 6-2 Accumulated leaf and stem mass (g DW/plant) of Puna, PG90 and Orchies chicory under 20 and 100 mm cutting treatments over 12 weeks (one missing value in Puna cut at 100 mm height) (Expt 2)

Cultivar	Puna		PG90		Orchies		s.e.m. (d.f.)
Cutting height	20 mm	100 mm	20 mm	100 mm	20 mm	100 mm	
Leaf							
Primary	3.6	5.1	0.3	18.4	17.2	20.3	3.85 (14)
Secondary	16.4	6.9	3.2	8.4	8.6	3.5	3.46 (14)
Axillary	0.3	19.2	0.2	12.8	1.1	3.9	1.78 (14)
Total	20.3	31.1	3.8	39.6	26.9	27.7	4.59 (14)
Stem							
Primary	-0.1	0.7	-0.4	6.7	0.4	0.1	1.47 (14)
Secondary	0.3	2.0	0.4	1.0	0.0	0.0	0.69 (14)
Axillary	0.0	6.0	0.0	14.9	0.0	0.3	2.64 (14)
Total	0.2	8.6	0.0	22.7	0.4	0.4	1.93 (14)

6.4.2 Shoot and root mass dynamics over time

In Expt 1, treatment effects on shoot mass were not significant until week 6 (after two cuttings). Cutting heights > 100 mm had more herbage mass than cutting height < 100 mm from week 6 onwards ($P < 0.05$, Figure 6-1a). In Expt 2, there were no significant interactions between cutting heights and cultivars at the first two cuttings, however, the main effect of cutting height at week 3 was significant ($P < 0.01$). From week 9 onwards, the interactions between cutting heights and cultivars were significant ($P < 0.05$, Figure 6-2). All plants of PG90 from week 9 onwards and of Puna at week 12 died under the 20 mm cutting treatment. PG90 under 100 mm cutting produced the highest mass at week 9 and 12 (Figure 6-2). Herbage mass of Orchies was constant under both cutting heights over the course of the experiment except for a large decrease in mass at the first cutting (Figure 6-2).

In Expt 1, cutting height had a significant effect on root masses after two cuttings ($P < 0.05$, Figure 6-1b). Root mass at 150 and 200 mm cutting heights was significantly greater than for plants cut < 150 mm. Root mass was highest at 200 mm cutting and lowest at 0 mm cutting (Figure 6-1b). In Expt 2, cutting height had no effect on root mass until week 9 (cutting 4), whereas cultivar differences existed over the whole experimental period ($P < 0.01$, Table 6-3). Cutting at 20 mm significantly decreased root mass at weeks 9 and 12 ($P < 0.01$, Table 6-3). The root mass of Orchies was significantly higher than that of Puna and PG90 ($P < 0.01$), but there were no significant differences in root mass between Puna and PG90 ($P > 0.05$).

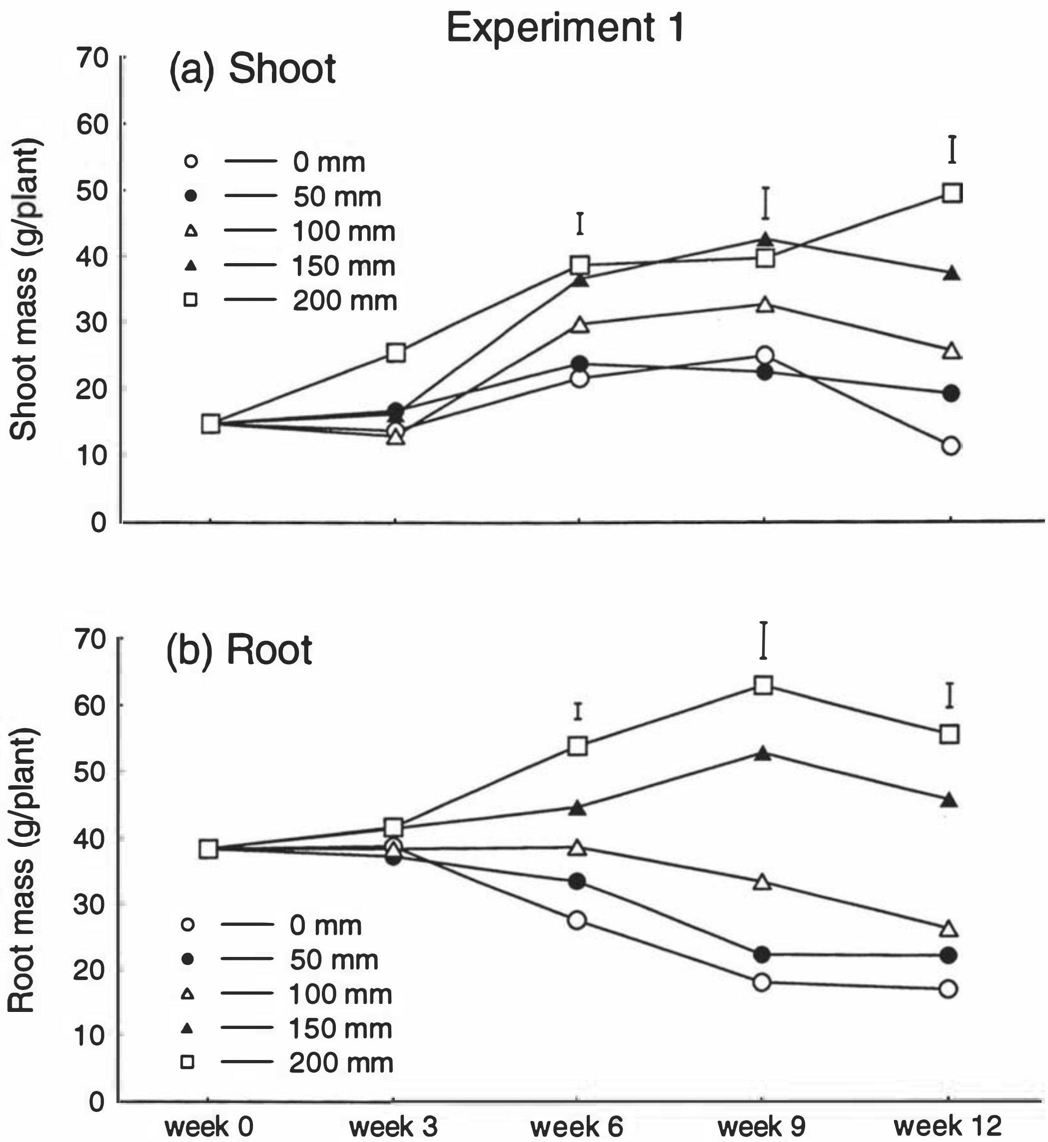

Figure 6-1 **(a) Shoot and (b) root mass of Puna chicory at cutting heights of 0, 50, 100, 150 and 200 mm at each cutting (Expt 1). Vertical bars represent s.e.m. (d.f. = 15).**

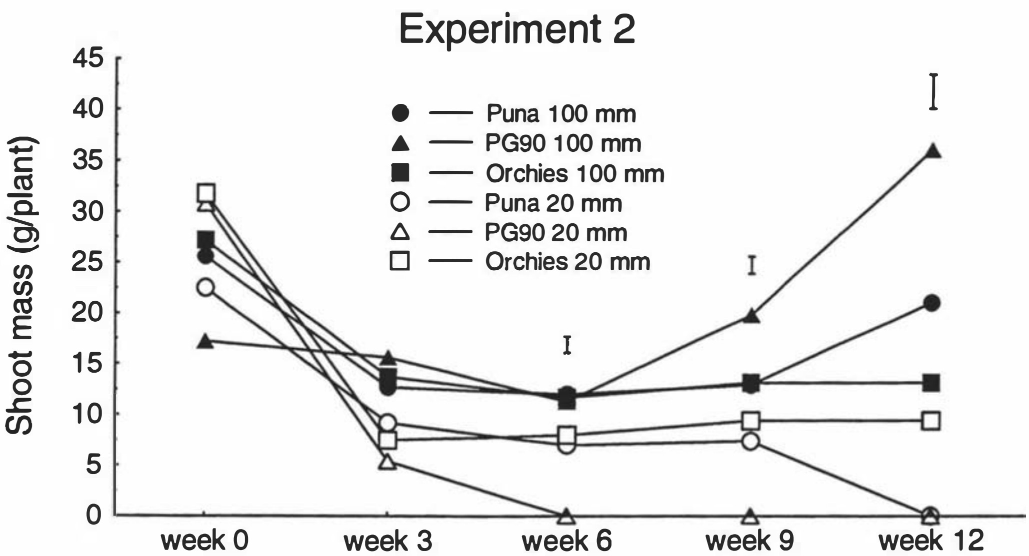

Figure 6-2 Shoot mass of Puna, PG90 and Orchies chicory at cutting heights of 20 and 100 mm at each cutting (Expt 2). Vertical bars represent s.e.m. (d.f. = 14, except at week 0, d.f. = 15).

Table 6-3 Root mass (g DW/plant) of Puna, PG90 and Orchies chicory under 20 and 100 mm cutting treatments at each cutting (one missing value in Puna cut at 100 mm height from week 3 onwards) (Expt 2)

	week 0	week 3	week 6	week 9	week 12
Cutting height					
20 mm	17.8	12.1	11.3	9.7	9.1
100 mm	15.3	16.0	12.6	19.5	22.1
s.e.m. (d.f.)	1.83 (15)	2.72 (14)	1.67 (14)	1.99 (14)	3.45 (14)
Cultivar					
Puna	12.3	6.7	5.3	7.7	9.5
PG90	6.9	3.1	2.5	3.5	3.8
Orchies	30.5	32.5	28.1	32.6	33.6
s.e.m. (d.f.)	2.25 (15)	3.43 (14)	2.11 (14)	2.50 (14)	4.34 (14)

6.4.3 Growth analysis

In Expt 1, the mean shoot RGR increased as cutting intensity increased for all periods with the highest shoot RGR in the 0 mm cutting treatment (Figure 6-3). However, there was no significant difference between cutting heights in total RGR on a whole plant basis. In Expt 2, neither the main effects nor interactions for cultivar and cutting height on RGR of shoot and whole plant were significant ($P > 0.05$, data not presented).

There were significant differences in RWR among cultivars in Expt 2 (Table 6-4), but no significant differences between cutting treatments for Puna in Expt 1 ($P > 0.05$, data not presented). Orchies had the highest RWR and PG90 the lowest at all cuttings, except at week 6 for PG90. Orchies distributed more than half of its biomass under-ground. In contrast, Puna and PG90 allocated more than half of their biomass above-ground (Figure 6-4). PG90 had more stem mass than the other two cultivars at week 12.

Leaf area ratio of Puna was significantly higher than that of PG90 and Orchies at weeks 6 and 12 ($P < 0.01$). Specific leaf area of Puna was also significantly higher than for the other two cultivars at weeks 6 ($P < 0.05$), 9 ($P < 0.10$) and 12 ($P < 0.05$). In contrast, LWR of PG90 was significantly higher than that of Puna and Orchies except at week 12 (Table 6-4). However, there were no significant effects of cutting height on LAR, SLA and LWR, except at week 9 when LAR and LWR were greater for plants cut at 0 mm, between cutting heights at all defoliations of Puna in Expt 1 ($P > 0.05$, data not presented).

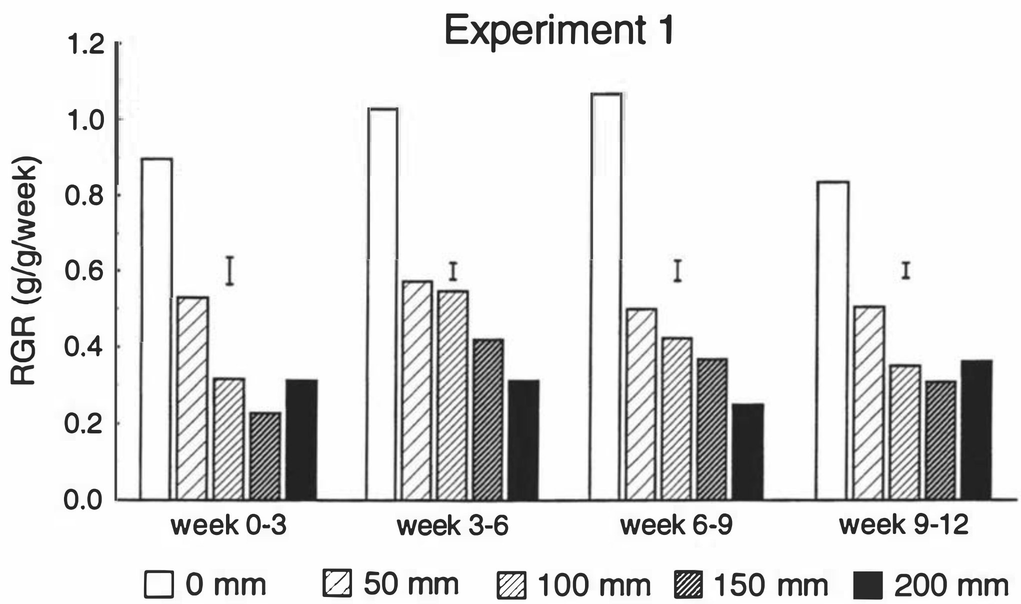

Figure 6-3 Shoot relative growth rate of Puna chicory at cutting heights of 0, 50, 100, 150 and 200 mm at each growth period (3 weeks) (Expt 1). Vertical bars represent s.e.m. (d.f. = 15).

