SULLA (*Hedysarum coronarium* L.); AN AGRONOMIC EVALUATION

A THESIS PRESENTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS

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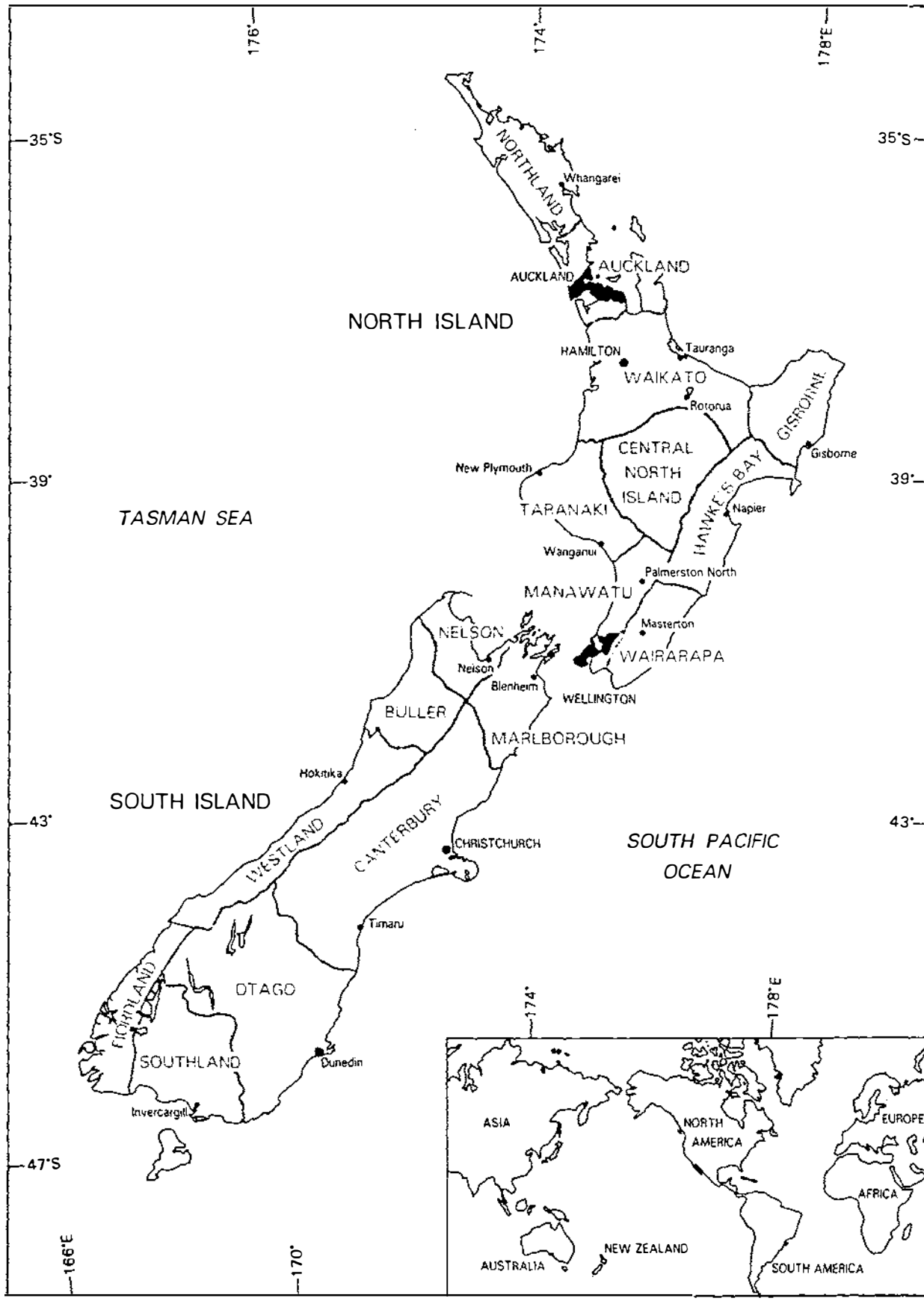
'THERE IS NOTHING GRATEFUL BUT THE EARTH; YOU CANNOT DO TOO MUCH FOR IT: IT WILL CONTINUE TO REPAY TENFOLD THE PAINS AND LABOUR BESTOWED UPON IT'

LORD RAVENSWORTH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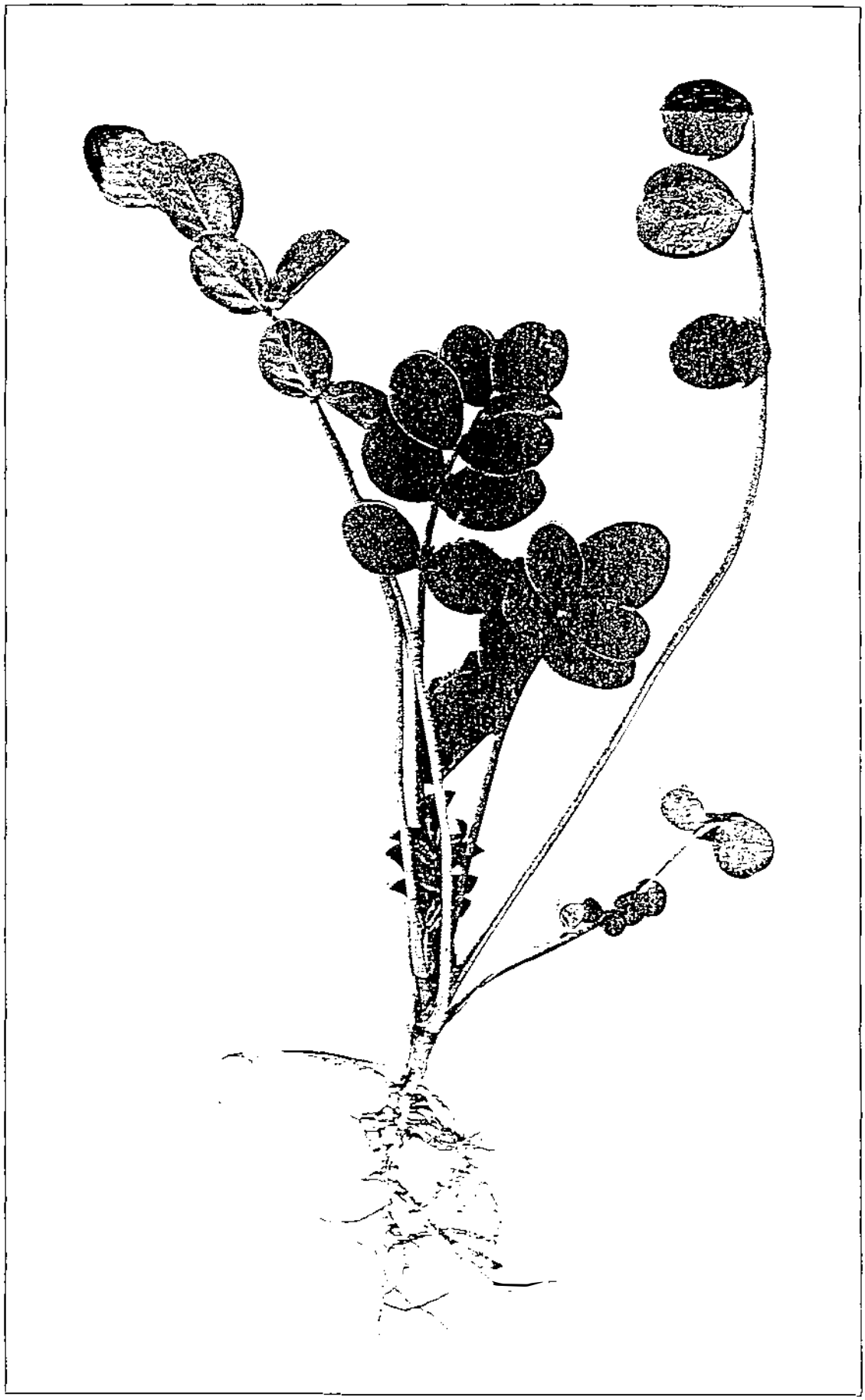

ABSTRACT

This thesis reports three studies conducted on the agronomic evaluation of the recently introduced forage legume species sulla (*Hedysarum coronarium* L.) cv. Necton, for its potential use in animal production systems in New Zealand. The utilisation of forages, grasses and legumes, in New Zealand is predominantly by grazing *in situ*. Sulla was introduced to New Zealand for soil conservation, but its use as a forage under a cutting regime is well known in the Mediterranean countries. Information was inadequate for its use under a grazing regime.

A preliminary study was conducted under sheep grazing to assess annual herbage production, seasonal patterns of DM production and persistence. Nodulation failure resulted in the application of 100 kg N ha^{-1} after each grazing. Severe grazing (H=70-75% herbage consumed) and less severe (L=60-65% herbage consumed) grazing intensities were imposed at the early reproductive (ER) and late reproductive (LR) growth stages. The resultant management treatments over one year were ERHHHH, ERHLLL, ERLHHH, ERLLLL, LRHHH and LRLLL. Grazing intensities did not affect herbage production as residual herbage senesced after grazing. The annual herbage production ranged from 12000-20000 kg DM ha^{-1} in the ERGS and LRGS treatments. Plant density declined 83 and 46% in the ERGS and LRGS respectively. Regrowth originated from the crown region in both growth stages. Autumn grazing management, ineffectively nodulated plants, inadequate weed control and poor stand persistence were identified as constraints to herbage production and needed further research. An effective *Rhizobium* strain ICMP 10149 was reisolated, and a concurrent trial elsewhere, not by the author of the thesis, identified Stomp 330 E a preemergent herbicide as suitable for sulla.

A greenhouse defoliation trial was conducted to elucidate the influence of plant growth stage at defoliation and grazing intensity on herbage accumulation in the absence of compounding factors such as selective grazing and trampling. Plants were defoliated to 1, 7, 15 and 30 cm at the late vegetative (LV), midstem elongation (MSE) and early flowering (EF) growth stages. Across growth stages, the residual leaf area was 0, 84, 180 and 415 cm^2 respectively. Destructive harvests were carried out on days 0, 14, 25, 40 and 60 after defoliation. Plant maturity at defoliation and defoliation intensity were determinants of herbage increase in 60 days of regrowth. Complete (1 cm) defoliation at the LV growth stage resulted in

a smaller root system, decreased starch accumulation and reduced plant size. Defoliating to 15 cm at the EF growth stage produced the maximum regrowth of herbage, maintained high taproot starch and root mass.

A grazing trial was designed to evaluate annual herbage production, seasonal patterns of DM production and plant persistence in an effectively nodulated stand with minimum weed competition. Severe (H=70-80% herbage consumed) and less severe (L=60-70% herbage consumed) grazing intensities were applied at the late vegetative (LV), midstem elongation (MSE) and early flowering (EF) growth stages. LVHHHH, LVLLLL, MSEHHHH, MSELLLL, EFHHH and EFLLL were the resultant management treatments over one year. Grazing intensity did not influence herbage produced as the postgrazing herbage senesced. Across intensities, the annual herbage produced ranged from 22000-25000 kg DM ha^{-1} for the various growth stages. Herbage accumulation rates were 55 kg DM ha^{-1} d^{-1} in early summer and peaked at 78 kg DM ha^{-1} d^{-1} in late summer and early autumn. Plant density declined 79, 74 and 29% over a year in the LV, MSE and EF treatments respectively and remaining plants subsequently disappeared. Late autumn grazing in wet soil conditions resulted in significant plant losses which affected spring herbage production.

Sulla was best grazed or cut at the EF growth stage for maximum herbage production and persistence. Complete removal of herbage maximised utilisation as remaining stubble senesced and did not contribute to herbage accumulation. Under grazing sulla was short-lived and thus should be managed as an annual forage species. Allowing seed to shatter may be a potential management tool for the maintenance of stands. An autumn sowing for spring utilisation to exploit winter growth activity may be advantageous. However, late autumn grazing especially with high stocking densities under wet soil conditions should be avoided, and, in general, damage to the crown should be minimised. Although a residual leaf area (200 cm^2) on the stubble would improve the rate of regrowth this would appear difficult to attain under grazing. It may be best to cut sulla to exploit its winter growth activity. Sulla has potential as a special purpose forage when summer and autumn/winter pasture deficits restrict animal production.

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CHAPTER 1. GENERAL INTRODUCTION AND OBJECTIVES

Sulla (*Hedysarum coronarium* L.), a herbaceous short-lived perennial legume of Mediterranean origin, was introduced in New Zealand principally for soil conservation. However, in a recent review (Watson, 1982) its potential use as a forage plant was emphasised. Subsequent work (Douglas, 1984; Douglas & Foote, 1985; Foote, 1988; Rys et al., 1988; Graham Kerr, unpublished data) have shown high annual herbage production potential ranging from 12000-19000 kg ha^{-1} in the Manawatu, Hawke's Bay and the Canterbury plains.

Sulla has been shown to be a high producer of herbage DM, has the ability to fix its own N, and is winter active in mild conditions. Also, Marshal et al. (1979) and Barry (1988) have identified the presence of condensed tannins in leaves and stems of sulla. It is known that forages containing condensed tannins are associated with reduced incidences of frothy bloat (Kendall, 1966).

In New Zealand, bloat is a critical problem in dairy cattle, but is not yet a serious problem in beef cattle or in sheep. The national annual loss of dairy cattle by death from bloat from 1964 to 1971 was 0.2 to 1.2% with mortality in individual herds exceeding 10%. The total annual losses for all aspects of bloat is likely to exceed $8 million (Clarke & Reid, 1974). Moreover, in a recent survey Towers (1984) estimated the annual losses due to bloat may well be in the region of $17 million.

High concentrations of condensed tannins in plant material may restrict voluntary intake and depress rumen fibre digestion. Lower concentrations however, appear to be beneficial through protecting dietary protein from degradation in the rumen and increasing the protein available for subsequent digestion and absorption (Barry, 1989). Condensed tannins in sulla ranged from 40-50 g kg^{-1} DM and did not suppress voluntary intake and resulted in high body growth rates in the trials of Rys et al. (1988) and Terrill et al. (1992). Also, lambs grazing *Lotus corniculatus* Car., another condensed tannin-containing forage, have consistently produced less fat in their carcasses than those fed on white clover (Purchas & Keogh, 1984). The lower fat content of lambs may be due to protein protection from tannin. Investigations at AgResearch Palmerston North have indicated that the condensed tannins in sulla

may be related to increased liveweight gains in lambs with high nematode burdens (Waghorn & Niezen, 1992). Consequently, farmers may reduce the need for drenches.

Thus, the possible role of sulla, in animal production systems based upon the grazing of fresh temperate forage plants (grasses and legumes), becomes apparent. However, previous research with sulla by others in New Zealand has been on seed production for soil conservation or herbage production under a cutting regime. No documented work on the grazing management of sulla is known to the author. In addition, basic information such as seasonal production, persistence under grazing and problems associated with its agronomy is scarce. This series of experiments were undertaken to gather information on the grazing management of sulla and other relevant aspects on its agronomy, and assess its possible role as complementing pasture in animal production systems in New Zealand.

CHAPTER 2. LITERATURE REVIEW

2.1 INTRODUCTION

In the first section, literature covering all aspects of the agronomy of sulla is reviewed. Relevant papers on its agronomy needed to be translated from Italian, as there is insufficient literature in the English language. In the subsequent sections, where particular aspects such as defoliation and herbage production, shoot growth and nonstructural carbohydrates were studied, the well documented literature on *Medicago sativa* L. is also reviewed and used as a model.

2.2 BOTANICAL CLASSIFICATION, ORIGIN AND DISTRIBUTION

The genus *Hedysarum* belongs to the family Leguminosae, subfamily Papilionoideae, tribe Hedysareae and subtribe Euhedysarinae (Polhill, 1981). The generic name is derived from two Greek words 'hedys' meaning 'sweet' and 'saron' meaning 'broom'. Some 70-100 species of annuals, biennials and perennial herbs, subshrubs or shrubs are widely distributed throughout the northern hemisphere. A large number of native *Hedysarum* species are found throughout North Africa, Southern Europe and the Near and Middle East. Species commonly known to have value as forage in the semi-arid and arid regions include *H. coronarium* L., *H. humile* L., *H. pallidum* Desf non Biv., *H. spinosissimum* L., *H. carnosum* Desf., and *H. flexuosum* L. (Kernick, 1978). In Northern America, about 10 species of *Hedysarum* occur in the Western United States ranging from Alaska to Dakota, New Mexico, Nevada and Oregon (USDA Forest Service, 1937). In Canada, *Hedysarum* spp. is frequently found in southwestern Alberta, scattered lightly over the prairies of Manitoba and through southern and central Saskatchewan (Bassendowski et al., 1989). *Hedysarum mackenzii* (Rich.) var. frazeri Boivin was reported to be an important source of forage in the Red Desert of Wyoming (USDA Forest Service, 1937). *H. boreale* Nutt. is the most common species in the United States (Allen & Allen, 1981). *H.boreale*, *H. mackenzii* and *H. occidentale* have a licorice-taproot and are edible (Facciola, 1990).

The plant *Hedysarum coronarium* L. (2n=16) commonly known as sulla, sweetvetch, french honeysuckle (See plate 2.1) is thought to have originated in the

Plate 2.1 SULLA - *Hedysarum coronarium* L.

southern part of the Apennine Peninsula and Sicily which forms part of the Mediterranean centre of origin (Vavilov, 1950).

It is a strongly taprooted biennial or sometimes perennial herb, 30-120 cm high, with moderately leafy, branching, almost erect stems and with branched secondary roots. Aerial parts of the plant are sparsely adpressed-pubescent. Leaves imparipinate; leaflets entire, numerous, 7-15 pairs, 1.5-3.5 x 1.2-1.8 cm, elliptic to obovate-orbicular, glabrous or subglabrous above and pubescent beneath, some finely pellucid-dotted; stipels absent; stipules free or connate, scarious. Flowers are large, showy, pink, red, violet, white and rarely yellow, borne on long peduncles with a crowded raceme of 10-35 flowers 2 cm across; bracts scarious or setaceous; bracteoles setaceous; calyx campanulate; lobes 5, subequal, awl-shaped; standard ovate or obcordate, reflexed, narrowed at the base; wings oblong, shorter than the standard; keel petals obliquely truncate, rarely subarcuate, longer than the wings and standard; stamens diadelphous, anthers uniform; ovary subsessile, 4- to many-ovuled; style filiform, inflexed above stamens; stigma small, terminal. Pods lomentaceous, plano-compressed, deeply indented along both margins and constricted between each seed, segments up to 8, oval, orbicular, or quadrate, readily separable but indehiscent; seeds usually flattened and kidney-shaped (Bentham & Hooker, 1865; Rollins, 1940; Allen & Allen, 1981; Huxley, et al., 1992).

2.3 IMPORTANCE AND BRIEF HISTORY OF THE INTRODUCTION OF SULLA IN NEW ZEALAND

Sulla is naturalised in the central and western Mediterranean basin, North Africa and is widely cultivated in Italy, Sicily, Greece, Spain, Portugal, Tunisia and Morocco (Kernick, 1978) where it is used for hay, silage, green feed and green manure. In southern Italy and Sicily, where 168000 ha of sulla is grown in comparison to 87000 ha of lucerne, sulla has about the same status as lucerne in the United States. Currently 280000 ha of sulla is grown in Italy and the neighbouring islands (Restuccia, 1976).

The plant has been introduced into the regions of Australia which have a Mediterranean climate (Cameron, 1960) and the United Kingdom (Cowling, 1954) and the United States (Duke, 1981). However, its performance in the US is still in

the experimental stage (Duke, 1981).

Sulla is also an important source of honey in the temperate Mediterranean regions. The flowers of sulla are cross-pollinated by bees. The honey bee (*Apis mellifera*) was found to be the best pollinator of sulla (D'Albore, 1983). In Italy, an introduction of 5-8 colonies of honeybees ha^{-1} was found to be satisfactory for seed production (Crane, 1984; Crane & Walker, 1984). The bumble bee has been observed to visit the flowers frequently in New Zealand (Watson, 1982; Krishna, pers comm).

Sulla was first introduced into New Zealand by the Botany Division, DSIR, in 1949, for evaluation as a potential forage legume. Evaluation indicated that sulla behaves much like an annual, and its release was consequently not approved. A possible reason for the short-lived nature of the plant was the lack of a suitable inoculum (Watson, 1982). Subsequently in 1956 sulla was reintroduced by an ex-serviceman, Mr. M. H. Craw of Linton. Seed material was donated to the National Plant Materials Centre, MWD Aokautere, Palmerston North for seed increase and field evaluation. Since 1971, additional genetic material was obtained from the Mediterranean basin for breeding suitable material for soil conservation (Lambrechtsen, 1986; Lambrechtsen & Douglas, 1986).

2.4 BREEDING HISTORY IN NEW ZEALAND

'Necton' and 'Aokau' are the two sulla cultivars known in New Zealand. The breeding objective of 'Aokau', a semi-erect cultivar was for soil conservation. Plant variety rights were granted in 1985 (NZ Plant Variety Rights, 1991). The cultivar was bred by Soil Conservation Centre, Aokautere (GB Douglas, pers comm), from three of the twelve accessions introduced into New Zealand. The accessions that make up 'Aokau' originated from Morocco, Portugal and Italy.

'Necton' sulla was bred by N. Cameron of Agriseeds Ltd., and the cultivar was granted plant variety rights in 1987 (NZ Plant Variety Rights, 1991). The cultivar is described as a semi-erect to erect, and the primary breeding objective was for its use as hay and for grazing *in situ*. It was developed by the open crossing of 15 selected lines of Spanish, Italian, Moroccan, French and Swiss origin and is maintained through generations by open crossing of progeny. The cultivar is similar

in height to 'Aokau' at flowering, but produces more flowering stems (5-20 vs 2-12), has larger central leaflets and more leaflet pairs (N. Cameron, pers comm). Currently, plant variety rights for 'Necton' sulla are sought in Australia (NZ Plant Variety Rights, 1990).

2.5 ECOLOGY - EDAPHIC AND ENVIRONMENTAL REQUIREMENTS

Sulla is best suited to deep, rich calcareous soils with pH ranging from 5.5-8.0, but gives good results in poor Ca rich compact soils. It performs poorly on very acid or saline soils or under waterlogged conditions (Whyte et al., 1953). In the coastal regions of North Africa, natural pastures of sulla are found primarily in clay soils. In Spain, it is known to grow in predominantly limestone soils (Kernick, 1978).

In New Zealand, it grows in any medium to heavy textured well drained soils, but its performance in sandy soils has been found to be poor (Foote, 1988). It has been known to persist on mudstone soils in Northland, Poverty Bay and King Country, limestone rock near Hastings, siltstone soils near Taihape, loess soils near Blenheim and Dunedin, schist soils at Bendigo Station and on soils derived from greywacke at Otematata (Watson, 1982).

Growth and development of sulla is best suited to Mediterranean type climate with characteristically warm summers and wet, mild winters. Morphologically, its deep taproot and numerous branched secondary root system allows an inherent degree of drought resistance. The *Hedysarum* spp have a strong woody taproot and woody crowns. The crown buds are lower than in lucerne, which may give effective protection from mechanical injury and low temperature damage (Bassendowski et al., 1989). It is known to tolerate annual temperatures between 5.7-29.6°C (Duke, 1981). It has been successfully established in New Zealand in sites where annual rainfall ranges from 360-2160 mm (Watson, 1982). The degree of drought and winter hardiness is dependent on the origin of ecotypes. Ecotypes from southern Italy and Sicily are usually more drought resistant, but less frost tolerant, than those from Northern Italy (Grimaldi, 1951), and the North African ecotypes are generally more frost tolerant than those of Italy or Spain (Kernick, 1978). In Australia, its winter hardiness and drought resistance has been observed (Cameron, 1960; Elliot et al., 1980). In the UK, however, its performance at the Grassland Research

Institute, Hurley, has been poor but its winter activity was emphasised (Cowling, 1954). In New Zealand, sulla grows actively in early spring through summer and autumn into early winter, and will exhibit continued winter growth under mild conditions.

2.6 CULTURAL REQUIREMENTS

2.6.1 SOIL FERTILITY

Sulla is a low fertility requiring plant but responds well to artificial and natural fertilisers (Whyte et al., 1953). In low pH soils, it responds well to the application of agricultural lime (Foote, 1988). On sites of low fertility, the rate of application of P and K fertilisers should be done in accordance with soil test results (Watson, 1982). In Italy, 100-120 kg ha^{-1} P_2O_5 and the same amount of K_2O is generally recommended in Ca rich soils (Sarno & Stringi, 1981). In Morocco, an application of 60-80 kg ha^{-1} P_2O_5, 40-60 kg ha^{-1} K_2O, mixed with the soil before sowing, followed by 20 kg ha^{-1} N at sowing has given good results (Kernick, 1978). Molybdenum applied on different soils in central and southwestern Spain has shown clear responses (Ratera et al., 1977). Sulla contributes toward soil fertility by a rapid build up of soil organic matter. It is estimated that two years in pasture produces about 20000 kg ha^{-1} of dry roots, equivalent to about 100 kg of N (Kernick, 1978).

2.6.2 INOCULATION

Rhizobia nodulating sulla appear to be host specific (Casella et al., 1984) and their presence is restricted to areas where sulla grows naturally. As a result, without the proper *Rhizobium* being endemic, artificial inoculation with selected *Rhizobium* strain is critical (Azcon-Aguilar et al., 1982). Studies on rhizobia strains for sulla have shown that these bacteria do not belong to any of the traditional cross-inoculation groups. Also, *Rhizobium* sp. isolates from other *Hedysarum* species do not nodulate *H. coronarium* (Glatzle et al., 1986). The rhizobia strains nodulating sulla are closely related to the classical fast-growing *Rhizobium* spp (Mozo et al., 1988). In Australia, the strains CC 1335 and CC 1337 have proved effective in nodulating sulla (Casella et al, 1984). No effective *Rhizobium* strain is known in New Zealand although NZPA 5410 has been used (Douglas & Foote, 1985). The best

method of inoculating sulla seed is by the use of a peat-based inoculant. Twenty percent (20%) gum arabic appears to be an excellent protector of the rhizobial strain (Rodriguez-Navarro et al., 1991). Production advantages have been reported for effectively nodulated over uninoculated controls (Roponen & Virtanen, 1964; Gurfel et al., 1982; Walsh et al., 1983).

2.6.3 ESTABLISHMENT

A fine seedbed preparation is preferable for a uniform establishment of sulla. In clay soils, the ground should be deep ploughed to 30-35 cm, whereas in medium soils a depth of 20-25 cm is preferable. A minimum of 2-3 cultivations are required after ploughing (Kernick, 1978; Sarno & Stringi, 1981). For forage and seed production, it is recommended that dehulled (hull removed) seeds be used for rapid germination and establishment of a uniform stand (Watson, 1982). Hard seeds usually comprise 15-20% of seed yield, which can be removed by scarification or soaking seed in hot water at 65-75 °C for 1 min (Whyte et al., 1953). Improved cultivars from Italy and Spain possess lower percentages of hard seeds. In New Zealand, the cultivar Necton is known to contain low percentage of hard seeds and a germination of 90-95% (G.Kerr pers comm).

Dehulled inoculated seeds are drilled in rows 15-20 cm apart to a depth of 2-3 cm, although seeds can be broadcast, harrowed and rolled (Sarno & Stringi, 1981). Seed rate recommendations vary widely, but a rate of 8-12 kg ha^{-1} is recommended when dehulled seeds are used (Watson, 1982). A higher seed rate between 25-40 kg ha^{-1} is recommended for unhulled seeds. Thousand seed weight ranges from 4-6 g (Douglas & Foote, 1985). The best soil temperatures for optimum germination range from 10-26°C although germination can take place between 5-6°C (Sarno & Stringi, 1981). Under favourable conditions, germination of dehulled seeds is complete between 5-10 days and unhulled seeds between 15-30 days (Kernick, 1978). Generally, dehulled seeds are used in New Zealand. A higher seed rate ensures a dense stand to facilitate harvesting seed and drying, as widely spaced plants tend to develop thick stems (Whyte et al., 1953). In the Manawatu, early autumn or spring sowing is generally successful (Foote, 1988).

2.6.4 WEED CONTROL

Effective control of weed competition during seedling growth is one of the most important factors in ensuring successful stand establishment. Under most environments sulla cannot effectively compete with fast growing weed species. A dense stand offers some weed control but generally the use of chemicals is necessary. Sulla tolerates a preemergence application of trifluralin at 0.8-1.6 kg ai ha^{-1}, and dinoseb acetate at 4 kg ai ha^{-1}. A postemergence application of dinoseb amine at 1.6 kg ai ha^{-1} and metribuzin at 0.6 kg ai ha^{-1} has been reported to control weeds successfully (Watson & Gilchrist, 1983). Dinoseb as a postemergent at these rates can cause scorching of leaves and suppress growth temporarily, and its use is currently discontinued (O'Connor, 1987). Foote (1988) has given a complete package for weed control in sulla by the strategic use of chemicals.

Before cultivation, glyphosate at 2.16 kg ai ha^{-1} or amitrole plus ammonium at 4.0 kg ai ha^{-1} should be sprayed to kill existing vegetation. Before sowing, trifluralin at 1.0 kg ha^{-1} should be used as a preemergent weed control. For the control of black nightshade (*Solanum nigrum*) or redroot (*Amaranthus* sp), bentazone at 0.96 kg ai ha^{-1} should be used with or without dinoseb at 1.44 kg ai ha^{-1}. For the control of perennial weeds, bentazone at 0.96 kg ai ha^{-1} and/or metribuzin at 0.7 kg ai ha^{-1} can be applied 12 months after sowing. Propryzamide at 1.25 kg ai ha^{-1} or fluazifop-butyl at 0.75 kg ai ha^{-1} offers good grass control. In winter, clovers can be controlled by the use of ethofumesate at 1.6 kg ai ha^{-1}. In autumn, dock (*Rumex* sp) control is offered by asulam at 1.6 kg ai ha^{-1}. Carefully controlled grazing can also aid in the control of weeds.

2.6.5 DISEASES AND PESTS

In New Zealand, the occurrences of diseases and pests in sulla are of minor significance, presumably due to the relatively recent introduction of the forage. Overseas, where the forage is of national importance, as in Italy, powdery mildew (*Erysiphe polygoni*) is a problem (Bonciarelli & Manotti, 1976). In the US, fungi known to infect sulla plants include *Anthostomella lasullae*, *A. sullae*, *Cercospora arimimensis*, *Erysiphe martii*, *E. polygoni*, *Leptsphaeria circinans*, *Phoma hedysari*, *Placosphaeria onobrychidis*, *Pleospora herbarum* and *Uromyces appendiculatus*. It

is also attacked by nematodes of the genus *Meloidogyne* (Duke, 1981). The significance of these diseases, however, is not known. Under poorly drained soil conditions, incidences of *Botrytis*, *Alternaria* and *Stemphylium* spp have been isolated from dying plants (Rys et el., 1988). Plants infected with *Stemphylium* usually exhibit brown flecking on the underside of leaves, which may coalesce to cover the entire leaf. The incidence, however, is sporadic and resistance to attack is known to exist in some ecotypes (Watson, 1982). Spread of disease may be accentuated by treading damage to the crown complex and may increase incidences of disease. Sporadic occurrences of the bean yellow mosaic virus and the alfalfa mosaic virus were observed in Canterbury (G.Kerr pers comm). The alfalfa mosaic virus is a naturally occurring virus in sulla (Edwarson & Christie, 1991).

Sulla appears to be resistant to most of the common pests, including aphids (Foote, 1988), and this may be associated with the high condensed tannin content in its leaves (Bernays, 1981).

2.6.6 MIXTURES

Sulla can be grown as a monocrop, with cereals in rotation, or sometimes in mixtures with other legumes such as lupins, red clover and used as pasture (Whyte et al., 1953; Sarno & Stringi, 1981). In North Africa and Southern Italy, sulla grows in association with *Phalaris truncata* (See plate 2.2), a short-lived perennial species common to calcareous clay soils. In the subhumid zones of Tunisia, mixtures of *Hedysarum coronarium*, *Phalaris truncata* and *Phalaris coerulescens* have attained annual DM production of up to 20000 kg ha^{-1} (Le Houerou, 1984). In New Zealand, sulla may be sown with prairie grass or phalaris and treated as permanent pasture, where it is suitable for erosion control with infrequent grazing. The maintenance of the sulla component in the sward is best achieved by allowing natural reseeding (Foote, 1988).