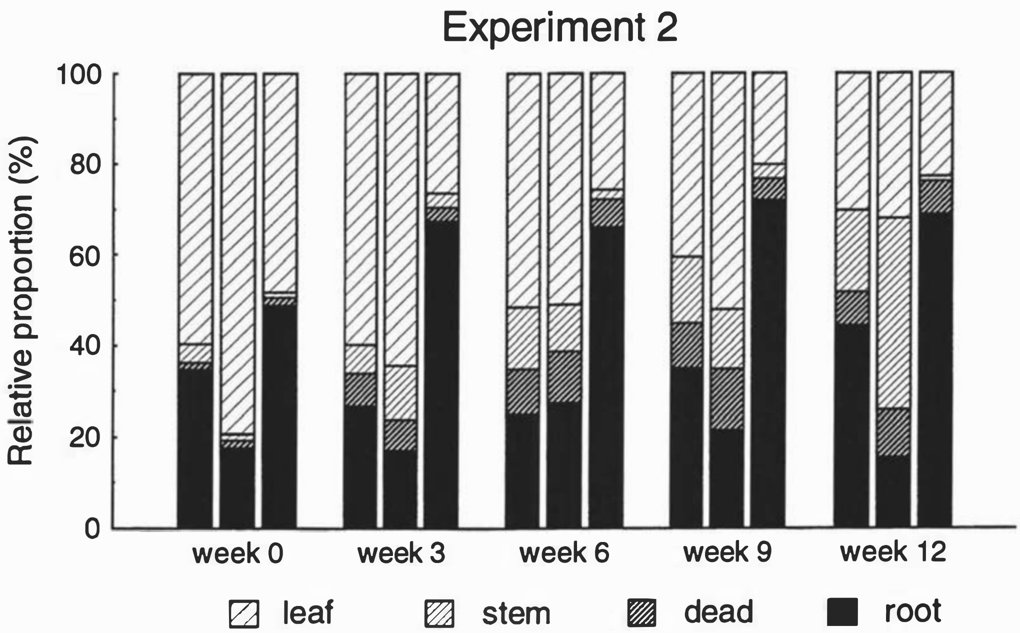

Figure 6-4 Relative proportion of leaf, stem, dead and root of Puna (left bars), PG90 (middle bars) and Orchies chicory (right bars) at each cutting (Expt 2).

Table 6-4 Leaf area ratio (LAR), specific leaf area (SLA), leaf weight ratio (LWR) and root weight ratio (RWR) of Puna, PG90 and Orchies chicory under 100 mm cutting treatment at each cutting (one missing value in Puna from week 3 onwards) (Expt 2)

	week 0	week 3	week 6	week 9	week 12
LAR (mm^2/mg)					
Puna	14.5	27.6	25.5	18.7	9.6
PG90	18.3	30.3	21.0	13.8	6.5
Orchies	13.5	7.6	7.0	5.4	4.0
s.e.m. (d.f.)	2.7 (6)	6.89 (5)	3.00 (5)	1.85(5)	0.82 (5)
SLA (mm^2/mg)					
Puna	23.8	40.7	45.0	43.0	29.1
PG90	22.3	44.2	36.4	22.5	19.9
Orchies	27.6	26.2	25.3	25.1	16.5
s.e.m. (d.f.)	3.03 (6)	9.82(5)	4.53 (5)	5.10(5)	2.76 (5)
LWR (g/g)					
Puna	0.60	0.65	0.57	0.45	0.33
PG90	0.81	0.69	0.58	0.60	0.35
Orchies	0.49	0.27	0.27	0.21	0.25
s.e.m. (d.f.)	0.046 (6)	0.043 (5)	0.088 (5)	0.055 (5)	0.048 (5)
RWR					
Puna	0.35	0.28	0.28	0.39	0.48
PG90	0.18	0.18	0.31	0.25	0.17
Orchies	0.50	0.69	0.70	0.76	0.74
s.e.m. (d.f.)	0.046 (6)	0.065 (5)	0.073 (5)	0.042 (5)	0.049 (5)

6.4.4 Carbohydrate reserves in root system

There were significant differences in the concentration and composition of total reducing sugars between cultivars (Table 6-5). Orchies had the highest concentrations of reducing sugars and fructose, but the lowest concentration of glucose, whereas PG90 was the opposite. Orchies had the highest total reducing sugar yield at each cutting and PG90 had the lowest (Figure 6-5). Over the course of experiment, the total reducing sugar yields of three chicory cultivars were higher at the beginning of growth (initial time) and at the end of the experiment (week 12), and lower in the middle (week 0 and week 6, Figure 6-5). The range for fluctuation in total reducing sugar yield for Puna was much wider than for PG90 and Orchies.

6.4.5 Morphological characteristics and persistence of Puna chicory under extreme defoliation

Severe cutting boosted the shoot numbers per unit area for Puna after the first cutting, but there were no effects on leaf numbers per unit area until week 6 (Table 6-6). There were more leaves under severe cutting at week 6, but less leaves at week 9 than under lax cutting. Severe cutting decreased the shoot size greatly, and resulted in a very small shoot size compared with lax cutting by week 9 ($P < 0.01$). The percentage of plants still alive at the end of the experiment was 27.1% for the severe cutting, and 96.4% for the lax cutting ($P < 0.01$, Table 6-6).

Table 6-5 Concentration and composition of total reducing sugars of Puna, PG90 and Orchies chicory over the season (Expt 2)

Cultivar	Reducing sugars	Fructose	Glucose	F/G
	(g/100g DM)	(%)	(%)	ratio
Puna (n = 12)	39.6	86.2	13.8	6.5
PG90 (n = 10)	32.1	85.7	14.3	6.3
Orchies (n = 14)	56.6	88.9	11.1	8.7
s.e.m. (d.f.)	4.01 (33)	0.93 (33)	0.93 (33)	0.63 (33)

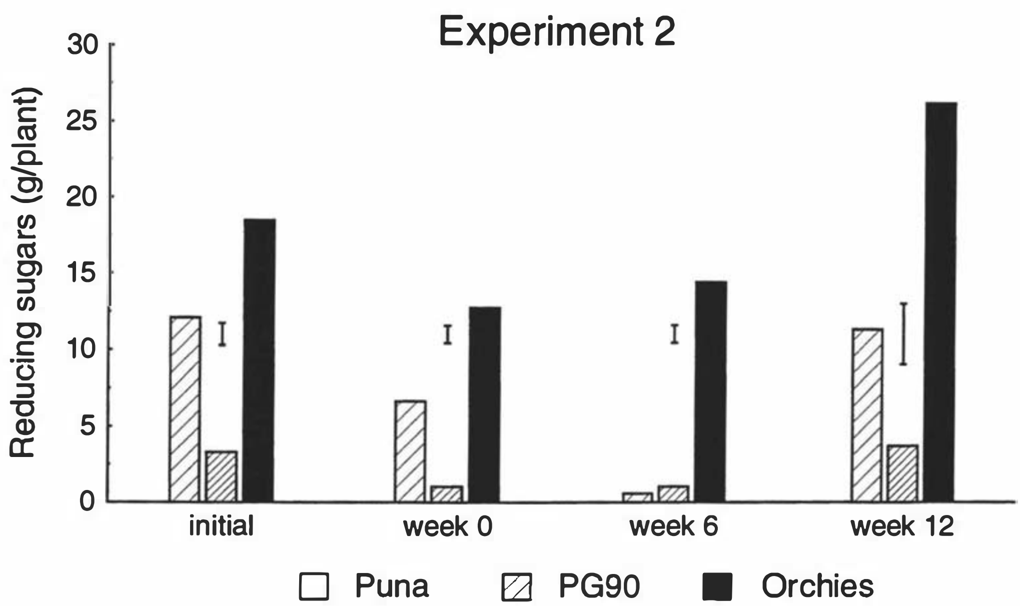

Figure 6-5 Yield of total reducing sugars of Puna, PG90 and Orchies chicory under 100 mm cutting treatment at different cutting times (Expt 2). Vertical bars represent s.e.m. (d.f. = 3 at initial, d.f. = 6 at week 0, d.f. = 5 at weeks 6 and 12).

Table 6-6 Morphological characteristics of transplanted Puna chicory plants under severe cutting (all shoots including visible buds > 5 mm on crown removed) and lax cutting (cut at 100 mm height) at each cutting (Expt 3)

Cutting height	week 0	week 3	week 6	week 9
Leaf (No/m^2)				
Severe	2920	2870	2860	850
Lax	2350	2500	1900	2040
s.e.m. (d.f.)	385 (6)	393 (6)	270 (6)	182 (6)
Shoot (No/m^2)				
Severe	202	937	700	170
Lax	167	177	173	180
s.e.m. (d.f.)	37.5 (6)	40.7 (6)	55.3 (6)	38.4 (6)
Size (g DW/shoot)				
Severe	7.63	0.07	0.18	0.22
Lax	-	-	-	1.64
s.e.m. (d.f.)	-	-	-	0.206 (6)
Plants alive (%)				
Severe	100	-	-	27.1
Lax	100	-	-	96.4
s.e.m. (d.f.)	-	-	-	4.64 (6)

- not applicable

6.5 DISCUSSION

Defoliation significantly changed the biomass allocation of chicory and had different effects on the regrowth of different plant parts. Although there were no significant differences in total leaf mass accumulation between cutting heights, Puna tended to accumulate more stem mass, especially axillary stem mass, under the cutting heights > 100 mm than those below this height in Expt 1, in agreement with the results of Li *et al.* (1994) under grazing conditions. Li *et al.* (1994) found that medium grazing (100-150 mm) at 3 weeks intervals represented a reasonable compromise between total herbage production and feed quality in a 4-year old Puna stand. Cutting height had no effect on accumulated secondary stem masses in both Expts 1 and 2, and secondary leaf mass in Expt 2, suggesting that all buds on the crown were vernalised either by the 4 week artificial low temperature (4-5°C) during seedling establishment in Expt 1, or by the natural cold temperature over winter in Expt 2. Axillary leaf and stem mass accumulations were associated with cutting height in both experiments. The higher the cutting height, the more axillary leaf and stem mass accumulated. Puna in Expt 1 accumulated more leaf mass than in Expt 2 at similar cutting heights. This difference could be explained by higher minimum and maximum air temperatures in Expt 1 than in Expt 2 as Puna responds quickly to warm temperatures in the field in spring (Lancashire and Brock, 1983).

Cutting height had a significant effect on both standing shoot mass and root mass after two cuttings at 3-week intervals in Expt 1. Hard cutting (> 100 mm) decreased root mass, whereas lax cutting (> 150 mm) increased root mass. Evans (1973) found that defoliation (cutting heights, 25, 50 and 100 mm) resulted in a decrease in root elongation in perennial ryegrass (*Lolium perenne* L.), white clover (*Trifolium repens* L.) and red clover, the most severe treatment having the greatest effect. Langer and Steinke (1965) reported that the root growth responded more strongly to cutting than the shoots for lucerne. Although greater cutting heights tended to have higher standing shoot mass after two cuttings, there were no significant differences in absolute growth rates between cutting heights during each growing period except at the last period (Li *et al.*, 1997c). However, the mean shoot RGR increased as cutting intensity increased at all periods, the most severe cutting (0 mm) having the highest relative growth rate. At week 9 only, the LAR and LWR for the most severe cutting were significantly greater than for the other cutting intensities. This suggests a trend towards leaf mass but not leaf thickness being allocated relatively more carbon under severe cutting.

Fructans were the major carbohydrate reserves in the three forage chicory cultivars in the current study, as > 85% of the reducing sugars were fructose (Table 6-5). Orchies had the highest concentration of total reducing sugars in its root (Table 6-5) as expected from its morphological characteristics, which were similar to chicory crops for fructose production (Chubey and Dorrell, 1974, 1978). Similar levels of root TNC concentrations were found by Brown *et al.* (1990) in two cultivars of lucerne. In combination with root mass, Orchies had the highest yield of reducing sugars among the cultivars at all measurement times (Figure 6-5), suggesting that Orchies stores more fructans as carbohydrate reserves than Puna and PG90. A positive association has been observed between root starch concentrations and regrowth of perennial legumes following defoliation (Leach, 1968; Nelson and Smith, 1968), this relationship was apparent under the 20 mm cutting treatment with Orchies accumulating more leaf mass than the other cultivars. However, when a larger residual leaf area was retained under the 100 mm cutting treatment, the cultivar Orchies did not accumulate more herbage mass than the other cultivars.

The results suggested that the three chicory cultivars had different patterns of utilisation of their root carbohydrate reserves. In Expt 2, the general trend of total reducing sugar yield over the whole experiment period was for it to be higher at the beginning of growth (initial time) and at the end of the experiment (week 12), and lower in the middle (weeks 0 and 6, Figure 6-5), which is similar to the pattern for root TNC concentrations of lucerne under cutting management, lowest in mid-summer and greatest in late autumn (Brown *et al.*, 1990). When all pots were moved back to the glasshouse (all pots cut to 50 mm as pre-treatment), chicory plants first formed a large leaf area for capturing light. This new leaf area was probably initiated by the plants using carbohydrate reserves in their root systems, as the total reducing sugar yield decreased greatly from pre-treatment (initial time) to the first cutting (week 0), with the greater decreases in Puna and PG90. In this phase the root grew slowly since most of the photoassimilates were diverted to leaf growth (Van den Ende *et al.*, 1996). Total reducing sugar yields of all cultivars increased when the vegetative growth ceased at the last cutting (week 12) with the greatest increase in Puna.

After the first cutting, Puna developed secondary shoots from the crown, as well as axillary shoots, due to the release of apical control of the primary shoot, and this resulted in a further decrease in reducing sugar yields from week 0 to week 6. Thus, cutting frequency would probably be more important than cutting intensity in Puna because this cultivar probably requires a longer period (> 3 weeks) to replenish its root carbohydrate reserves. Stubble height of Puna is important, however, when cutting is so frequent that carbohydrate storage in the roots is limited, as was the case with 3-week intervals. Langer and Steinke (1965) also found that close defoliation of lucerne can be tolerated only if rapid re-establishment of the foliage can be assured through the presence of a large root system. Repeated severe cutting kills plants by depleting root carbohydrate reserves in a short period because a perennial herbaceous plant, when totally defoliated, must draw on carbohydrate reserves to regenerate photosynthetic tissue (Wolf, 1978). Severe and frequent cuttings have an even greater effects on chicory regrowth when meristems are removed as shown by the high death rate in severe cutting treatment in Expt 3.

Regrowth of PG90 after cutting would be more dependent on residual leaf area than root carbohydrate reserves due to its lower level of total reducing sugars during the growth period. Therefore, PG90 could be defoliated more frequently, but not closely, as evidenced by the plant deaths after two 20 mm cuttings. Davis *et al.* (1995) suggested that leaving residual leaf area might be important to the regrowth of annual lespedeza (*Kummerowia* spp.) as it maintains relatively small amounts of root TNC. Beardsley and Anderson (1960) found that the amount of stubble left after cutting was more important to the maintenance of birdsfoot trefoil than of lucerne as the root carbohydrate reserves in birdsfoot trefoil remained low during the growing season even when left uncut. Thus, a tall stubble on birdsfoot trefoil provides green leaves to produce the energy needed for regrowth after cutting. Smith (1962) also stated that birdsfoot trefoil could be harvested frequently, but not closely, and that lucerne could be defoliated closely, but not frequently from the viewpoint of stand persistence. Cooper and Watson (1968) found that the carbohydrate synthesis in sainfoin (*Onobrychis viciifolia* Scop.) was similar to birdsfoot trefoil, and that these species should not be grazed too closely as adequate leaf material was needed for assimilation.