2.6.7 FORAGE PRODUCTION

Herbage production in New Zealand and overseas is largely assessed under cutting regimes. In Italy, under 490-670 mm precipitation, the average herbage

Plate 2.2 *Phalaris aquatica* found growing in association with *Hedysarum coronarium* L. in experimental plot.

production reported ranged from 7000-13000 kg DM ha^{-1} in the 1st year, 9000-16000 kg DM ha^{-1} in the 2nd year and 8000-15000 kg DM ha^{-1} in the 3rd year. In the lower rainfall regions like Tunisia and Morocco, production ranged between 2400-3600 kg DM ha^{-1} in the 1st year, 3600-6000 kg DM ha^{-1} in the 2nd year and in certain years production peaked at 8400-10800 kg DM ha^{-1} (Kernick, 1978). In New Zealand, Douglas & Foote (1985) and Foote (1988) attained 15400 kg DM ha^{-1} in the 1st year and 12700 kg DM ha^{-1} in the 2nd year. In Canterbury, annual production ranged from 8500-12500 kg DM ha^{-1} with most of the production available in spring and summer (G.Kerr, unpublished data). In the drier regions of the Hawke's Bay where rainfall is less than 1000 mm, the 1st year production ranged from 13500-18600 kg DM ha^{-1} whereas the 2nd year production was from 2300-6200 kg DM ha^{-1} (Rys et al., 1988).

2.6.8 HAY AND SILAGE

Sulla produces nonbloating forage and is readily eaten by all classes of stock. The forage is generally utilised by cutting for hay or silage although it is sometimes grazed. In North Africa, cutting at the beginning of flowering gives the maximum forage production and protein yield (Kernick, 1978). When ensilaged, the crop should be wilted to approximately 30% DM content, and then chopped before being placed in a silage pit. Compaction with heavy machinery is recommended (Kernick, 1978). The thick stems in sulla can pose problems in drying before baling. The cut stems should be rolled to flatten the stems, to facilitate easy drying (T. Phelps, pers comm). Leaves adhere well to the stem when dry, and this is an advantage over lucerne when making hay (Whyte et al., 1953).

2.6.9 SEED PRODUCTION

Sulla is a long-day or short night plant; flowering normally occurs from October through to January (Southern Hemisphere) and seed pods take 3-4 months to develop (G.Kerr, unpublished data). For seed production, an early autumn sowing will produce a crop for seed harvesting the following summer. When spring sown, the stand can be grazed in early autumn and early spring before being closed for seed in October (Foote, 1988). Later closing has resulted in decreased seed yields

(Watson, 1982). An earlier cut of herbage in October, with the aim of reducing the bulk of herbage at harvesting, improves drying and allows the crop to be mown and threshed readily. The necessity of rolling the stand with a roller to assist drying may arise (Watson, 1982).

In Italy, seed harvest takes place when the pods become brown. The crop is cut and dried in the field and subsequently threshed. About 500-1000 kg ha^{-1} of unhulled seed yields approximately 150-250 kgs of dehulled seeds (Sarno & Stringi, 1981). In the Manawatu, dehulled seed yields, averaged over three years, ranged between 300-460 kg ha^{-1} (Watson, 1982; Douglas, 1984; Douglas & Foote, 1985). Regions proposed for potential seed production included Hawke's Bay, Malborough and Canterbury, where dry summers prevail (Watson, 1982).

2.6.10 NUTRITIVE VALUE

Sulla is a nonbloating forage containing 40-50 g kg^{-1} DM of condensed tannins (Marshall et al., 1979; Barry 1989; Terril et al., 1992). It is palatable and readily accepted by stock up to the appearance of first flowers. However, four days after flowering, stems lignify and the plant is soon avoided by stock (Kernick, 1978). The nutritive value of sulla is close to that of red clover, and in spite of stem thickness the crude fibre content of sulla hay is lower than that of lucerne (Maymone et al., 1951). Lamb growth rates on sulla, evaluated over 4 weeks in early summer, gave liveweight gains of 180 g $head^{-1}$ d^{-1} which was comparable to lucerne (Rys et al., 1988). Lamb growth rate on pasture over similar period was 3.5 times lower indicating poor quality pasture on offer. Details on the chemical composition of sulla (Maymone et al., 1951) are presented in Tables 2.1, 2.3 & 2.4. Preliminary studies on the nutritive value of sulla in New Zealand were carried out in Courtenay, Central Canterbury (G. Kerr, unpublished data) and at Massey University (Deadman, 1989). Details of analyses are presented in Tables 2.5, 2.6, 2.7 & 2.8.

Table 2.1 Chemical composition of stem, leaves and inflorescence of sulla. Data presented on a % dry weight basis.

Plant Part	Crude protein	Crude fats	Crude fibre	Ash	N (free extract)
Stem at first bloom	19.37	2.40	43.83	7.82	26.58
Whole plant at same stage	20.25	3.20	22.27	12.32	41.94
Stem at full bloom	7.87	1.31	42.50	7.59	40.73
Whole plant at same stage	18.81	2.79	21.22	12.19	44.99
Stems in advanced bloom	7.50	0.94	46.50	8.42	36.64
Whole plant at same stage	20.44	2.97	18.35	13.74	44.50

Table 2.2 Mineral composition of sulla in 100 g of ash.

Growth stage	Na	K	Ca	Mg	P	S	Cl	Fe	Si
First bloom	10.89	26.40	9.02	1.96	2.74	5.93	3.39	0.60	1.57
Full bloom	10.32	23.64	9.27	2.32	4.93	4.19	3.31	0.70	2.03
Hay	11.38	17.68	13.10	2.47	2.68	3.14	3.16	0.67	2.77

Table 2.3 Vitamin content of sulla at pre-flowering stage

Vitamin	In 100 g green matter	In 100 g dry matter
Beta carotene	2820 IU	18200 IU
Thiamin (Vit. B_1)	300 IU	1935 IU
Riboflavin (Vit. B_2)	230 mg	1485 IU
Tocopherol (Vit. E)	2.86 mg	18.5 mg
1-ascorbic acid (Vit. C)	47.0 mg	310.0 mg

Table 2.4 Total digestible nutrients of sulla on a percentage moisture free basis

Growth stage	Digestible crude protein	Total digestible nutrient
First bloom	13.69	68.3
In full bloom	8.02	57.3
Hay	7.65	47.1

Table 2.5 Some nutritive aspects of sulla cut at the early flowering growth stage (% dry weight basis) at Courtenay, Christchurch.

	Leaf	Stem	Whole plant
Protein	19	5.6	14
Fibre	20	46.0	37
Digestibility	70	40-50	50-60

Table 2.6 Nutrient content of healthy sulla at Courtenay, Christchurch. Samples were taken in late spring.

Nutrient	%	Nutrient	ppm
N	3.50	Fe	307
P	0.24	Mn	59
K	1.30	Zn	18
S	0.57	Cu	8
Ca	1.80	Bo	33
Mg	0.32	Mo	0.1
Na	0.59		

Table 2.7 Predicted *in vivo* digestibility of the feed on offer to grazing lambs (n=3)

Analysis†	Sulla		Pasture	SEM§
	Early vegetative	Late vegetative		
ASH%	9.5	9.8	12.9	0.84
DMD%	84.8	77.6	72.3	1.24
DOMD%	80.8	73.6	68.1	1.06
OMD%	88.3	81.4	77.6	1.22
MJME/KG DM	13.2	12.0	11.1	0.17

Table 2.8 Predicted *in vivo* digestibility of the feed selected by the grazing animal (n=8).

Analysis	Vegetative sulla	Pasture	SEM
ASH%	15.9	22.3	1.04
DMD%	81.5	81.7	0.65
DOM%	73.4	70.1	0.92
OMD%	84.8	85.9	0.80
TOTAL N (% DM)	3.69	2.92	0.50

† DMD=dry matter digestibility
DOMD=digestible organic matter per 100 g dry matter
OMD=organic matter digestibility
MJME=mega joules metabolisable energy

§ Standard error of the mean

2.7 DEFOLIATION MANAGEMENT AND HERBAGE PRODUCTION

2.7.1 FUNDAMENTAL CONCEPTS

Grime (1974) suggested that competition, stress and disturbance are the three major determinants of vegetation balance. Defoliation, defined as the process of complete or partial removal of the above-ground parts of plants, living or dead, by grazing animals or cutting machines (Hodgson, 1979), is considered as disturbance. Defoliation is usually defined in terms of three management variables (Harris, 1978). Firstly, intensity i.e the proportion of herbage removed, usually measured by residual mass, height or leaf area index. Secondly, frequency i.e the time interval between successive defoliations. Finally, timing or growth stage, i.e the date or developmental stage of the forage at the time of defoliation. The effects of defoliation can be quantified in terms of total herbage production, herbage composition, seasonal distribution and changes in plant species composition. The effects of defoliation have normally been measured by the amount of herbage DM per unit area removed (herbage harvested), the amount removed by grazing (herbage consumed) and the amount accumulated between successive grazings (herbage accumulation). These three measures may differ from one another, and none directly measures the actual rates of growth of herbage (Hodgson et al., 1981), which has seldom been measured in cut or grazed pasture.

The response of forages to defoliation has been a subject of considerable research and of several reviews (Donald, 1941; Jameson, 1963; Alcock, 1964; Harris, 1978; Korte & Harris, 1987). Herbage production is usually reduced by more frequent and more intense defoliation, whether by cutting or grazing. More recent investigations show that this generalisation applies to both temperate and tropical forage species in many environments (Humphreys, 1966; Keoghan, 1967; Harris, 1978; Sheaffer et al., 1988). The effect of more frequent and intense defoliation has been attributed to reduced light interception by photosynthetic tissue, depletion of metabolic energy, reduced uptake of nutrients and water and damage to meristem or depletion of root reserves. The relative importance of these factors depends on environmental conditions and forage species (Harris, 1978). In the US, the level of reserve carbohydrates has been a useful indicator of the need for rest from grazing (Dahl & Hyder, 1977). In contrast, the effects of light interception have been

stressed in New Zealand, where nutrient deficiencies are less likely to occur.

Forage survival is associated with the capacity of a forage plant to regrow following imposition of successive defoliation. The herbage accumulation rate of a forage species increases with increased biomass, provided this increases photosynthetic capacity by increasing leaf area and light interception. Both initial growth following dormancy and regrowth following defoliation exhibit a sigmoid growth curve typical of biological organisms. A period of very slow initial growth is followed by a period of rapid increase in biomass which eventually reaches a plateau. At this plateau generally 95-100% of incident light is intercepted, and is commonly referred to as the critical or optimum leaf area index (LAI) when herbage accumulation rate attains a maximum. There generally follows a period of constant growth at this maximum rate (Brougham, 1955). It remains debatable whether there is a clearly defined optimum LAI (Milthorpe & Davidson, 1966), and what determines the length of the linear phase. As biomass accumulation continues, LAI increases to a ceiling where death of leaves lower in the canopy equals the emergence of new leaves. Further regrowth is at an ever diminishing rate, until a ceiling biomass is reached when respiratory and decomposition losses equal photosynthetic gains.

2.7.2 DEFOLIATION MANAGEMENT OF *Medicago sativa* L.

Considerable research on the defoliation management of *Medicago sativa* L. has been conducted, and the basic principles involved in its management are well documented. As there is scant work on the defoliation management of sulla, importance aspects of defoliation management of a taprooted forage plant like lucerne, predominantly in the US, is reviewed.

2.7.2.1 DEFOLIATION BASED ON FIXED INTERVAL

Cutting or grazing at fixed intervals, or using a fixed number of cuts or grazings per season with no particular attention paid to stage of development, is a common practice. Fixed interval defoliation has been extensively studied in *Medicago sativa* L. in the US. Since fixed interval cutting does not account for the effects of environmental conditions and dormancy differences among cultivars, the most satisfactory interval between cuttings will vary with location, climate, and

season of the year (Sheaffer et al., 1988).

A fixed system of cutting, based on calendar or time intervals, may allow easier scheduling of cutting with other field activities, such as irrigation. In the western part of the US, producers of lucerne cutting 6 to 10 times per season use a fixed time interval to schedule cutting during the warmer months, and rely on plant development to schedule cutting during cooler months. However, in northern states, cool, cloudy weather often delays floral development in the first spring regrowth in lucerne. In southern Minnesota, producers frequently cut lucerne before 1 June, regardless of stage of maturity, to avoid the high probability of inclement weather in early June and potential delays in subsequent cutting. It is therefore evident that a combination of cutting by stage of growth and calendar date may be advantageous in the production of lucerne (Sheaffer et al., 1988).

2.7.2.2 DEFOLIATION BY GROWTH STAGE

Defoliating at a specific phenological stage of development in lucerne has been the subject of considerable research (Weir et al., 1960; Feltner & Massengale, 1965; Langille et al., 1965; Smith, 1968; Winch et al., 1970). A cutting schedule based on plant maturity depends on the stage of plant development to indicate the proper time to cut and the number of cuttings possible in a season.

Fixed interval does not consider the effects of environmental conditions and cultivar characteristics on morphological and physiological development. It also disregards the fact that plant maturity on a particular date will vary among years, locations and cultivars. Temperature and cultivar characteristics greatly influence the rate of maturation (Marten, 1970; Smith, 1970; Christian, 1977).

Defoliating according to stage of development is superior to defoliating at fixed intervals in obtaining consistent herbage DM and quality (Weir, et al., 1960; Robinson & Massengale, 1968; Marten, 1970). In three studies from southern to northern Wisconsin in the US, Smith et al. (1966) showed the advantage of cutting whenever the first flowers appeared (10% flowering) until early September, as compared with three cuttings by date. With the first flower cutting regime, yields of crude protein (CP) and *in vitro* dry matter digestibility (IVDMD) from 'Vernal' and 'DuPuits' lucerne were increasingly higher from the south to north because of the

progressively later maturity of the stand. It was concluded that stage of maturity was the best criterion on which to base time of defoliation and ensure high quality herbage over a broad latitude.

In the northern areas where three to four cuttings per season are common, most investigations have shown that cutting winter-dormant cultivars at first flower (10% flowering) is the best compromise to optimise herbage production and nutrient yields and stand persistence (Smith, 1972a). First flower is a stage: (i) that approximates 10% flowering when a near maximum yield of nutrients is attained; (ii) that is easier to recognise than 10% flowering; (iii) when root reserves have been restored to a reasonably high level; (iv) when the herbage accumulation rate began to decrease markedly (Fuess & Tesar, 1968; Nelson & Smith, 1968a).

In contrast, in the southwestern and western US, where winters are milder and non-winter dormant cultivars are grown, cutting at 25-50% flowering ensures high herbage production, reasonable forage quality and good persistence (Feltner & Massengale, 1965; Robinson & Massengale, 1968). Feltner & Massengale (1965) obtained the highest herbage DM by cutting at 10% flowering for 3 years, but later Robinson & Massengale (1968) reported that cutting at 50% bud to 10% flowering did not provide sufficient time for roots to accumulate nonstructural carbohydrate reserves (NSC), resulting in retarded regrowth, reduced production and loss of stands by the summer of the second year. Rapid stand loss occurred when temperatures, especially at night, were extremely high (Feltner & Massengale, 1965; Robinson & Massengale, 1968; Sheaffer et al., 1988).

In low-latitude areas of the northern and southern hemisphere, growth continues slowly throughout the winter months where daylength is inadequate to promote flowering. Under these conditions, flowering cannot be used as guide to cutting and fixed-interval is preferred (Sheaffer et al., 1988).

2.7.2.3 DEFOLIATION BY CROWN SHOOT DEVELOPMENT

In lucerne, regrowth occurs from crown buds and axillary buds on stems. Crown buds are responsible for spring regrowth and are primarily formed during the previous autumn (Grandfield, 1943; Musgrave & Langer, 1977). Additional crown buds also develop in spring before initiation of regrowth (Nelson & Smith, 1968a).

If lucerne is not cut, one or more additional regrowths may originate from the crown during the growing season (Nelson & Smith, 1968a). If cut, regrowth occurs from crown and axillary buds located on the stubble of the previous cut (Leach, 1968; Singh & Winch, 1974). Bud origin and rate of regrowth are influenced by cultivar, stage of cutting and cutting frequency within a system (Sheaffer et al., 1988).

If lucerne is cut at full flowering or at a later stage of maturity when NSC reserves are high, buds on the stubble are more basal, more numerous and more developed (Bibbey, 1960; Leach, 1970a; Singh & Winch, 1974). Meyer & Larson (1975) in North Dakota reported that when 'Vernal' lucerne was cut to a 7.5 cm stubble height at full flower, 92% of the new stems originated from the crown, but for a first-flower cut only 80% of the stems originated from the crown. With a 2.5 cm stubble, all new stems originated from the crown of lucerne cut at first and full flower. Taller stubble provides more sites for regrowth, but may suppress crown bud development (Leach, 1968; Leach, 1979). Langer & Steinke (1965) reported that in systems with frequent cuttings, there were fewer crown buds and regrowth occurred mainly from axillary buds on the cut stems.

2.7.2.4 DEFOLIATION HEIGHT

Defoliation intensity or cutting height can influence herbage production and survival of lucerne when carbohydrate root reserves are reduced by frequent cutting (Monson, 1966; Keoghan, 1967; Janson, 1982; Douglas, 1986). A high stubble provides more photosynthetic area, that in turn furnishes additional energy for initial regrowth after cutting lucerne (Leach, 1968; 1970b). Langer & Steinke (1965) reported that in frequent cutting systems where the number of crown buds was inadequate, a high stubble provides more sites for axillary bud development. For cutting systems that do not deplete NSC reserves, high herbage DM and nutrient yields are obtained with short versus high cutting heights (Van Riper & Owen, 1964; Monson, 1966; Smith, 1972a). In a Wisconsin study (Smith & Nelson, 1967), 'Vernal' lucerne was cut three, four, five or six times before early September for 2 years, leaving stubble of 2.5, 5.0, 7.6 and 15.0 cm. Herbage production decreased as cutting frequency or stubble height decreased. Averaged over all cutting

frequencies, herbage DM decreased as stubble height increased. A high stubble was needed to maintain high herbage production only with the most frequent cutting schedule. Meyer & Larson (1975) reported that for two- and three-cut systems in North Dakota, total seasonal herbage production decreased approximately 1100 kg ha^{-1} for each additional 5 cm of stubble above 2.5 cm to a height of 13 cm. Although cutting at increased heights generally increased forage CP and IVDMD concentrations, yields of CP and IVDMD were greater for 2.5 or 7.5 cm stubble.

Leach (1968) suggested that the advantage of leaving a stubble (5 cm with or without leaves as compared to no stubble) is that there are more sites available for regrowth, and that this may be more important than root NSC reserve level or residual leaf area. Watters & Henderlong (1978) reported that cutting at 13 and 25 cm increased axillary bud development, and resulted in 8 to 76% of new shoots originating above 5 cm on the old stubble. Plants cut at 2.5 cm height at 3- or 4-week intervals maintained NSC levels comparable to a control cut every 5 weeks to a 3-5 cm stubble height. In a greenhouse study, Cowett & Sprague (1962), found that cutting to a 7.5 cm stubble height increased lucerne axillary bud and stem formation, and increased plant DW compared to cutting at a 2.5 cm stubble height. In contrast, Wolf & Blaser (1981) in a field experiment, reported that stems originating from axillary buds on old stems contribute less to herbage regrowth than those originating from the crown buds.

The value of residual leaves has been questioned (Brown et al., 1966; Langer & Keoghan, 1970). Older and less efficient basal leaves may be more of a hindrance than a benefit to regrowth, especially if they photosynthesize slowly, shade the plant base and prevent new shoot development. Similarly, Leach (1968) suggested that the rapidity with which new leaves are formed after cutting may be more important than the amount of leaf area left on the stubble.

Since bases of mature lucerne stem are of lower quality and usually contain fewer leaves than stem tops (Buxton et al., 1985), defoliating the upper portion of a canopy results in higher quality forage.

2.7.2.5 AUTUMN DEFOLIATION MANAGEMENT

Cutting or grazing lucerne in autumn has been associated with reduced persistence and DM production in early spring (Silkett et al, 1937; Douglas, 1971; Robinson & Abbott, 1971; Janson, 1975; Wynn-Williams, 1976). In a very cold-environment, Douglas (1971) obtained greatest early-spring production, under a cutting regime. However, under a simulated grazing treatment, a defoliation after autumn growth stopped resulted in early spring production equivalent to that of total spelling. This utilised autumn production that would otherwise have been lost through frosting and greatly increased total cool season production (autumn + winter + spring). Therefore, in a cold winter climate, it is recommended that lucerne be grazed in the autumn following the cessation of growth. While this may not increase early-spring production, it will significantly increase cool season utilisation.

In a milder climate, Janson (1975) obtained greater early-spring production, when lucerne was spelled over the entire autumn-winter period. Whether the lucerne was irrigated or not, grazings in late-April and/or mid-June depressed spring production, and autumn production did not compensate for this loss. Winter grazing alone reduced spring production more than autumn grazing alone, but not as much as autumn plus winter grazing. The total deficit in cool season production was reduced under irrigation, because of greater autumn production.

In contrast, Wynn-Williams (1976) has found autumn and/or winter cutting to have little or no effect on early spring production. Autumn-winter defoliations depressed early-spring production by an average of 150 kg ha^{-1}, and production from lucerne spelled over the autumn-winter period failed to compensate for the feed lost through frosting. As noted by Douglas (1971), Wynn-Williams found autumn cutting to be beneficial, provided it occurred after autumn growth ceased and before the herbage was lost through frosting, as this resulted in significantly greater total production.

These results suggest that autumn-winter defoliations can be likened to those of frequent or premature defoliations (Langer, 1968). The effect it has on production is determined by previous management, as it affects plant vigour, the number of premature defoliations and subsequent stand management. Robinson & Abbot (1971) also obtained markedly depressed spring production from frequent autumn

grazing, compared to grazings that allowed a greater bulk of herbage to develop. These contrasting results obtained by Janson (1975) and Wynn-Williams (1976) may be due to the heavier soil type in which lucerne was grown which enable vigorous autumn growth, and greater accumulation of root reserves.

The effects of autumn-winter management may, however, be more critical in winter-active cultivars. In his review of environmental effects on lucerne growth, Christian (1977) concluded that in winter-dormant cultivars, dormancy of crown buds is established at the time of hardening-off, and next season's growth originates from these overwintering buds and those initiated in spring. In more winter-active types however, buds continue to develop at colder temperatures although at reduced rate, and are therefore more vulnerable to grazing and frosting. Palmer et al., (1975) found similar results when comparing cultivars with a range of winter activity.

The influence of winter treading by sheep on winter-dormant lucerne was investigated by Wynn-Williams et al., (1989; 1991). Plots were stocked at 500 sheep ha^{-1} on a free draining soil for 1, 2, and 4 weeks in winter. Results indicated that treading in winter did not affect herbage production in spring, stand density or crown health. White & Lucas (1989; 1990) showed that grazing winter-active lucernes in autumn and winter depressed production in spring, compared to winter-dormant ones. They also found that root carbohydrate in winter-active cultivars were lower compared to dormant ones, although the winter production was much higher. They suggested that the reduction of spring production may be due to the grazing in autumn/winter which depleted carbohydrate reserves to very low levels as TNC is diverted into growth rather than accumulation.

2.8 THE IMPORTANCE OF ORGANIC RESERVES IN FORAGE MANAGEMENT

2.8.1 INTRODUCTION

Perennial and biennial legumes and grasses store energy as readily available carbohydrates in various plant components (McIlroy, 1967). The principle storage organs may be the roots as in *Medicago sativa* L, *Trifolium pratense* and *Pueraria* spp; the stolons as in *Trifolium repens*, *Paspalum notatum*, and *Stenotaphrum secundatum*; the rhizomes as in *Bromus inermis*, *Phalaris arundinacea*, and *Agropyron smithii*; or the stem bases as in *Dactylis glomerata*, *Paspalum dilatatum*,

and *Andropogon gerardi* and *Andropogon scoparius* (Smith, 1980).

Carbohydrate reserves are used by plants as a substrate for growth and respiration. Adequate carbohydrate reserves are important in perennial plants for winter survival, early spring growth initiation, regrowth initiation after defoliation and when the photosynthetic production is inadequate to meet growth demands. They also are used to develop heat and cold resistance, to support life during periods of dormancy, to promote flower and seed formation and for many processes that go on within the plant during its life. Reserve carbohydrates are essential to the life of perennial and biennial forage species, since regeneration is dependent on an adequate supply of stored reserves (Smith, 1980).

2.8.2 DEFINITION OF ORGANIC RESERVES

Graber et al., (1927) first defined reserve energy constituents as "those carbohydrate and nitrogen compounds elaborated, stored and utilised by the plant as food for maintenance and for the development of future top and root growth". Weinmann (1952) further refined the definition by the addition of the words "stored in the more permanent organs of the plant body". These carbohydrates, termed total available carbohydrates (TAC), are those providing available energy to the plant (Weinmann, 1947). Smith (1969a) suggested that the term total nonstructural carbohydrates (TNC) be adopted, because it is more applicable to both animal and plant investigation.

2.8.3 STARCH AND FRUCTOSAN ACCUMULATORS

Starch is the primary nonstructural carbohydrate accumulated in storage organs of forage species in the Leguminoseae family (Sheard, 1973). Information on the accumulation of starch in sulla is lacking. In lucerne roots however, starch is the major storage carbohydrate. A typical analyses of TNC in roots revealed a composition of 90% starch amd 10% sugars (Smith & Marten, 1970; Ueno & Smith, 1970). The sugars in lucerne such as glucose, fructose and sucrose exist principally as intermediates in the synthesis and degradation of starch (Ueno & Smith, 1970). Sucrose becomes the major carbohydrate fraction during periods of drought, the onset of cold hardening and early spring regrowth following winter dormancy

(Nelson & Smith, 1968b).

Grasses of tropical and subtropical origin also accumulate starch, but grasses of temperate origin (species in the Hordeae, Aveneae and Festuceae tribes) accumulate fructosan in their vegetative tissues (Smith, 1968; Ojima & Isawa, 1968; Smith, 1969b). Species in the Hordeae tribe accumulate only short-chain fructosan, those in the Aveneae tribe accumulate a series of fructosan predominated by long-chain, while species in the Festuceae tribe represent both types of fructosan accumulators (Smith, 1968; 1969a). Plants that accumulate short-chain fructosan do so during their whole life, whereas those that primarily accumulate long-chain fructosan do so during the later stages of growth (Smith, 1972b).

2.8.4 SEASONAL AND ENVIRONMENTAL VARIATION

The maintenance of organic reserves in the storage organs is essential to keep a plant vigorous and productive. Generally plants go through periods when organic reserves are used and when they are stored, and a cyclic pattern occurs between early growth and maturity (Graber et al., 1927; Grandfield, 1935; Weinmann, 1961; Smith, 1962; Sonneveld, 1962). The seasonal pattern of carbohydrate accumulation in the principal storage organs of perennial legumes and grasses are essentially similar, but is influenced by morphology and growth behaviour of the species and by environmental conditions.

In lucerne, the warming temperatures in spring promote vegetative growth of shoots from the crown buds, and this growth is initially supported by TNC in the roots and crown. Once the expansion of leaf area allows photosynthetic carbon assimilation to exceed the needs of shoot growth and whole plant respiration, the decline in TNC ceases and the accumulation in the roots and crown commences. The accumulation of maximum TNC in the roots occurs between 10% flower and full bloom (Reynolds & Smith, 1962; Cooper & Watson, 1968). Following 10% flowering there is a small decline of TNC concentrations, and this has been attributed to two sinks. Firstly, the developing fruit (Dobrenz & Massengale, 1966; Dovrat et al., 1969; Cohen et al., 1972) and secondly, as a consequence of growth of new crown buds (Brown et al., 1972). In most forage species, the maximum level of organic reserves in the storage organs is reached after stem elongation has

ceased or at maturity (Smith, 1980).

The cyclic pattern of carbohydrate use and accumulation is influenced by the prevailing environmental conditions. The time from start of growth to maturity may proceed rapidly with warm temperatures, limited moisture and an abundance of sunshine. It may be prolonged by cool temperatures, abundance of moisture and cloudy weather (Smith, 1980). For example, temperature is a critical environmental factor affecting carbohydrate storage in lucerne roots. As temperature decreases in autumn, shoot growth is slowed and carbohydrate accumulates in the root (Feltner & Massengale, 1965; Nelson & Smith, 1969).

Seasonal pattern of TNC levels of red clover roots follow the same pattern as lucerne, except that TNCs are maintained at lower levels in red clover than in lucerne (Smith, 1962). In contrast, seasonal TNC patterns in birdsfoot trefoil and sainfoin differ from that of lucerne or red clover. The TNC in roots of sainfoin and birdfoot trefoil decrease until flowering, and then increase until seed had matured. At seed maturity, new basal growth is accompanied by a slight decrease in TNC, followed by an increase and stabilisation of TNC level in early autumn (Smith, 1966; Cooper & Watson, 1968; Mowrey & Matches, 1991).

Seasonal carbohydrate root reserve trends help to explain why birdsfoot and sainfoin do not survive close defoliation as lucerne and red clover do. Carbohydrate reserves are used to initiate the spring growth, but are not restored in the roots of birdsfoot trefoil and sainfoin at flowering as they are in lucerne and red clover (Smith, 1966; Cooper & Watson, 1968). They remain at a low levels in the roots of birdsfoot trefoil and sainfoin through summer, until growth slows down in autumn. Unlike lucerne or red clover at bloom, a high stubble may be necessary when birdsfoot trefoil or sainfoin is cut or grazed, so that photosynthetic tissues are available to furnish energy needed for regrowth, since little energy is available from the roots.

2.8.5 DEFOLIATION VARIATION

Cutting or grazing when organic reserves are at a low level may leave insufficient energy to resume new growth. The greatest damage is done when cutting or grazing occurs during periods of minimum organic reserves. Intensity and

frequency of defoliation have been shown to be complementary in their impact on levels of organic reserves (Jameson, 1963; May, 1960). In lucerne, the characteristic pattern of carbohydrate accumulation and depletion in the roots and crown occurs in response to herbage removal and subsequent regrowth (Wolf & Blaser, 1981). Frequent cutting at an immature growth stage will eventually exhaust the plant, and weaken it to the extent of death. Plants weakened by too early, too intensive, or too frequent defoliation usually are more susceptible to drought, heat, winter injury and invading diseases. Ideally, the closer to plant maturity that cutting or grazing occurs, the higher the stored organic reserves will be, and the easier it is to maintain vigour and productivity.

Extensive work (White, 1973; Smith, 1980; Deregibus et al., 1982) on the subject of defoliation on organic reserves, showed that excessive, frequent defoliation is more damaging to the plant than is severe intensity of defoliation. Successive cuts at frequent intervals will cause continuous decline in the level of reserves, and will not allow the plant to regain the levels previously accumulated. Very light defoliations that provoke little or no reduction in organic reserves levels cause little damage to the plant (Deregibus et al., 1982).

A severe defoliation of herbage to the soil level will require a regrowth based primarily on organic reserves. If these plants are not defoliated again until organic reserves are replenished, the major damage done is a reduction in the rate of regrowth caused by the lack of stubble, but the plants will survive and regain vigour. Lucerne is a classic example where intense defoliation can be accomplished without severe damage to the plant, provided defoliations are not too frequent (Keoghan, 1967; Deregibus et al., 1982). Moreover, tall growing species with most of the leaf area high on the plant are almost totally dependent on stored organic reserves for recovery, since all or most of the photosynthetic area is removed with close defoliation (Smith, 1980).

2.8.6 ORGANIC RESERVES AND REGROWTH

Organic reserves influencing the rate of regrowth in plants, following herbage removal, has been a subject of extensive research and many reviews (Graber et al., 1927; Graber, 1931; Weinmann 1948, 1961; Troughton, 1957; May, 1960; Priestly,

1962; Jameson, 1963; Cook, 1966; McIlroy, 1967; White, 1973; Deregibus et al., 1982). Although some researchers have pointed out that the role of organic reserves in the control of regrowth is still not clear (May, 1960; Jameson, 1964), others believe that present evidence indicates that both the stubble leaf area and organic reserves determine regrowth potential (Youngner, 1972; Deregibus et al., 1982).