In contrast, Orchies with its thick taproots was insensitive to cutting intensity and would be insensitive to cutting frequency as well because total reducing sugar yields remained high over all growth periods. This characteristic was at the expense of slower vegetative development at establishment and relatively lower herbage mass accumulation (under the 100 mm cutting treatment) compared with Puna and PG90.

Orchies is different from Puna and PG90 in several aspects. Firstly, Orchies had thicker tap roots (39.2 ± 0.07 mm versus 24.1 ± 0.09 mm and 22.4 ± 0.07 mm in diameter) and more root mass than Puna and PG90 chicory (Table 6-3). Over 70% of the biomass in Orchies was distributed underground, whereas < 50% was allocated underground in Puna and PG90 (Figure 6-4). Secondly, Orchies was at least 3 weeks slower to develop, both vegetatively and reproductively, than Puna and PG90. Thirdly, Orchies was insensitive to cutting height as no significant differences between treatments existed in accumulated leaf and stem masses (Table 6-2) and in standing shoot mass at each cutting (Figure 6-2). This insensitivity in Orchies was probably due to its large buffer of root carbohydrate reserves (Table 6-3 and Table 6-5), whereas Puna and PG90 were very sensitive to the cutting height, with resultant plant death. Finally, Orchies had lower LWR (leafiness) than Puna and PG90 except at week 12 when Puna and PG90 were all at reproductive stages with more stems (Table 6-4). Orchies also tended to have thinner leaves than Puna and PG90 after week 6, except at week 9 where Orchies had slightly higher SLA than PG90, but much lower than Puna (Table 6-4). Compared with PG90, Puna was more tolerant to the defoliation intensity with reasonably high accumulated leaf mass under both 20 and 100 cutting treatments and much lower stem mass accumulation under the 100 mm cutting treatment (Table 6-2).

Overall, Orchies had the greatest potential for persistence due to its large taproot. PG90 had the highest leaf and stem production under the 100 mm cutting height treatment but the least persistence under the 20 mm cutting height treatment. Puna was intermediate in terms of persistence and herbage production. There appears to be the possibility of improving the persistence and enhancing the regrowth leaf production of Puna by increasing taproot size without unduly prejudicing herbage production by means of plant breeding.

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7. MORPHOLOGICAL DEVELOPMENT OF FORAGE CHICORY UNDER DEFOLIATION IN THE FIELD AND GLASSHOUSE†

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7.1 ABSTRACT

Four field and two glasshouse experiments were carried out to study the morphological development of forage chicory under defoliation in both field and glasshouse from 1993 to 1996 at Massey University, Palmerston North, New Zealand. 'Grasslands Puna' chicory (*Cichorium intybus* L.) was used in all experiments except the last one, where three cultivars, 'Grasslands Puna', 'PG90' and 'Orchies', were compared. Puna chicory produced two separate growths from the crown, one in spring and the other in autumn, when left ungrazed. Defoliation stimulated the development of secondary shoots, but suppressed the development of the primary shoot. Axillary shoots, however, developed fully regardless of whether or not plants were defoliated. The main source of feed from chicory for livestock was primary leaves during spring, and secondary and axillary leaves during summer and autumn. Orchies produced more primary leaves than Puna and PG90 because it had a larger crown, but there were no differences in the number of secondary shoots among cultivars. The development of axillary shoots varied with cultivars. It is concluded that defoliation at 50-100 mm in height with 3 week intervals in spring, and 100-150 mm with 5 week intervals in summer and autumn, could maximise the leaf formation and minimise the stem development of chicory.

Keywords: *Cichorium intybus,* crown, grazing, leaf, shoot, stem

7.2 INTRODUCTION

AN UNDERSTANDING of the seasonal dynamics of the morphological development of forage chicory (*Cichorium intybus* L. cv. Grasslands Puna) under defoliation is required if productivity and persistence are to be maximised (Clark *et al.*, 1990a; Moloney and Milne, 1993; Li *et al.*, 1994, 1997a). Currently, there is little information available on the morphological responses to defoliation by either grazing or cutting. The morphological development of undefoliated chicory is, however, known from research on seed crops (Hare, 1986; Hare *et al.*, 1990) and witloof chicory (Arya and Sharma, 1985; Schoofs and Langhe, 1988).

Undefoliated chicory remains vegetative, with a rosette of large leaves from a tap-rooted crown, until it is vernalised (George, 1985; Hare *et al.*, 1987). After vernalisation, a primary reproductive stem is produced from the crown that flowers when approximately 1-2 m tall (Rumball, 1986). Axillary branches are formed on the primary stem. In autumn vegetative secondary shoots are produced from the crown that are dormant over winter (Lancashire and Brock, 1983). It has been observed that seed crops of chicory are long lived over five years (J. G. Hampton, personal communication), but that grazed forage chicory is short-lived, with more than half of the plants dying within two years (Li *et al.*, 1997a, b).

Grazing and cutting intensity and frequency have been shown to affect the morphological development, and thereby the productivity and persistence, of several tap-rooted perennial forages, such as lucerne (*Medicago sativa* L.), red clover (*Trifolium pratense* L.) and birdsfoot trefoil (*Lotus corniculatus* L.) (Nelson and Smith, 1968; Leach, 1969, 1979; Volenec *et al.*, 1987; Bowley *et al.*, 1988), and appear likely to have similar effects on forage chicory. For example, Li *et al.* (1994, 1997a) found that grazing controlled the primary shoot growth and stimulated secondary and axillary shoot development of chicory. Primary shoots were the major feed supplier in spring, whereas the major contributors to herbage mass in summer and autumn were the secondary and axillary shoots for chicory under grazing conditions.

Crown buds are important for many tap-rooted perennial forages as the spring growth starts from them. For lucerne and birdsfoot trefoil, plants produced many crown buds during autumn and these buds overwintered and were initiated in early spring (Nelson and Smith, 1968). Both species also developed many new buds from the crown during spring, but the crown of birdsfoot trefoil was inactive during summer, and active again in early autumn (Nelson and Smith, 1968). Smith (1972) stated that defoliation during autumn reduced the number of crown buds available for growth in lucerne in spring. Stem bud development largely depended on the remaining stubble, which was closely related to defoliation intensity. There were more shoots when cutting height was high because there were more sites available for regrowth after cutting for lucerne (Leach, 1968). However, bud development of forage chicory has been rarely studied.

The objectives of the research were to determine the changes in morphological development of forage chicory when defoliated at different intensities and frequencies, and at different growth stages to enable more effective defoliation managements to be developed.

7.3 MATERIALS AND METHODS

Four field experiments and two glasshouse experiments were conducted from 1993 to 1996 at the Pasture and Crop Research Unit (PCRU), the Deer Research Unit (DRU) and the Plant Growth Unit (PGU), Massey University, Palmerston North, New Zealand.

7.3.1 Expts 1 and 2: Morphological development of marked plants under grazed and ungrazed conditions

Two experiments were carried out from September 1994 to April 1995 at PCRU (Frewen block) and at DRU, respectively. 'Grasslands Puna' chicory, a commercial cultivar released in 1985 in New Zealand (Rumball, 1986), was used in these experiments. It was in its first growing season at PCRU and its third growing season at DRU. Mature aged Romney ewes, and red and hybrid (0.25 elk : 0.75 red) deer were used as grazing animals at PCRU and DRU, respectively. At PCRU, the crop was grazed to stem stubble of 50-100 mm until mid January, and thereafter to 100-150 mm at 2 week intervals (see Li *et al.*, 1997a for details), whereas the crop at DRU was grazed to stem stubble of 100-150 mm with approximately 5 week intervals before January and 7.5 week intervals afterwards (see Li *et al.*, 1997b for details). Details of climate, soil type, fertility level and fertiliser application at each site were given in Li *et al.* (1994, 1997a).

A transect technique (Bircham and Hodgson, 1983), with 10 plants in each 2 m transect, was used to mark plants. Twelve transects with 120 plants were randomly located in four plots, three transects in each plot as subsamples, at PCRU and at DRU under grazed conditions. At PCRU, another 12 transects with

120 plants were marked in ungrazed plots. All marked plants were monitored once a month. The number of leaves, stems and shoots, the lengths of shoots, and the crown diameter of each marked plant were recorded. Leaf, stem and shoot were further separated into primary, secondary and axillary parts, respectively.

An entire branch with a set of leaves and stem, if any, was defined as a shoot, whereas a stem was defined as a shoot with stem. The initial shoots coming from the crown were defined as 'primary shoots', lateral shoots coming from the crown as 'secondary shoots', and all the shoots coming from axils of primary and secondary shoots as 'axillary shoots'. The definitions were applied to all experiments.

Data for year 1 ungrazed and grazed chicory and year 3 grazed chicory were analysed separately in each situation by the SAS GLM procedure using the model of repeated measures (SAS Institute, 1990) over the season.

7.3.2 Expts 3 and 4: Effect of grazing on bud and leaf numbers

Two experiments were undertaken from September 1993 to May 1994 at PCRU (Moginie block) and DRU, respectively. Puna chicory used in these experiments was in its second growing season at DRU and its fourth growing season at PCRU. Grazing animals were the same as in Expt 1. At DRU, a similar grazing management was used as in Expt 1. At PCRU, four grazing intensities, 0-50, 50-100, 100-150 and 150-200 mm stem stubble, were used with four blocks in a Latin square design. The grazing frequency was three weeks before January and five weeks afterwards (see Li *et al.*, 1994 for details). Details of climate, soil type, fertility level and fertiliser application at each site were given in Li *et al.* (1994, 1997b).

At DRU, pre- and post-grazed primary, secondary and axillary leaf numbers were counted each month by digging out 20 plants inside and outside of two exclosure cages (1 × 2 m). The number of buds on the crown (crown buds) and stems (stem buds) of pre-grazed plants were also recorded at each measurement. At PCRU, crown and stem bud numbers were counted by digging out 10 pre-grazed plants from each plot as subsamples. All buds of 2-10 mm in length were counted.

The bud numbers at PCRU were averaged over all treatments as there were no significant differences between treatments. Crown and stem buds were compared using a model for two treatments in a completely randomised design (SAS Institute, 1990) for each month on each site, respectively. The data for pre- and post-grazed primary, secondary and axillary leaf numbers at DRU were analysed each month using the same model as that for bud number analysis.

7.3.3 Expt 5: Effect of defoliation intensity on leaf and shoot numbers

The experiment was carried out in a glasshouse from 14 September 1993 to 15 March 1994. Only Puna chicory was used in this experiment and seedlings were vernalised artificially for four weeks (4-5°C) before treatments were applied. There were three plants per pot. A standard long term medium was used, made up of peat and pumice (3:2 by volume) amended with lime (1.0 kg/m^3), dolomite (3.0 kg/m^3), and Osmocote® (long term 8-9 m, 2.0 kg/m^3 and short term 3-4 m, 1.0 kg/m^3) as a base starter fertiliser. The pot size was 280 mm in diameter and 300 mm in depth. Air temperatures were maintained by heating or ventilating at 10-15°C/25-30°C (night/day). All pots were automatically watered with liquid nutrients (1 g/l) twice daily (5 min each time). The liquid fertiliser used was Peters® Professional water soluble NPK fertiliser (27 + 6.5 + 10) plus trace nutrients (Mg, B, Cu, Fe, Mn, Mo, Zn). See Li *et al.* (1997c) for details.

The experimental design was a completely randomised design (CRD), with five cutting heights (0, 50, 100, 150 and 200 mm above media level) and four replications. For the 0 mm cutting treatment, buds on the crown were uninjured. There were five defoliations in total at 3-week intervals. At each defoliation, 20 pots were destructively harvested and the remaining pots were cut to the treatment heights. The number of primary, secondary and axillary leaves and shoots was recorded at each defoliation. For brevity, only the data for the two extreme treatments, the 0 and 200 mm cutting heights, are presented. Treatments were compared using a CRD model (SAS Institute, 1990) at each defoliation.

7.3.4 Expt 6: Comparison of the morphological characteristics of cultivars

The experiment was conducted from 10 March 1995 to 9 January 1996. Three chicory cultivars, 'Grasslands Puna', 'PG90' and 'Orchies', were used. 'Orchies' is a root type cultivar bred in France for the extraction of the reducing sugar inulin, and 'PG90' is a selection from the Italian leaf vegetable type Spadona (A. V. Stewart, personal communication).

Seeds of Puna, PG90 and Orchies chicory were sown directly into pots in autumn (10 March 1995), three plants per pot were established, and seedlings underwent vernalisation over winter. The pot size, medium preparation, water and nutrition supply, and environment in glasshouse were all the same as in Expt 5. Pesticide, fungicide and bactericide applications were fully described in Li *et al.* (1997c).

Three cultivars with four replicates were arranged in a randomised complete block design (RCB). The defoliation intensity was 100 mm above media level and frequency was three weeks between defoliations, five defoliations in total. The defoliations began and finished three weeks later for Orchies than for Puna and PG90 because of slower phenological development. At each defoliation, four pots in each cultivar were destructively harvested and the remaining pots were cut to the designated treatment heights. The number of primary, secondary and axillary leaves, stems, shoots and crown diameter of each plant were recorded at each defoliation.

All data were analysed using the SAS GLM procedure (SAS Institute, 1990). Four pots of Puna were accidentally destroyed early in the experiment, therefore, type III sums of squares were used for the F-test whenever missing data were involved. The three cultivars were compared for the number of leaves, stems and shoots, and crown diameters using a RCB model for each defoliation. As there were no significant differences in the number of leaves, stems and shoots between cultivars until weeks 9 and 12, only the results of the last two defoliations are reported.

7.4 RESULTS

7.4.1 Morphological characteristics of marked plants over seasons

Year 1 chicory only developed one primary shoot at the beginning of the season (Figure 7-1a, b), whereas year 3 chicory started with about four primary shoots (Figure 7-1c). The primary shoot of year 1 chicory stayed alive throughout the season under ungrazed conditions, while the number of primary shoot(s) decreased over time under grazing for both year 1 and year 3 chicory. Axillary shoots increased greatly for both year 1 and year 3 chicory regardless of whether or not they were grazed (Figure 7-1a, b, c). However, the axillary shoots were generated from different positions on the plants. All axillary shoots of year 1 chicory were from the primary shoot under ungrazed conditions, whereas axillary shoots on grazed plants were from both primary and secondary shoots, and secondary stem borne axillary shoots were the major proportion of axillary shoots during summer and autumn under grazing for both year 1 and year 3 chicory. No secondary shoots developed until March (autumn) under ungrazed conditions for year 1 chicory (Figure 7-1a). In contrast, the number of secondary shoots increased quickly from November onwards under grazing for both year 1 and year 3 chicory (Figure 7-1b, c). There were large decreases in axillary shoots in April for both year 1 and year 3 chicory under grazing (Figure 7-1b, c).

The total stem numbers had similar patterns for both year 1 and year 3 grazed chicory (Figure 7-1e, f). Compared with axillary shoots, the development of axillary stems was one month later under grazing for both year 1 and year 3 chicory. In contrast, for year 1 ungrazed chicory, the development of axillary shoots and stems was almost simultaneous (Figure 7-1a, d). For year 3 chicory, primary stems increased from October till December, and remained about one stem/plant over summer, then decreased from February onwards (Figure 7-1f). Nearly all secondary shoots produced in autumn remained vegetative under ungrazed conditions (Figure 7-1a, d).

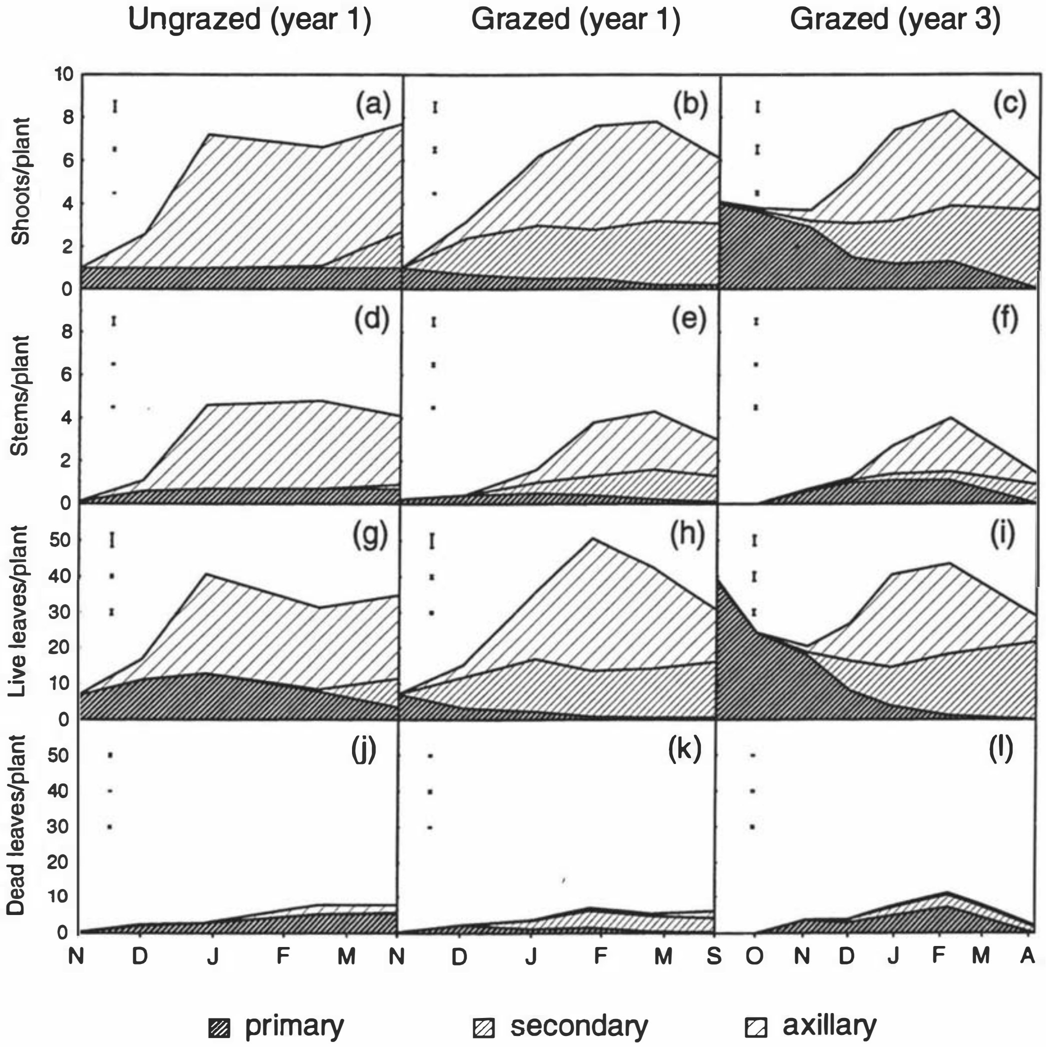

Figure 7-1 (a-l) Morphological characteristics of year 1 and year 3 Puna chicory under ungrazed and grazed conditions. Vertical bars represent s.e.m. of axillary (top), secondary (middle) and primary (bottom) parts of chicory in each figure (d.f. = 12 for ungrazed year 1 chicory; d.f. = 15 for grazed year 1 chicory; d.f. = 18 for grazed year 3 chicory). Letters on x-axis are the initial letters of months.

When chicory was left ungrazed, primary leaf numbers remained relatively stable during spring and summer, and decreased in autumn due to senescence (Figure 7-1g). In contrast, primary leaf numbers decreased over time under grazing, especially for year 3 chicory (Figure 7-1h, i). Axillary leaves increased greatly in late spring and early summer regardless of whether or not they were grazed, and reached a peak in summer under grazed and ungrazed conditions. Axillary leaves decreased in autumn under grazing for both year 1 and year 3 chicory (Figure 7-1g, h, i). There were no secondary leaves until mid-February when plants were ungrazed, whereas secondary leaf numbers increased from November onwards under grazing, and remained at relative stable levels over the rest of the season for both year 1 and year 3 chicory (Figure 7-1g, h, i).

For year 1 chicory, there were more dead primary leaves for ungrazed than for grazed plants, and from January onwards most dead leaves were secondary leaves under grazing (Figure 7-1j, k). For year 3 chicory, most dead leaves over the season were primary leaves, except in September when there were no dead leaves (Figure 7-1l). Few axillary leaves died under any of the conditions (Figure 7-1j, k, 1).

There were significant differences in primary shoot length between ungrazed and grazed year 1 chicory (Table 7-1). The primary shoot length reached its peak in March under ungrazed conditions, whereas the length of the primary shoot was less than 72 mm over the season under grazing, except for the initial length in November. When plants were ungrazed, there were no secondary shoots until January and the lengths were less than 17 mm, except in April (125 mm). However, the lengths of secondary shoots under grazing were over 57 mm from December onwards. There were no significant differences in axillary shoot length over the season except in December (Table 7-1). Crown diameters were significantly greater for grazed plants than ungrazed plants from January onwards (Table 7-1).

Table 7-1 Shoot length (mm) and crown diameter (mm) of year 1 Puna chicory under grazed and ungrazed conditions over the season

	Nov	Dec	Jan	Mar	Apr
Primary shoot					
Ungrazed	240	485	797	881	706
Grazed	289	72	48	19	20
s.e.m. (d.f. = 3)	14.3	85.9	107.4	83.5	72.6
significance	ns	*	*	**	**
Secondary shoot					
Ungrazed	0	0	1	17	125
Grazed	0	57	78	92	111
s.e.m. (d.f. = 3)	–	4.0	1.9	11.8	20.0
significance	–	**	**	*	ns
Axillary shoot					
Ungrazed	0	9	90	158	155
Grazed	0	29	62	90	77
s.e.m. (d.f. = 3)	–	3.4	18.3	34.7	31.6
significance	–	*	ns	ns	ns
Crown diameter					
Ungrazed	7	8	9	10	10
Grazed	8	9	14	16	15
s.e.m. (d.f. = 3)	0.2	0.3	0.6	0.3	0.8
significance	ns	ns	**	**	*

– not applicable.

* $P < 0.05$; ** $P < 0.01$; ns, not significant. $n = 4$.

7.4.2 The development of crown and stem buds under grazing management

There were more crown buds than stem buds during spring and early summer ($P < 0.05$) for year 2 chicory, but no differences for the rest of the season. Over the season, crown buds increased from early spring till early summer, then decreased and maintained a lower level over the autumn with more buds in April and May, whereas stem buds remained relatively constant over the season (Figure 7-2a). Although there were no significant differences in either crown buds or stem buds between grazing intensities for year 4 chicory (data not presented), the seasonal patterns of crown and stem buds were different. There were more buds on the stems than on the crowns during summer, but there were more crown buds than stem buds in spring and autumn (Figure 7-2b).

7.4.3 The seasonal dynamics of leaf numbers under grazing management

The overall pre-grazed leaf numbers increased over the season for year 2 chicory. However, the positions of leaves were different at different periods. Nearly all the leaves pre- and post-grazing during early spring were primary leaves. The secondary and axillary leaves started to develop from late spring and they were the major contributors to total leaf number from December onwards (Figure 7-3). There were less than three primary leaves per plant after December. There were significant differences in total leaf numbers between pre- and post-grazed plants except in early spring and early autumn (Figure 7-3). There were no significant differences in secondary leaves between pre- and post-grazed plants in February-April. The axillary leaf number was more variable with significant differences between pre- and post-grazed plants in January ($P < 0.01$), April ($P < 0.05$) and May ($P < 0.01$).

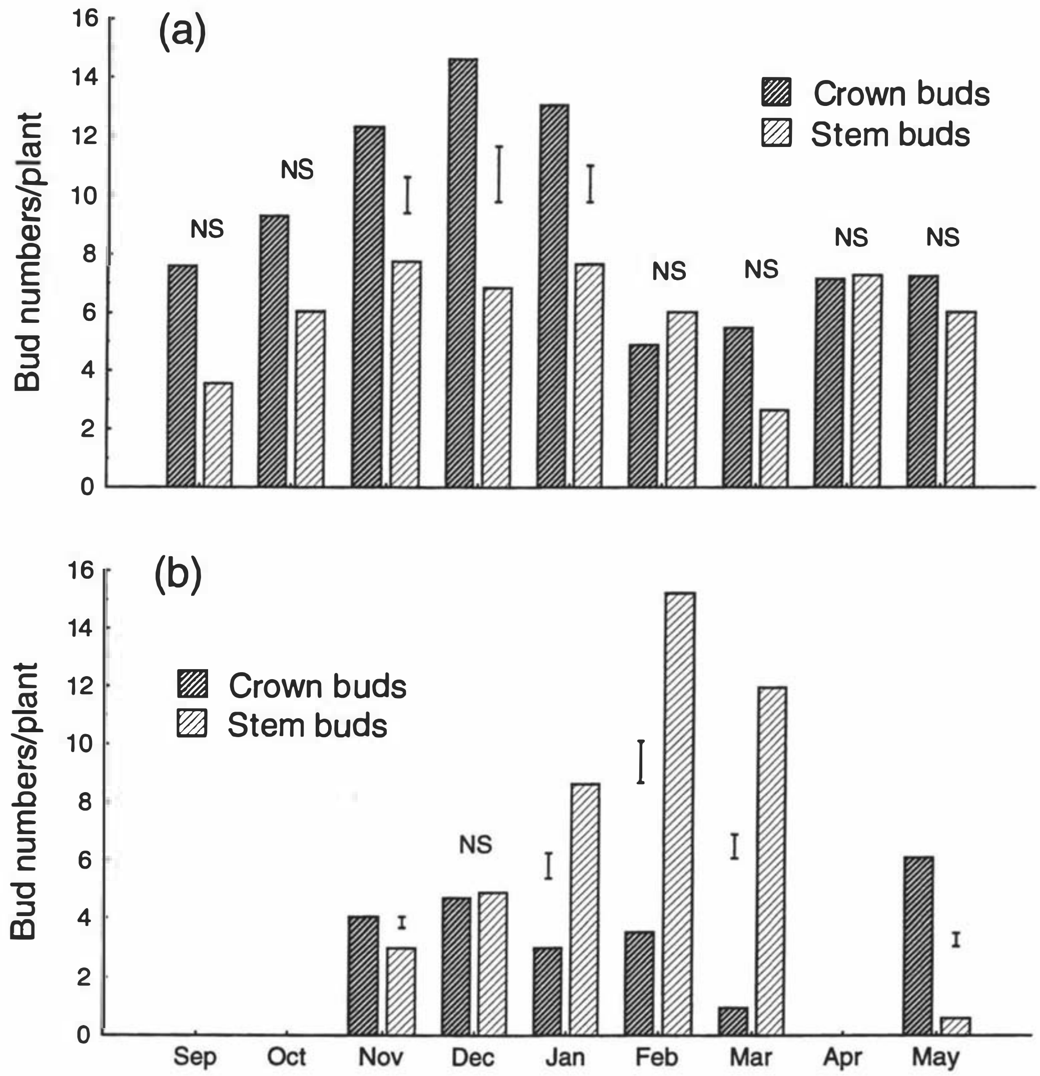

Figure 7-2 Buds on crown and on stems for (a) year 2 (n = 20) and (b) year 4 Puna chicory (n = 16). Vertical bars represent s.e.m. (d.f. = 38 for year 2 chicory; d.f. = 30 for year 4 chicory; NS, not significant).