There may be many factors that may obscure the relationship between TNC and plant regrowth, particularly in graminoids; these are (i) cutting or grazing as methods of defoliation may produce different results (Matches, 1968; Cuykendall & Marten, 1968); (ii) the amount of carbohydrate, rather than the more commonly presented concentration, may be important in interpreting plant dependence on TNC (Caldwell et al., 1981); (iii) TNC used for regrowth may reside in specific stem base components (Volenec, 1986); and (iv) compounds other than carbohydrate such as proteins may serve as sources of regrowth assimilate (Richards & Caldwell, 1985; Volenec et al., 1991).

Mobilisation of carbohydrates from organs remaining after defoliation, using radiocarbon tracer technique (^{14}C), has been observed in many studies. In lucerne, numerous studies have demonstrated that carbohydrates stored in roots and crowns support vegetative regrowth following herbage removal. Evidence for this utilisation include the regrowth in darkness of lucerne shoot (Graber et al., 1927; Cralle, 1983), the depletion of TNC in crowns and roots after defoliation (Smith, 1962; Reynolds & Smith, 1962; Feltner & Massengale, 1965; Barta, 1978; Cralle & Heichel, 1981) and the mobilisation of stored ^{14}C from crown and roots to new shoots during regrowth (Hodgkinson, 1969; Pearce et al., 1969; Smith & Silva, 1969; Smith & Marten, 1970; Cralle, 1983).

Although the decline in stored carbohydrate in the roots and crowns, measured as depletion of TNC or ^{14}C-labelled carbohydrates, was greatest during the early phase of vegetative growth (Smith & Marten, 1970), bidirectional transport of C compounds still occurs. Partitioning of photosynthate from leaves to the roots was observed within 7 days following herbage removal (Hodgkinson, 1969; Pearce et al., 1969; Cralle, 1981). Despite this partitioning, the decline in the concentration of root TNC during early vegetative regrowth was accompanied by a reduction of

root cambial activity, with consequent cessation of root growth (Rapoport & Travis, 1984). Root cambial activity and growth resumed only with the recovery in TNC concentration (Rapoport & Travis, 1984).

The magnitude of decline in carbohydrate reserves, following defoliation, depends upon the physiological condition of the plant and the proportion of leaf area removed. Robinson & Massengale (1968) found in lucerne that a greater decline in root TNC concentrations after defoliation occurred at 50% flower, than at 10% flower. When lucerne was shaded to retard shoot growth after defoliation, less ^{14}C-labelled compounds were partitioned from the roots to the shoots than in unshaded plants (Hodgkinson, 1969). This result indicated a close relationship between rate of shoot growth and rate of carbohydrate utilisation.

There may be intershoot competition for these reserves and for recent photosynthate after herbage removal. Individual shoots on plants with only one or two shoots were longer than those on plants with four or eight shoots (Leach, 1971). The decline in TNC concentrations of roots and crowns was greater following total than partial shoot removal (Wolf & Blaser, 1971; Cralle & Heichel, 1981). Brown et al., 1972, concluded that in lucerne, 25% of the reserve C compounds consumed following defoliation were lost in root respiration, 39-45% were lost in respiration of the crown and shoots, and 30-36% were incorporated into shoot growth. Escalada & Smith (1972) found 63% of root TNC utilised during lucerne regrowth came from the root wood and 37% from the root bark. While starch and sugars accounted for 62 and 32% respectively of the TNC consumed during regrowth, the accumulation of TNC in roots during later vegetative growth consisted of 88% starch and 12% sugar. Thus, the primary source of C for shoot regrowth, following herbage removal, is starch in the root wood of the upper 10 cm segment of the taproot.

2.9 SHOOT AS A COMPONENT OF HERBAGE PRODUCTION

Components of herbage production in forage plants are a function of vegetative growth rate and plant morphology. The components of herbage production of forage plants are (i) number of plants per unit area (ii) number of shoots per plant and (iii) mass per individual shoot (Fick et al., 1988).

In most taprooted forage plants, the region where shoots arise is termed the crown. In lucerne, Hayward (1938) and Grove & Carlson (1972) considered the crown as a complex morphological structure, encompassing an area of several separate structures, which consists of perennial portions of the stem which included the upper portion of the taproot. Thomas (1980) defined the crown in red clover as the short compressed stem on top of the taproot, which bears buds and from which the basal leaf rosette and shoots arise. Growth and expansion of axillary buds of the cotyledons, primary shoot and branches give rise to a large number of axillary buds at the top of the taproot (Fergus & Hollowel, 1960).

The number of shoots per plant in lucerne typically increased with advancing age, but in any growth cycle the maximum was usually set within 14 days of the start of regrowth (Leach, 1969), and then declined as the canopy matured (Nelson & Smith, 1968a; Singh & Winch, 1974). In the establishment year, McLaughlin & Christie (1980) found the mean number of shoots to increase from 2.4-3.9 to 6.2-6.5 stems plant^{-1} in four sequential defoliations. In the year following establishment, Singh & Winch (1974) reported that 'Vernal' lucerne had more shoots per plant than 'Saranac' at the early vegetative stage, but differential shoot mortality was responsible for the absence of differences by bud stage, when there were 5.4-7.4 shoots plant^{-1}. Smith (1969b, 1970) and Cowett & Sprague (1962) observed no consistent temperature effect on lucerne shoot growth. MacLaughlin & Christie (1980) however, observed in a large number of genotypes compared, that plants with higher shoot numbers mature earlier and had lower optimal growth temperatures than plants with lower shoot numbers.

The number of basal buds and the number of shoots per plant is reduced substantially by moisture stress (Cowett & Sprague, 1962; Cohen et al., 1972; Perry & Larson, 1974). Brown & Tanner (1983) showed that the effect was expressed in the first 14 days of regrowth, and that water stress after the first 14 days had no influence on stems per plant. Cameron (1973) pointed out that flooded soil conditions reduced stem per plant, with a greater reduction at 33 than 21°C. Lucerne flooded immediately after defoliation was more severely affected than that grown for 5 days before flooding. Leach (1971) recorded an increase in stems plant^{-1} with 'Rhizoma' at 33 or 27°C compared to 21 or 15°C. Stem numbers in 'Totana'

were not influenced by temperature, while at 15°C the rate of appearance of new stems was reduced in both cultivars.

Leach (1968, 1969, 1970b, 1971), and Singh & Winch (1974) studied the origin, number and size of individual lucerne shoots, in a series of experiments. In these investigations, regrowth following defoliation generally came from axillary buds. Removal of axillary buds caused crown buds to elongate, delayed regrowth, and reduced the number of stems. Leach (1971) found that the size of individual shoots did not depend on the number of shoots per plant, except under the most favourable growing conditions. At 33°C, the most favourable growing conditions studied, four or eight shoots plant^{-1} gave smaller individual shoots than one or two shoots plant^{-1}, after 10 days of regrowth. Singh & Winch (1974) measured up to 0.74 g stem^{-1} in 40 days of regrowth and up to 5 g stem^{-1} in undefoliated canopies. They found that mass per shoot depended on cultivar, and decreased in successive defoliations during the growing season.

2.10 DEFOLIATION EFFECTS ON THE ROOT SYSTEM

Root growth of most plant species is reduced by defoliation, a direct result of the reduction in amount of photosynthetically active tissue. If grasses are completely defoliated, all the roots stop extending within 24 to 48 hours (Crider, 1955). Numerous studies on many species reviewed by Troughton (1957) showed that the lower the cutting height or the more frequent the cutting interval, the greater is the reduction in root weight. The intensity and frequency of defoliation are complementary; a reduced severity of one will offset an increased severity of the other as they affect the root system (Youngner, 1972). The extent of these changes caused by defoliation depends on species, growth habit, defoliation severity and frequency and the prevailing environmental conditions (Troughton, 1957; Evans, 1971, 1973; Sheath, 1978; Chapin & Slack, 1979).

In legumes, losses in both root and nodules occur following defoliation (Wilson, 1942; Smith & Graber, 1948). It has been suggested that perennial legumes often lose their nodules after defoliation and that new ones form during shoot regrowth (Vance et al., 1979). Wilson (1942) reported that white clover lost about a third of its nodules after defoliation. Butler et al (1959) found that defoliation

and shading of red clover and birdsfoot trefoil caused a severe reduction in nodule number, while nodules of white clover apparently were not affected. Whiteman (1970) reported that defoliation of *Desmodium intortum* DC and *Phaseolus atropurpureaus* (Jacq.) DC decreased nodule weight and nodule number. Moustafa et al., (1969) reported that defoliation of white clover caused a sharp decrease in acetylene reduction activity within 24 hours, as compared to undefoliated controls. Vance et al., (1979) found that acetylene reduction in defoliated lucerne remained low for 13 days after defoliation, and no substantial changes in nodule fresh weight occurred.

Reduction in taproot weight following defoliation is generally thought to be the result of redistribution and utilisation of organic compounds (May, 1960; Wolf, 1978). Willard (1930) estimated that the average loss in root dry weight of lucerne two weeks after defoliation was approximately 200 kg ha^{-1}. In lucerne and birdsfoot trefoil, increasing severity and/or frequency of defoliation reduced root weight. The latter species was found to be more responsive to cutting height, while the former to frequency (Smith & Nelson, 1967). Dennis et al., (1959) reported that taproot weight of lucerne decreased with increasing defoliation frequency. Constable et al., (1977) demonstrated the negative effect of the length of defoliation period (sequential defoliation) on root weight.

A comparative study by Evans (1973a, 1973b) indicated that root growth of legumes like white and red clover was less inhibited by defoliation than grasses. He thought reserve carbohydrates in taproots were used to sustain extension of lateral roots. Hodgkinson & Bass Becking (1978) have shown that the root growth of severely defoliated lucerne was sustained, and early resumption of translocation of current photosynthate into lateral roots occurred by about the fifth day after defoliation.

2.11 SUMMARY

In this chapter, the available information in English and several papers in Italian on the agronomy of sulla have been reviewed. The general concepts of herbage production such as timing or growth stage at defoliation, intensity and frequency of defoliation, leaf area index (LAI) and the pattern of regrowth following

defoliation of forages were considered. Important aspects in the defoliation management of lucerne were highlighted with the supposition that sulla, a strongly taprooted plant like lucerne, may exhibit similar responses to defoliation as lucerne. Research findings have also been presented showing the importance of organic reserves in the management of taprooted plants for maximum productivity and persistence. The influence of organic reserves on regrowth, an area of controversy, has also been reviewed. The effects of defoliation, apart from physiological changes in the root system of legume forages, have also been considered.

CHAPTER 3. A PRELIMINARY AGRONOMIC EVALUATION; THE RESPONSE OF SULLA (*Hedysarum coronarium* L.) cv. NECTON TO DIFFERENT GRAZING MANAGEMENT SYSTEMS OVER ONE YEAR.

3.1 INTRODUCTION

The merits of sulla (*Hedysarum coronarium* L.) as a forage plant have been stressed since the early 1980's (Watson, 1982), and trials in the Manawatu (Douglas, 1984; Douglas & Foote, 1985; Foote, 1988), Hawke's Bay (Rys et al., 1988) and Canterbury (G. Kerr, unpublished data) have shown high herbage production potential. Although sulla has shown promise as a high quality non-bloating forage, its history of management has been under cutting for use as hay or silage (Whyte et al., 1953; Kernick, 1978), and no systematic work on its grazing management is reported in New Zealand[1] or overseas. The utilisation of sulla in New Zealand would normally be by sheep or cattle *in situ*. Their pattern of defoliation could result in a greater removal of leaf material than a cutting regime, and so could affect the regrowth potential of the plant.

The danger of extrapolating from cutting trials to grazing practice is well known (Humphreys, 1966; Davidson, 1968). Further, grazed plants are subjected to mechanical injury and quite different nutrient application through the varied return of dung and urine, which is not simulated under cutting. While the importance of these factors has been stressed (Brown & Evans, 1973; Sun, 1992), the most drastic effect of grazing is the sudden removal of leaf material through selective grazing (McKinney et al., 1970; Rys et al., 1988).

If sulla is to be used as a forage crop in New Zealand, an understanding of its response to intensity and frequency of defoliation would be essential to its planning and utilisation. A more thorough knowledge of its growth responses is needed to develop proper grazing practices. There is a need to develop grazing management guidelines for sulla and improve its establishment and persistence (Douglas, 1984; Douglas & Foote, 1985; Rys et al., 1988). In addition, information

[1]Some of the results of the preliminary trial has been reported in the Proceedings of the NZ Grassland Association 1990 Conference and the paper is included in appendix 3.11.

on its pattern of growth over the season is important. Therefore the objectives of the preliminary trial were:

1. to examine the effect of plant growth stage at grazing and grazing intensity on the production and persistence of sulla over one year;
2. to gain experience with its establishment, and to identify problems associated with its husbandry, and
3. to ascertain the origin of its regrowth under grazing.

3.2 MATERIAL AND METHODS

3.2.1 SITE INFORMATION

The trial site of 0.22 ha was located at Frewens 7, Massey University (See plate 3.1), Palmerston North, 40°23′S 175°37′E, 34 m asl. Soil type is a loess Tokomaru silt loam (Typic Fragiaqualf), pH ranging between 5.5-6.0 and low in available phosphorus (Olsen P<10). The general characteristics of these soils are similar to the Marton silt loam and profiles are similar in colour, structure and consistency to Matapiro soils of the Wairarapa-Gisborne region (See appendix 3.1 and 3.2 for pedology). The duration of the trial was from September 1988 to September 1989. About 1000 mm rainfall fell over the trial site and most of it was received in the late autumn-winter months. Site soil samples were taken presowing for analysis to ascertain any mineral deficiency and the desired pH. A postsowing soil sample was also taken to indicate the initial nutrient status of the soil (See appendix 3.3 & 3.4).

The soil was ploughed in early spring 1988 and agricultural lime at 4 t ha^{-1} was incorporated to raise the pH from 5.5 to 6.0. Thirty percent (30%) potassic super (P_2O_5 7%, K_2O 15%, S 8%) at the rate of 450 kg ha^{-1} was applied at sowing. Dehulled sulla cv. Necton (germination 70-80%, 1000 seed weight 5.2 g) supplied by NZ Agriseed Limited, was inoculated with peat slurry containing the rhizobia strain NZPA 5410. The inoculated seeds were then air dried in a cool environment and drilled at 7.0 kg ha^{-1} to 2-3 cm soil depth in 15 cm rows within 24 hours.

Apparent nodulation failure resulted in pronounced yellowing of herbage, and visual examination of roots revealed a large number of ineffective root nodules. As

Plate 3.1 General view of trial site located at Frewens 7 Massey University.

a consequence, to overcome N deficiency, urea was broadcasted at 100 kg N ha^{-1} on 17 October 1988 and subsequently after each grazing. The 3rd leaf from the canopy top was sampled for tissue analysis, to monitor remedial measures taken (See appendix 3.5). A viable rhizobia strain was reisolated from the field using a technique described by Brockwell (1980), and reisolates were stored in agar slopes at 4°C (Dalton 1980) for use in future trials. The reisolate ICMP 10149 for sulla is now part of the national collection and is commercially available. Herbage samples were analysed for *in vitro* digestibility by the Massey Animal Science Laboratory using the procedures of Roughan & Holland (1977).

3.2.2 DESIGN AND TREATMENTS

The experimental design was a randomised complete block with 6 management treatments and in 3 replicates. Plots were 120 m^2 and grazed with sheep. Individual plots were electric fenced and with separate access (See appendix 3.6 for field layout). A flow chart of the grazing management treatments imposed on sulla over 365 days is presented in Table 3.1. There were four grazing intensity treatments imposed at the early reproductive growth stage (ERGS) (See plate 3.2) and two at the late reproductive growth stage (LRGS) (See plate 3.3), making up a total of six grazing management treatments.

The grazing intensity treatments in the ERGS began when the plants were at mid to late stem elongation 85 days after sowing (DAS). Plots were either severely grazed i.e approximately 70-75% of the leaf and stem material eaten, leaving a residual of 500-700 kg DM ha^{-1} (See plate 3.4), or less severely grazed i.e approximately 60-65% of the leaf and stem material eaten, leaving a residual of 1000-1200 kg DM ha^{-1} (See plate 3.5). The previously severely and less severely grazed plots at the ERGS were subsequently grazed either severely or less severely, resulting in four treatments at the end of the trial.

The grazing intensity treatments in the LRGS began when the plants reached 10% flowering and this occurred at 105 DAS.These plots were either severely or less severely grazed as described above. Subsequent grazings in the LRGS plots were either severe or less severe, resulting in two treatments.

Plate 3.2 Sulla sward at the early reproductive growth stage

Plate 3.3 Sulla sward at the late reproductive growth stage

Plate 3.4 Severely grazed treatment

Plate 3.5 Less severely grazed treatment

Plate 3.6 Sheep grazing sulla

Table 3.1 Flow chart of the grazing intensity treatments imposed on sulla at the early reproductive (ER) and late reproductive (LR) growth stage, at each grazing, over 365 DAS. H=severe and L=less severe grazing.

Growth Stage	Grazing intensity				Total number of grazings	Resultant grazing management
	1	2	3	4†		
ER	H	H	H	H	4	ERHHHH
				L	4	ERHLLL
		L	H	H	4	ERLHHH
			L	L	4	ERLLLL
LR	H	H	H		3	LRHHH
	L	L	L		3	LRLLL

† Grazing sequence.
Note that the final grazing in the EF treatment is included in the final sequence.

All subsequent grazings were governed by the physiological status of the plant at the time when each treatment was first grazed, that is based on growth stage. As a consequence, the ERGS and LRGS plots were grazed four and three times respectively. A grazing schedule is presented in Table 3.2. About 18-24 sheep, equivalent to 1500-2000 sheep ha^{-1}, were used in each plot (See plate 3.6), and the duration of grazing was between 1-2 days, depending on the amount of feed on offer. Once the desired residual herbage mass was reached, and this was determined visually by close monitoring of the grazing, the sheep were removed.

3.2.3 MEASUREMENTS

One 0.4 m^2 quadrat per plot was taken to estimate herbage mass (kg DM ha^{-1}) before and after grazing, and to monitor plant density. Soil around the crown was carefully removed before plants were counted to ensure that individual plants were

Table 3.2 Grazing schedule as determined by plant growth stage at each grazing over 365 DAS.

Grazing sequence	Early reproductive			Late reproductive		
	Grazing date	DAG†	DAS§	Grazing date	DAG	DAS
1	22/12/88	-	85	11/01/89	-	106
2	16/02/89	55	140	18/03/89	66	172
3	29/05/89	100	240			
4	28/09/89	125	365	28/09/89	193	365

Sowing date: 27 September 1988.
† Days after grazing
§ Days after sowing

being counted. Herbage samples were cut to ground level (Hodgson, 1979; 1981a) using a sickle. Samples were thoroughly washed to remove soil particles, separated into leaf, stem, flower (if any) and weed fractions and weighed. Subsamples were forced air oven dried at 70-75°C for 24 hours and weighed for DM determination. Herbage mass (leaf + stem + flower) and its components, individual plant dry weight, leaf-to-stem mass ratio, herbage accumulation rate and weed mass were calculated from the DM and plant density data. The pregrazing herbage mass at the second and subsequent grazings in sulla was mostly new growth, as the herbage mass after each grazing subsequently died and decayed, and did not contribute towards subsequent herbage accumulation. Herbage consumed by sheep was defined as pregrazing minus postgrazing herbage mass, cut to ground level.

Fifteen grazed plants were dug at random from the severely and less severely grazed treatments, in the ERGS plots at 18 days after the first grazing, and 48 days after the first grazing in the LRGS plots. Plants were thoroughly washed and were then soaked in water for 1-2 hours to maintain turgor. Individual plants were then dissected and the origin (primary stem, secondary stem and crown - See Fig 3.9) and number of shoots on these sites, shoot length (defined as the length

of the new stem on which leaves originate), petiole length and leaf area were measured. Area of leaves was measured with a Li-Cor Area Meter Model 3100 and cumulative area was recorded. Results are reported on a per plant basis.

3.2.4. STATISTICAL ANALYSIS

The statistical analysis used was analysis of variance (ANOVA), which was conducted using the General Linear Model (GLM) procedure of the Statistical Analysis System (Steel & Torrie, 1981; SAS, 1989) on total herbage accumulation and its components, plant density, individual plant dry weight (DW), leaf-to-stem mass ratio[2] and total weed accumulation over 365 DAS. Orthogonal contrasts, involving the partitioning of treatment degrees of freedom and sums of squares into component comparisons, were conducted to separate the effects of growth stage, grazing intensity and the interaction between the two (Little & Hills, 1978). Since grazings were not synchronised, data from the ERGS and LRGS at individual harvests were analyzed (ANOVA) independently, concentrating only on the effects of grazing intensity treatments within growth stage, but the results of each analysis are discussed together.

Detailed preliminary regrowth studies were analyzed as a randomised complete block, separating regrowth site as a classification variable. As the sampling was carried out at two separate times, that is at 18 days after grazing (DAG) in the ERGS and 48 DAG in the LRGS, the study was treated as two separate preliminary studies and ANOVA was conducted accordingly.

Treatment means were compared, using Fisher's protected least significant difference (LSD) procedure (Carmer & Walker, 1985). Unless otherwise stated, the 0.05 level of probability was used to determine differences.

3.3 RESULTS

3.3.1 CLIMATE

The climate data during the trial, recorded at the DSIR climate station

[2]Data was not transformed as the components that make up the ratio are continuous variables and therefore normally distributed (Steel & Torrie, 1981).

Table 3.3 Summary of climate data at the trial site from September 1988 to September 1989, recorded at the DSIR climate station (40°23′S 175°37′E, 34 m asl).

Month	Total Rain (mm)	Air temperature °C			Soil Temp °C	Sun-shine hours	RH%
		Mean	Max	Min			
Sept	144	12.5	15.6	9.4	11.6	48	83
Oct	98	13.7	17.1	10.2	13.0	138	75
Nov	63	15.4	19.8	10.9	15.2	182	76
Dec	57	18.1	22.9	13.4	18.2	225	70
Jan	92	19.6	24.1	15.2	19.1	223	74
Feb	75	13.0	23.1	12.9	17.7	193	75
Mar	89	17.2	22.0	12.4	16.8	172	78
Apr	44	14.5	19.2	9.8	13.6	175	76
May	111	11.9	15.4	8.4	11.8	64	88
Jun	88	8.8	12.6	5.0	8.7	73	89
Jul	53	7.7	12.3	3.1	6.2	142	86
Aug	53	9.8	14.2	5.3	7.2	124	84
Sept	25	12.4	16.5	8.3	10.7	151	78

approximately 1 km from the trial site, are summarised in Table 3.3. Annual rainfall received over the trial site was 967 mm, which was close to the Palmerston Northaverage of 1000 mm. See appendix 3.7 for 50 years mean climate data recorded in Palmerston North. Overall maximum and minimum temperatures were slightly higher than average, and the relative humidity was close to the long term mean. Sunshine hours received were lower than the average. Above average rainfall fell in September and October, which in combination with a soil temperature (100 mm depth) of more than 12°C at the time of sowing contributed to favourable germination and establishment of the stand.

3.3.2 HERBAGE AND COMPONENTS OF HERBAGE ACCUMULATION

The total herbage and components of herbage accumulated over 365 DAS are presented in Table 3.4. There were no significant differences between the grazing intensity management treatments within growth stage. However, there was a significant ($P<0.01$) difference between the ERGS and LRGS treatments in the total herbage accumulated over 365 days. The total herbage accumulated for the

Table 3.4 The effect of plant growth stage at grazing and grazing intensity on the total herbage and components of herbage accumulated (kg DM ha^{-1}) in sulla, over 365 DAS.

Grazing Management Treatment†	Total Herbage Accum.	Components of total herbage accumulated		
		Leaf	Stem	Flower
ERHHHH	10147	8200	2853	94
ERHLLL	12754	9563	3131	60
ERLHHH	10777	8367	2183	227
ERLLLL	14630	11087	3413	130
LRLLL	20050	10817	9080	153
LRHHH	19327	12070	7123	133
$LSD_{0.05}$§	6474	NS	4105	NS

† See Table 3.1 for explanation.
§ LSD at the 0.05 level of significance.
NS=Means within columns are not significant at the $P<0.05$ level.

four grazings that eventuated in the ERGS treatment was 12077 ± 1027 (SEM)[3] kg DM ha^{-1} y^{-1}. This was about 40% less than the total herbage accumulated of 19689 ± 1453 kg DM ha^{-1} y^{-1} for the three grazings that eventuated in the LRGS treatment.

The total leaf accumulated did not differ significantly between the grazing intensity management treatments within growth stage or between the ERGS and LRGS treatments. However, there was a significant ($P<0.001$) difference in the total stem accumulated between the ERGS and LRGS treatments. The LRGS treatment resulted in 8102 ± 652 kg DM ha^{-1} y^{-1}, whereas it was 2645 ± 921 kg DM ha^{-1} y^{-1} in

[3] Standard error of a treatment mean

the ERGS treatment. No differences were significant in the total flower accumulated between the growth stage treatments or grazing intensity management treatments within the growth stages.

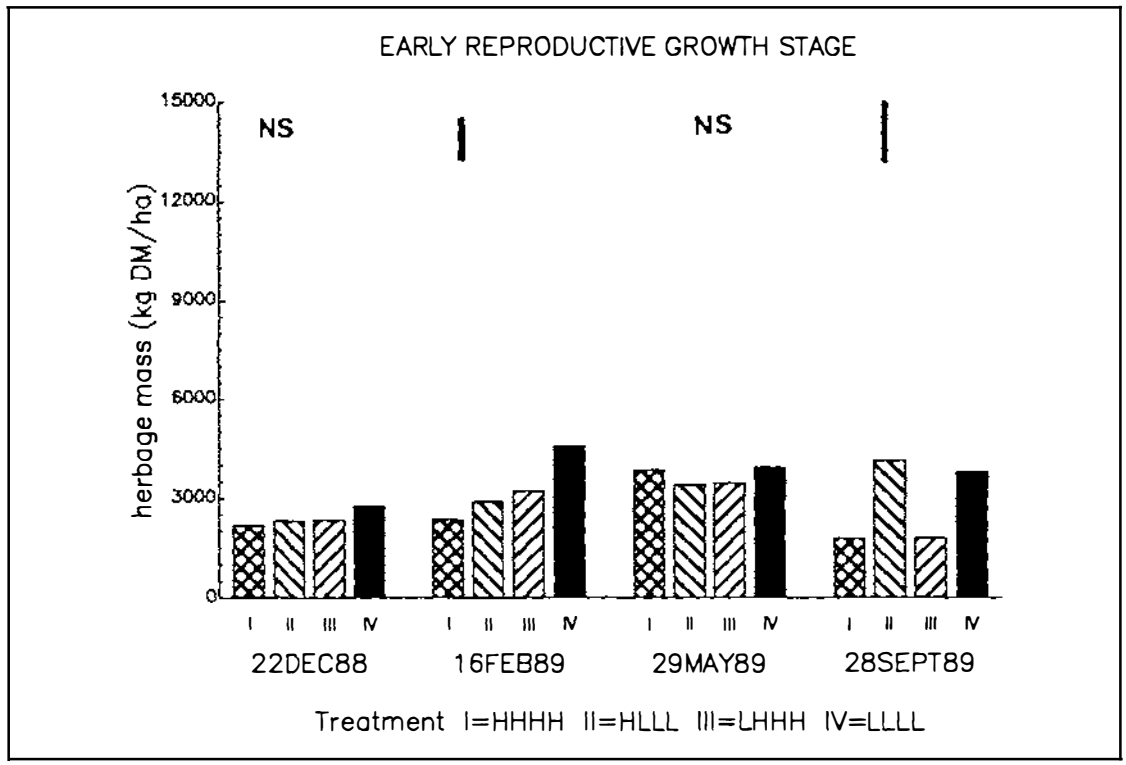
3.3.3 HERBAGE MASS AT EACH GRAZING

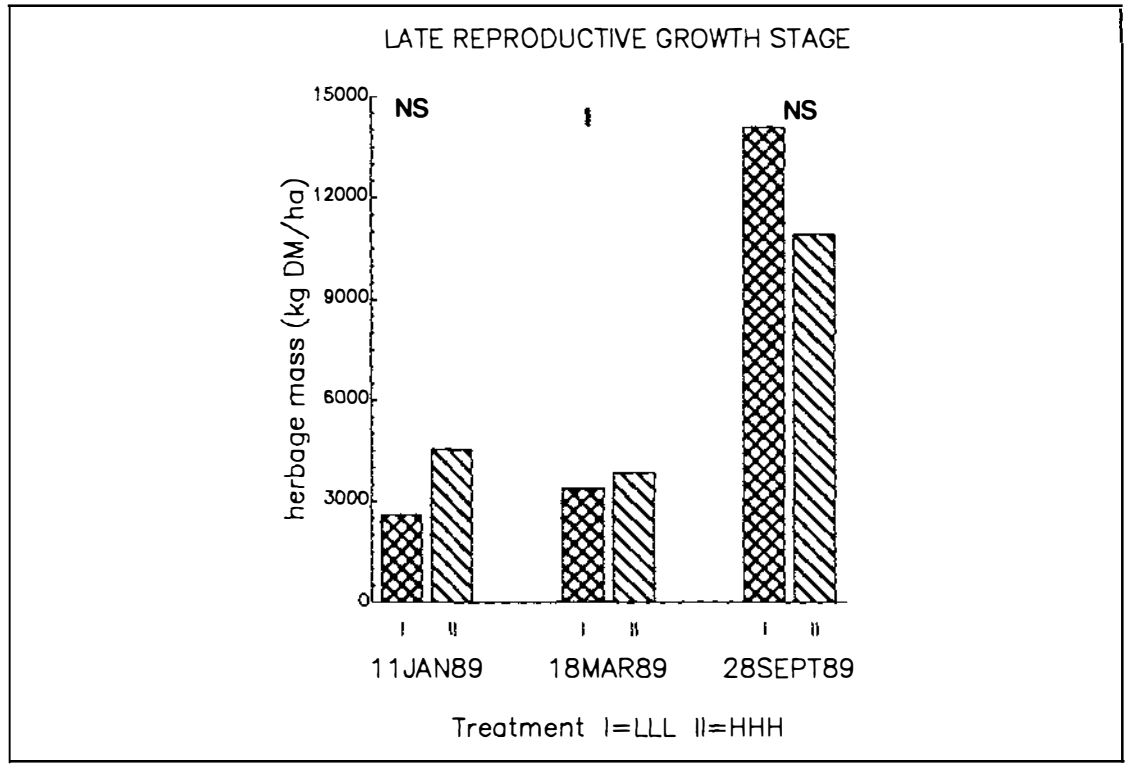
At the time of the commencement of the grazing treatments in the ERGS on 22 December 1988, the pregrazing herbage mass in the grazing intensity treatment was not significantly different (Fig 3.1a) and the overall mean was 2399 ± 254, which was equivalent to 28 ± 3 kg DM ha^{-1} d^{-1} (Table 3.5). At the second grazing

Table 3.5 The effect of plant growth stage (ERGS) at grazing and grazing intensity on the herbage acccumulation rate (kg DM ha^{-1} d^{-1}) in sulla, at each grazing over 365 DAS.

Grazing Intensity	Early reproductive growth stage			
	22/12/88	16/2/89	29/5/89	28/9/89
HHHH	26	43	38	14
HLLL	27	53	34	33
LHHH	27	58	34	14
LLLL	33	83	39	27
$LSD_{0.05}$	NS	24	NS	15

on 16 February 1989, there were significant ($P<0.05$) differences between the grazing intensity treatments. The herbage mass in the less severely grazed treatment was significantly higher than in the severely grazed treatment. The herbage accumulation rates (HAR) in these treatments ranged from 43-83 kg DM ha^{-1} d^{-1}. However, the grazing intensity treatments did not differ significantly at the third grazing on 29 May 1989, and the mean across all treatments was 3653 ± 191 kg DM ha^{-1}, which was accumulated at the rate of 37 ± 2 kg DM ha^{-1} d^{-1} respectively. At the final grazing on 28 September 1989, there were significant





Figs 3.1a (above) & 3.1b (below) The effect of plant growth stage at grazing and grazing intensity on the pregrazing herbage mass in sulla, at each grazing over 365 DAS. KEY: Bars represent least significant difference at the 0.05 level of probability, NS=not significant at the similar level, H=severe grazing and L=less severe grazing.

($P<0.05$) differences between the grazing intensity treatments. The herbage mass in the less severely grazed treatments was higher than in the severely grazed treatments. The herbage mass in treatments HHHH and LHHH were 45% less than in the HLLL and LLLL treatments. Moreover, the HAR in the severely grazed treatments was significantly lower than in the less severely grazed treatments. There were no significant differences between the HHHH and the LHHH treatments, nor between the HLLL and the LLLL treatments.

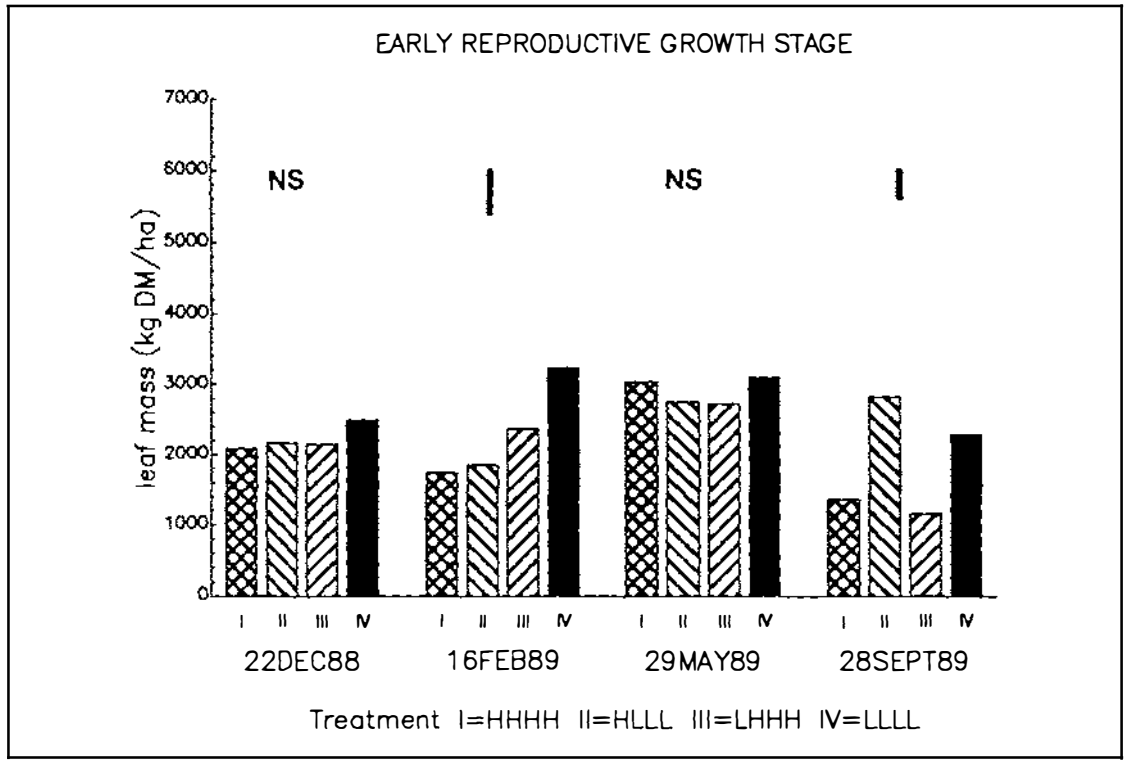
When the grazing treatments commenced in the LRGS on 11 January 1989, the pregrazing herbage mass was not significantly different in the grazing intensity treatments (Fig 3.1b). The overall mean was 3567 ± 475 kg DM ha^{-1} which was equivalent to 34 ± 5 kg DM ha^{-1} d^{-1} (Table 3.6). At the second grazing on 18 March 1989, there was a significant ($P<0.05$) difference between the grazing intensity treatments. The herbage mass in the less severely grazed treatment was 14% less than in the severely grazed treatment, which was accumulated at 51 ± 1 and 58 ± 1 kg DM ha^{-1} d^{-1} respectively. However, the grazing intensity treatments did not differ significantly at the final grazing on 28 September 1989, and the overall mean was 12500 ± 865 kg DM ha^{-1} accumulated at the rate of 65 ± 5 kg DM ha^{-1} d^{-1}.

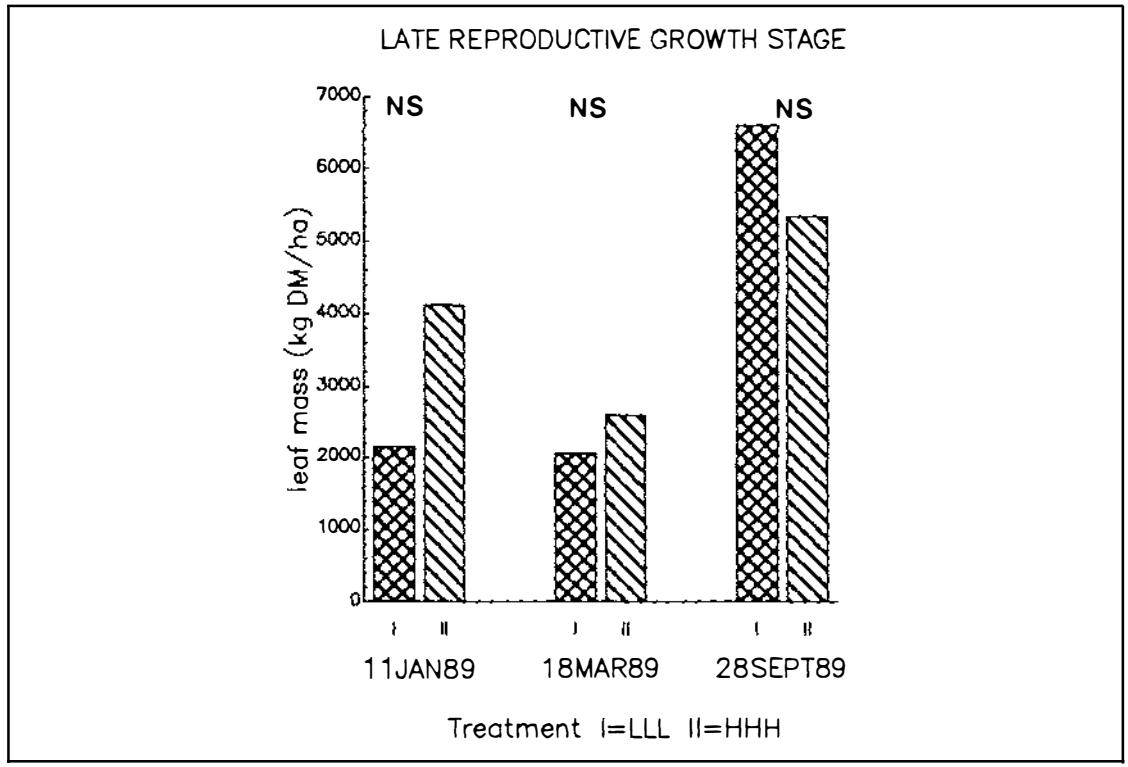
Table 3.6 The effect of plant growth stage (LRGS) at grazing and grazing intensity on the herbage accumulation rate (kg DM ha^{-1} d^{-1}) in sulla, at each grazing over 365 DAS.

Grazing Intensity	Late reproductive growth stage		
	11/1/89	18/3/89	28/9/89
LLL	24	51	73
HHH	43	58	57
$LSD_{0.05}$	NS	6	NS

3.3.4 LEAF MASS AT EACH GRAZING

At the time of the first grazing in the ERGS on 22 December 1988, the





Figs 3.2a & 3.2b The effect of plant growth stage at grazing and grazing intensity on the pregrazing leaf mass in sulla, at each grazing over 365 DAS. Refer figures 3.1a&b for key to treatments.

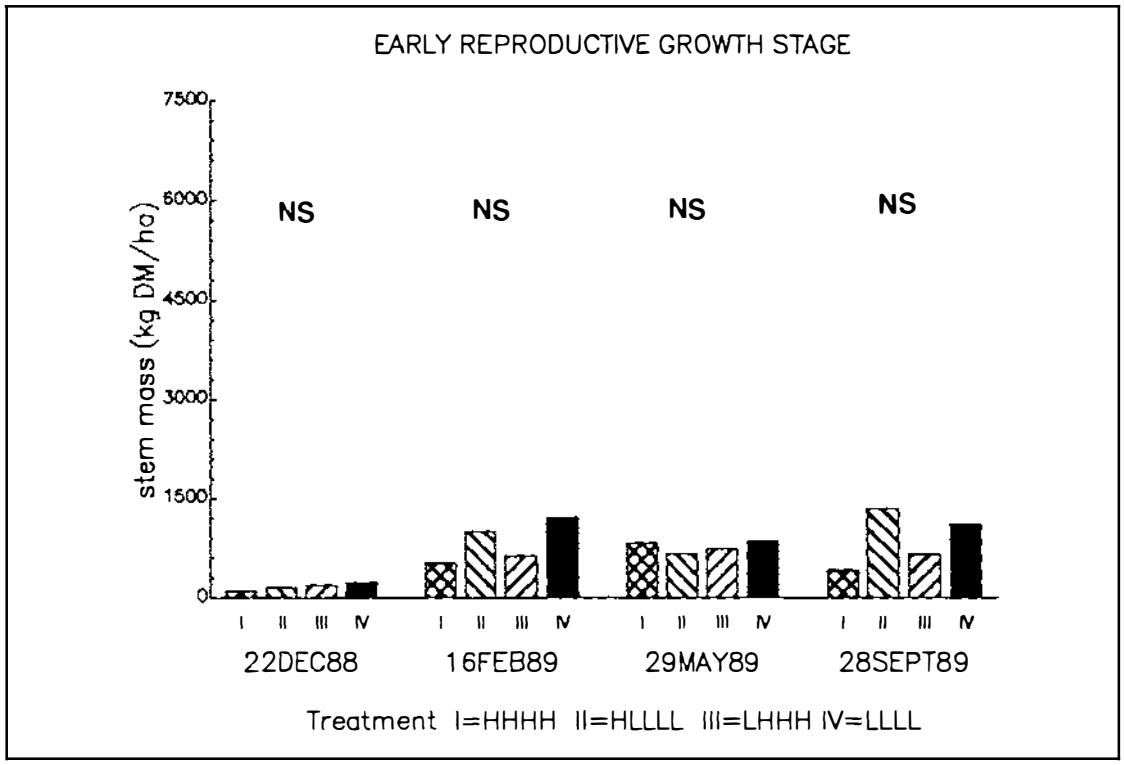
pregrazing leaf mass was not significantly different in the grazing intensity treatments (Fig 3.2a), and the overall mean was 2222 ± 213 kg DM ha^{-1}. The grazing intensity treatments differed significantly ($P<0.05$) at the second grazing on 16 February 1989. The pregrazing leaf mass in the less severe grazing treatment was significantly higher than in the other treatments. The grazing intensity treatments did not differ significantly at the third grazing on 29 May 1989. However, at the final grazing on 28 September 1989, differences were significant ($P<0.05$) between the grazing intensity treatments. The pregrazing leaf mass in the less severely grazed treatments was higher than the severely grazed treatments. The leaf mass in the HHHH and LHHH treatments was 49% less than in the HLLL and LLLL treatments. There were no significant differences between the frequent less severely grazed treatments and between the frequent severely grazed treatments.

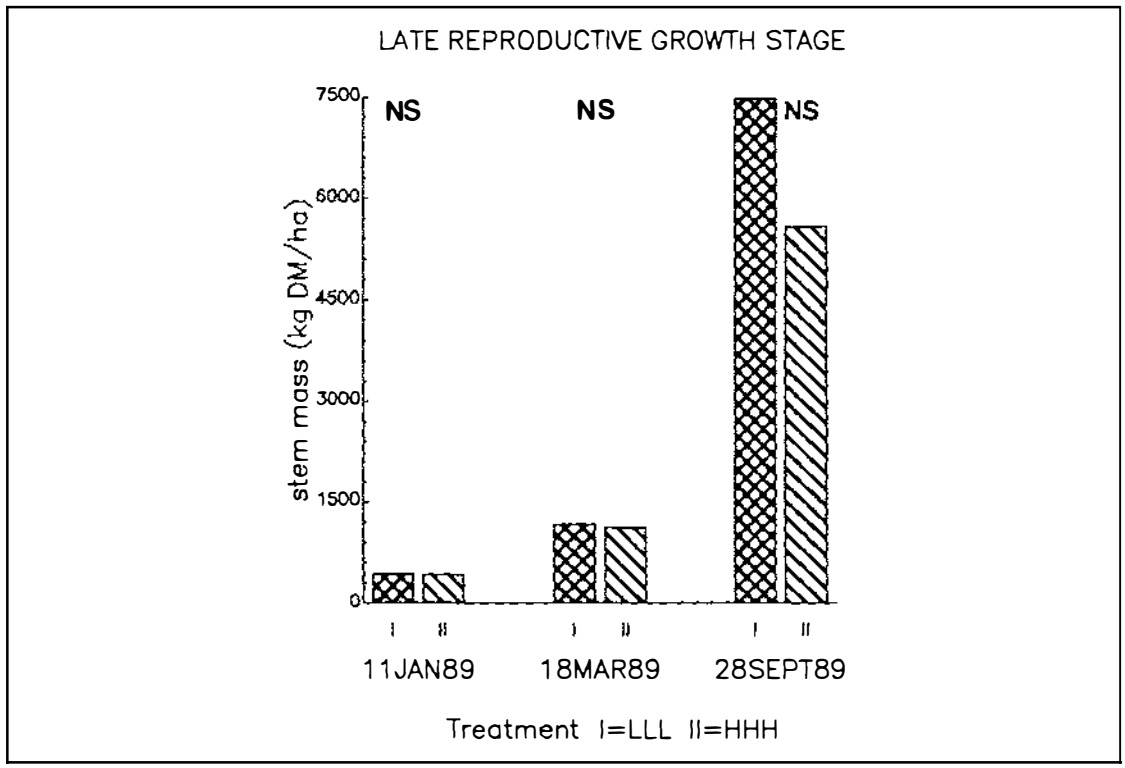
The pregrazing leaf mass at the first grazing on 11 January 1989 in the LRGS was also not significantly different in the grazing treatments at the second intensity treatments (Fig 3.2 b), and the overall mean was 3140 ± 411 kg DM ha^{-1}. There was no significant difference between the less severe and severe grazing and third grazing, and the pregrazing leaf mass across the treatments was 2333 ± 83 and 5970 ± 423 kg DM ha^{-1} respectively.

3.3.5 STEM MASS AT EACH GRAZING

At the commencement of the first grazing on 22 December 1988 in the ERGS, the pregrazing stem mass was not significantly different in the grazing intensity treatments (Fig 3.3a), and the overall mean was 178 ± 53 kg DM ha^{-1}. Also, the grazing intensity treatments did not differ significantly at the subsequent grazings, and the pregrazing stem mass across all treatments at the second, third and fourth grazings was 833 ± 113, 762 ± 63 and 873 ± 180 kg DM ha^{-1} respectively. However, the stem mass at the final grazing on 28 September 1989 in the less severely grazed treatments was greater than in the severely grazed treatments, although the results were not significantly ($P=0.07$) different.

In the LRGS at the first grazing on 11 January 1989, the pregrazing stem mass did not differ in the grazing intensity treatments (Fig 3.3b), and the overall mean was 427 ± 74 kg DM ha^{-1}. Also, the pregrazing stem mass did not differ





Figs 3.3a & 3.3b The effect of plant growth stage at grazing and grazing intensity on the pregrazing stem mass in sulla, at each grazing over 365 DAS.

significantly at subsequent grazings, and the mean across all treatments at the second and third grazing was 1145 ± 89 and 6530 ± 489 kg DM ha^{-1} respectively.

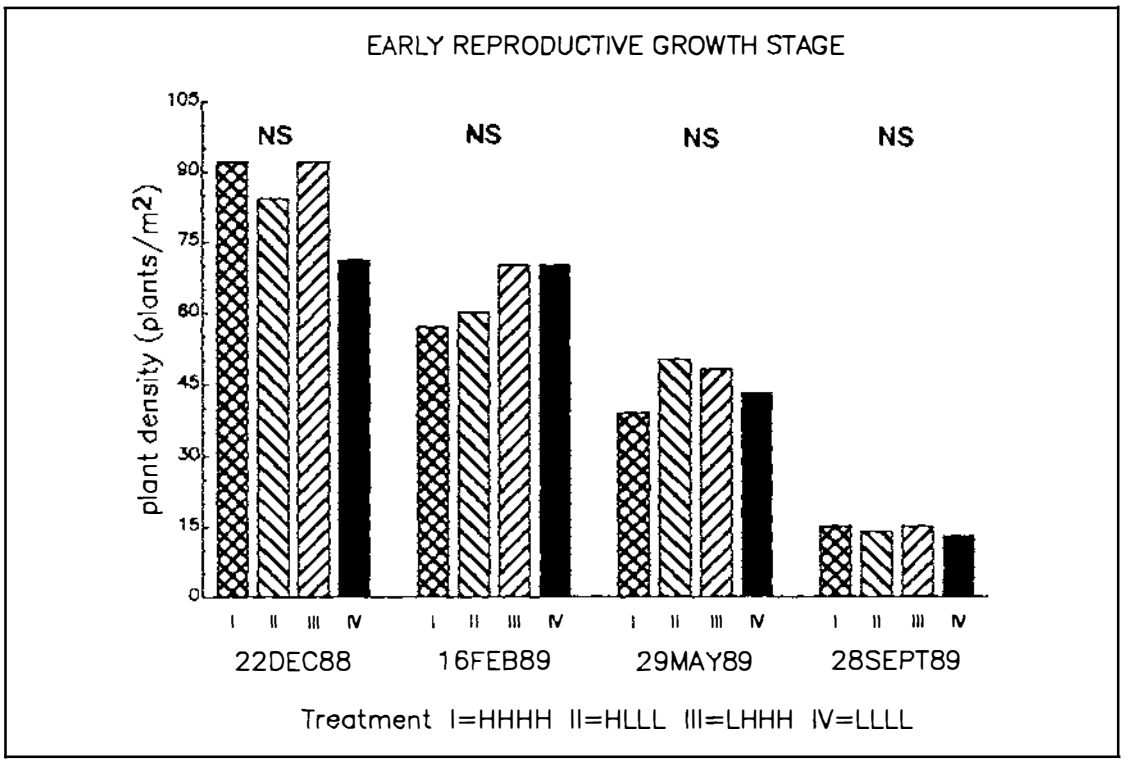
3.3.6 PLANT DENSITY

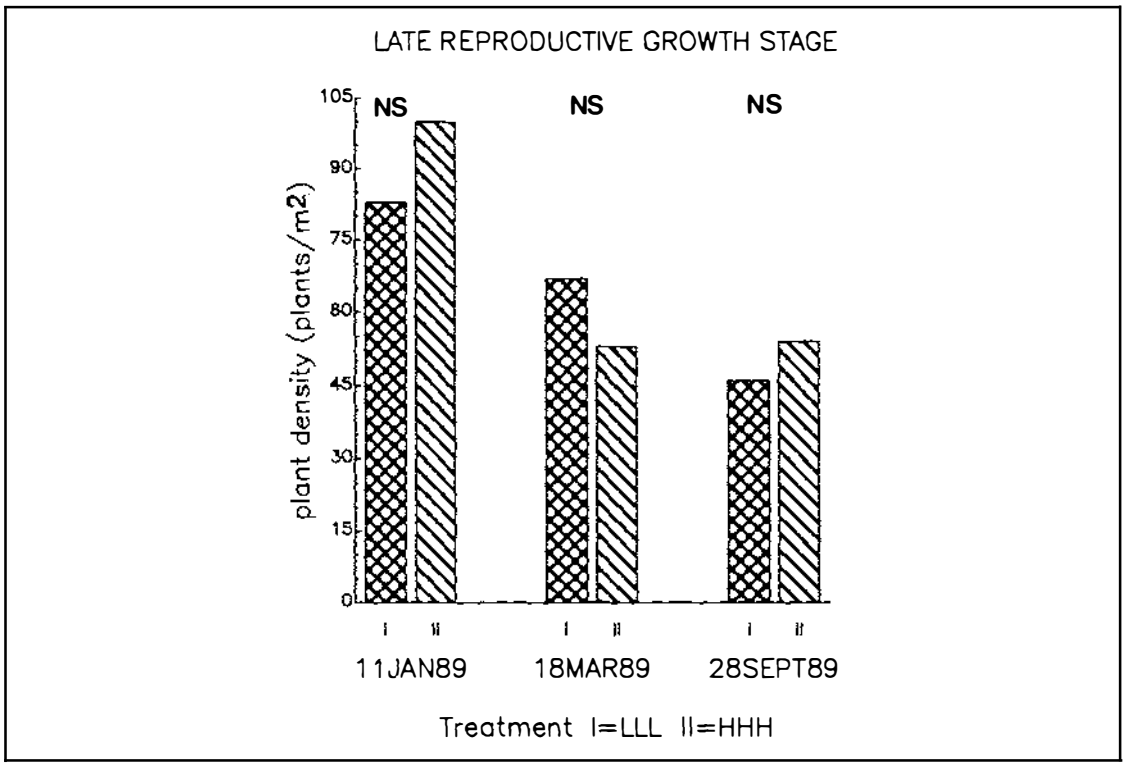
At 365 DAS, there were no significant differences in plant density between the grazing intensity management treatments within growth stages (Table 3.7). However, there was a significant ($P<0.001$) difference between the ERGS and LRGS treatments.The resultant plant density in the ERGS and LRGS treatments was 14 ± 1 and 50 ± 2 plants m^{-2} respectively at the conclusion of the trial.

Table 3.7 The effect of plant growth stage at grazing and grazing intensity on the final plant density in sulla, at 365 DAS.

Grazing management Treatment	Plant density (plants m^{-2})
ERHHHH	15
ERHLLL	14
ERLHHH	15
ERLLLL	13
LRLLL	46
LRHHH	54
$LSD_{0\,05}$	9

At the time of the first grazing on 22 December 1988 in the ERGS, the pregrazing plant density in the grazing intensity treatments was not significantly different (Fig 3.4a), and the overall mean was 84 ± 8 plants m^{-2} respectively. There were no significant differences between the grazing intensity treatments at the subsequent grazings. The pregrazing plant density across all treatments at the





Figs 3.4a & 3.4b The effect of plant growth stage at grazing and grazing intensity on the pregrazing plant density in sulla, at each grazing over 365 DAS.

second, third and fourth grazing was 64 ± 5, 45 ± 3 and 14 ± 1 respectively. There was a decline between 25-30% in plant numbers after each grazing and a greater decline of 69% between 29 May and 28 September 1989. At the conclusion of the trial the decline in plant numbers was 83% when compared to the density at the start of trial.

Whereas, at the time when the LRGS was first grazed on 11 January 1989, the pregrazing plant density in the grazing intensity treatments was also not significantly different (Fig 3.4b) and the overall mean was 92 ± 2 plants m^{-2}. There were no significant differences between the grazing treatments at subsequent grazings. When meaned across all treatments, the pregrazing plant density at the second and third grazing was 60 ± 5 and 50 ± 2 plants m^{-2} respectively. There was a 35% decline on plant numbers after the first grazing on 11 January and after the second grazing on 18 March 1989. Grazing in late summer, on 18 March, resulted in a marginal decline in plant numbers when counted on 28 September 1989. At the end of the trial the decline in plant numbers was 46% when compared to the density at the start of the trial.

3.3.7 INDIVIDUAL PLANT DRY WEIGHT

At 365 DAS, there was a significant ($P<0.01$) interaction between the growth stage and grazing intensity management on the final individual plant dry weight (DW) (Table 3.8). The grazing management treatments with the more frequent severe grazings at the ERGS, that is the ERHHHH and ERLHHH, resulted in significantly smaller plants, and the individual plant DW was 11.8 ± 3.8 and 12.6 ± 3.8 g respectively. The ERHLLL, ERLLLL, LRHHH and LRLLL treatments did not differ significantly, and the individual plant DW in these treatments ranged from 20-30 g.

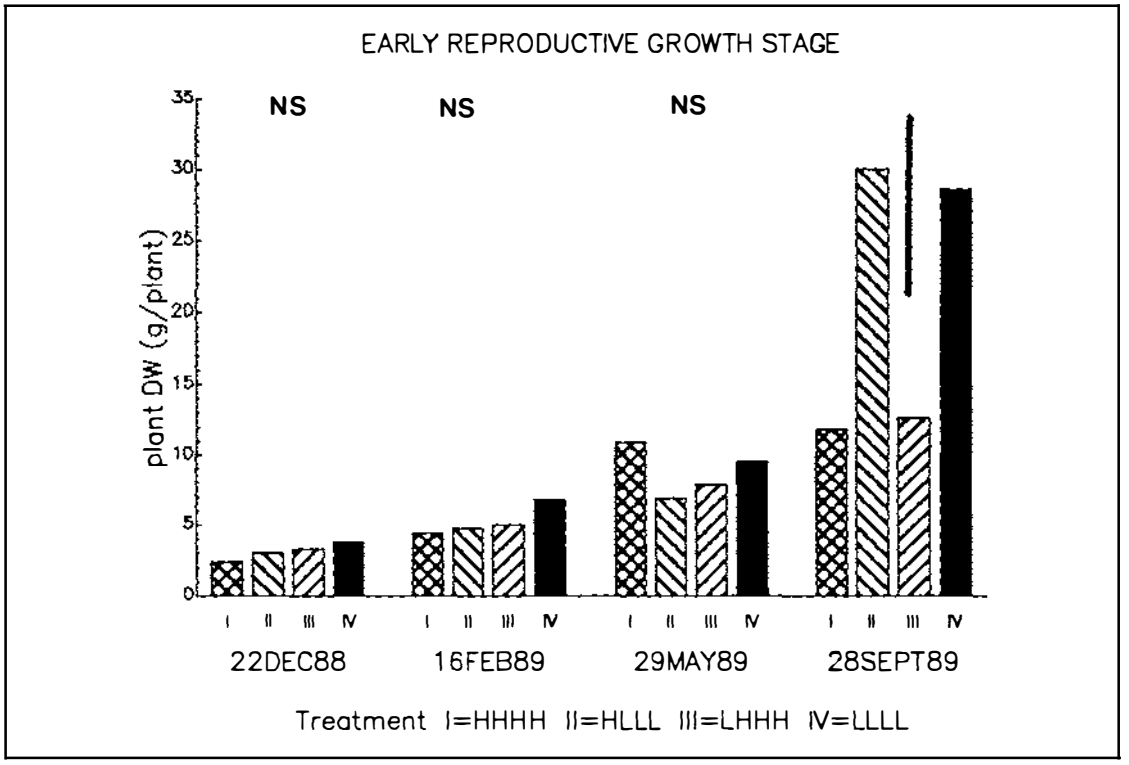
At the commencement of the grazing treatments, that is on 22 December 1988 in the ERGS, the pregrazing plant DW in the grazing intensity treatments did not differ significantly (Fig 3.5a), and the overall mean was 3.2 ± 0.2 g $plant^{-1}$ respectively. There were also no significant differences between the grazing intensity treatments at second and third grazing, and the overall mean was 5.3 ± 0.4 and 8.8 ± 1.1 g $plant^{-1}$. However, at the final grazing on 28 September 1989, there

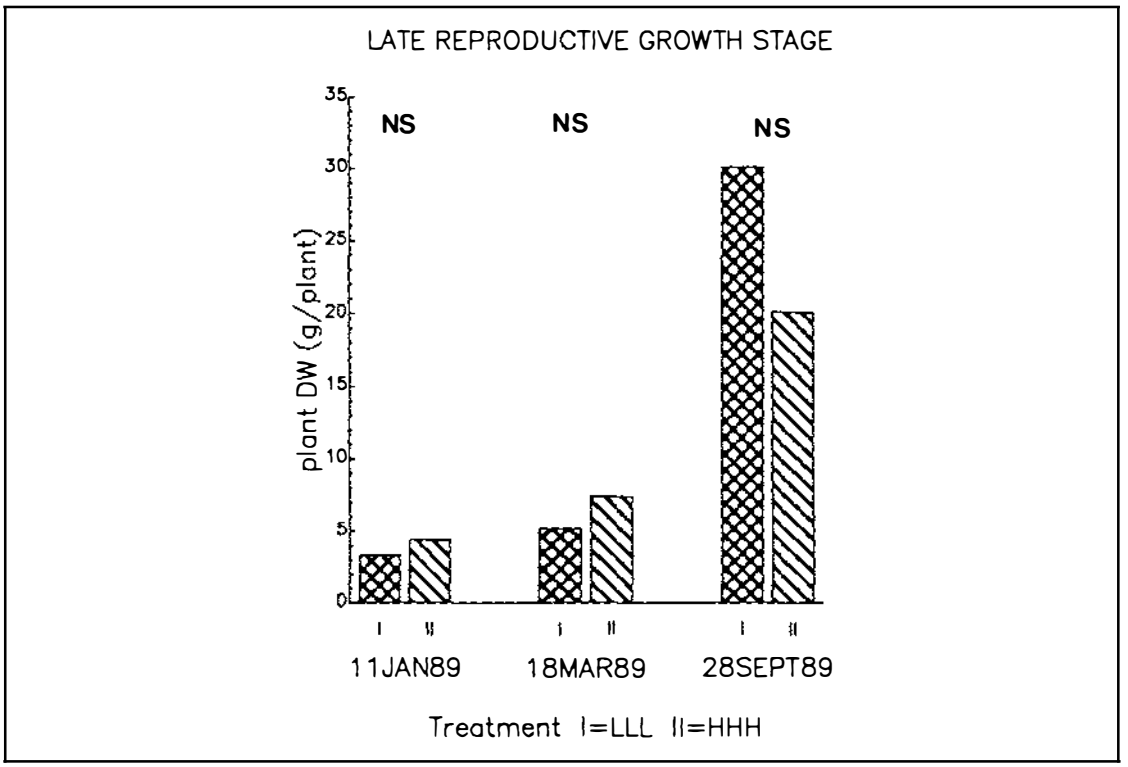
Table 3.8 The effect of plant growth stage at grazing and grazing intensity on the final plant dry weight in sulla at 365 DAS.

Grazing management Treatment	Plant DW (g plant^{-1})
ERHHHH	11.8
ERHLLL	30.0
ERLHHH	12.6
ERLLLL	26.6
LRLLL	30.0
LRHHH	20.3
$LSD_{0.05}$	12.0

were significant ($P<0.05$) differences between the grazing intensity treatments and the results are as discussed at 365 DAS above.

When the grazing treatments commenced in the LRGS on 11 January 1989, the pregrazing plant DW in the grazing intensity treatments was also not significantly different (Fig 3.5b), and the overall mean was 3.9 ± 0.5 g plant^{-1}. There was also no significant differences between the grazing intensity treatments at the second and third grazing, and the pregrazing plant DW meaned across the treatments was 6.3 ± 0.7 and 25.2 ± 2.6 respectively.





Figs 3.5a & 3.5b The effect of plant growth stage at grazing and grazing intensity on the pregrazing individual plant dry-weight (DW) in sulla, at each grazing over 365 DAS.

3.3.8 RELATIONSHIP BETWEEN PLANT DRY WEIGHT AND PLANT DENSITY

A scatterplot showing the relationship between $\log_{10}$ plant DW and $\log_{10}$ plant density is presented in Fig 3.6. The points represented on the graph are individual $\log_{10}$ values for each replicate in each treatment combination, at the end of the experiment. Two contrasts are evident. First, the LRGS populations were substantially greater than the ERGS populations, but ranges in plant size were similar. Second, within the ERGS population, severely grazed plants were smaller than the less severely grazed plants but had similar plant density. Differences in plant weight between the grazing intensity treatment combinations in the LRGS population were smaller.