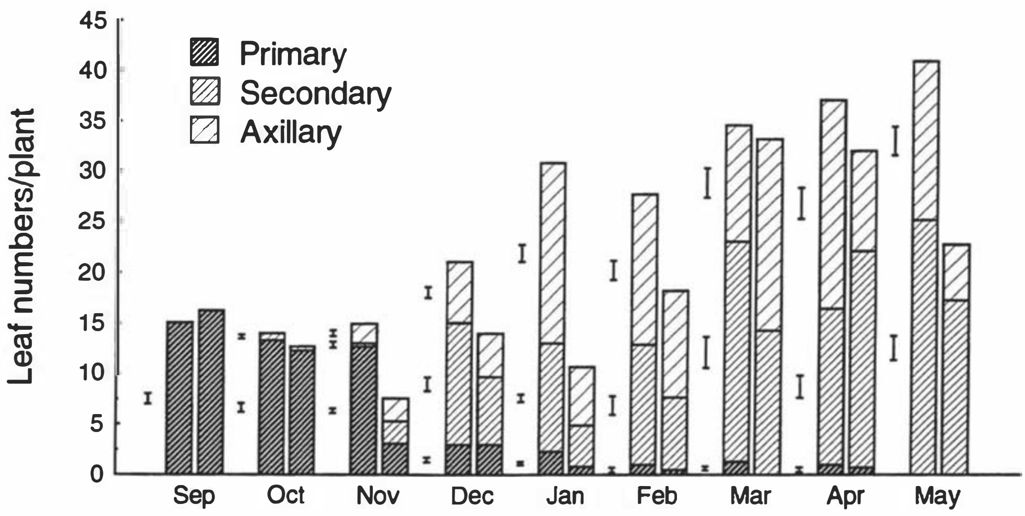

Figure 7-3 Primary, secondary and axillary leaf numbers per plant of year 2 Puna chicory under grazing management over the season. In each group left bars represent pre-grazed leaf numbers (n = 20) and right bars represent post-grazed leaf numbers (n = 20). Vertical bars on the left side of each group represent the associated s.e.m. (d.f. = 38) of primary (bottom), secondary (middle) and axillary leaf numbers (top), if applicable, between pre- and post-grazed plant parts.

7.4.4 The seasonal patterns of leaf and shoot numbers under defoliation

There were significant differences between the 0 and 200 mm cutting treatments in primary, secondary and axillary shoots per plant from week 6 onwards (Table 7-2). The 0 mm cutting significantly suppressed primary and axillary shoot numbers, but stimulated secondary shoot development from week 3 compared with the 200 mm cutting. Accordingly, there were more primary and axillary leaves under the 200 mm cutting treatment than the 0 mm cutting treatment from week 6 onwards, and the primary leaf response was even earlier (Table 7-2), whereas secondary leaves did not entirely follow the same trend as secondary shoots. However, there were significant differences in secondary leaves between the 0 and 200 mm cutting treatments at weeks 3 and 9 (Table 7-2).

Table 7-2 Leaf and shoot numbers per plant of Puna chicory for the 0 and 200 mm cutting height treatments in glasshouse conditions

		week 3	week 6	week 9	week 12
			Leaves/plant		
Primary	0 mm	25.6	20.4	2.2	0.0
	200 mm	39.7	45.5	33.9	15.6
	s.e.m.(d.f. = 6)	2.26	4.14	5.54	4.19
	significance	**	**	**	**
Secondary	0 mm	56.1	71.2	132.5	122.3
	200 mm	30.3	50.1	48.5	88.3
	s.e.m.(d.f. = 6)	8.33	16.63	15.12	16.53
	significance	*	ns	*	ns
Axillary	0 mm	0.7	0.0	1.2	3.8
	200 mm	3.3	15.0	94.5	106.1
	s.e.m.(d.f. = 6)	2.40	6.03	31.53	20.78
	significance	ns	*	**	**
			Shoots/plant		
Primary	0 mm	1.0	0.8	0.2	0.0
	200 mm	1.0	1.0	1.0	1.0
	s.e.m.(d.f. = 6)	–	0.10	0.06	0.00
	significance	–	*	**	**
Secondary	0 mm	5.8	6.9	12.2	10.9
	200 mm	2.5	2.7	2.3	4.1
	s.e.m.(d.f. = 6)	0.64	1.48	1.01	1.09
	significance	*	+	**	**
Axillary	0 mm	0.3	0.0	0.6	1.8
	200 mm	1.1	5.0	6.9	11.0
	s.e.m.(d.f. = 6)	0.80	1.93	2.53	2.50
	significance	ns	*	*	**

– not applicable.

+ $P < 0.10$; * $P < 0.05$; ** $P < 0.01$; ns, not significant. $n = 4$.

7.4.5 Morphological characteristics of three chicory cultivars under defoliation

There were no significant differences between chicory cultivars in the number of secondary leaves, shoots and stems over the whole experiment ($P > 0.05$), and there were no significant differences in the number of primary and axillary leaves, shoots and stems between cultivars until week 9 (data not presented before week 9). At week 9, Orchies had not developed axillary shoots, but had similar numbers of primary leaves to PG90 (Table 7-3). The number of axillary leaves was similar for both Puna and PG90 at week 9. Orchies had the highest number of primary leaves and the lowest number of primary stems among cultivars at week 12, whereas PG90 was the opposite with the highest numbers of axillary leaves, shoots and stems among the cultivars at week 12 (Table 7-3). The numbers of primary and axillary leaves, shoots and stems of Puna were intermediate at week 12 compared with the other two cultivars (Table 7-3). The crown diameter of Orchies was significantly thicker than those of Puna and PG90 throughout the experiment (Table 7-4).

Table 7-3 Leaf and shoot numbers per plant of Puna, PG90 and Orchies chicory for the 100 mm cutting height treatment in glasshouse conditions

	Primary	Secondary	Axillary	Primary	Secondary	Axillary
	week 9			week 12		
Leaf						
Puna	5.3	32.4	44.5	12.5	7.1	84.1
PG90	24.4	34.4	38.8	9.0	9.8	122.3
Orchies	25.5	7.8	0.0	34.3	10.4	1.4
s.e.m.(d.f. = 5)	4.83	11.21	8.82	5.27	5.52	25.96
significance	*	ns	*	*	ns	*
Shoot						
Puna	0.8	5.1	5.7	0.8	0.5	8.1
PG90	0.9	3.7	11.5	0.9	1.0	13.5
Orchies	0.9	0.9	0.0	0.9	0.8	0.3
s.e.m.(d.f. = 5)	0.12	1.17	1.53	0.16	0.43	3.17
significance	ns	ns	**	ns	ns	*
Stem						
Puna	0.6	0.7	1.6	0.5	0.4	1.6
PG90	0.8	0.8	1.2	0.9	0.4	8.0
Orchies	0.2	0.0	0.0	0.1	0.0	0.0
s.e.m.(d.f. = 5)	0.19	0.47	0.66	0.21	0.18	1.36
significance	ns	ns	ns	*	ns	**

* $P < 0.05$; ** $P < 0.01$; ns, not significant. $n = 4$ for PG90 and Orchies, $n = 3$ for Puna.

Table 7-4 Crown diameter (mm) of Puna, PG90 and Orchies chicory for the 100 mm cutting height treatment in glasshouse conditions

	week 0	week 3	week 6	week 9	week 12
Puna	27	22	21	25	25
PG90	21	24	22	24	24
Orchies	40	40	38	41	41
s.e.m.(d.f.)	1.2 (6)	1.6 (5)	2.1 (5)	2.7 (5)	1.0 (5)
significance	**	**	**	**	**

** $P < 0.01$. $n = 4$ except for Puna at week 3 onwards, where $n = 3$.

7.5 DISCUSSION

During its first growing season, Puna chicory produced two separate growths from the crown when left ungrazed. Axillary shoots with stems, generated from the primary shoot, dominated the canopy during the first growth. Lack of secondary shoot development during the first growth may have been due to the very active growth of upper branches. The second growth, with a few vegetative secondary shoots, started in autumn after most of the seed matured. Smith (1962) observed that during a growing season at Madison, Wisconsin, Vernal lucerne produced three separate growths from the crown when left uncut, whereas uncut Empire birdsfoot trefoil produced only one growth from the crown (spring), and subsequent growth arose from the upper axillary buds on the previous growth. In contrast, grazing stimulated the development of secondary shoots, but suppressed the development of the primary shoot for both year 1 and year 3 chicory. Axillary shoots, however, developed fully regardless of whether or not plants were grazed. These findings were in agreement with the results on a dry weight basis for chicory (Li *et al.*, 1994, 1997a, b). The decrease in axillary shoots as well as leaves in autumn was simply due to grazing, as axillary leaves were the most easily accessed feed for livestock.

Ungrazed chicory produced more stems, presumably low in quality (Clark *et al.*, 1990b; Li *et al.*, 1997a) compared to grazed chicory. However, grazing resulted in more secondary stem development, but pushed the date of axillary stem emergence back one month later than no grazing. The height of fully developed chicory (average length of the primary shoot), based on individual plants, was less than 1 m in its first growing season as some of the marked plants were very small and remained vegetative throughout the season when ungrazed. This height was much lower than that recorded by Rumball (1986) (over 2 m). It is possible that this report referred to maximum height, but the age of the plants was not noted.

Year 1 chicory normally had one primary shoot with one crown. The crown enlarged as the plant aged, especially under grazing (Table 7-1) due to rapid development of secondary shoots. The enlarged crown split apart during the next growing season and formed multi-crowned plants. Secondary shoots survived over winter to become primary shoots in the following season as they had their own crowns, as evidenced by more than two primary shoots per plant after the second growing season (Li *et al.*, 1997b). In the current experiment, year 3 chicory started with about four primary shoots in spring (Figure 7-1c). A similar phenomenon has been observed for lucerne plants (Nelson and Smith, 1968; Leach, 1979).

The initial spring growth of chicory was from the crown as it is for many tap-root perennial forages (Nelson and Smith, 1968). The large number of crown buds in spring and early summer ensured continuous generation of secondary shoots under grazing management for year 2 plants. The crown buds on mature plants decreased in late summer, and increased in autumn. The autumn crown buds survived over winter and supplied initial growth in spring. Similarly, Nelson and Smith (1968) found that the crown of birdsfoot trefoil was active in early spring and early autumn, developing many new buds, but inactive in summer. The dynamics of stem buds reflected the dynamics of axillary shoot development, which was related to primary and secondary stem development. Therefore, good grazing management should aim at preserving crown bud development to maintain productivity and persistence. Chicory has been shown to be sensitive to hard grazing at these times (Li *et al.*, 1997a).

Primary leaves were the main source of feed for livestock during spring. The number of primary leaves was unaffected by grazing during early spring as they all developed from the crown before stem elongation. When stems started to elongate, grazing removed most of the primary leaves, including the stem with its apical growth point, which initiated the development of secondary and axillary shoots. From December onwards, secondary and axillary leaves replaced the primary leaves as the major feed resource for livestock. The development of axillary leaves was closely related to the development of secondary shoots with large variation under grazing conditions. Mechanical topping in February (Li *et al.*, 1994) removed many axillary growth sites but stimulated the growth of secondary shoots. However, the retained stubble made the secondary leaves less accessible to livestock, resulting in no significant difference in secondary leaves between pre- and post-grazed plants in February-April. There was a period of leaf flush in late autumn (May), which was probably important for plants to replenish root carbohydrate reserves. However, autumn grazing significantly reduced both secondary and axillary leaf numbers, which might be detrimental to the persistence of chicory (Li *et al.*, 1997a).

Repeated 0 mm defoliations totally eliminated primary shoot growth but maximised secondary shoot and leaf numbers. In contrast, the 200 mm defoliation treatment left the primary shoot growing with little interruption and allowed the axillary shoots to fully develop. Although the number of axillary shoots and leaves under 200 mm defoliation was similar to the number of secondary shoots and leaves under the 0 mm defoliation treatment, the mass produced was less as axillary leaves were smaller than secondary leaves (Li *et al.*, 1997c). The shoots closer to the crown were more vigorous and larger in size for both lucerne and birdsfoot trefoil (Leach, 1968, Nelson and Smith, 1968). Leach (1969) found that on the lucerne plants the first shoots on the plants cut most severely grew larger than those on the plants cut less severely. However, for chicory rapid development of secondary shoots was at the expense of decreased root mass (Li *et al.*, 1997c).

Although Orchies had a significantly larger crown than the other two cultivars, there were no differences in the number of secondary shoots developed from the crown compared with Puna and PG90. The dry mass produced from secondary shoots was also the same for all three chicory cultivars (Li *et al.*, 1997c). This suggested that the bud numbers on the crown were similar for all three cultivars. The early development of secondary shoots suggested that all buds on crowns were formed and vernalised over winter. The initial growth of secondary shoots was triggered by defoliation which released the apical dormancy. This was confirmed by the results from Expt 1 where no secondary shoots developed until autumn when plants were left uncut (Figure 7-1a, d, g). However, the larger crown of Orchies did supply more sites for primary leaf development as evidenced by more primary leaves produced on Orchies, especially at week 12 (Table 7-3).

The development of axillary shoots depended on the available sites on primary and secondary shoots and varied with cultivars. PG90 is a fast growing and erect cultivar (A. V. Stewart, personal communication). The fully developed primary stem supplied more axil sites and an axillary shoot developed from the axil of almost every completely-opened leaf on the primary stem, compared with Puna which had a slower stem development. However, these axillary shoots lignified quickly with poor feed quality although they produced a large number of small leaves. The morphological development of Puna was intermediate between Orchies and PG90 with more axillary leaves and stems at week 9 and less axillary leaves and stems at week 12 compared with PG90. The low number of primary leaves in Puna could be increased by selecting for enlarged crown size.

Overall, defoliation altered the normal growth pattern of chicory. Defoliation, such as 50-100 mm in height with 3 week intervals in spring and 100-150 mm with 5 week intervals in summer and autumn, controlled the growth of primary stems, and stimulated the development of secondary shoots to maximise the leaf formation and minimise the stem development. The unwanted axillary stems in summer were not controlled by defoliation and mechanical topping would be the only way to remove them. Autumn defoliation should be avoided as it may affect the formation of crown buds, resulting in poor plant vigour in the following season.

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8. GENERAL DISCUSSION

8.1 INTRODUCTION

HERBAGE YIELD, nutritive value and persistence are key parameters to evaluate a plant species. Chicory has been proven to be an excellent forage with high yield and quality (Hare *et al.*, 1987; Clark *et al.*, 1990a; Niezen *et al.*, 1993), except for the rapid reproductive stem growth and relatively poor persistence (Lancashire and Brock, 1983; Clark *et al.*, 1990b; Hume *et al.*, 1995). Despite previous research, there was still a need to understand the growth and development of chicory and its response to defoliation. A series of field and glasshouse experiments were conducted to study the persistence and the seasonal patterns of herbage mass production and morphological development of forage chicory under defoliation. The results were discussed in detail in Chapters 3-7. In this chapter, an integrated general discussion will be focused on the relationship between herbage accumulation and plant persistence, and the growth and development of chicory under defoliation. Some practical recommendations will be given at the end of each section.