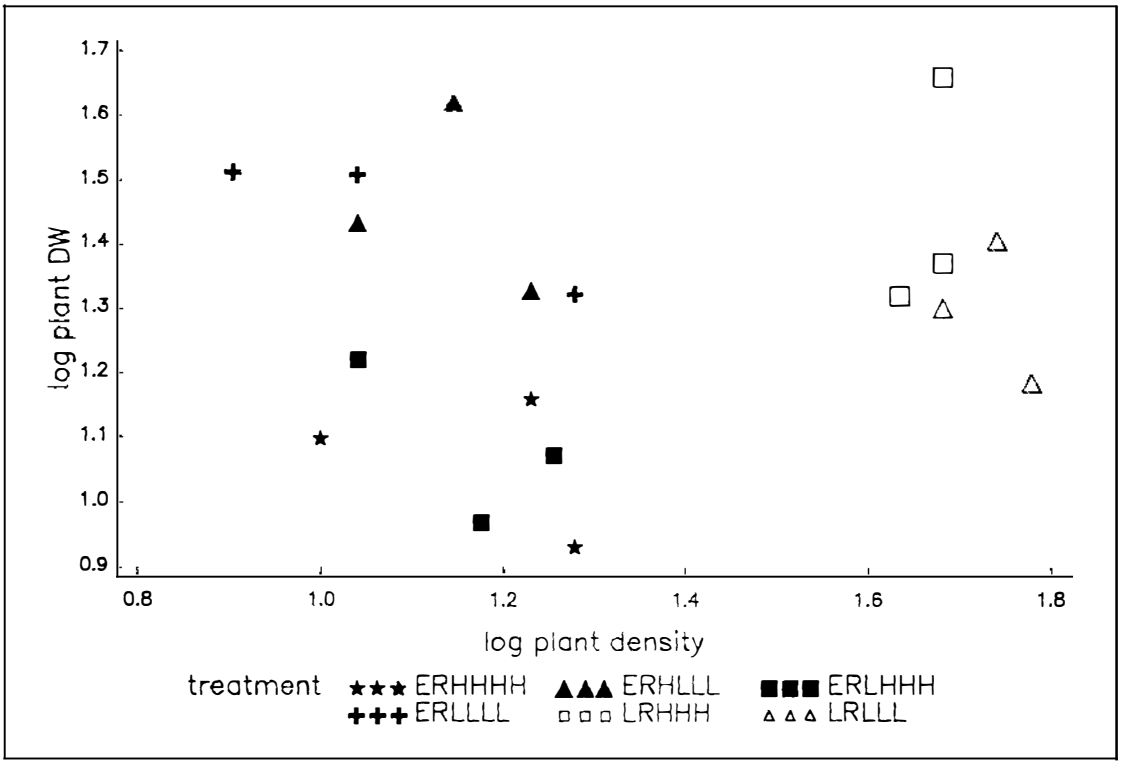


Fig 3.6 Scatterplot showing the relationship between $\log_{10}$plant dry-weight (DW) and $\log_{10}$plant density at the end of the experiment. Points represent replicates in each treatment combination. KEY: ER=early reproductive growth stage, LR=late reproductive growth stage, H=severe grazing and L=less severe grazing.

3.3.9 LEAF-TO-STEM MASS RATIO

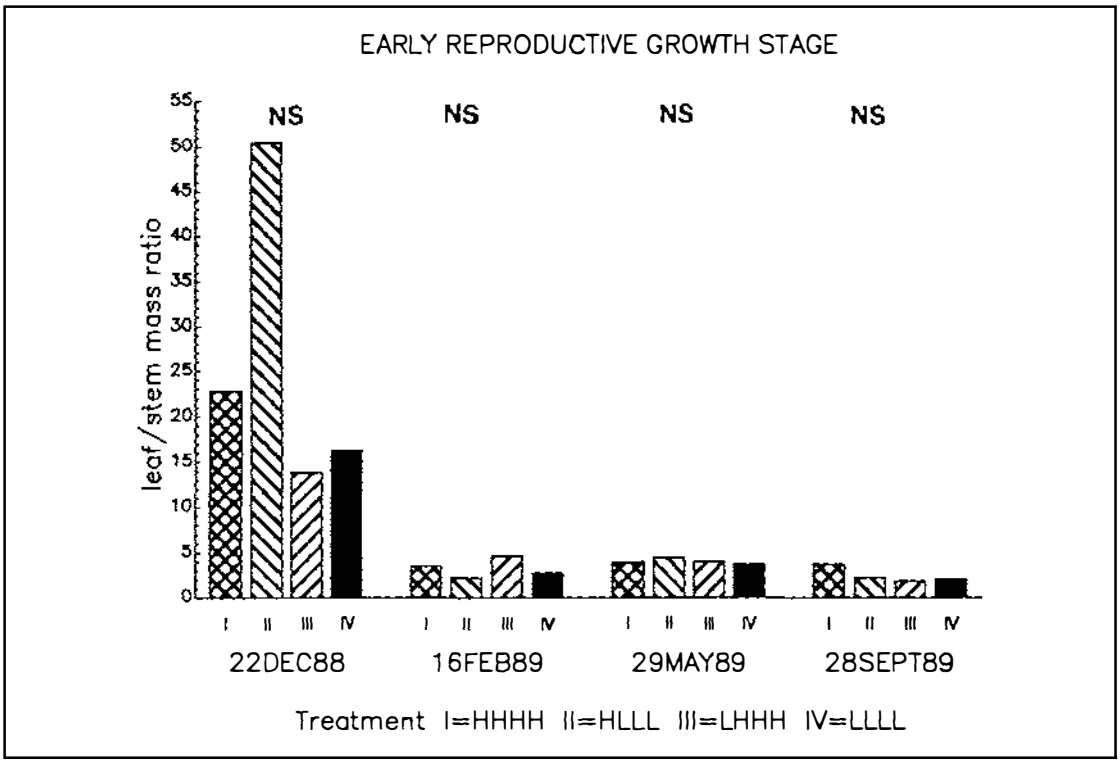
At the conclusion of the trial at 365 DAS, there were no significant differences between the grazing intensity management treatments within growth stage on the leaf-to-stem mass ratio (LSR) of the total herbage accumulated (Table 3.9). However, there was a significant ($P<0.001$) effect of growth stage on the LSR. The LSR in the ERGS and LRGS treatments was 3.8 ± 0.2 and 1.6 ± 0.3 respectively.

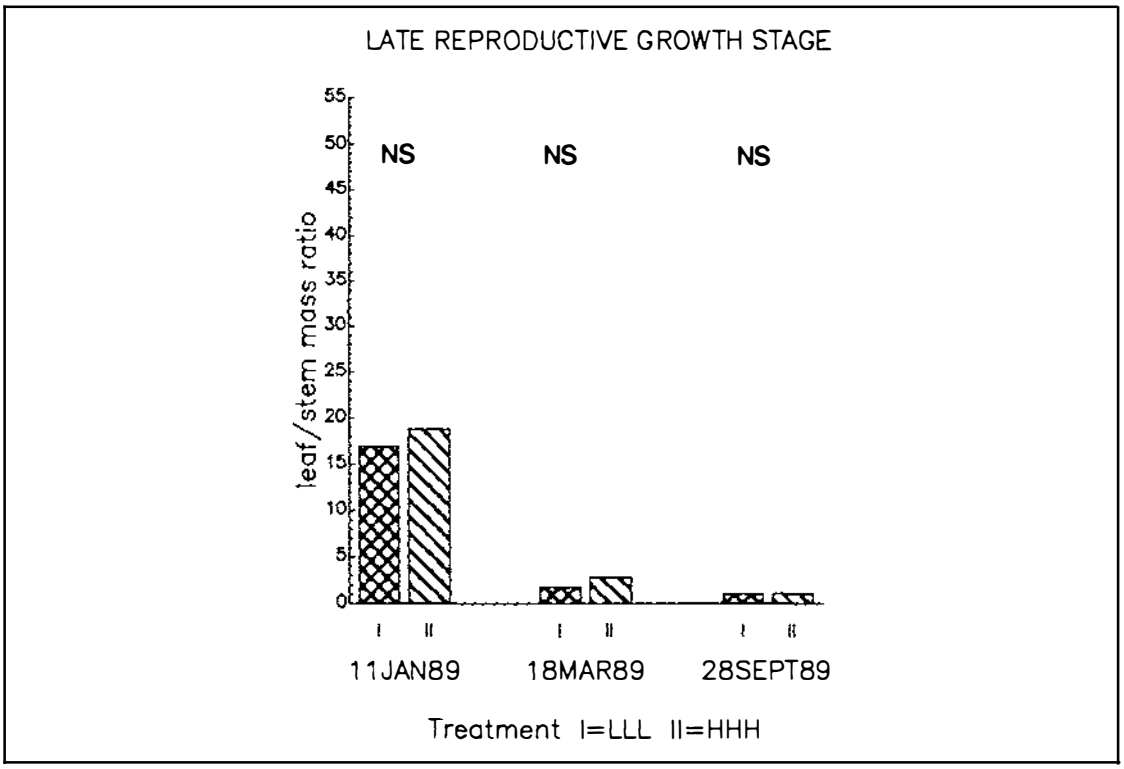
At the time when the grazing treatments commenced, that is on 22 December 1988 in the ERGS, the pregrazing LSR in the grazing intensity treatments was not significantly different (Fig 3.7a), and the overall mean was 25.8 ± 6.5. There were no significant differences between the grazing intensity treatments at subsequent grazings. The pregrazing LSR across all the grazing

Table 3.9 The effect of plant growth stage at grazing and grazing intensity on the total accumulated leaf-to-stem mass ratio in sulla over 365 DAS.

Grazing management Treatment	Leaf-to-stem mass ratio
ERHHHH	4.4
ERHLLL	3.4
ERLHHH	4.0
ERLLLL	3.3
LRLLL	1.3
LRHHH	1.9
$LSD_{0.05}$	1.5

treatments at the second, third and fourth grazings was 3.3 ± 0.4, 4.0 ± 0.4 and 2.5 ± 0.2 respectively. Following the first grazing in the ERGS, the LSR narrowed by 87% and remained less than 4.0 in the subsequent grazings.





Figs 3.7a & 3.7b The effect of plant growth stage at grazing and grazing intensity on the pregrazing leaf-to-stem mass ratio in sulla, at each grazing over 365 DAS.

When the grazing treatments was first imposed in the LRGS on 11 January 1989, the pregrazing LSR in the grazing intensity treatments did not differ significantly (Fig 3.7b) and the overall mean was 17.8 ± 6.0. No differences were significant at subsequent grazings. The pregrazing LSR over all the grazing intensity treatments was 2.3 ± 0.4 and 1.0 ± 0.1 at the second and third grazing respectively. The LSR also narrowed by 87% following the first grazing and remained less than 3.0 in the subsequent grazings. Most of the stem material in the LRGS treatment was utilisable with an organic matter digestibility (OMD) ranging from 70-85%. An *in vitro* digestibility analysis of herbage components of sulla, sampled at the late reproductive growth stage, is presented in Table 3.10.

Table 3.10 Chemical and estimated *in vivo* digestibilities of herbage components in sulla, sampled at the late reproductive growth stage.

Plant component	%DM	%N (DM)	%ASH	†Estimated *in vivo*%		
				DMD	DOMD	OMD
Leaf-top 70 cm	89.54	4.76	9.1	82.53	76.86	85.39
Stem-top 70 cm	86.87	1.79	9.2	79.07	73.60	82.32
Leaf-whole plant	90.02	3.81	9.8	80.96	74.99	83.97
Stem-whole plant	90.64	1.29	9.3	68.29	63.58	72.74
Leaf+Stem (Whole plant)	89.54	2.29	10.1	72.11	66.55	75.92

† Samples were analysed for *in vitro* digestibility using pasture standards within the following *in vivo* digestibility ranges:

Dry matter digestibility (DMD%) 65.40-86.16
Digestible organic matter per 100 g dry matter (DOMD%) 60.40-81.00
Organic matter digestibility (OMD%) 72.10-90.65

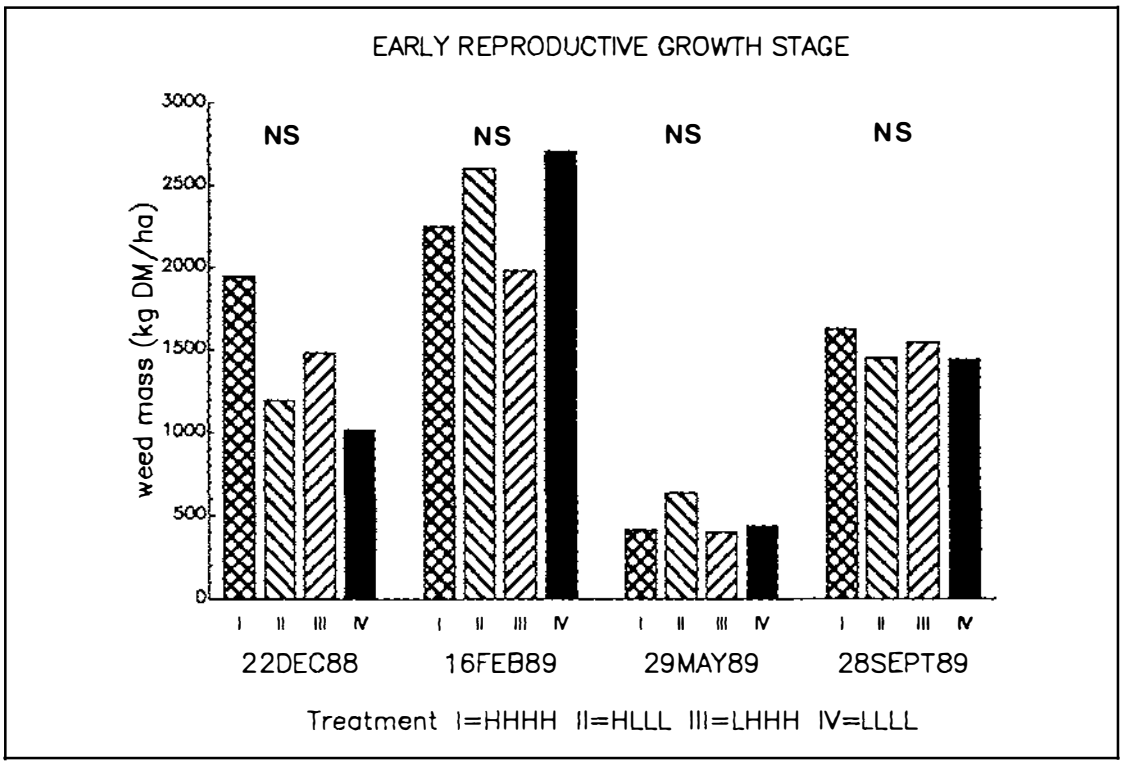
3.3.10 WEED ACCUMULATION

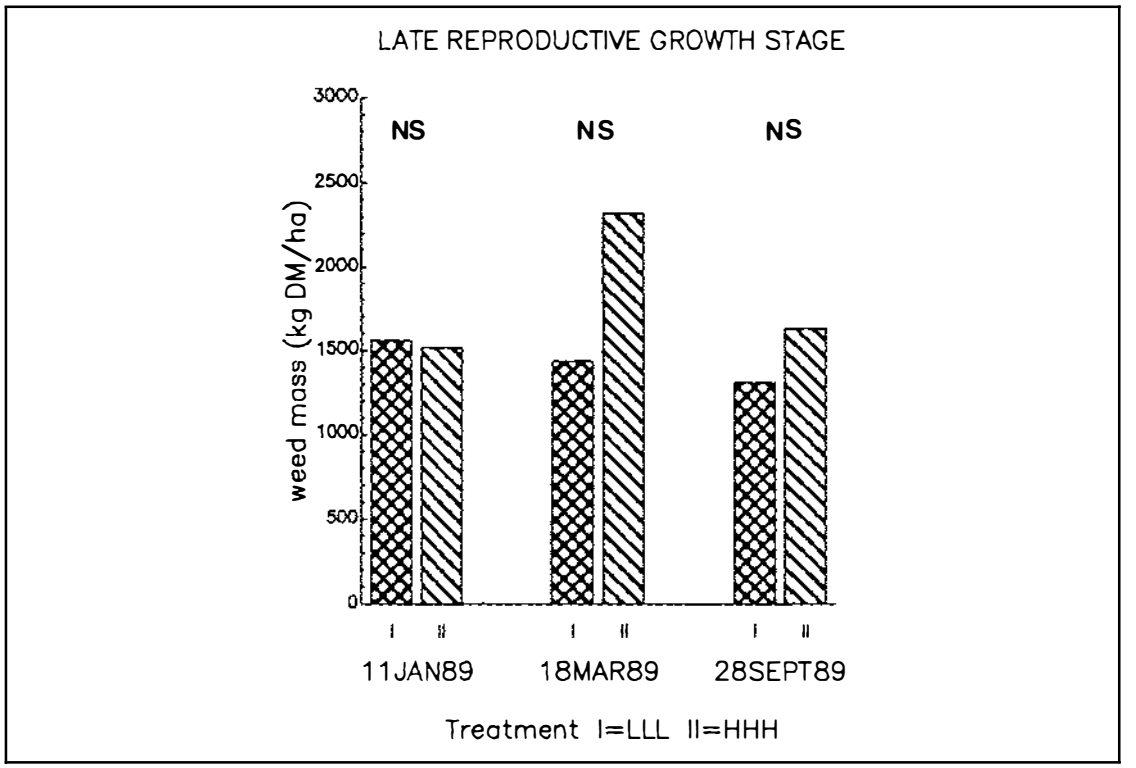
The total weed accumulated over the duration of the trial was not significantly different between the grazing intensity treatments within growth stage or between growth stages (Table 3.11). When meaned over all management treatments, total weed accumulated was 5476 ± 213 kg DM ha^{-1} y^{-1}. Weed comprised about 30% of the total herbage accumulated in sulla.

At the time of the imposition of the grazing intensity treatments in the ERGS on the 22 December 1988, the pregrazing weed mass was not significantly different in the grazing intensity treatments (Fig 3.8a), and the overall mean was estimated at 1408 ± 158 kg DM ha^{-1}. There were also no significant differences between the grazing intensity treatments at subsequent grazings. When meaned over all treatments, the pregrazing weed mass at the second, third and fourth grazing was 2380 ± 250, 472 ± 39 and 1513 ± 93 respectively.

Table 3.11 The effect of plant growth stage at grazing and grazing intensity on the total weed accumulated (kg DM ha^{-1}) in sulla, over 365 DAS.

Grazing management Treatment	Total Weed Accumulated
ERHHHH	6223
ERHLLL	5870
ERLHHH	5403
ERLLLL	5597
LRLLL	4303
LRHHH	5460
$LSD_{0.05}$	NS





Figs 3.8a & 3.8b The effect of plant growth stage at grazing and grazing intensity on the pregrazing weed mass in sulla, at each grazing over 365 DAS.

When the grazing treatments commenced in the LRGS on 11 January 1989, the pregrazing weed mass was also not significantly different in the grazing intensity treatments (Fig 3.8b), and the overall mean was 1538 ± 222 kg DM ha^{-1}. Also no differences were significant between the grazing treatments at subsequent grazings. The pregrazing weed mass over all the treatments at the second and third grazings was 1875 ± 127 and 1468 ± 131 kg DM ha^{-1} respectively.

3.3.11 HERBAGE CONSUMPTION

Herbage, herbage components, and weed consumed in terms of amount of herbage grazed by sheep is presented in Table 3.12, and percentages of total accumulation removed are included in parenthesis. The total herbage consumed between the grazing intensity management treatments within growth stages was not significantly different over the 365 days. Nevertheless, the percent consumption of herbage was significantly ($P<0.05$) greater in the more frequent severe grazing than in the more frequent less severe grazing combinations. There was a significant ($P<0.001$) effect of growth stage on the total herbage consumed. The total herbage consumed in the ERGS and LRGS treatments was 8064 ± 785 and 16179 ± 1110 kg DM ha^{-1} y^{-1}, which was equivalent to 67 ± 3 and 82 ± 3% of the total herbage accumulation respectively. Sheep consumed more herbage in the LRGS treatment than in the ERGS treatment.

Total leaf tissue consumed by sheep was not significantly different between the grazing intensity management treatment within growth stage, but differed significantly ($P<0.001$) between growth stages. The total leaf tissue consumed over the 365 days in the ERGS and LRGS treatments was 6640 ± 414 and 10958 ± 586 kg DM ha^{-1} y^{-1}, equivalent to 72 ± 3 and 96 ± 3% of the leaf component of herbage on offer respectively. The stem component of the herbage consumed also did not differ significantly between the grazing intensity treatments within growth stage. However, there was a significant ($P<0.001$) difference between the growth stage treatments. The percent stem tissue consumed in the ERGS and the LRGS treatment was 48 ± 5% and 62 ± 5%, equivalent to 1309 ± 475 and 5078 ± 72 kg DM ha^{-1} y^{-1} respectively. There were no significant differences between the grazing intensity management treatments within growth stage or between growth stages on

Table 3.12 The effect of plant growth stage at grazing and grazing intensity on the total herbage, herbage components and weeds consumed (kg DM ha^{-1}), over 365 DAS. Figures in brackets are percentages (%) of total accumulation grazed by sheep.

Grazing management	Herbage consumed	Herbage components consumed			Weeds consumed
		Leaves	Stems	Flowers	
ERHHHH	7170 (71)	6293 (77)	783 (42)	93 (100)	2327 (37)
ERHLLL	8304 (64)	6843 (71)	1401 (41)	60 (100)	1906 (32)
ERLHHH	7252 (68)	5743 (69)	1308 (59)	200 (91)	2463 (42)
ERLLLL	9530 (65)	7680 (69)	1747 (51)	103 (75)	2067 (37)
LRLLL	15667 (78)	10317 (95)	5197 (55)	153 (100)	2082 (45)
LRHHH	16691 (86)	11600 (95)	4958 (69)	133 (100)	3803 (71)
$LSD_{0.05}$	4949	2611	2993	NS	NS

flowers consumed. The overall flowers consumed was 124 ± 29 kg DM ha^{-1} y^{-1} and sheep ate almost all of the flowers on offer. There was no significant effect of grazing intensity management treatment on weeds consumed, and the mean across all treatments was 2441 ± 235 kg DM ha^{-1} y^{-1}, which was 44 ± 4% of the total weed accumulated in the sward. Herbage and herbage components consumed by sheep in the ERGS and LRGS at each grazing over 365 DAS are included in appendices 3.8 & 3.9.

3.3.12 REGROWTH SITE AND REGROWTH SITE CHARACTERISTICS IN SULLA

Sulla regrew from axillary buds originating from leaf axils or leaf scars. The potential regrowth sites were the primary stem, secondary stem or stems and the crown (See Fig 3.9). The crown included the upper 50 mm of the taproot. Severe or less severe grazing intensities did not have any significant effect on the regrowth characteristics in plants harvested at 18 days after grazing (DAG) in the ERGS plots and at 48 DAG in the LRGS plots. Therefore, only the effect of growth sites on the regrowth characteristics of sulla is discussed. No valid comparison between growth stages was made as the harvest times were not comparable.

3.3.12.1 SHOOT NUMBER

The regrowth site characteristics at 18 DAG in the ERGS and 48 DAG in the LRGS are presented in Tables 3.13 and 3.14. The total shoot number arising on the various regrowth sites in the plants harvested at 18 DAG from the ERGS plots was 6.3 per plant. All the new shoots arose from leaf axils or scars on the primary stem, secondary stem(s) and the crown. There were significant differences ($P<0.01$) between the regrowth sites in the number of shoots produced from leaf axils or scars. The primary stem produced about 19% of the total shoots, whereas the secondary stem and the crown contributed an equal number of shoots.

The total number of shoots in the plants harvested at 48 DAG from the LRGS plots was 8.9 per plant. Almost 85% of the new shoots arose on the crown. The number of shoots on the primary stem and secondary stem(s) was not significantly different, and their mean contribution to the total number of shoots produced by the

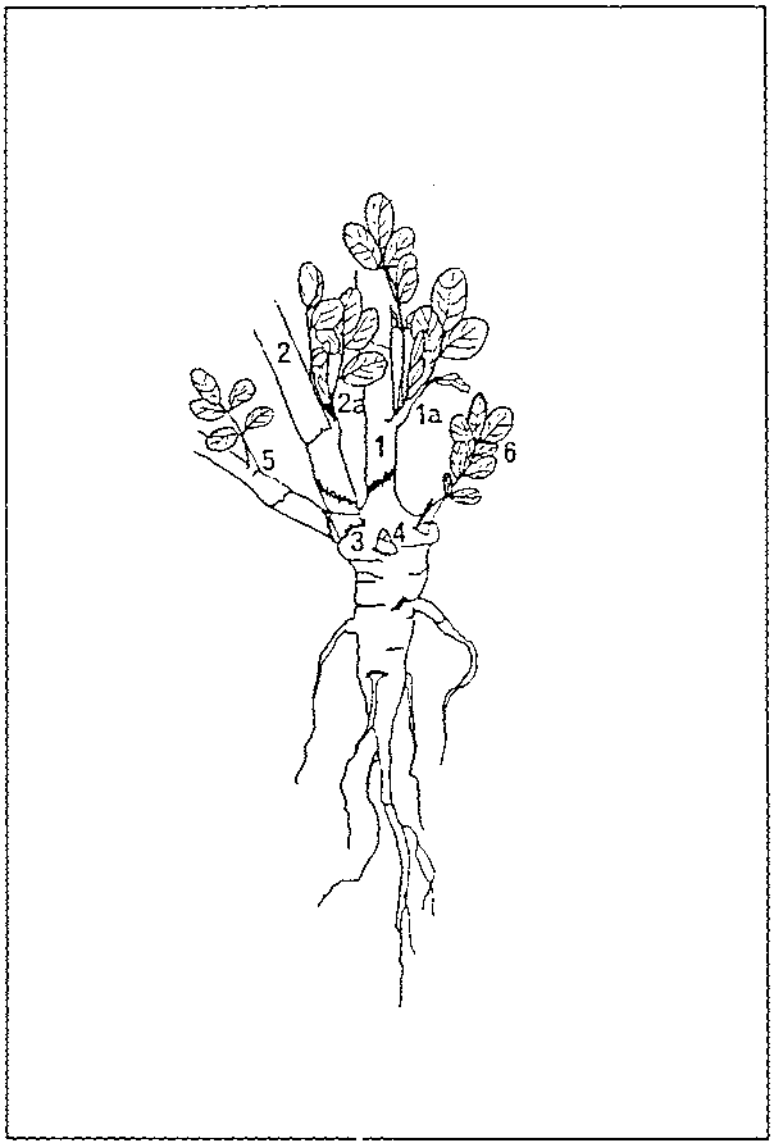


Fig 3.9 REGROWTH SITES OF A SULLA PLANT.
(1) Primary stem; (1a) Primary stem axillary shoot; (2) Secondary stem; (2a) Secondary stem axillary shoot; (3) Leaf scar; (4) Axillary bud; (5) Leaf axil; (6) Crown axillary shoot.
(Drawing by Cally L. McKenzie, Massey University).

Table 3.13 The origin of leaf axil buds on regrowth sites, and regrowth site characteristics in sulla, grazed at the early reproductive growth stage (85 DAS), 18 days after first grazing. Data meaned over all intensities.

Regrowth Site	Regrowth site characteristics				
	Shoot Number	Shoot Length (mm)	Leaf Number	Petiole Length (mm)	Leaf Area (cm^2)
Primary Stem	1.2	8.6	4.9	101.9	85.3
Secondary Stem	2.3	5.7	6.6	54.2	60.8
Crown	2.8	19.9	8.1	92.9	114.8
$LSD_{0.05}$	1.0	9.7	NS	26.3	NS

Table 3.14 The origin of leaf axil buds on regrowth sites, and regrowth site characteristics in sulla, grazed at the late reproductive growth stage (106 DAS), 48 days after first grazing. Data meaned over all intensities.

Regrowth Site	Regrowth site characteristics				
	Shoot Number	Shoot Length (mm)	Leaf Number	Petiole Length (mm)	Leaf Area (cm^2)
Primary Stem	0.2	5.3	0.7	12.5	2.2
Secondary Stem	1.1	7.9	3.6	33.6	16.2
Crown	7.6	27.6	26.4	137.4	190.7
$LSD_{0.05}$	1.4	10.5	5.0	23.0	33.8

plant was only 0.7.

3.3.12.2 SHOOT LENGTH

Shoot length, used as an indicator of extension rate, at the regrowth sites was significantly ($P<0.01$) different between the regrowth sites in the plants harvested at 18 DAG from the ERGS plots. The crown shoots extended to 19.9 mm, more than twice the length of the primary stem and secondary stem(s) shoots in the 18 days of regrowth. Shoots arising on the primary stem and secondary stem(s) were not significantly different and meaned at 7.2 mm.

The shoot length followed a similar trend in the plants harvested at 48 DAG in the LRGS plots. The crown shoot length measured 27.6 mm, more than four times the length of the primary stem or secondary stem(s) shoots. The comparatively greater crown shoot length in the ERGS and LRGS indicated a faster extension rate of the crown shoots.

3.3.12.3 LEAF NUMBER

The number of leaves arising from the new shoots over all the regrowth sites did not differ significantly in the plants harvested in the ERGS plots at 18 DAG. The total leaf number over all the regrowth sites was 19.6 per plant. However, there was a significant difference in leaf number amongst the regrowth sites in the plants harvested at 48 DAG from the LRGS plots. The crown shoots accounted for 86% of the total leaves produced by the plant. The contribution from the primary stem and secondary stem(s) was marginal, with a total of four leaves.

3.3.12.4 PETIOLE LENGTH

The petiole length, in the plants harvested at 18 DAG from the ERGS plots, did not differ significantly between the primary stem shoots and crown shoots. The secondary stem petiole length was 54 mm, about half the length of the primary stem shoots or crown shoots. In the plants harvested at 48 DAG from the LRGS plots, the length of the petiole of shoots arising on the crown was six times greater than that in the primary stem and secondary stem(s) shoots. However, the petiole length on the primary stem and secondary stem(s) shoots did not differ significantly.

3.3.12.5 LEAF AREA

At 18 DAG, the mean total leaf area per plant in the ERGS plots was 260.9 cm^2. Leaf area on the primary stem, secondary stem(s) and crown shoots were not significantly (P=0.06) different. Nevertheless, the crown shoots produced 114.8 cm^2 leaf area, which was approximately one and half times the leaf area produced by the primary or secondary stem(s) shoots. The total leaf area on the plants in the LRGS plots harvested at 48 DAG was 209.1 cm^2. The crown shoots accounted for 91% of the total leaf area produced in the 48 days of regrowth. The primary stem and secondary stem(s) shoots contributed marginally to the total leaf area on the plant.

3.4 DISCUSSION

3.4.1 Herbage production.

The annual herbage production of sulla cv. Necton ranged between 10000-20000 kg DM ha^{-1} over the grazing management treatments, which was similar to the 12000-19000 kg DM ha^{-1} for cv. Aokau reported under cutting (Douglas, 1984; Douglas & Foote, 1985; Rys et al., 1988), but higher than the 7000-9000 kg DM ha^{-1} for cv. Grimaldi reported in southern Italy under irrigation (Corleto & Magini, 1985). Sulla grew throughout the year with high summer herbage accumulation rates and relatively lower rates in winter, and showed considerable autumn-winter activity under the mild winter conditions experienced in the Manawatu.

The annual herbage production was unaffected by the grazing intensity treatments imposed. These findings were similar to those of Rys *et al.*, 1988, who found that cutting sulla at frequent (5-10% flowering) or infrequent (70-80% flowering) intervals, at 3 or 10 cm cutting height, did not affect the herbage production in the first year. The reduction in herbage accumulation in the ERGS, following the grazing at the end of May, was probably affected either by growth stage or by grazing in late autumn or a combination of both. The experimental design did not allow for the possible effects of late autumn grazing on plant density to be determined. Nevertheless, the sharp decrease in plant density and the consequent decrease in herbage accumulation rate in the ERGS treatment grazed in late May suggested that grazing in late autumn should be avoided.

3.4.2 Plant density, plant size and their relationship.

As grazing studies in sulla are scarce and little emphasis on its study under grazing is given overseas, whenever literature is lacking, lucerne or other crown forming forage legumes provide a basis of comparison.

The decline in plant density with an increase in plant size was consistent with other perennial forage legumes like lucerne (Palmer & Wynn-Williams, 1976; Leach, 1979; Enguita, 1989; Smith et al., 1989), red clover (Hay & Ryan, 1989), sainfoin (Mowrey & Matches, 1991), and conformed to the observations made by Rys et al. (1988) in sulla grown in the Hawke's Bay. The factor that had the severest effect on plant density was the late autumn grazing, whereas the interaction between severe grazing and late autumn grazing had the greatest effect on plant size.

The lower plant density in the ERGS treatment, at the conclusion of the trial in late spring, was not compensated for by an increase in plant size relative to plants in treatment LRGS, suggesting that the maximum plant size for the management conditions imposed had been attained. Therefore, grazing in late autumn, and particularly severe grazing, decreased herbage accumulation by decreasing plant density below the point that could be compensated for by an increase in plant size. Presumably, plants die during the wet autumn conditions from possible treading damage to growing points (Edmund, 1966; Brown & Evans, 1973; Smallfield, 1982), lack of carbohydrate reserves (Graber et al., 1927; Grandfield, 1935; Smith, 1962; White & Lucas, 1989), insufficient active leaf area (Keoghan, 1967; Robinson & Massengale, 1968) or disease (Carr, 1971; Close & Sanderson, 1977; Rys et al., 1988).

The log plant weight/density relationship (See Fig 3.6) at the end of the experiment demonstrated the effect of severity of grazing primarily in the late autumn at an immature growth stage (ERGS), on the reduction of herbage accumulation in the subsequent spring. Plants subjected to severe grazing at the ERGS in late autumn were unable to compensate for the decline in plant density with an increase in plant weight, whereas those in the less severe grazing treatment were able to compensate under similar plant densities. Thus, plants in the less severe grazing treatment showed a greater phenotypic compensation ability. In contrast plants in the LRGS treatment, where late autumn grazing did not occur

under the less frequent grazing management, had greater plant density compared to the ERGS treatment. Compensation in the LRGS treatment was evident, although plants grazed at either severity following grazing at a more mature growth stage (LRGS) showed smaller differences in either plant weight or density.

Plants that survived complete defoliation in the severe grazing treatment, especially in late autumn at an immature growth stage, presumably contained insufficient preaccumulated reserves of nonstructural carbohydrate. Furthermore, the cool, cloudy, wet weather and low soil temperatures (See Table 3.3), and reduced intensity of incoming photosynthetically active radiation (PAR) in winter, did not favour recovery growth. Under such environmental conditions build up of leaf area was diminished, leading to lower herbage accumulation rates and subsequent reduction in herbage accumulation in spring. The contribution of preaccumulated nonstructural carbohydrate reserves to recovery growth has been demonstrated in other crown forming plants like lucerne (Hodgkinson, 1969).

3.4.3 Changes in leaf-to-stem mass ratio.

Sulla has the ability to carry large quantities of herbage through summer, without apparent visual deterioration of herbage. As sulla advanced in maturity, the stem material increased and the leaf-to-stem mass ratio (LSR) decreased. The decrease in LSR is a major factor contributing to the low quality herbage in forages (Nicol & Barry, 1980; Oustad & Fick, 1983). A narrow LSR in the LRGS treatment at 365 DAS indicated a large contribution of stem material to the total herbage accumulated, whereas it was largely leaf material in the ERGS treatment. An *in vitro* digestibility analysis of herbage components at the late reproductive growth stage ranged from 60-85%, with stems less digestible than leaves (See Table 3.10). The LSR in this trial was higher than those reported by Douglas (1984) at comparable growth stages. The regrowth LSR was less than that when the forage was first grazed, suggesting a possible morphological adaptation to grazing (Jameson, 1963; Briske, 1986).

The LSR of spring growth in lucerne is frequently less than that of the regrowth herbage at the same morphological stage (Onstad & Fick, 1983). This may be attributed to: differences in temperature and daylength patterns (Van Soest et

al., 1978); origin of stem, which comes from crown buds in spring growth, in contrast to mostly axillary basal buds in regrowth (Nelson & Smith, 1968a); or effects of a larger water deficit during summer compared to spring (Vough & Marten, 1971).

3.4.4 Weed infestation.

The unavailability of a suitable postemergence selective herbicide for sulla caused severe weed infestation at the establishment phase, and consequently led to high weed content in the herbage sampled, which was accentuated by a decrease in plant density. The grazing management treatments did not affect weed infestation. Manual weeding was ineffective in keeping weeds under control. The weeds were predominantly black nightshade (*Solanum nigrum*) and dock (*Rumex* spp). Rys et al., (1988) reported similar problems in sulla sown in the Hawke's Bay. Weed control at the establishment phase was identified as critical; a suitable herbicide was used in subsequent studies (See Chapter 5).

3.4.5 Efficiency of grazing.

Sulla was readily eaten by sheep, and their pattern of defoliation was flowers (almost all eaten) followed by leaves and stems. The percent utilisation was higher in the severe grazing than in the less severe grazing management in the two growth stages, and ranged from 71-86% of the total herbage accumulated being consumed. Consumption of herbage and its components was higher in the LRGS treatment than in the ERGS treatment. This was related to the differences in total herbage accumulated and the similar grazing intensities imposed. The total herbage produced in the LRGS treatment was higher than in the ERGS treatment, and the need to maintain similar herbage mass after each grazing in both the growth stages led to a greater removal of herbage by sheep in the LRGS treatment, resulting in higher herbage consumption. Weeds were poorly utilised, as the predominant weed black nightshade was avoided by sheep, whereas other weeds like dock and fathen were eaten.

3.4.6 Origins of regrowth in sulla.

The regrowth in sulla was predominantly from the leaf axils or scars located on the crown. This was in accordance with other crown forming plants like lucerne (Langer & Keoghan, 1970; Leach, 1970a), sainfoin (Percival & McQueen, 1980) and red clover (Fergus & Hollowell, 1960), but was in contrast to birdsfoot trefoil, where the regrowth largely arises from axillary buds at the upper ends of the cut shoots (Nelson & Smith, 1968a). Contribution of new shoots on the primary stem and secondary stem(s) to regrowth was marginal. My study was in contrast to Watson (1982), who claimed that regrowth in sulla originated primarily from the axillary buds located on the stubble, and Foote (1988), who recommended a grazing height not lower than 15 cm to ensure satisfactory regrowth from the remaining axillary buds, as overgrazing enhanced plant mortality.

At the early stages of regrowth in sulla, shoots arising from the crown were comparatively greater in number than those from the other regrowth sites. This trend appeared to continue to the later stages of regrowth, where the vigorous crown shoots dominated growth and extension. Similar findings were reported in lucerne, where shoots closer to the crown were more vigorous when compared to shoots on the stubble, the latter which were found to be slower in development and extension (Willard et al., 1934; Leach, 1968). In these studies, sheep selectively grazed leaves as reported also by Arnold (1960) and Rys et al.(1988), and the remaining stubble subsequently died. This excluded the possible contribution to regrowth of new shoots located on the primary and secondary stem(s).

3.4.7 Persistence problems.

As the trial was planned to run only for a year, plant density was no longer measured after the final grazing in late spring. However, the rapid decline in plant numbers suggested poor persistence of sulla. Visual observations after the final grazing in late spring indicated sparse recovery, and isolated recovered plants subsequently died.

3.4.8 Conclusions and further research.

1. Sulla has the potential to provide large quantities (10000-20000 kg DM ha^{-1}) of nonbloating forage over spring, summer and autumn.

2. It should be grazed between the late stem elongation and 10% flowering growth stages.

3. Severe grazing which removed most of the herbage did not affect plant regrowth potential, but gave maximum percent utilisation.

4. Stubble remaining after grazing subsequently died and decayed.

5. Regrowth after grazing was predominantly from the crown region.

6. Grazing in late autumn or winter killed many plants and decreased herbage accumulation in spring.

7. The death of sulla plants grazed in late autumn-winter was identified as a management problem and needed further study, particularly as sulla is a winter growing species.

8. Adequate chemical weed control and the use of the reisolated rhizobia strain for the successful establishment of sulla was envisaged in future trials.

9. Sulla appeared very short-lived under the grazing management treatments imposed.

10. Effectively nodulated plants need to be further evaluated under grazing to determine the optimum grazing management for herbage production and stand persistence.

CHAPTER 4. THE REGROWTH OF DEFOLIATED SULLA (*Hedysarum coronarium* L.) cv. NECTON; A GREENHOUSE PHYSIOLOGICAL EVALUATION.

4.1 INTRODUCTION

The physiological principles governing the regrowth of perennial forages are applicable both under cutting and grazing (Van Keuren & Matches, 1988). Defoliation by cutting or grazing physically removes all or part of the photosynthetic tissue. Until sufficient photosynthetic tissue is produced to support growth, continued growth must come from carbon compounds previously accumulated in the plant. This was principally inferred from two studies. Firstly, Graber et al., (1927) in a widely quoted publication, found that when lucerne plants were placed in darkness after defoliation, top growth accounted for 17% of the original dry weight. Secondly, the carbohydrate content of legume roots fluctuates, with a decrease after defoliation and subsequent increase thereafter (Grandfield, 1935; Smith, 1962).

Evidence to support this view was reviewed by Weinmann (1948, 1961,) and Deregibus et al., (1982). However, several other researchers including May (1960), questioned whether a cause-effect relationship existed between depletion of taproot carbohydrate reserves and shoot regrowth. He drew attention to the role of carbohydrates in root respiration following the removal of leaves. Davidson & Milthorpe (1965, 1966) pointed out the possible use of other metabolites as respiratory substrate following severe defoliation in grasses, whereas Mitchell & Denne (1967) drew attention to the possible loss of absorbing surfaces by the roots. Recent experiments by Richard & Caldwell (1985) involving etiolation of *Agropyron* spp, supported the laboratory studies of Davidson & Milthorpe (1966) and the review of May (1960). Culvenor et al., (1989a) concluded in their study of defoliated subterranean clover swards that partitioning of growth to lamina and mobilization of carbohydrates and nitrogen were important for the recovery from defoliation. Further, in a concurrent study with the same sward, Culvernor et al., (1989) showed that root respiration comprised a large respiratory cost of up to 75% of net photosynthesis during regrowth. In addition, other studies on the role of carbohydrate in relation to stress tolerance in lucerne (Fankhauser et al., 1989;

Fankhauser & Volenec, 1989; Habben & Volenec, 1990; Volenec et al., 1991; Boyce & Volenec, 1992), suggest that high taproot starch concentrations may be important for tolerance of specific environmental stresses, but broad applicability of this concept to encompass all stresses, including defoliation, were not consistent in their studies.

In New Zealand, the role of reserves in the recovery of ryegrass/white clover swards after defoliation is not considered significant, but it is unequivocally acknowledged to be a recognised factor in the management of lucerne pastures (Langer & Keoghan, 1970; Sheaffer et al., 1988; White & Lucas, 1990).

Leaf area is a widely recognized determinant of regrowth following defoliation in a range of plant species (Watson, 1947; Donald & Black, 1958; Brown & Blaser, 1968), and the basic concepts have been extended to pasture grasses and legumes (Brougham, 1956; Davidson & Donald, 1958). However, even in an erect growing species like lucerne there have been conflicting views of the importance of residual leaf area after defoliation. It is considered as of little value in some situations (Brown et al., 1966; Leach, 1969; Langer & Keoghan, 1970), but in others it has influenced the rate of regrowth (Langer & Steinke, 1965; Smith & Nelson, 1967; Hodgkinson et al., 1972), possibly because photosynthetic rates of residual leaves rejuvenate when exposed to full daylight just after cutting (Hodgkinson, 1974).

Thus, a knowledge of the accumulation and use of reserve carbohydrate, and the role of residual leaf area following defoliation, is fundamental to the understanding of management responses in perennial legumes. The extrapolation of the responses of one species may not always be used to explain those of another species (Smith, 1962). Although sulla is widely used in the Mediterranean countries such as southern Italy for hay and silage, and to a lesser extent in New Zealand, information on its physiological response to defoliation is lacking. This study investigated the effects of plant growth stage at first defoliation and defoliation intensity on the physiological response of sulla over the first regrowth cycle, in the absence of confounding factors such as selective grazing, treading and excretion imposed by the grazing animal.

4.2 MATERIAL AND METHODS

4.2.1 SITE INFORMATION

A greenhouse trial was conducted from August 1989 to February 1990 at the Massey University Plant Growth Unit (See plate 4.1). Top soil from the preliminary field trial was thoroughly mixed with pumice in a concrete mixer in the ratio of 1:1 and incorporated with a complete fertiliser (Hanan et al., 1978). The soil mixture was packed in 400 polythene bags measuring 180 x 360 mm, arranged in rows on the greenhouse floor in four sections. A timed trickle irrigation system was set out to deliver water into individual bags via tubes to field capacity twice daily. A soil drench Previcur N a.i propamocarb [propyl 3-(dimethylamino) propylcarbamate], a systemic fungicide, at 250-300 ml in 10-20 litres of water per cubic metre of soil mixture, was used as a preventive measure for the control of damping off (*Phythium* spp) and root rot (*Phytophora* spp). Approximately 10 seeds were sown per bag on the 28 August, 1989, and on the 11 October 1989 seedlings were thinned to allow four plants per bag. About a week later the plants were inoculated with the reisolated *Rhizobium* strain ICMP 10149, by drenching the soil with liquid culture containing the rhizobia. The maximum and minimum temperatures, and relative humidity in the greenhouse were recorded by a hydrothermograph, placed in an aspirated wooden box about 50 cm above the floor (See plate 4.2). At the start of the experiment 1600 healthy effectively nodulated sulla plants were established (See plates 4.3a & b). A total of 240 bags containing 4 uniform plants/bag were selected, and the remaining bags were retained as replacements. The polythene bags were closely arranged at 157 plants m^{-2}, so as to simulate near sward conditions (Christie & Keoghan, 1979) (See plate 4.4).

Plate 4.1 General view of greehouse no.3 located at Massey University Plant Growth Unit.

Plate 4.2 Hydrothermograph enclosed in an aspirated wooden box.

Plates 4.3 a & b *Hedysarum coronarium* L. effectively nodulated by *Rhizobium* strain ICMP 10149

Plate 4.4 Simulated sulla sward actively growing in greenhouse

4.2.2 DESIGN AND TREATMENTS

The experimental design was a randomised complete block with 12 treatments replicated 16 times (4 internal and 4 external replicates). See appendix 4.1 for experimental layout in the greenhouse. The factors and their combinations in the experimental design are presented in Table 4.1.

The treatments were a full factorial combination of three growth stages at first defoliation and four defoliation intensities. The growth stage treatments were late vegetative (75 DAS), midstem elongation (85 DAS) and early flowering (105 DAS). The late vegetative (LV) growth stage was defined as when the plants were at the commencement of stem elongation (See plate 4.5), the midstem elongation (MSE) growth stage as when the plants were between mid and late stem elongation (See plate 4.6) and the early flowering (EF) stage as when the first flowers appeared (See plate 4.7).

Cutting heights imposed were 1, 7, 15 and 30 cm and a graduated rod was used to measure and cut the plants from soil level. Leaf area retained in each cutting treatment was estimated by the difference between the total leaf area at destructive harvest and the area removed in each cutting height treatment. It was ensured that shoots were pulled upright at cutting, to maintain uniformity in defoliation. The cutting treatments were first imposed in the LV treatment on 8 November, the MSE treatment on 21 November and in the EF treatment on 8 December 1989, and the treatments were randomly allocated. A pretreatment destructive harvest provided a common starting point in the analysis of the 12 treatments. The defoliated plants were then allowed to regrow and four destructive harvests were carried out on days 14, 25, 40 and 60 after defoliation. A destructive harvest schedule is presented in Table 4.2.

Table 4.1 Summary of the treatments imposed on greenhouse grown sulla.

Growth stage	Plant height† at defoliation (cm)	Cutting height (cm)	Estimated residual leaf area/plant in each cutting treatment (cm^2)	Factorial combination
Late vegetative (LV) 75 DAS§	52 ± 7	1	0	LV-1
		7	52	LV-7
		15	230	LV-15
		30	392	LV-30
Midstem elongation (MSE) 85 DAS	72 ± 10	1	0	MSE-1
		7	45	MSE-7
		15	220	MSE-15
		30	458	MSE-30
Early Flowering (EF) 105 DAS	84 ± 18	1	0	EF-1
		7	53	EF-7
		15	290	EF-15
		30	500	EF-30

† Plant height was measured from soil level to length of the fully extended leaf.
§ Days after sowing.

Plate 4.5 Sulla plants at the late vegetative growth stage

Plate 4.6 Sulla plants at the midstem elongation growth stage

Plate 4.7 Sulla plants at the early flowering growth stage

Table 4.2 Defoliation date and destructive harvest schedule of greenhouse grown sulla.

Harvest Number	DAD†	Late Vegetative (LV)	Midstem Elongation (MSE)	Early Flowering (EF)
0	0	08/11/89	21/11/89	08/12/89
1	14	25/11/89	07/12/89	27/12/89
2	25	06/12/89	18/12/89	07/01/90
3	40	21/12/89	03/01/90	22/01/90
4	60	10/01/90	23/01/90	11/02/90§

†Days after defoliation.
§Destructive harvest was not carried out due to aphid infestation and damage to plants.
Day 0 - Pretreatment harvest as a common starting point.

4.2.3 MEASUREMENTS

At the pretreatment destructive harvest (day 0), one bag containing four plants was removed from each external replicate. The total number of leaves was counted and recorded. The plants from each bag were then cut at the soil level and the leaf and stem (including the crown) fractions were separated. Area of leaves including petiole was measured using a LI-COR Model 3100 area meter. Following the leaf area measurement, the leaf and stem fractions were bulked and weighed. Subsequently the bulked stem and leaves were dried in a forced-air oven at 70-75°C for 24 hours, and weighed for DW determination. Roots for DW determination were carefully washed on a sieve (2 mm mesh size), and the soil attached to the roots was removed. All except the finest roots were extracted. A fresh root subsample was taken, finely chopped and stored at -4°C in labelled plastic containers for starch determination at a later date. The remaining roots were weighed and then oven dried. Similar measurements were carried out at each destructive harvest. Dead tissue was not included in the dry weight measurements.

Starch Determination

The fresh root subsamples were freeze dried for 72 hours at 0.1 mm Hg vacuum pressure at -15°C, ground in a hammer mill to pass through a 0.5 mm mesh, and stored in sealed vials at -4°C. The subsamples were later analyzed in the laboratory for starch, using a modified method described by Haslemore & Roughan (1978). Soluble sugars (mono- and disaccharides) were removed from the taproot tissue, by extracting ground samples (100 mg) in 10 mL of 625 mM L^{-1} methanol at 55°C for 20 min and with two further extractions in 10 mL pure methanol at 100°C. The methanol extracted residue was boiled in 4 mL deionised water for 60 min at 100°C to gelatinise the starch. Two (2) mL of 250 mM L^{-1} sodium acetate (pH 4.5) was then added to the samples. Oligo- and polysaccharides in samples were hydrolysed, by incubating tissues at 55°C for 60 min using 70 enzyme units of a highly potent amyloglucosidase from *Aspergillus niger* (Product no. 102857, Boehringer Mannheim, Auckland). The free glucose in the starch hydrolysate was further determined by the glucose oxidase technique (Kiburn & Taylor, 1969). Subsamples were duplicated in the analysis. Starch concentration in the root tissue is reported as mg starch in 100 mg of root DW $plant^{-1}$. Quantity of starch (g $plant^{-1}$) was calculated as the product of root DW and concentration of starch. See appendix 4.2 for a detailed description of the technique used in the starch determination.

Starch analysis was carried out for four harvests only, including the pretreatment harvest. Root samples at day 60 harvests in the LV and MSE growth stages and day 40 harvest in the EF growth stage were not analyzed, as samples decayed in cool storage.

Growth Analysis

A 'classical' or interval growth analysis approach was taken and the mean relative growth rate (RGR), mean unit leaf rate (ULR), and mean leaf area ratio (LAR) were calculated (Radford, 1967; Hunt, 1978; Evans, 1982; Chiariello et al., 1989) using the combined top and root DW, leaf area and the following equations:

$$\text{Mean RGR} = \frac{(\ln W_2 - \ln W_1)}{(t_2 - t_1)} \quad (g\ g^{-1}\ d^{-1});$$

$$\text{Mean ULR} = \frac{(W_2 - W_1)}{(t_2 - t_1)} \cdot \frac{(\ln A_2 - \ln A_1)}{(A_2 - A_1)} \quad (g\ cm^{-2}\ d^{-1});$$

$$\text{Mean LAR} = \frac{(A_1/W_1) + (A_2/W_2)}{2} \quad (cm^2\ g^{-1})$$

Where:

A_1 = initial leaf area (cm^2)

A_2 = final leaf area (cm^2)

W_1 = initial plant weight (g)

W_2 = final plant weight (g)

t_1 = initial time (days)

t_2 = final time (days)

For the validity of the application of the above formulae the following assumptions were used (Radford, 1967):

1. In the RGR calculations it was assumed the W varied without discontinuity throughout the period t_1 and t_2.
2. The relationship between W and A was determined graphically and found to be linear (See appendix 4.3).
3. LAR was assumed to be linearly related with time.

Aphid Damage

Severe aphid infestation, prior to the final harvest in the EF growth stage treatment, caused plants to become stunted and shrivelled. Investigations revealed that the aphids responsible for the damage were the green aphid (*Acyrthosiphon pisum*) and black aphid (*Aphis craccivora*). Consequently the final harvest in the EF treatment was discarded.

4.2.4 STATISTICAL ANALYSIS

Analysis of variance (ANOVA) was conducted, using the Statistical Analysis System General Linear Model (GLM) procedures guide (Steel & Torrie, 1981; SAS, 1989), on data in all destructive harvests, and the discarded final harvest in the EF treatments was treated as missing data. A variance homogeneity test (Winer, 1971; Steel & Torrie, 1981), conducted on the preliminary ANOVA, was declared significant at the 0.05 level of probability in all the variables studied, except those pertaining to growth analysis, suggesting heterogeneity of error variance. Consequently the data was natural logarithm ($\log_e$) transformed and reanalysed to stabilise the variance (Bartlett, 1947; Box & Cox, 1964; Finney, 1989). Wherever needed, a value of 1.0 was added to the raw data to avoid negative values in the ANOVA. Treatment means were compared using the Fisher's protected least significant difference (LSD) procedure (Carmer & Walker, 1985). Unless otherwise stated the 0.05 level of probability was used to determine differences. The results are reported as back transformed geometric means on a per plant basis.

4.3 RESULTS

4.3.1 GREENHOUSE CLIMATE

Over the period of the experiment from 28 August 1989 to 11 February 1990, hydrothermograph readings estimated the mean minimum and maximum temperatures in the greenhouse to be 13.4 and 25°C respectively. The relative humidity ranged between 36-80% and was related to watering procedures in the remainder of the greenhouse.

4.3.2 LEAF NUMBER

There were no significant ($P>0.05$) interactions between plant growth stage at defoliation x defoliation intensity x sampling date on any of the parameters measured. However, there were first order interactions and main effects, and these are discussed wherever significant.

Over growth stages and defoliation intensities, there was a significant ($P<0.001$) effect of sampling date on the number of leaves per plant (Fig 4.1). There was a reduction in leaf number at day 14 and an increase thereafter.

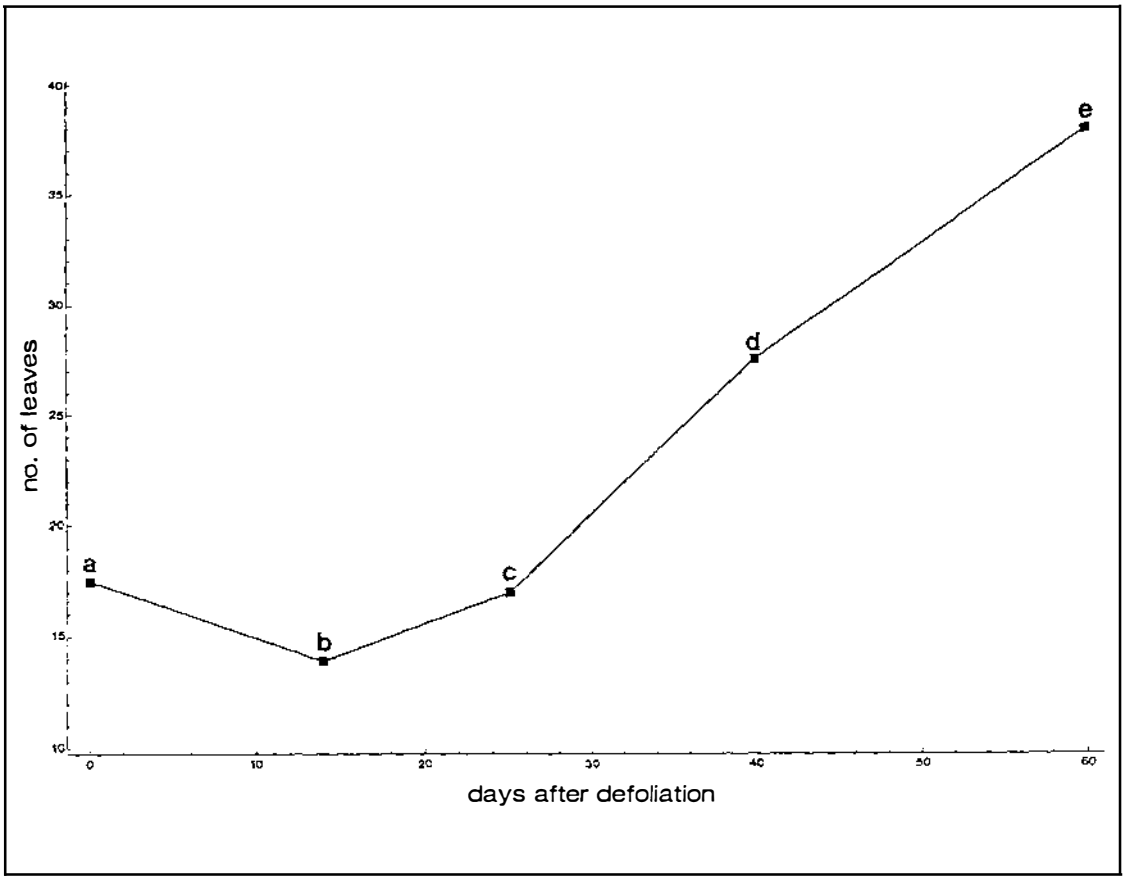


Fig 4.1 The effect of regrowth period on the leaf number in sulla. Data meaned over growth stages and defoliation intensities. Means within a given time interval and with the same letter are not significantly different at the $P<0.05$ confidence level.

Meaned over sampling dates and defoliation intensities, there was a significant ($P<0.001$) effect of growth stage on leaf number. Plants in the LV treatment produced approximately 13% less leaves than in the MSE and EF treatments (Fig 4.2). The leaf number in the MSE and EF treatment did not differ and averaged 21 leaves.

Across growth stages and sampling dates, there was a significant ($P<0.001$) difference in leaf number between the cutting height treatments (Fig 4.3). Plants in the 1 cm treatment produced 29% less leaves than in the 7, 15 and 30 cm treatments. However, there were no significant differences between the 7, 15 and 30 cm cutting heights, which averaged 22.0 leaves.

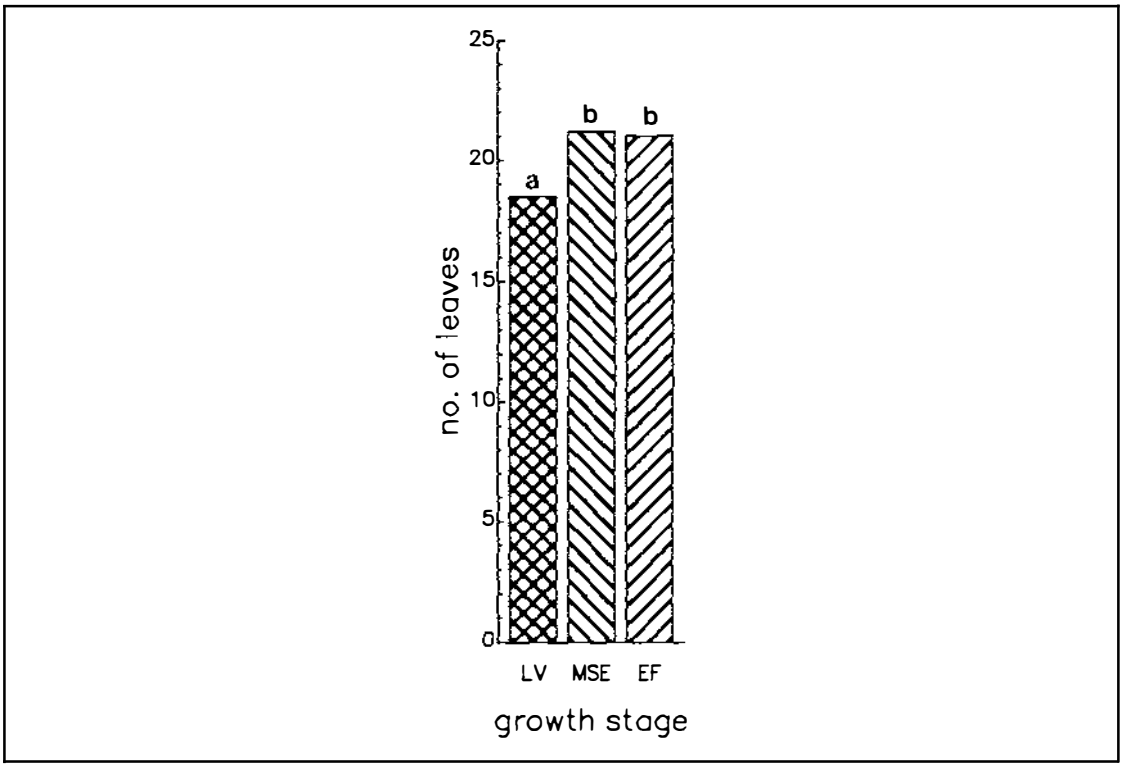


Fig 4.2 The effect of plant growth stage at defoliation on the number of leaves in sulla. Data meaned over defoliation intensities and sampling dates. Bars with the same letter are not significantly different at the 0.05 level of probability.

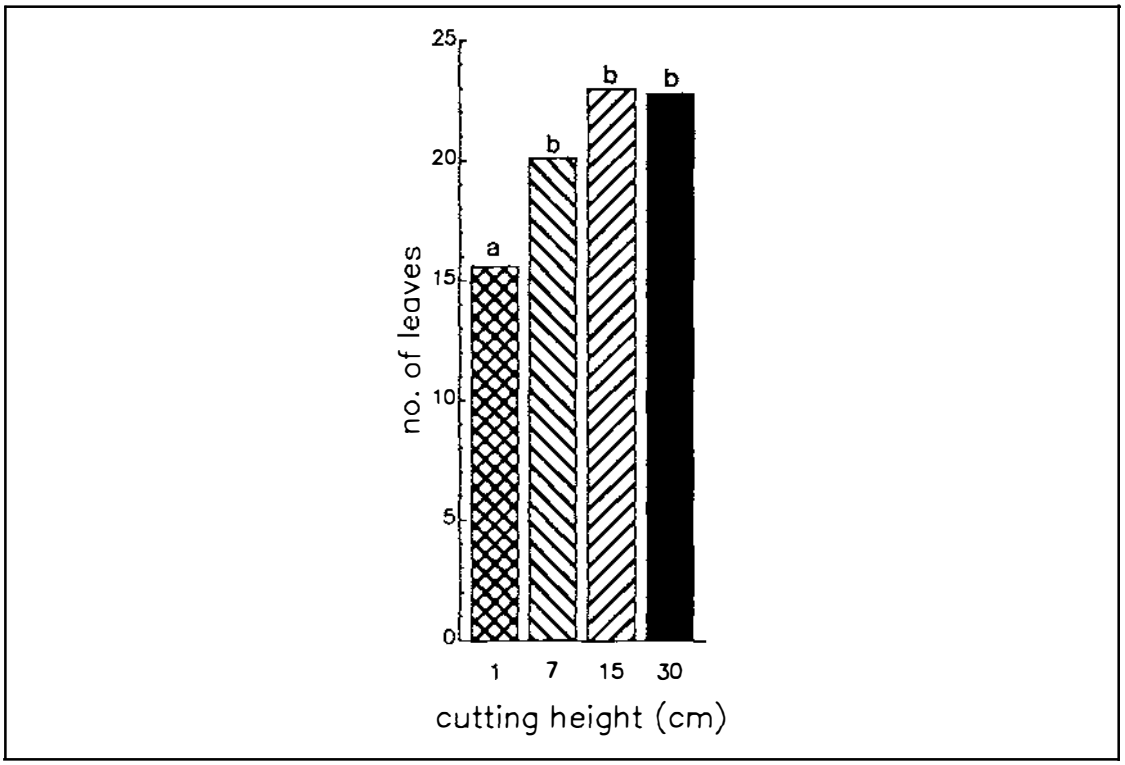


Fig 4.3 The effect of defoliation intensity on the number of leaves in sulla. Data meaned over growth stages and sampling dates. Bars with same letter are not significantly different at the 0.05 level of probability.