8.2 HERBAGE ACCUMULATION AND PERSISTENCE

8.2.1 Annual

Herbage accumulation of Puna chicory on well drained, medium fertility silt loam soil with an annual precipitation of 1000 mm in the Manawatu was over 8.5 t DM/ha from November to April under grazing conditions, for at least the first two years. This was similar to the results of other experiments conducted in New

Zealand and USA (Table 8-1). However, herbage production halved in the fourth year. There was a close relationship between plant density and herbage accumulation. Plant density remained constant over the first three year, and decreased in the fourth year. In contrast, plant size (shoots/plant) increased over the years, particularly in the fourth year due to the low plant density (Table 8-1, Chapter 5). It was concluded that the optimum plant density and plant size to maintain high herbage production were over 50 plants/m^2 with 2-4 shoots/plant (Figure 8-1). In the fourth year, although shoot density (shoots/m^2) was similar to the density in previous years, the shoot size (g DM/shoot) was much smaller, resulting in significantly less herbage accumulation compared with younger chicory stands (Chapter 5). The characteristics of a grazed chicory crop that had deteriorated to the point of not being able to accumulate half of its maximum herbage mass were found to be 25 plants/m^2, six or more shoots/plant, or less than 150 shoots/m^2 (Figure 8-1). Stands in this state need to be oversown or cultivated (Figure 8-1).

8.2.2 Seasonal

Chicory is a summer active species and responds quickly to temperature increases (Lancashire and Brock, 1983). Most of its annual yield was distributed in spring and summer (Table 8-2), except for year 1 chicory in the current research where limited spring growth was due to lateness of sowing (late autumn) (Chapter 4). A similar pattern was exhibited by chicory in mixed pastures (Hume *et al.*, 1995). Chicory was dormant in winter (Rumball, 1986) as confirmed by the negligible growth rates.

The plant density decreased over the growing season, with a significant decline during late spring and early summer where hard grazing was applied to control primary reproductive stem growth (Table 8-2), especially in the younger stands (Chapters 3 and 5). As plants aged, the influence of grazing on persistence declined. For instance, plant density remained constant during spring and summer for year 4 chicory (Table 8-2). In contrast, plant size (shoots/plant) increased gradually over the growing season, with a shoot flush in autumn (Chapter 3), which was quite important for the persistence and regrowth of chicory in the following season. There was evidence to show that autumn grazing, especially hard grazing, was detrimental to plant persistence (Chapter 4). Therefore, spring and autumn grazing management is critical for the persistence of a chicory crop.

Grazing was one of the major causes of plant death (Chapters 3, 5) due to depletion of the root carbohydrate reserves (Chapter 6). It was observed that sheep graze some plants, particularly the young and small plants, to ground level and remove all shoots above the crown, leaving others to produce reproductive stems. Sheep would re-graze the new growth from previously grazed plants down to ground level again during the next grazing. This repeated hard grazing depleted the root carbohydrate reserves, reduced plant vigour and finally killed the plants, as evidenced by the extreme defoliation treatment (removing all visible buds over 5 mm in length on the crown) in a glasshouse experiment (Chapter 6). Although nearly all plants that died succumbed to diseases eventually, the initial reason for their sensitivity to diseases was poor vigour due to grazing. The only pathogens isolated were *Fusarium* spp. from plant samples from field experiments (Chapter 4), and *Pseudomonas* spp. from plant samples from glasshouse experiments (Chapter 6). *Sclerotinia* spp. were reported to be the cause of plant death in some research (Arias-Carbajal 1994; Hume *et al.*, 1995), but were not observed in any of the experiments reported here.

Table 8-1 Annual total herbage yield and dynamics of plant density and plant size for Puna chicory

	Year 1	Year 2	Year 3	Year 4	Source
Yield (t DM/ha)	4.8	9.5	10.6	6.1	Hume *et al.*, 1995†
	9.5	9.2	n/a	n/a	Jung *et al.*, 1996†
	7.5	7.7	n/a	n/a	Volesky, 1996‡
	8.5*	9.4	-	4.6	Chapters 4 and 5‡
Plant density (number/m^2)	46	30	21	15	Hume *et al.*, 1995
	48	46	n/a	n/a	Volesky, 1996
	66	68	49	24	Chapters 3 and 5
Plant size (shoots/plant)	2.9	2.7	4.1	6.7	Chapters 3 and 5

* Total annual yield measured from November to April.

- Not measured; n/a: not applicable.

† Mixed pastures; ‡ Pure stands.

Figure 8-1 Chicory management decision chart

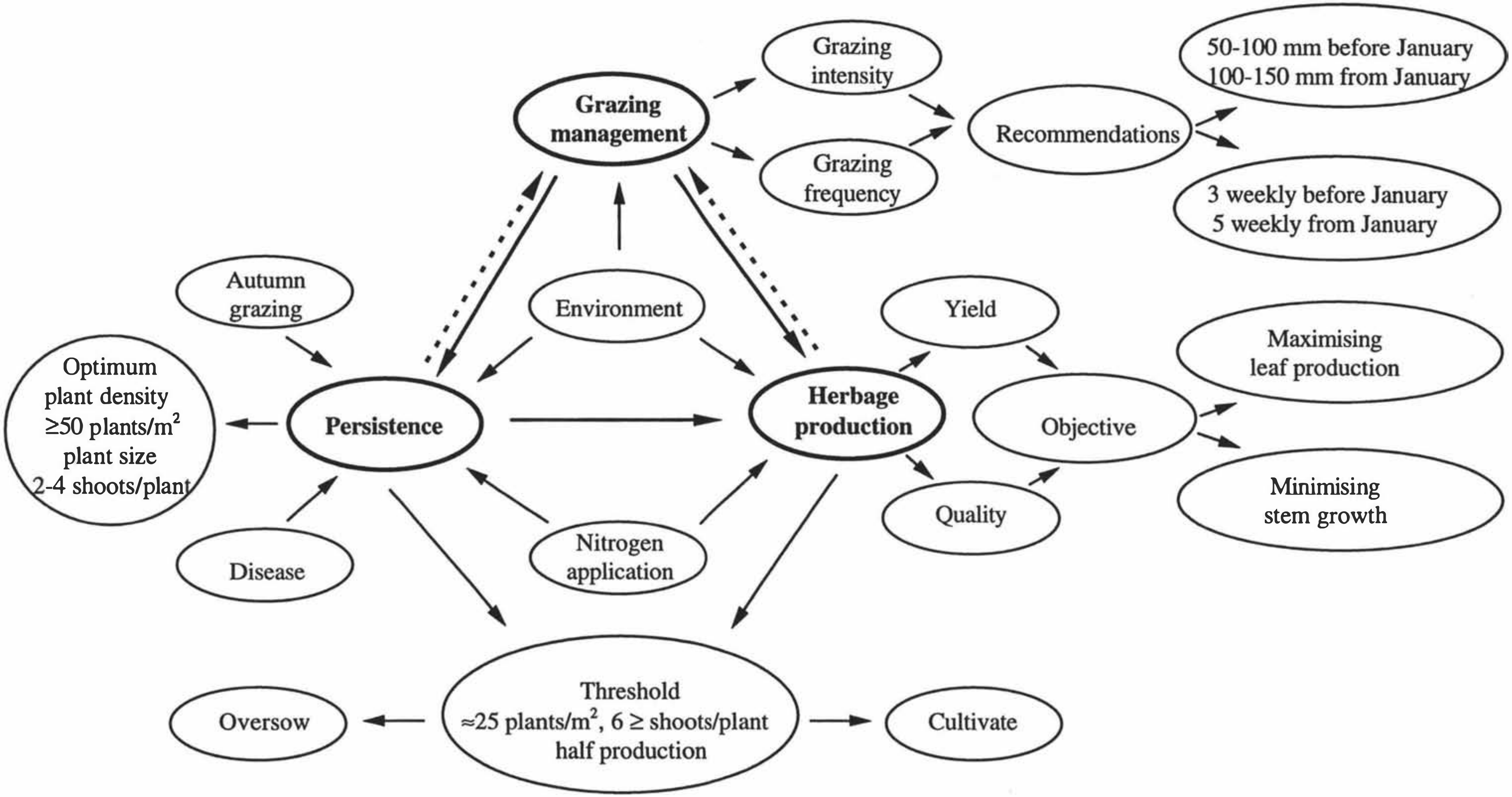

Table 8-2 Seasonal distribution (%) of total herbage yield and relative percentages (%) of plant density and plant size compared to spring as 100% for Puna chicory.

	Year	Spring	Summer	Autumn	Winter	Source
Yield	Year 1-4†	32	49	14	5	Hume *et al.*, 1995
	Year 1‡	21	47	32	-	Chapters 4 and 5
	Year 2‡	37	32	31	-	Chapters 3 and 5
	Year 4‡	43	33	24	-	Chapters 3 and 5
Plant density	Year 1	100	78	73	-	Chapters 4 and 5
	Year 2	100	86	92	99	Chapters 3 and 5
	Year 3	100	82	66	-	Chapters 3 and 5
	Year 4	100	102	90	-	Chapters 3 and 5
Plant size	Year 1	100	135	148	-	Chapters 4 and 5
	Year 2	100	132	159	159	Chapters 3 and 5
	Year 3	100	105	138	-	Chapters 3 and 5
	Year 4	100	118	192	-	Chapters 3 and 5

† Four year average in mixed pastures.

‡ Percentages were based on total yield without winter yield as winter growth rates were negligible.

- not measured.

Unlike legumes, chicory needs an external nitrogen supply. Nitrogen application can increase herbage production, and thus prolong the life span of chicory (Clark *et al.*, 1990b, Figure 8-1). The spring response to 1 kg of nitrogen was 10.6 kg DM/ha (rates up to 50 kg/ha), similar to that of ryegrass and white clover pasture, however, 60% of the response was in stem production (Clark *et al.*, 1990b).

Chicory performed well in mixed pastures (Table 8-1), however, winter dormancy (Rumball, 1986) results in difficulty in selecting companion species (Hare *et al.*, 1987) and balancing feed supply all year round (Hume *et al.*, 1995). Further work is need to study the response of chicory to defoliation when it is used in mixed pasture.

8.3 GROWTH AND DEVELOPMENT UNDER DEFOLIATION

Appropriate grazing management controlled the growth of primary reproductive stems in spring, but did not prevent the development of secondary stems in summer and autumn (Chapters 3-5), indicating that all buds produced in the previous year were vernalised through winter. Axillary stems, however, developed fully regardless of whether or not plants were defoliated (Chapter 7). However, primary leaves and stems were the main source of feed from chicory for livestock during spring, and secondary and axillary leaves during summer and autumn (Chapters 3-5).

The key issue in chicory management is to maximise leaf production and minimise stem production through grazing (Moloney and Milne, 1993; Hume *et al.*, 1995, Figure 8-1). Clark *et al.* (1990a) suggested the optimum leaf to stem ratio is 70%:30%. Grazing intensity had no effect on the total leaf production

(Clark *et al.*, 1990b, Chapters 3-6), but increased the proportion of stem as grazing intensity decreased (Chapter 3). The 0-50 mm grazing intensity produced the greatest leaf production, whereas the 150-200 mm intensity had the greatest stem production for year 4 chicory (Chapter 3). However, there were no significant differences in either leaf or stem mass between grazing intensities (hard and hard-lax grazing) for year 1 chicory (Chapter 4). Grazing frequency had significant effects on the accumulated leaf and stem mass (Clark *et al.*, 1990b, Chapters 4). In the current research, the 4-week interval treatment accumulated the highest leaf and stem mass, and the 1-week interval the lowest (Chapter 4). Clark *et al.* (1990b) also found that two 4-weekly cuts had no effect on persistence or regrowth, whereas four 2-week cuttings to 0 mm decreased plant density and affected regrowth. Studies of root carbohydrate reserves in the glasshouse experiment (Chapter 6) showed that Puna chicory used its root carbohydrate reserves for the regrowth after defoliation, and thus requires time to replete reserves. Therefore, it was concluded that Puna chicory was more sensitive to grazing frequency than grazing intensity. That is, Puna chicory can be grazed closely, but not frequently.

Overall, it was concluded that defoliation at 50-100 mm in height at 3 week intervals in spring, and at 100-150 mm at 5 week intervals in summer and autumn, maximised the leaf formation and minimised stem development of chicory. However, if optimal grazing control is missed in spring, mechanical topping appears to be the only way to remove old stem stubble and control secondary and axillary stem development in summer.

Grazing decreased the plant density of chicory regardless of grazing intensity or frequency (Chapters 3 and 4). Autumn grazing, especially hard grazing, was detrimental to plant persistence (Chapters 4). It was concluded that less grazing pressure through the growing season cannot be used to improve persistence without compromising leaf growth rate, but that avoidance of grazing in late autumn will improve the persistence of chicory.

Results from the glasshouse experiments (Chapters 6 and 7) suggested that Orchies was the most persistent cultivar but had the slowest growth rate, and that PG90 was the least persistent but had the highest growth rate, whereas the performance of Puna was intermediate. It was concluded that the persistency of Puna would be more sensitive to cutting frequency than cutting intensity due to its medium level of root carbohydrate reserves. In contrast, PG90 could be defoliated frequently, but not closely. However, Orchies with its thick taproot was insensitive to cutting intensity and would also be insensitive to cutting frequency due to its larger root carbohydrate reserves. It was suggested that to improve the persistence and enhance the leaf production of Puna by plant breeding the emphasis should be on increasing taproot size without unduly prejudicing herbage mass accumulation.

8.4 CONCLUSIONS

The most important conclusions on the defoliation responses of chicory drawn from this research were:

i) grazing controlled the growth of primary stems, but did not prevent the development of secondary and axillary stems, indicating that all buds produced in autumn were vernalised through winter;

ii) grazing decreased plant density regardless of grazing intensity or frequency, with the significant decrease in late spring and early summer when primary shoots were controlled, suggesting that the main cause of plant death was due to grazing depleting the root carbohydrate reserves; and

iii) autumn grazing, especially hard grazing, was detrimental to plant persistence, suggesting that grazing should cease early enough before chicory stops growing (at least one month) in order to replete the root carbohydrate reserves.