4.3.3 LEAF AREA

Averaged across growth stages, there was a significant ($P<0.001$) interaction between defoliation intensity x sampling date for leaf area per plant. Cutting the plants to a range of heights resulted in uniform defoliation treatments differing distinctly in leaf area (Fig 4.4). Plants in the 1 cm treatment were completely defoliated, whereas those in the 7, 15 and 30 cm were partially defoliated retaining

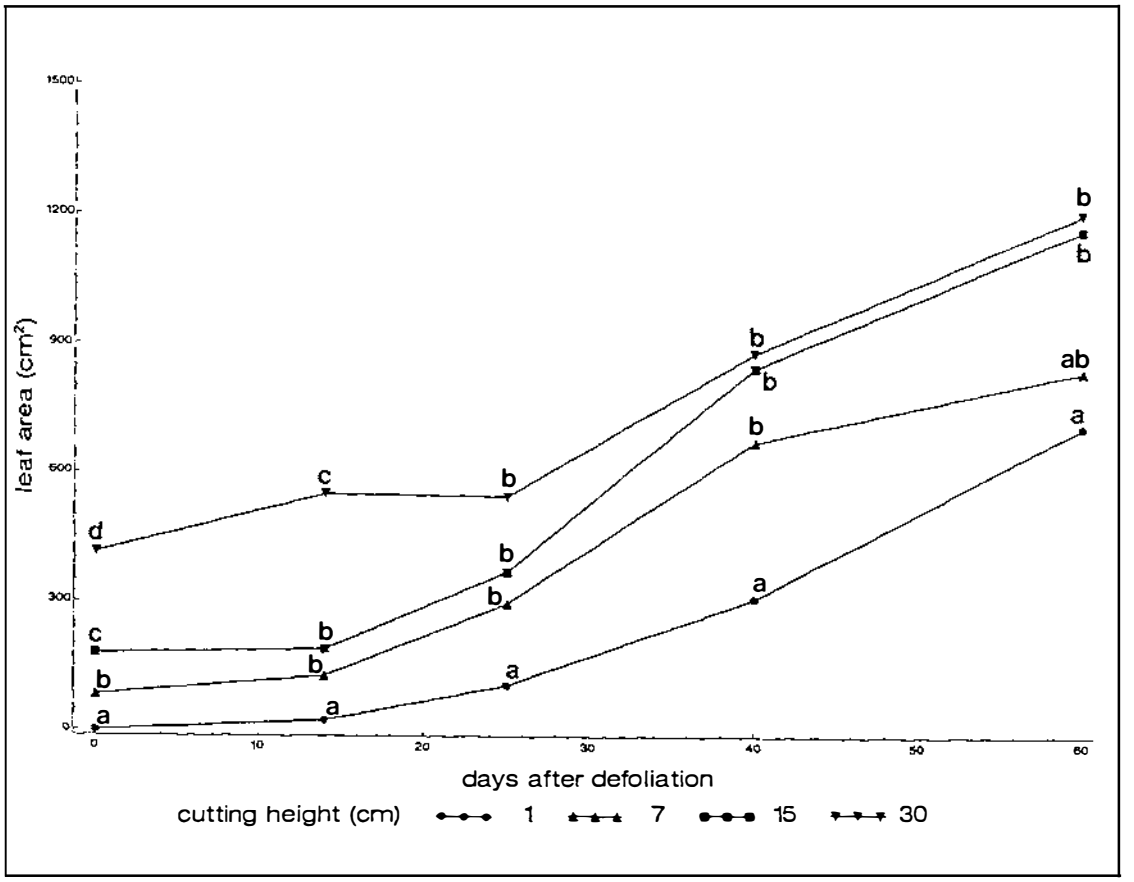


Fig 4.4 The effect of defoliation intensity on the leaf area in sulla, over 60 days of regrowth. Data meaned over growth stages. Means within a given time interval and with the same letter are not significantly different at the $P<0.05$ confidence level. Day 0 values are estimated residual leaf area in each cutting treatment.

84, 180 and 415 cm^2 residual leaf area respectively. Plants in the complete and partially defoliated treatments regrew gradually with an increase in leaf area. At day 60, leaf area in the completely defoliated plants was 40% less than in the 15 and

30 cm treatments, but did not differ from that in the 7 cm treatment. The net increase in leaf area in the 1, 7, 15 and 30 cm treatment is 705, 752, 983 and 784 cm^2 respectively. The net herbage production in the 15 cm treatment was 32% greater than in the other treatments.

When averaged across sampling dates, there was a significant ($P<0.001$) interaction between growth stage x defoliation intensity for leaf area. Leaf area production was directly proportional to defoliation intensity, as illustrated by the response surface diagram (Fig 4.5). Within the LV growth stage, leaf area in 1, 7,

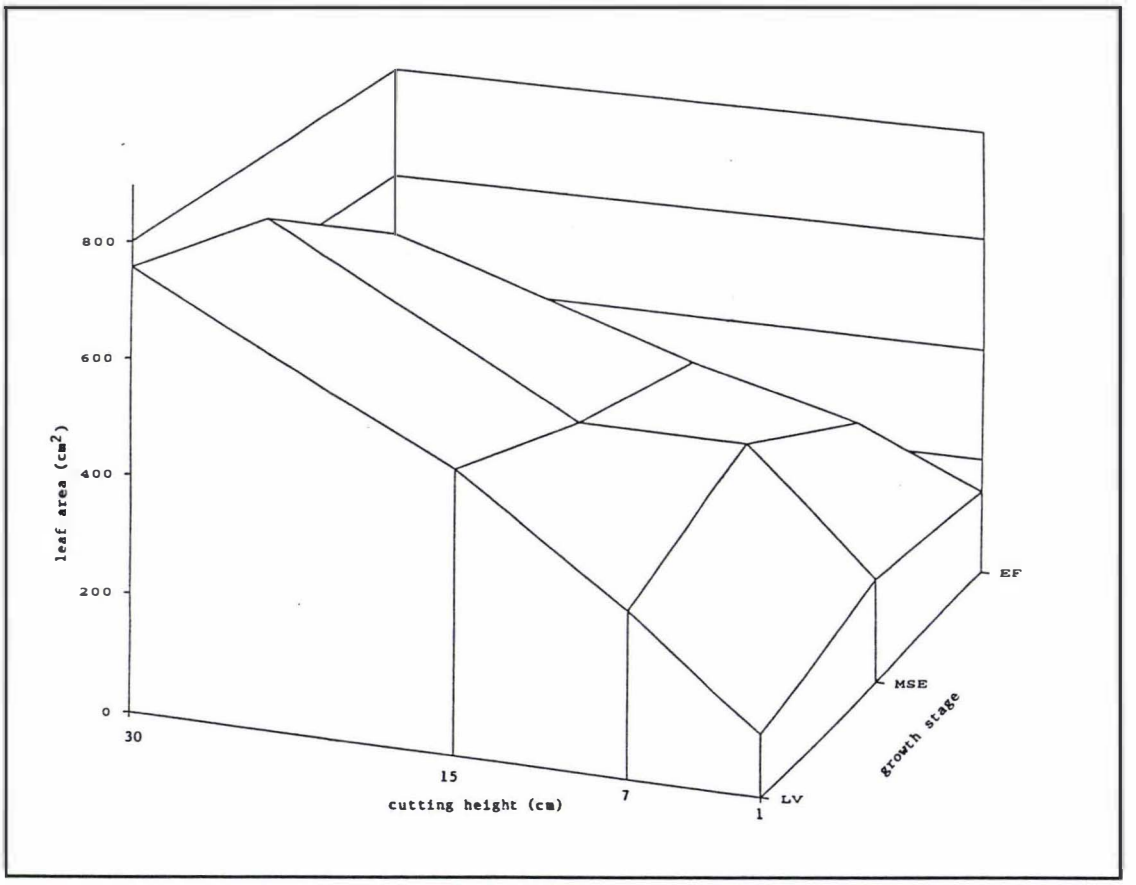


Fig 4.5 Response surface diagram illustrating the effect of the interaction between plant growth stage at defoliation and defoliation intensity on leaf area. Data meaned over sampling dates.

15 and 30 cm cutting treatments differed significantly. However, within the MSE and EF growth stages, the 7 and 15 cm treatments did not differ significantly. Moreover, within the 1 cm treatment, the MSE growth produced about 39% more leaf area than in the LV and EF growth stages. In addition, within the 7 cm treatment, the MSE treatment accumulated 59% greater leaf area than in the EF treatment, but did not differ significantly from the LV growth stage. Within the 15 and 30 cm treatments, the LV growth stage accumulated greater leaf area than in the EF treatment, but did not differ significantly from that in the MSE treatment. The leaf area produced in the MSE treatment did not differ significantly from that in the EF treatment.

4.3.4 SHOOT DRY WEIGHT

Across defoliation intensities, there was a significant ($P<0.01$) interaction between growth stage at defoliation x sampling date in the shoot DW per plant. The residual shoot DW was directly proportional to growth stage (Fig 4.6). There was a significant increase in shoot DW in the LV treatment, no change in the MSE treatment and a slight decrease in the EF treatment, in the early phase of regrowth. Significant increase in shoot DW in the MSE and EF treatments did not occur till 25 and 40 days respectively. The net increase in shoot DW in the LV and MSE treatments was 7.7 and 8.4 g, respectively.

When meaned over growth stages, there was a significant ($P<0.001$) interaction between defoliation intensity x sampling date in the shoot DW (Fig 4.7). At the start of the experiment the residual shoot DW in the 1, 7 and 15 cm treatments did not differ significantly, but the 30 cm treatment differed significantly from the other treatments. Shoot DW in the 1 and 7 cm treatment decreased in the early stage of regrowth but later increased. However, there was not a period of decreased shoot DW in the 15 and 30 cm treatments.

At day 60, the shoot DW did not differ significantly between the 1 and 7 cm treatments, or between the 15 and 30 cm treatments, and the mean shoot DW was 7.5 and 12.6 g plant^{-1} for these pairs of treatments respectively. Plants cut to 15 and 30 cm accumulated 68% greater DM than those in the 1 and 7 treatments. When compared to the initial residual DW, the net accumulation in the 1 and 7 cm, and

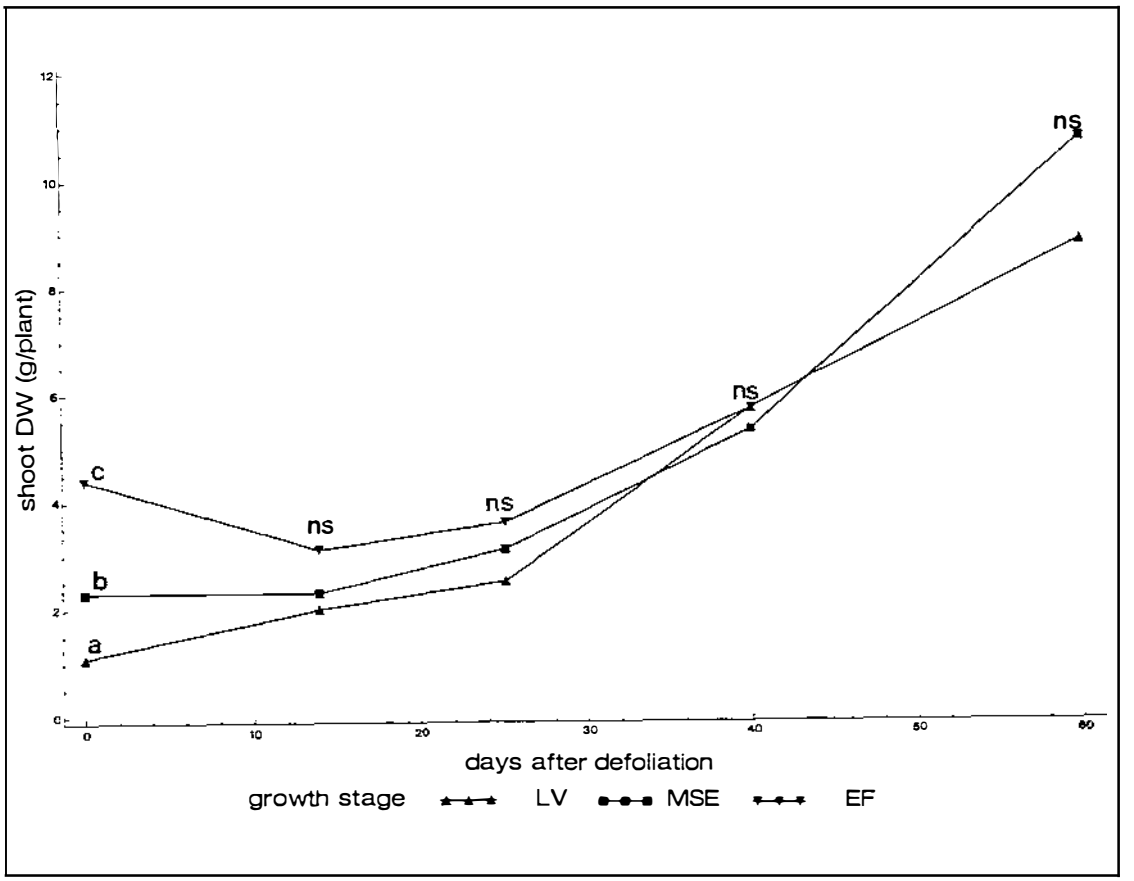


Fig 4.6 The effect of plant growth stage at defoliation on the shoot DW in sulla, over 60 days of regrowth. Data meaned over defoliation intensities. Days 0 values are residual shoot DW in each cutting treatment. ns=not significant.

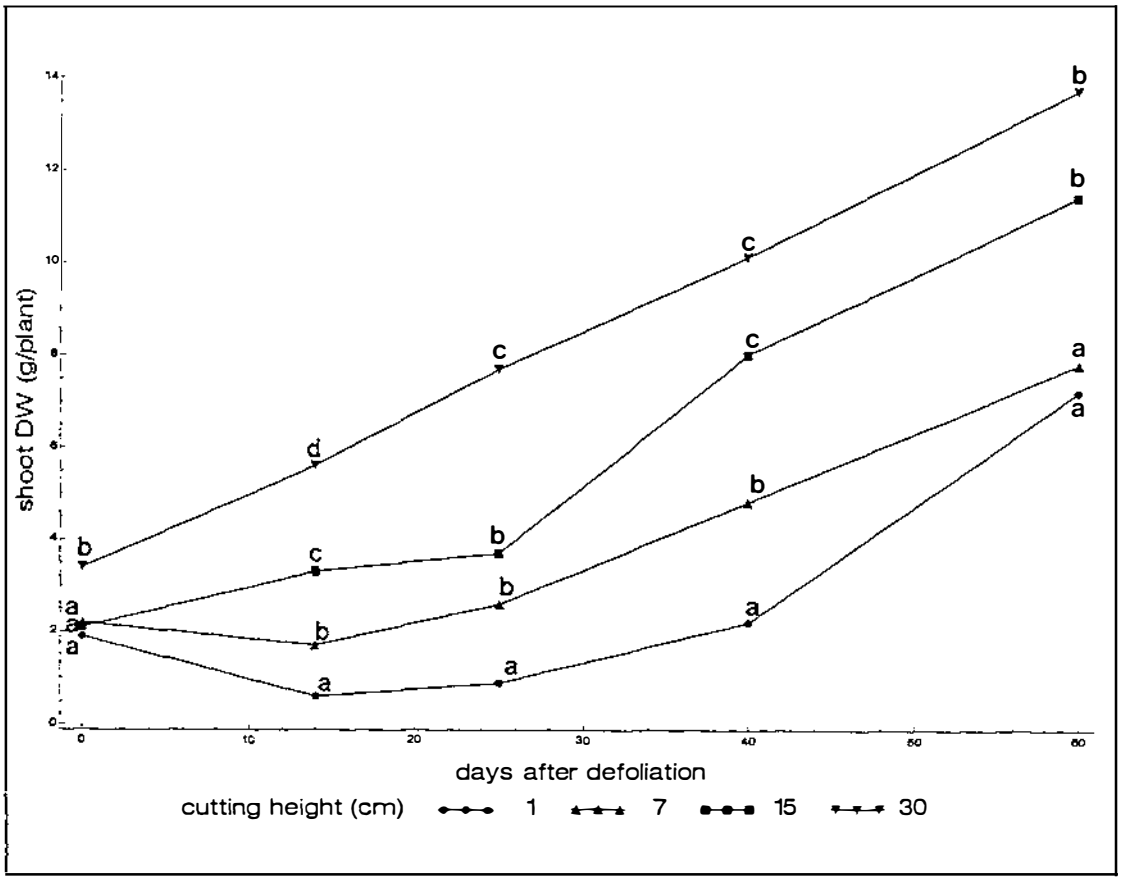


Fig 4.7 The effect of defoliation intensity on the shoot DW in sulla, over 60 days of regrowth. Data meaned over growth stages.

15 and 30 cm treatments over the period of regrowth was 5.5 and 9.8 g plant^{-1} respectively.

4.3.5 RELATIONSHIP BETWEEN SHOOT DW AND LEAF AREA

Throughout the experiment, shoot DW and leaf area per plant were linearly related according to the regression equation $y=0.76 + 0.0086 \pm 0.0004x$, where y equals shoot DW and x equals leaf area per plant (cm^2). The coefficient of determination (r^2) was 0.75 ($P<0.001$) (Fig 4.8).

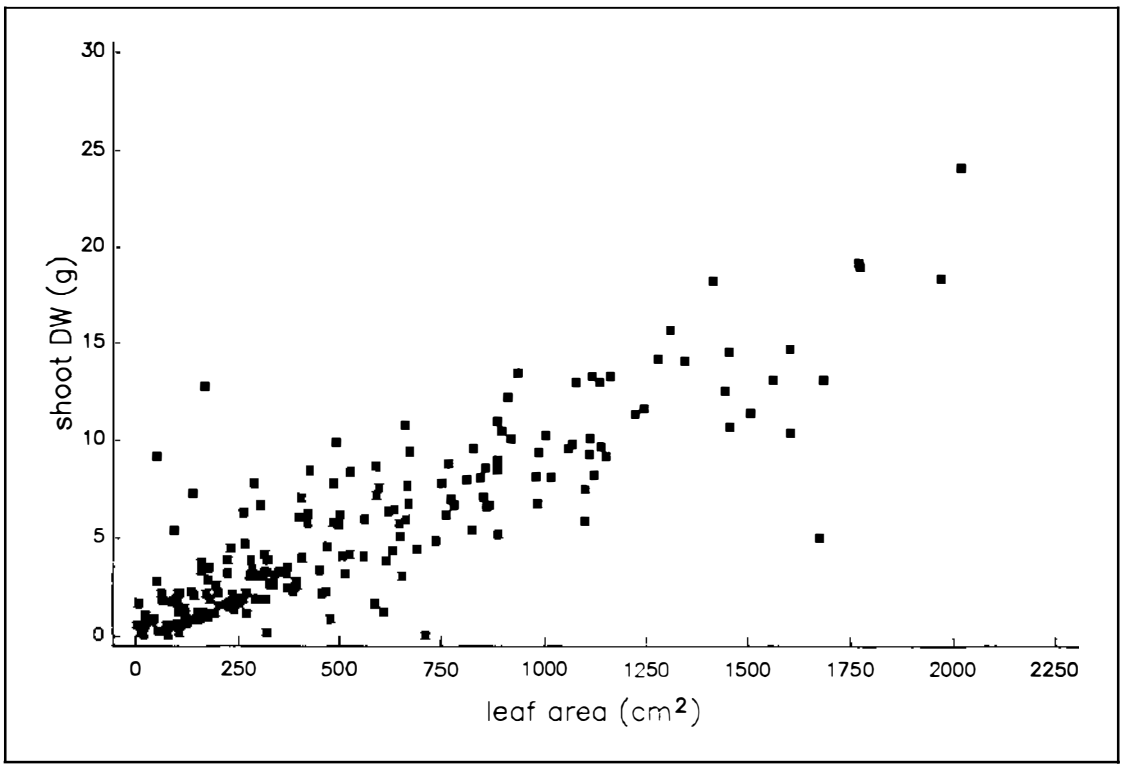


Fig 4.8 The relationship between shoot DW and leaf area throughout the experiment.

4.3.6 ROOT DRY WEIGHT

When meaned over defoliation intensities, a significant ($P<0.05$) interaction occurred between growth stage x sampling date in the root DW per plant. The pretreatment root DW in the LV, MSE and EF growth stage treatments was directly proportional to the plant growth stage at defoliation (Fig 4.9). The day 0 values in the MSE treatment were twice as great as those for the LV growth stage and about 2.6 times less than in the EF treatment. Over the period of regrowth, treatment

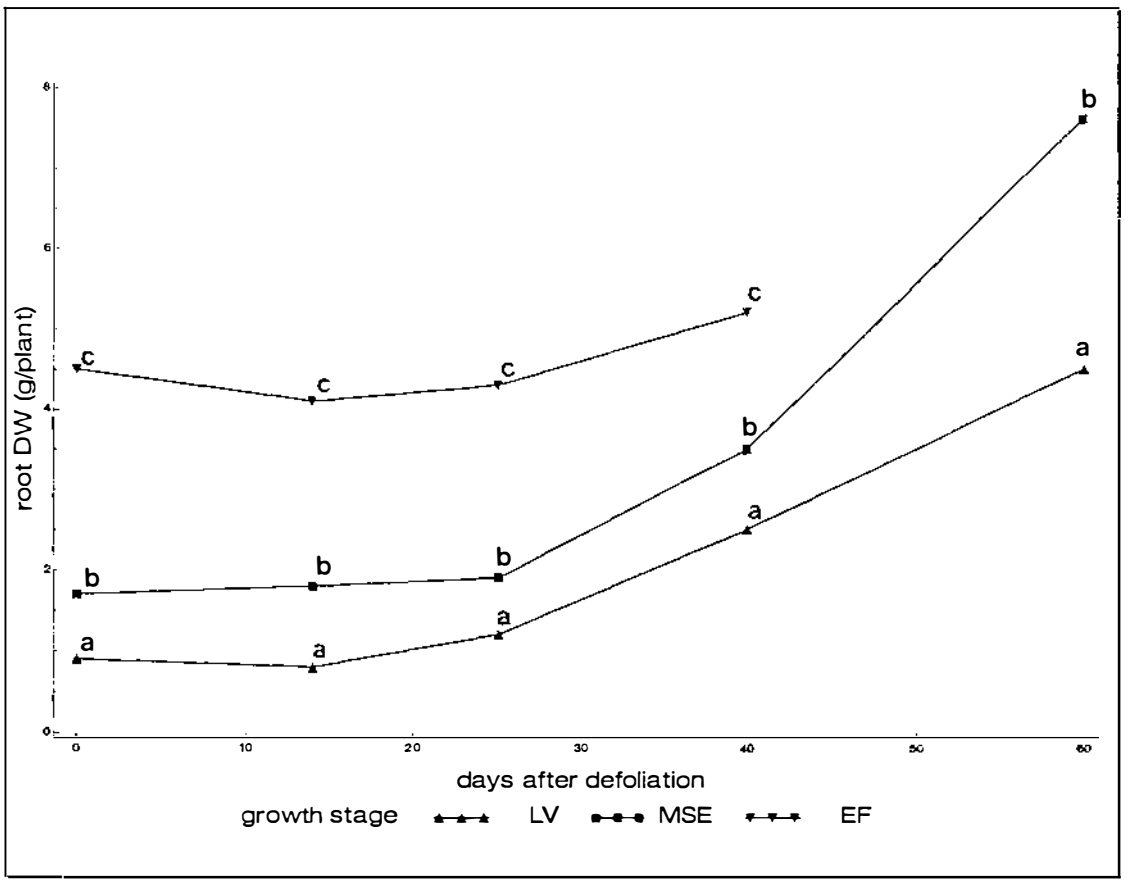


Fig 4.9 The effect of plant growth stage at defoliation on the root DW in sulla, over 60 days of regrowth. Data meaned over defoliation intensities.

effects remained significant, and at day 60 root DW in the LV treatment was 41% less than in the MSE treatment. Significant increases in root DW, compared to the initial root weight, did not occur till day 40 in the LV and MSE treatments. Over the 40 days of regrowth, plants in the EF treatment did not vary significantly in their root DW.

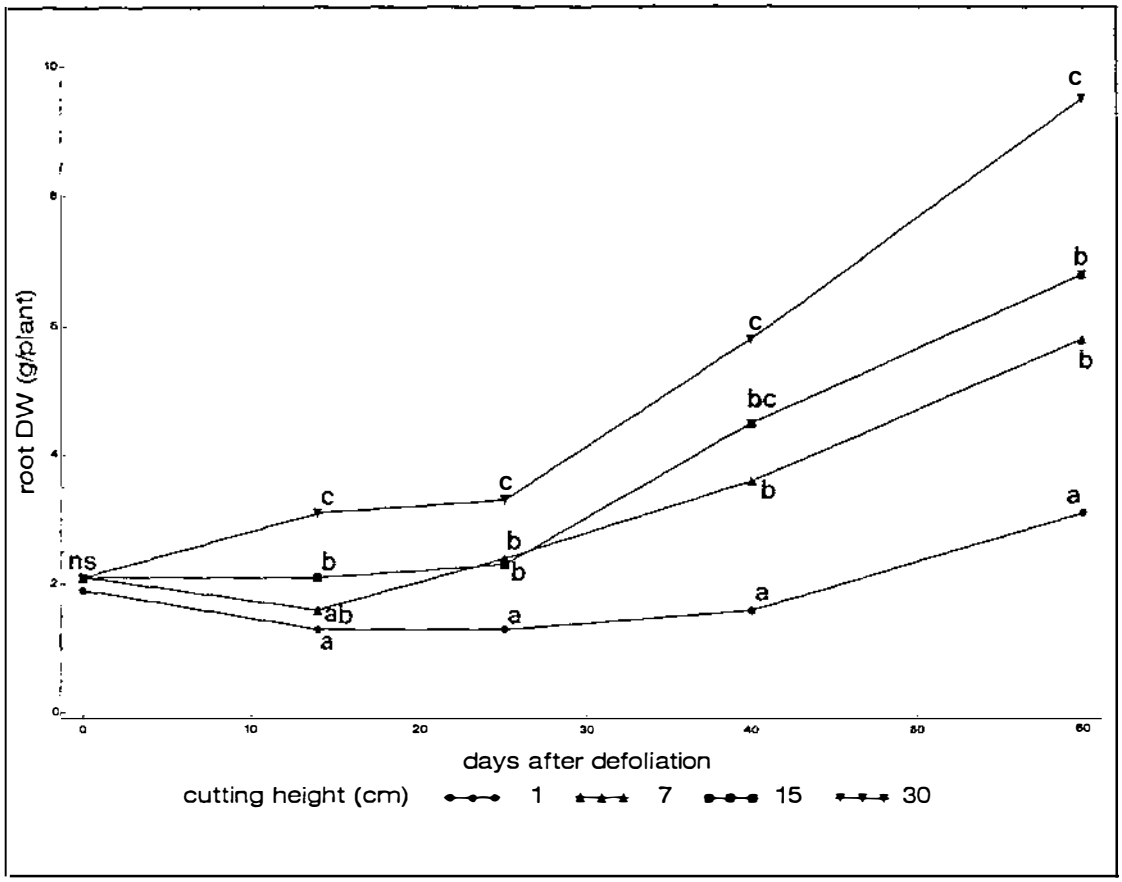


Fig 4.10 The effect of defoliation intensity on the root DW in sulla, over 60 days of regrowth. Data meaned over growth stages.

When meaned across growth stages, an interaction between defoliation intensity x sampling date affected the root DW significantly ($P<0.001$). At day 0, there were no significant differences between the cutting height treatments in the root DW (Fig 4.10). Root DW in the 1 and 7 cm treatments showed a slight decrease in the early stages of regrowth and increased thereafter. However, the

root DW in the 15 and 30 cm treatments grew uninterruptedly over the 60 days. In the 60 days of regrowth, plants in the 1 cm treatment produced half as much root DW as in the 7 cm treatment. Significant increases in root DW in the 1 cm treatment, when compared to day 0, did not occur till day 60, and day 40 in the 7 and 15 treatments. Root growth continued in the 30 cm treatment following defoliation.

4.3.7 ROOT STARCH CONCENTRATION

A significant ($P<0.001$) interaction occurred between growth stage and sampling date in the root starch concentration per plant, when data were averaged over defoliation intensities. Root starch concentration (RSC), analyzed at the LV, MSE and EF growth stage treatments, differed significantly at defoliation (Fig 4.11), and was directly proportional to plant maturity at the time of defoliation. The RSC in the EF treatment was 2.6 times greater than in the MSE growth stage, at defoliation. Over the period of regrowth RSC remained proportional to the concentration at defoliation. There was a slight decrease in RSC in the LV treatment in the early part of its regrowth. However, the MSE and EF treatments were not affected. Over the 40 days of regrowth, RSC in the EF treatment did not vary significantly.

When meaned over growth stages, there was a significant ($P<0.01$) effect of defoliation intensity on the RSC over the 40 days of regrowth. At the start of the trial the pretreatment RSC in the cutting treatments did not differ significantly (Fig 4.12). There was a slight decrease in RSC in the 1 and 7 cm treatments in the early stage of regrowth. In the 40 days of regrowth, the RSC in the 1 and 7 cm treatments did not regain their initial levels. However, the RSC in the 15 and 30 cm treatments was unaffected, as there were subsequent increases in RSC following defoliation. At day 40, the RSC in the 1 cm treatment was 38% less than in the 7 cm treatment, and the 7 cm treatment about 45% less than in the 15 cm treatment. The RSC in the 15 and 30 treatments did not differ significantly and averaged 21.3 mg 100 mg^{-1} root DW.

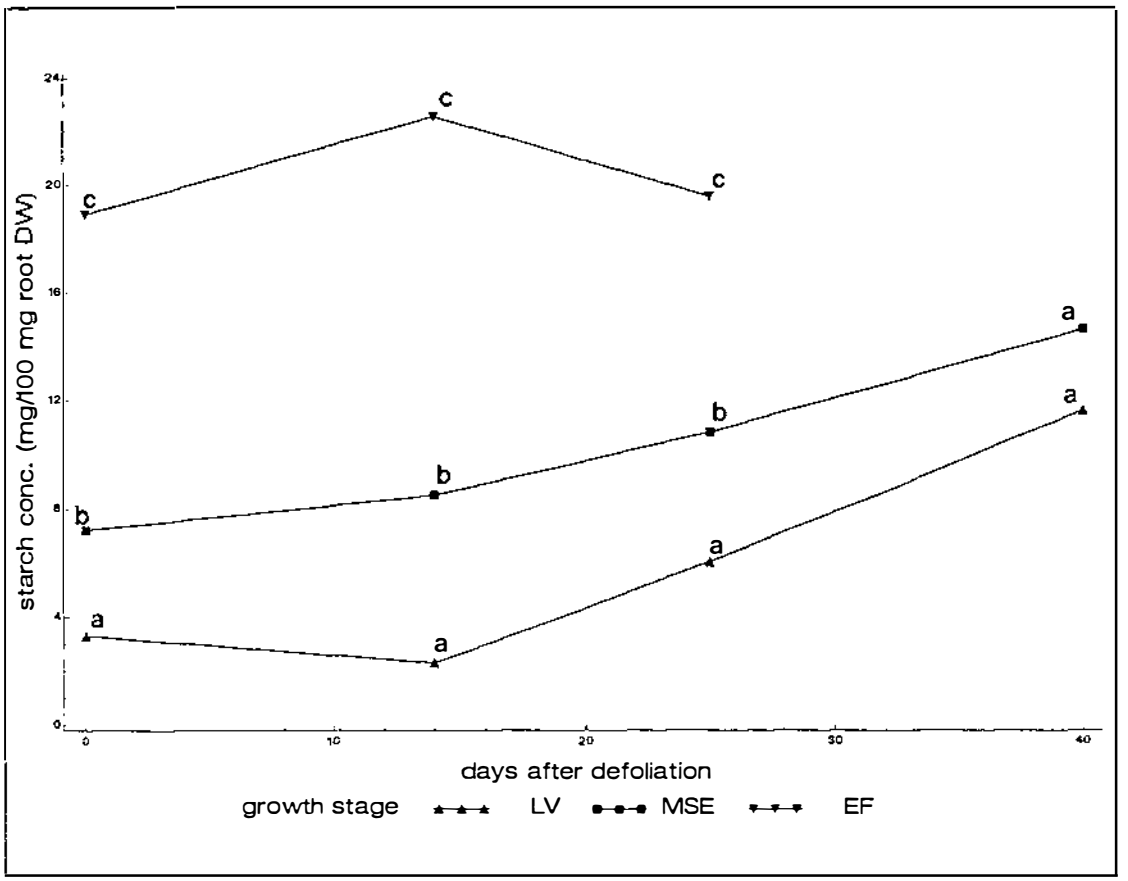


Fig 4.11 The effect of plant growth stage at defoliation on the starch concentration in sulla, over 40 days of regrowth. Data meaned over defoliation intensities.