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APPENDIX I

EFFECT OF DEFOLIATION INTENSITY ON THE ABSOLUTE AND RELATIVE GROWTH RATES OF 'GRASSLANDS PUNA' CHICORY†

† This appendix has been accepted for publication in *Proceedings of XVIII International Grassland Congress*, Winnipeg, Manitoba, Saskatoon, Saskatchewan, Canada (Li *et al.*, 1997).

1.1 ABSTRACT

The response of absolute and relative growth of 'Grasslands Puna' chicory (*Cichorium intybus* L.) to defoliation intensity was examined in a glasshouse. Five defoliation intensities (0, 50, 100, 150 and 200 mm above media level), at 3 week intervals with 4 replications were arranged in a completely randomised design. The aboveground relative growth rate of Puna chicory increased exponentially as defoliation intensity increased, resulting in defoliation intensity not decreasing average absolute growth rate until weeks 9-12. However, there were significant differences in belowground mass between defoliation intensities from week 6 onwards. Defoliation above 150 mm, with 3 week intervals, is suggested to maintain aboveground absolute growth rate and belowground mass.

Keywords: Puna chicory, absolute growth rate, relative growth rate, defoliation intensity

1.2 INTRODUCTION

THE REGROWTH of perennial forages after defoliation is critical to the performance of grazing systems. Plant absolute growth rate (AGR) depends on the amount of plant biomass and its relative growth rate (RGR). The removal of biomass by defoliation should result in a reduction in AGR unless defoliation increases RGR in such a way that the loss of biomass is fully compensated for by the increase in RGR (Hilbert *et al.*, 1981; Oesterheld, 1992). The effects of defoliation intensity and the time for recovery from a defoliation event on the aboveground and belowground RGR and AGR of several grasses has been studied (Oesterheld and McNaughton, 1991; Oesterheld, 1992), but there has been no similar study on forage chicory (*Cichorium intybus* L. cv. 'Grasslands Puna'). Our objective was to examine the effect of defoliation intensity on the absolute and relative growth rates of Puna chicory in glasshouse conditions.

1.3 MATERIALS AND METHODS

The experiment was conducted from 14 September 1993 to 15 March 1994 in a glasshouse, the Plant Growth Unit, Massey University, Palmerston North, New Zealand (latitude 40°23' S). Seeds of Puna chicory were germinated in trays (300 × 400 mm) of sand under mist in a glasshouse. Seedlings underwent vernalisation artificially for 4 weeks, 4-5°C at night and 25°C during daylight. When the fifth true leaf appeared, the seedlings were transplanted to pots (PB 28, 16.8 litre in volume, 300 mm in depth), with six plants per pot initially, then thinned to three plants per pot three weeks later. A standard long term medium was used, made up of peat and pumice (3:2 by volume) amended with lime (1.0 kg/m^3), dolomite (3.0 kg/m^3), and Osmocote® (long term 8-9 months, 2.0 kg/m^3 and short term 3-4 months, 1.0 kg/m^3) as a base starter fertiliser. Air temperatures were maintained by heating or ventilating at 10°C-15°C/25°C-30°C (night/day). Liquid nutrients (1 g/litre) were supplied through the automatic irrigation system twice daily (5 mins each time). The liquid fertiliser used was Peters® Professional water soluble NPK fertiliser (27 + 6.5 + 10) plus trace nutrients (Mg, B, Cu, Fe, Mn, Mo, Zn). The experimental design for each harvest was a completely randomised design with 5 defoliation intensities (0, 50, 100, 150 and 200 mm above media level) and 4 replications. Five harvests with 3 week intervals were accomplished. For the 0 mm cutting treatment, crown buds were uninjured. Total aboveground and belowground masses at each defoliation were measured. All mass data are presented on a dry weight basis, oven-dried at 80°C for 48 hours.

The aboveground AGR for each period and belowground mass at each defoliation were analysed by using a completely randomised design model (SAS Institute, 1990). The relationship between aboveground RGR and defoliation intensity was analysed by using a regression model (SAS Institute, 1990).

1.4 RESULTS AND DISCUSSION

The aboveground RGR of Puna chicory increased exponentially as defoliation intensity increased for the first 3 harvests (Figure 1-1a, b, c), similar to the defoliation responses of two perennial grass species, *Briza subaristata* and *Stipa bavioensis* from the flooding pampa of Argentina in a controlled environment (Oesterheld 1992). The aboveground AGRs of Puna chicory were not affected by any defoliation intensities until weeks 9-12 (Table 1-1). However, there were significant differences in belowground mass between defoliation intensities from week 6 onwards (Table 1-1).

Table 1-1 Aboveground absolute growth rate (AGR) and belowground mass for Puna chicory under different defoliation intensities

Defoliation height	week 0-3	week 3-6	week 6-9	week 9-12
	Aboveground AGR (g/plant/week)			
0 mm	4.6	7.2	8.3	3.8
50 mm	4.7	6.8	6.1	5.2
100 mm	2.8	8.3	8.0	5.8
150 mm	2.9	9.0	9.8	7.5
200 mm	5.6	7.9	7.1	11.1
s.e.m.	1.10	1.13	1.47	1.26
significance	NS	NS	NS	**
	Belowground mass (g/plant)			
	week 3	week 6	week 9	week 12
0 mm	38.9	27.7	18.2	17.1
50 mm	37.4	33.7	22.4	22.2
100 mm	38.5	38.8	33.6	26.3
150 mm	41.6	44.8	52.8	45.8
200 mm	41.8	53.9	62.9	55.5
s.e.m.	3.73	2.32	5.33	3.59
significance	NS	**	**	**

** $P < 0.01$; NS, not significant.

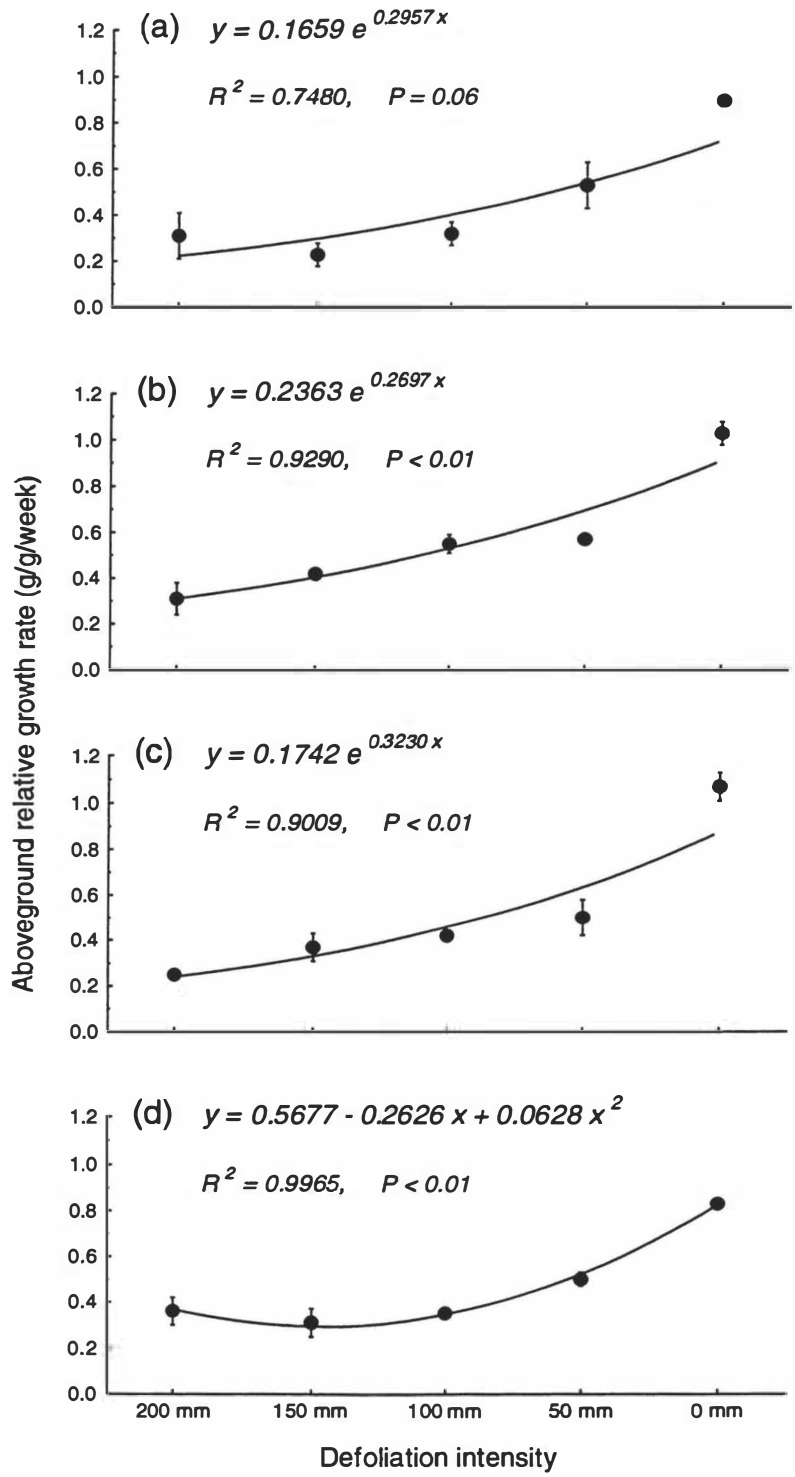

Figure 1-1 Relationships between aboveground relative growth rate of Puna chicory and defoliation intensity at (a) weeks 0-3, (b) weeks 3-6, (c) weeks 6-9 and (d) weeks 9-12.

The aboveground mass removed was fully compensated by the exponential increase in the aboveground RGR over 9 weeks, in agreement with the results of Oesterheld (1992). However, this increase was at the expense of a decrease in belowground mass, suggesting taproots of Puna chicory supplied the most immediate energy for regrowth after defoliation, especially for the 0 mm cutting treatment. Nevertheless, this compensation capacity was depleted by repeated defoliations as the belowground mass decreased continuously, particularly under the more severe defoliation treatments. Eventually, the aboveground AGR decreased significantly as defoliation intensity increased during weeks 9-12. The relationship between aboveground RGR and defoliation intensity during this period was no longer exponential, but polynomial (Figure 1-1d).

More severely defoliated plants would appear to require more time to recover compared with less severely defoliated plants. Belowground mass was unaffected by the 150 and 200 mm defoliations, but declined under the 0, 50 and 100 mm cutting treatments (Table 1-1). It is suggested that defoliation above 150 mm with 3 week intervals will not be detrimental to the persistence of Puna chicory, in agreement with the results from grazing experiments with Puna chicory (Li *et al.*, 1997), but more severe defoliation will be detrimental unless the regrowth time is increased so that belowground mass recovers.

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APPENDIX II

PERSISTENCE OF CHICORY[†]

[†] This appendix has been published in *Proceedings of the 1994 Massey Deer Farmers' Conference*. Linton Camp Community Centre, Manawatu, Palmerston North, New Zealand. pp 56-59 (Li *et al*., 1994).

2.1 INTRODUCTION

DEER HAVE a high demand for quality forage from late spring to autumn. Chicory (*Cichorium intybus* L. cv. Grasslands Puna) is one of the specialist forage crops that have growth rates greater than those of perennial ryegrass (*Lolium perenne* L.)/white clover (*Trifolium repens* L.) pastures over summer. Chicory growth rates are typically in the range of 50-150 kg DM/ha/day over summer (Hare *et al.*, 1987; Matthews *et al.*, 1990), and deer growth rates on chicory exceed those on pastures (Kusmartono, personal communication).

A drawback with chicory is it only persists as a productive crop for three to four years. This relatively poor persistence is due to the decline in plant density (i.e. plants/m^2) over time. Chicory has an initial plant density of approximately 200 plants/m^2. Once plant declines to about 20-30 plants/m^2, low growth rates and weed invasion result in the chicory crop being unproductive.

The causes of the decline in chicory plant density require elucidation if the persistency of chicory is to be improved. Possible causes are treading damage, disease, stress such as drought, and insufficient vegetative bud renewal. This study is aimed at describing the dynamics over one season of the plant density and shoot production of chicory grazed by deer.

2.2 MATERIALS AND METHODS

The experiment was on the Deer Research Unit (DRU) at Massey University. The soil is Tokomaru silt loam. A crop of Puna chicory starting its second growing season was used. The deer were hinds and weaners and were a mix of red deer and Wapiti crosses.

The chicory was rotationally grazed at 3-5 weekly intervals, depending on the growth rate, and was grazed to a stem stubble height of 100-150 mm. Li *et al.* (1994) suggested that this grazing regime results in control of reproductive stem growth and produces high leaf growth rates. There were four replicates of 0.5 ha plots.

Grazing started in October 1993 and finished in May 1994. In January the old stubble was mown to 80-100 mm after grazing. Plant density and shoot number per plant were monitored each month in 28 quadrats (500 × 500 mm) per plot. Data were analysed by repeated measures using the SAS GLM procedure.

2.3 RESULTS

Plant density decreased from 116 to 66 plants/m^2 between October and June (Figure 2-1a). Most of this 43% decrease in plant density occurred in the November-December period. The apparent increase in plant density in April was due to plants reappearing above soil level during the autumn rain that followed the dry summer (Figure 2-1 a).

Shoot number per plant increased throughout the growing season from a low of 1.1 shoots per plant in October to 3.9 shoots per plant in June (Figure 2-1b). Shoot density (shoot/m^2) approximately doubled over the season from 133 shoots/m^2 to 253 shoots/m^2 in June (Figure 2-1c).

2.4 CONCLUSIONS

The decline in plant numbers of chicory was compensated by the increase in shoot number over the season. Although the chicory plant density was permanently decrease by nearly half over the season, this decrease would not have been immediately reflected in the chicory growth rate due to the doubling in shoot density over the season. Nevertheless if a similar death rate occurs in this crop next season it will approach the critical threshold of 20-30 plants/m^2. That is, this crop on the DRU would appear to have a productive life of three years.

The sudden decrease in plant numbers in November-December was unexpected and requires further investigation. The pattern of a sudden decline followed by a very gradual decline in plant numbers suggested that there was a single factor involved in the decline rather than it being due to constant treading or grazing damage or to disease attack. No disease problems were observed. Although this sudden decline in November-December required further confirmation in other experiments and other years we hypothesise that it is due to plant death after producing a reproductive stem or due to an interaction between grazing management and plant development. Whatever the cause of the poor persistency of chicory, there is clearly a need to improve it. Apart from examining grazing management particularly in November-December the oversowing of chicory into low density stands will also be trialled.

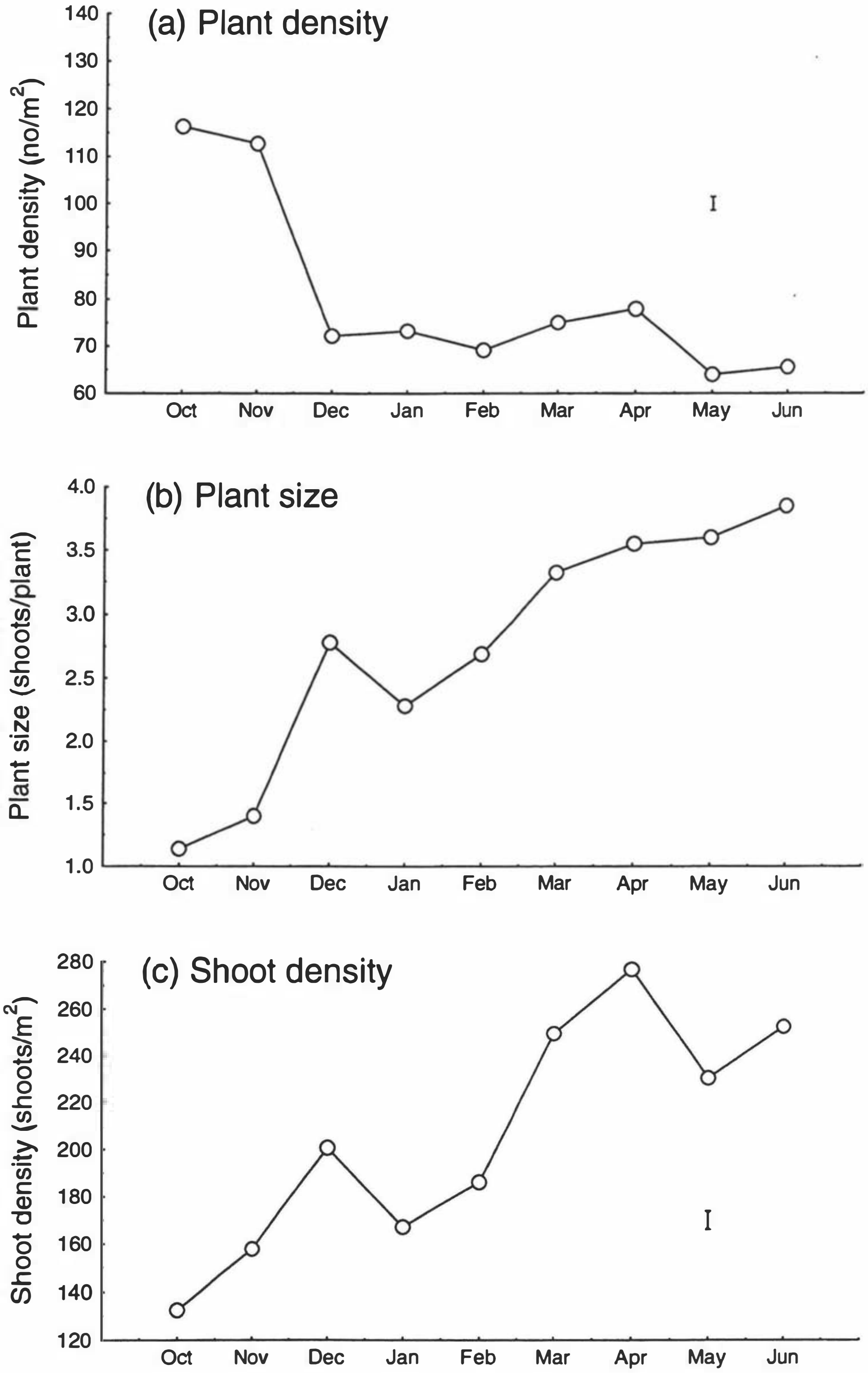

Figure 2-1 Plant density and plant size over the season. Vertical bars represent s.e.m.

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APPENDIX III

PERSISTENCE OF PUNA CHICORY UNDER GRAZING MANAGEMENT†

† This appendix has been published in *Proceedings of the 1995 Massey Deer Farmers' Conference*. Linton Camp Community Centre, Manawatu, Palmerston North, New Zealand. pp 89-93 (Li *et al.*, 1995).

3.1 INTRODUCTION

CHICORY IS an important feed for deer farming because of its high feed value (Hoskin *et al.* 1994), high animal performance (Kusmartono *et al.*, 1994; Niezen *et al.*, 1993) and its fast vegetative growth rate during spring and summer (Hare *et al.*, 1987; Li *et al.*, 1994a). Research has shown that introducing chicory either as a pure stand or as a proportion of a farm system improves animal performance. Harvey and Stantiall (1994) reported that introducing 10% or 20% chicory into a farm system would have more stags achieve 92 kg liveweight by end of November. Pasture with no chicory had 70% stags achieve this target whereas pasture plus either 10% or 20% chicory in the system had 86% and 100% stags reaching the target. A pure chicory stand boosts the growth of weaners to faster than that on pasture, especially for hybrid stags (Kusmartono *et al.*, 1993).

The plant density of chicory stands declines rapidly with age (Smith, 1995). Within one year, the decrease in plant density is large and variable (Li *et al.*, 1994b). This study aimed to confirm the hypothesis that plant density decreases the most during November-December, and to attempt to find the reason for this decrease.

3.2 MATERIALS AND METHODS

Plant density and plant size of chicory were observed monthly over 20 months from September 1993 to April 1995 at the Deer Research Unit (DRU), Massey University, Palmerston North. The Puna chicory crop was sown in 1992 and it was in its second and third growing seasons. The grazing animals were hinds and weaners of red deer and of hybrids of red deer and Wapiti.

The chicory was rotationally grazed to a stem height of 100-150 mm at three to five week intervals from October to May every growing season. The plots were mowed once to 80-100 mm after grazing in January-February each year to clean up the inedible stubble.

All the measurements were made in four 0.5 ha plots, each plot being one replicate. Plant numbers were counted in ten $0.5 \times 0.5\ m^2$ quadrats in each plot. Also, 10 plants were dug from the each plot to count the shoot numbers per plant.

Data were analysed as a pooled completely randomised design by using SAS.

3.3 RESULTS

Plant density decreased 71% from 131 plants/m^2 in September 1993 to 38 plants/m^2 in April 1995 (Figure 3-1a). There was a large decrease in plant density during early spring each year. Plant density decreased 37% and 38% from October to December in 1994 and 1995, respectively. Shoot numbers per plant, on the other hand, increased throughout the season (Figure 3-1b). In autumn each year, there was a rapid increase in shoot number per plant. Shoot number per plant increased 57% (from 2.3 to 3.6) and 46% (from 3.9 to 5.8) from January to April in 1994 and 1995, respectively.

Figure 3-2 shows the percentage of surviving plants from September 1994 to April 1995. Plant numbers decreased about 22% from October 1994 to April 1995 and most of this decrease (15%) happened during November-January.

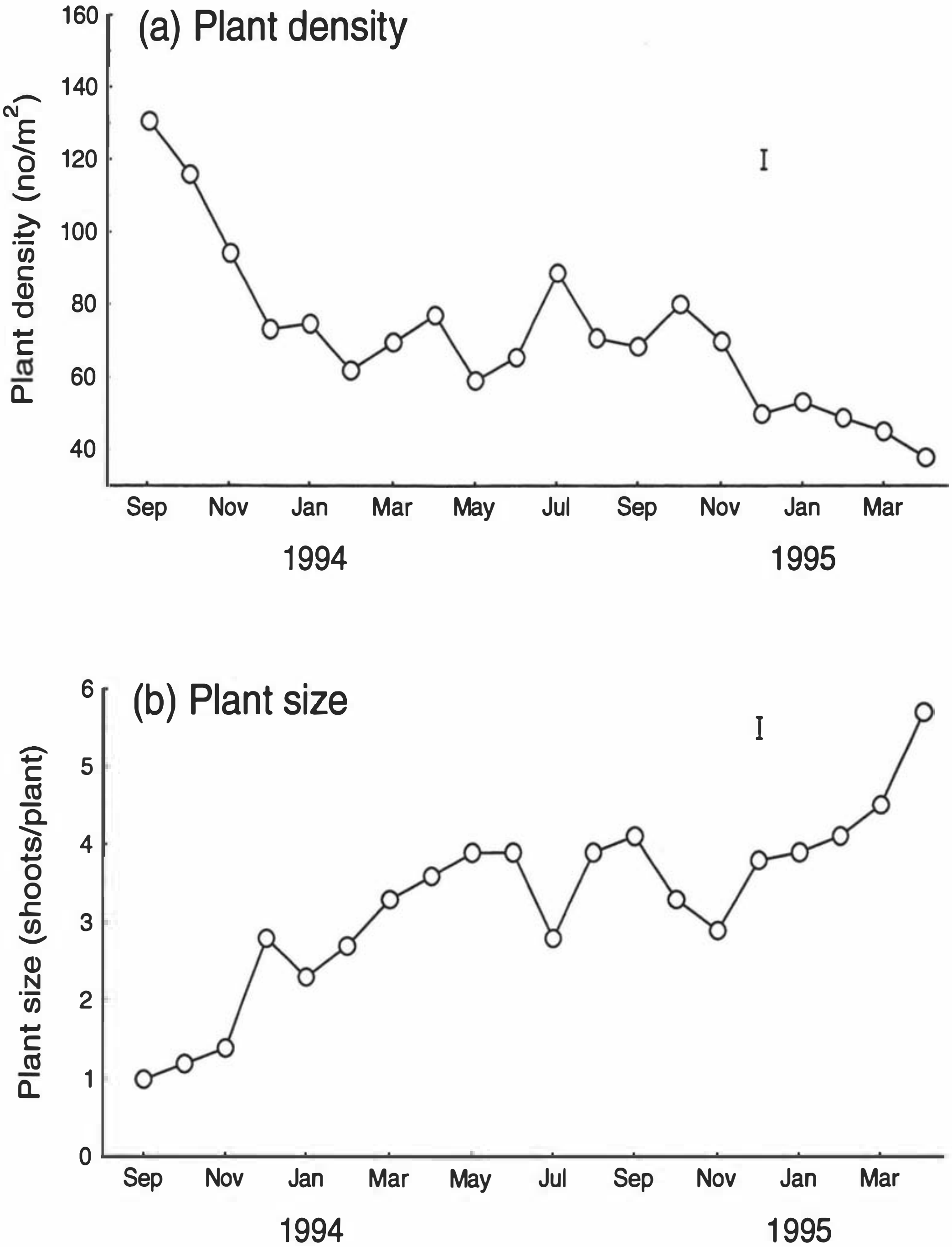

Figure 3-1 Plant density and plant size on the Deer Research Unit over two seasons. Vertical bars represent s.e.m.

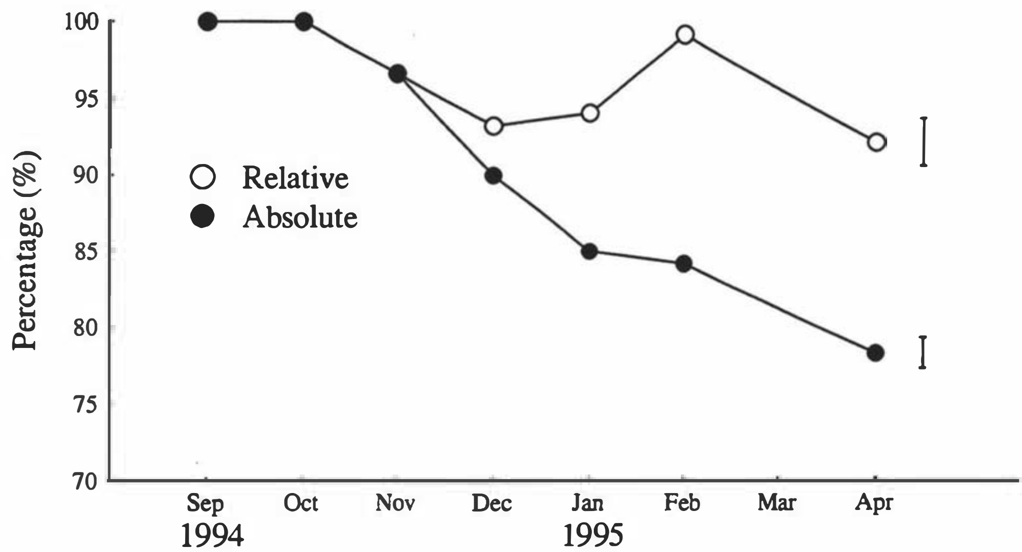

Figure 3-2 Percentage of surviving plants (absolute percentage based on the initial plant numbers in September 1994 and relative percentage based on the previous plant numbers observed). Vertical bars represent s.e.m.

3.4 DISCUSSION

Plant density of chicory grazed by deer decreased by more than 35% each year, with the greatest decrease in spring. Smith (1995) found a similar decrease in chicory density in crops grazed with cattle and sheep in Gisborne, Hawkes Bay and Wairarapa. Observation of individual marked plants of chicory at the DRU confirmed that 68% of the plants died from October 1994 to April 1995 did so during spring (Li, unpublished). The major cause of plant death appeared to be related to the inability of some plants to recover after grazing but the final cause of death was sometimes root rots (*Fusarium* spp.). Therefore, spring is a critical period in the management of chicory, in which chicory has a very high growth rate but also has a high plant death rate.

Hard grazing will decrease stem development but also depress the plant vigour (Li *et al.*, 1994a). Previous research suggested that medium grazing (100-150 mm stem stubble) with a 3-4 week interval will give a reasonable compromise between total herbage production and feeding value (Li *et al.*, 1994a) without excessively prejudicing the persistency of chicory. However, when this management was used on the chicory at the DRU there was still a 35% decline in plant numbers per year. Moloney (1995) recommended harder grazing of chicory in spring and throughout the growing season than used in this trial. It is suggested that severe grazing of chicory in spring (i.e. 50 mm or less stem stubble) is likely to exacerbate the decline in plant density at this time.

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