Averaged over sampling dates, there was a significant ($P<0.05$) interaction between growth stage x defoliation intensity in the RSC. The RSC increased with increasing plant maturity and increasing cutting height (Fig 4.13). At the 1 cm cutting height, the RSC in the EF treatment was significantly higher than in the MSE treatment, and the MSE treatment significantly higher than in the LV treatment. A similar trend followed when plants were cut to 7, 15 and 30 cm. Within the LV treatment, there was no significant difference in RSC between plants cut to 15 and 30 cm, whereas at the MSE growth stage the 1, 7 and 15 cm treatments did not differ significantly. The RSC was also not significantly different than when plants were cut to 7, 15 and 30 cm at the EF growth stage, although the RSC in the 1 cm treatment was not significantly greater than in the 30 cm treatment cut at the MSE growth stage.

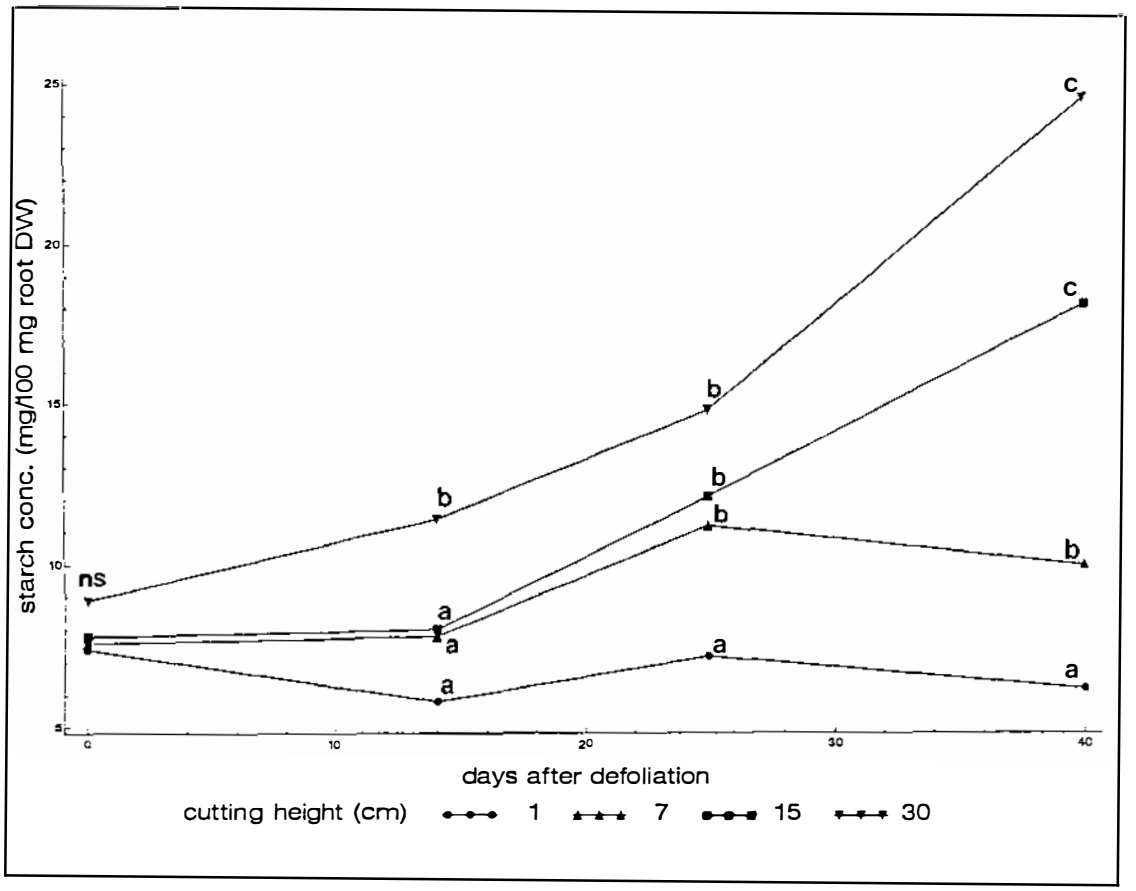


Fig 4.12 The effect of defoliation intensity on the starch concentration in sulla, over 40 days of regrowth. Data meaned over growth stages.

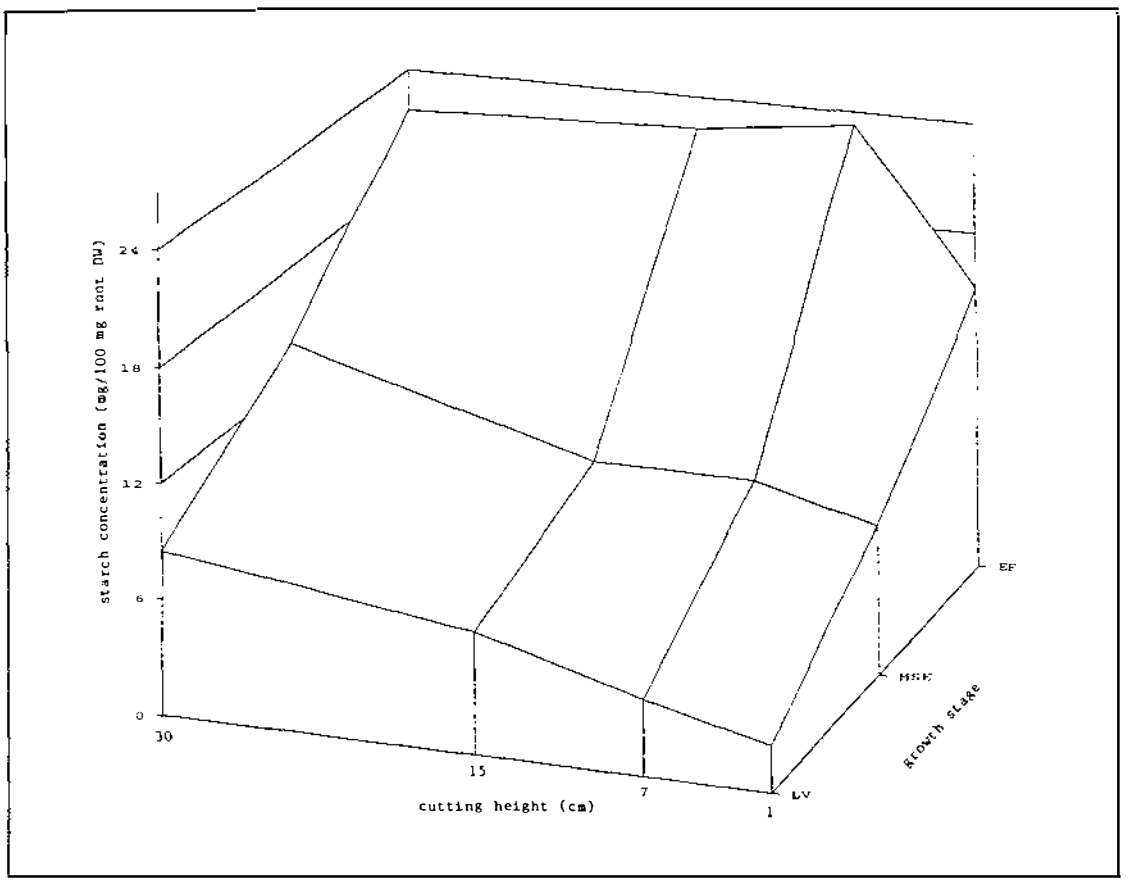


Fig 4.13 Response surface diagram illustrating the interaction between plant growth stage at defoliation and defoliation intensity in root starch concentration. Data meaned over sampling dates.

4.3.8 ROOT STARCH CONTENT

When meaned over defoliation intensities, a significant ($P<0.001$) interaction occurred between growth stage x sampling date in root starch content per plant. The pretreatment root starch content (RSCt) was directly proportional to plant maturity at defoliation (Fig 4.14). RSCt in the LV treatment was four and twenty-nine times less than in the MSE and EF treatment respectively. Following defoliation,

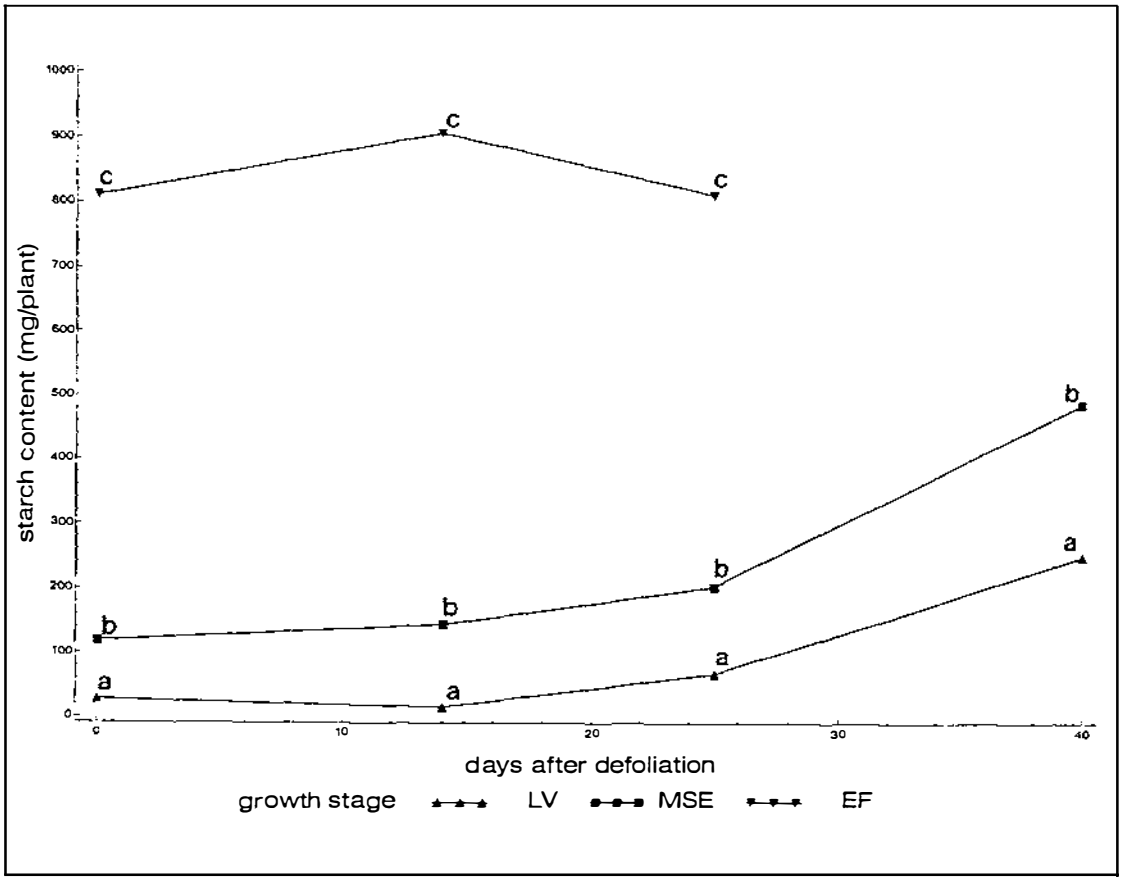


Fig 4.14 The effect of plant growth stage at defoliation on the starch content in sulla, over 40 days of regrowth. Data meaned over defoliation intensities.

there was a decrease in RSCt in the LV treatment at day 14. Over 25 days of regrowth, RSCt in the LV and MSE treatment remained lower than in the EF treatment. Plants in the EF treatment did not show any significant change in the 25 days of regrowth, and their RSCt ranged from 800-910 mg plant^{-1}. At day 40, RSCt in the LV treatment was half as much as in the MSE treatment.

When meaned over growth stages, there was a significant ($P<0.001$) interaction between defoliation intensity x sampling date in the RSCt (Fig 4.15). The pretreatment RSCt in the cutting height treatments did not differ significantly. Following defoliation, there was a significant decrease in RSCt in the 1 cm treatment at day 14. RSCt in the 7 and 15 cm treatments decreased slightly in the

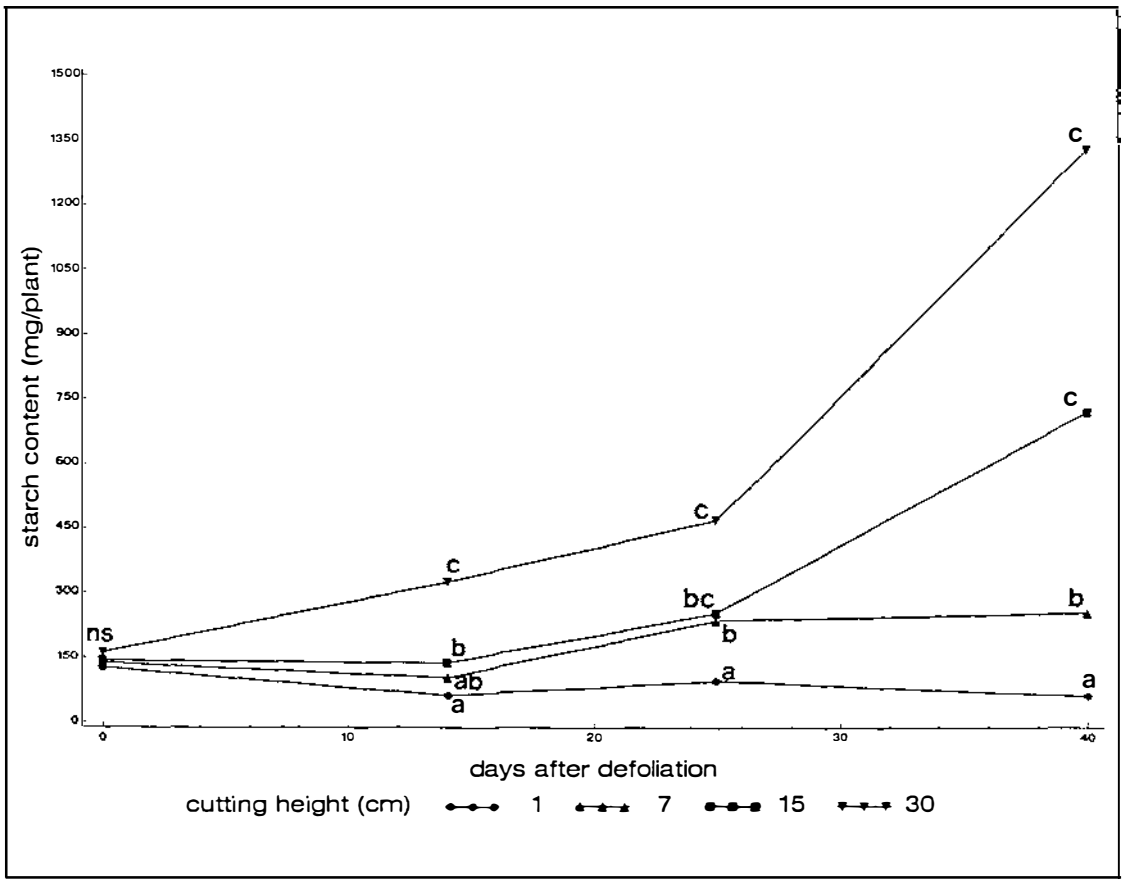


Fig 4.15 The effect of defoliation intensity on the starch content in sulla, over 40 days of regrowth. Data meaned over growth stages.

early stage of regrowth, but the differences were not significant. Over the period of regrowth, plants in the 1 and 7 cm treatment did not recover to their initial starch content. However, the starch content in the 15 cm treatment was significantly different from the initial value at day 60. The RSCt accumulation in the 30 cm treatment increased steadily following defoliation. At day 40, RSCt in the 1 cm treatment was 76% less than in the 7 cm treatment. RSCt in the 15 and 30 treatment meaned at 1022 g plant^{-1}.

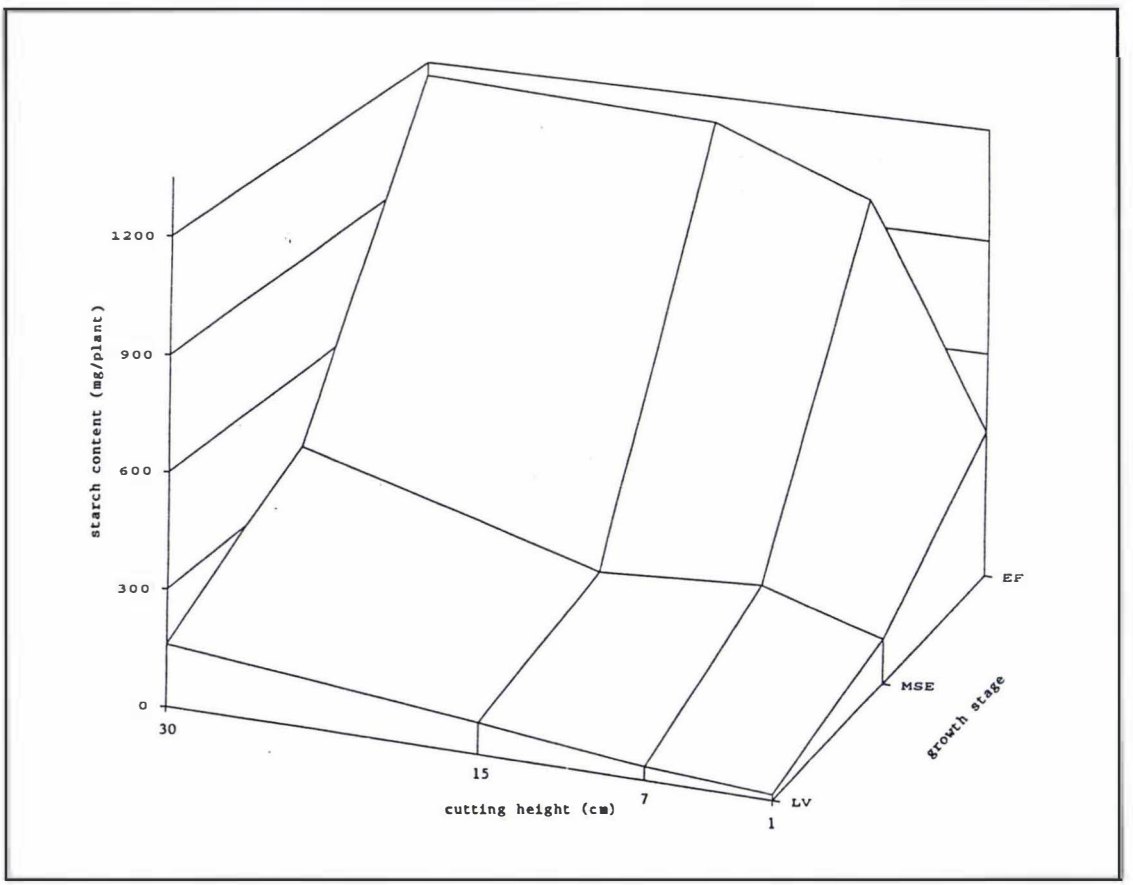


Fig 4.16 Response surface diagram illustrating the effect of the interaction between plant growth stage at defoliation and defoliation intensity on the starch content in sulla. Data meaned over sampling dates.

Across sampling dates, a significant ($P<0.05$) interaction between growth stage x defoliation intensity occurred in the RSCt. The RSCt increased with increasing plant maturity and increasing cutting heights (Fig 4.16). Within the 1 cm treatment the RSCt in the LV, MSE and EF growth stages differed significantly. The LV treatment contained 8.0 times less RSCt than in the MSE treatment, whereas the MSE treatment contained about 3.5 times less than in the EF treatment. At the LV growth stage cutting height influenced the RSCt markedly, with each cutting height significantly different from each other. However, at the MSE growth stage this distinction was less marked, as the RSCt in the 7 and 15 cm treatments did not differ significantly. At the EF growth stage it was marginal as there were no significant differences in the RSCt between the 7, 15 and 30 cm treatments.

4.3.9 SHOOT/ROOT RATIO

There was a significant interaction ($P<0.001$) between defoliation intensity x sampling date, and a main effect of plant growth stage on the shoot/root DW ratio (S/R) per plant. The pretreatment values in the 1, 7 and 15 cm treatments were half that in the 30 cm treatment (Fig 4.17). S/R in the 1 cm treatment decreased significantly at day 14 relative to the other treatments, but increased to be significantly greater than the other treatments by day 60. The S/R however, did not differ significantly between the 7, 15 and 30 cm treatments and meaned at 1.5.

Across defoliation intensities and sampling dates, there was a significant ($P<0.001$) main effect of growth stage at defoliation on the S/R ratio. The S/R ratio was inversely proportional to the degree of plant maturity and was less than one in the EF treatment (Fig 4.18).

4.3.10 WHOLE-PLANT DRY WEIGHT

Averaged over defoliation intensities, there was significant ($P<0.001$) interaction between growth stage and sampling date on whole-plant DW (WPDW). The pretreatment WPDW was directly proportional to growth stage at defoliation (Fig 4.19). There was no significant decrease or increase in WPDW in any growth stage treatment at the early stage of regrowth. Differences were consistent up to 25 days of regrowth, with plants defoliated at the LV growth stage remaining smaller

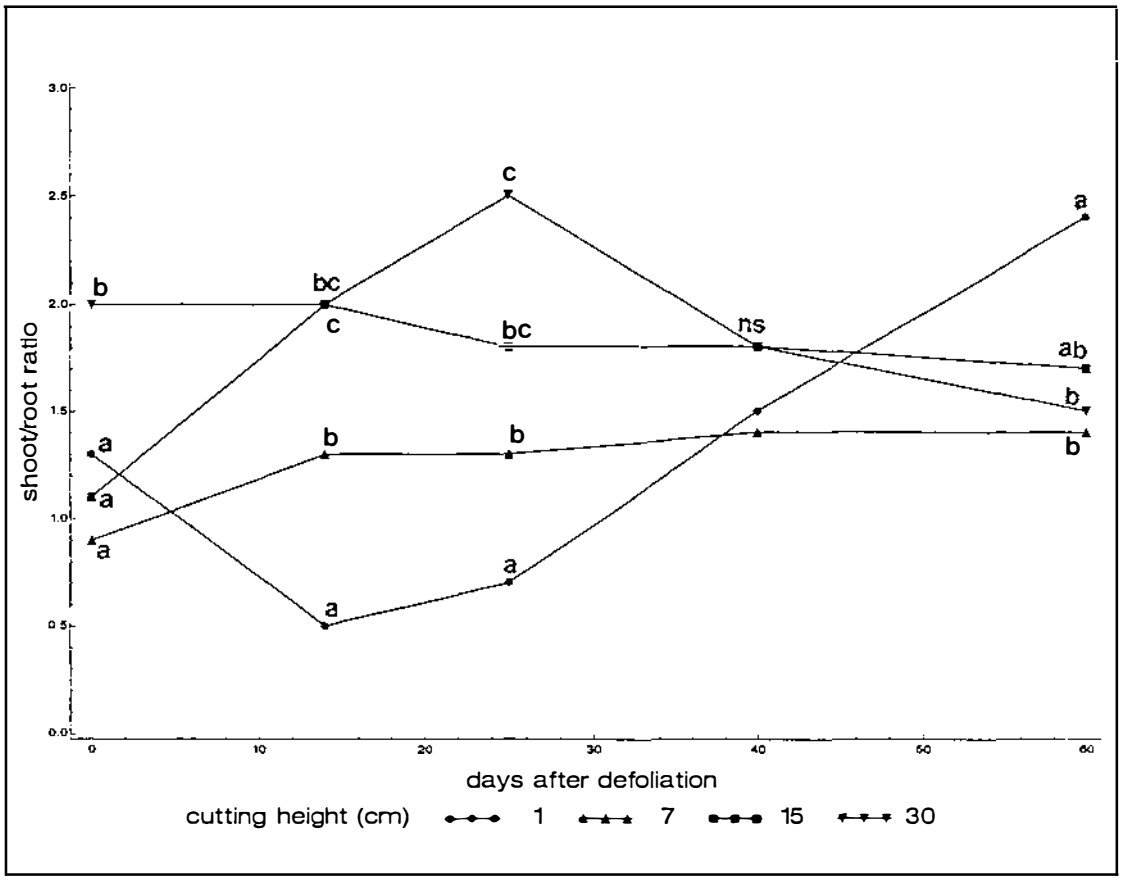


Fig 4.17 The effect of defoliation intensity on the shoot/root DW ratio in sulla, over 60 days over regrowth. Data meaned over growth stages.

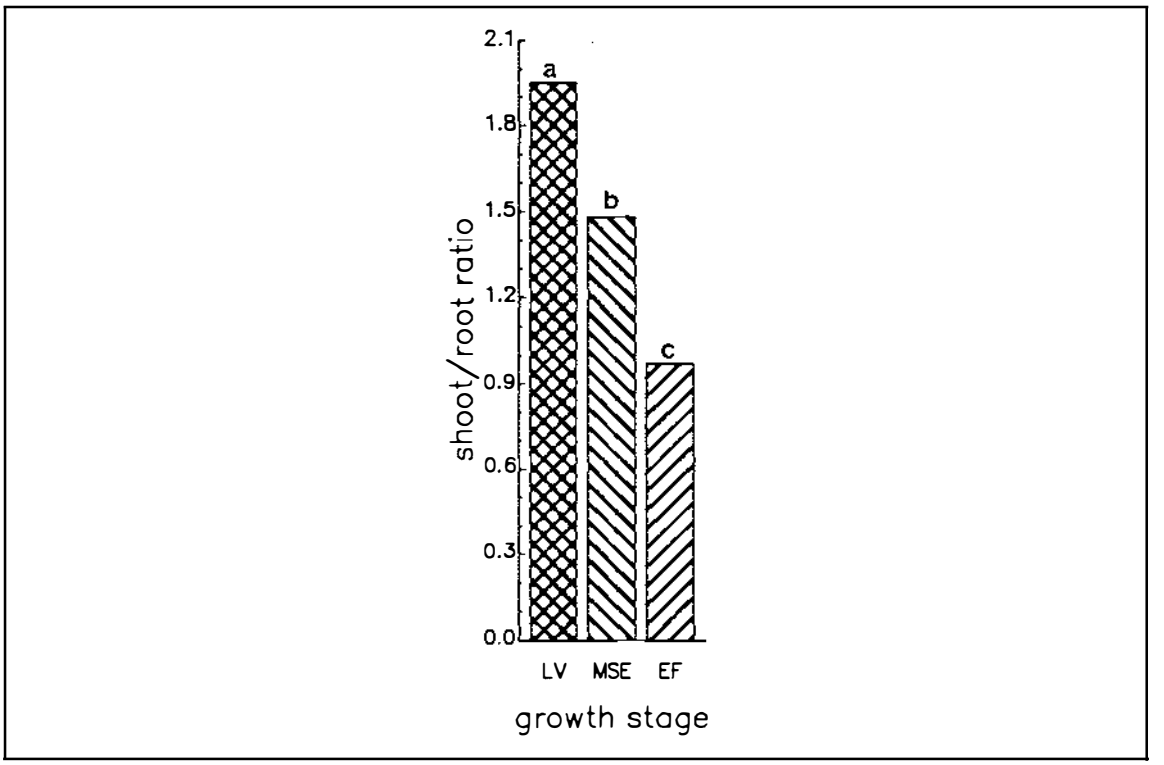


Fig 4.18 The effect of plant growth stage at defoliation on the shoot/root DW ratio of sulla. Data meaned over defoliation intensities and sampling dates. Bars with the same letter are not significantly different at the 0.05 level of probability.

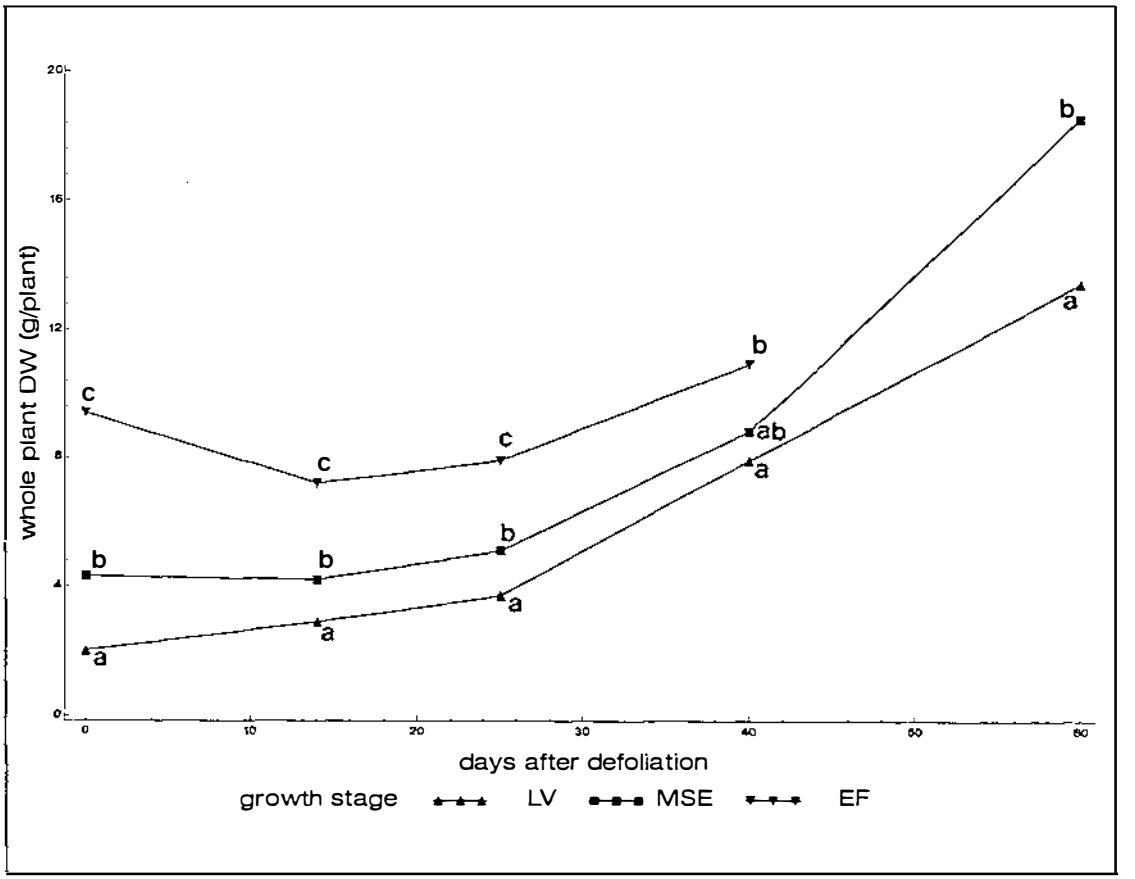


Fig 4.19 The effect of plant growth stage at defoliation on the whole-plant DW in sulla, over 60 days of regrowth. Data meaned over defoliation intensities. Whole -plant DW values at day 0 are residual shoot DW plus root DW.

than those in the MSE and EF treatments. At day 60, the WPDW in the LV treatment was 30% less than in the MSE treatment. Defoliation at the LV growth stage resulted in significantly smaller plants, compared to those defoliated at the MSE growth stage.

When the data was averaged over growth stages, there was a significant ($P<0.001$) interaction between defoliation intensity x sampling date in the WPDW (Fig 4.20). The pretreatment values in the 1 ,7, 15 and 30 cm treatments did not differ significantly, and averaged 4.5 g plant^{-1}. At day 14, there was a significant decrease in WPDW by 51% in the 1 cm treatment, no changes in the 7 and 15 cm treatments, and a 56% increase in the 30 cm treatment. Subsequently, a gradual increase in weight occurred in all treatments. However, at day 60 plants in the 1 cm

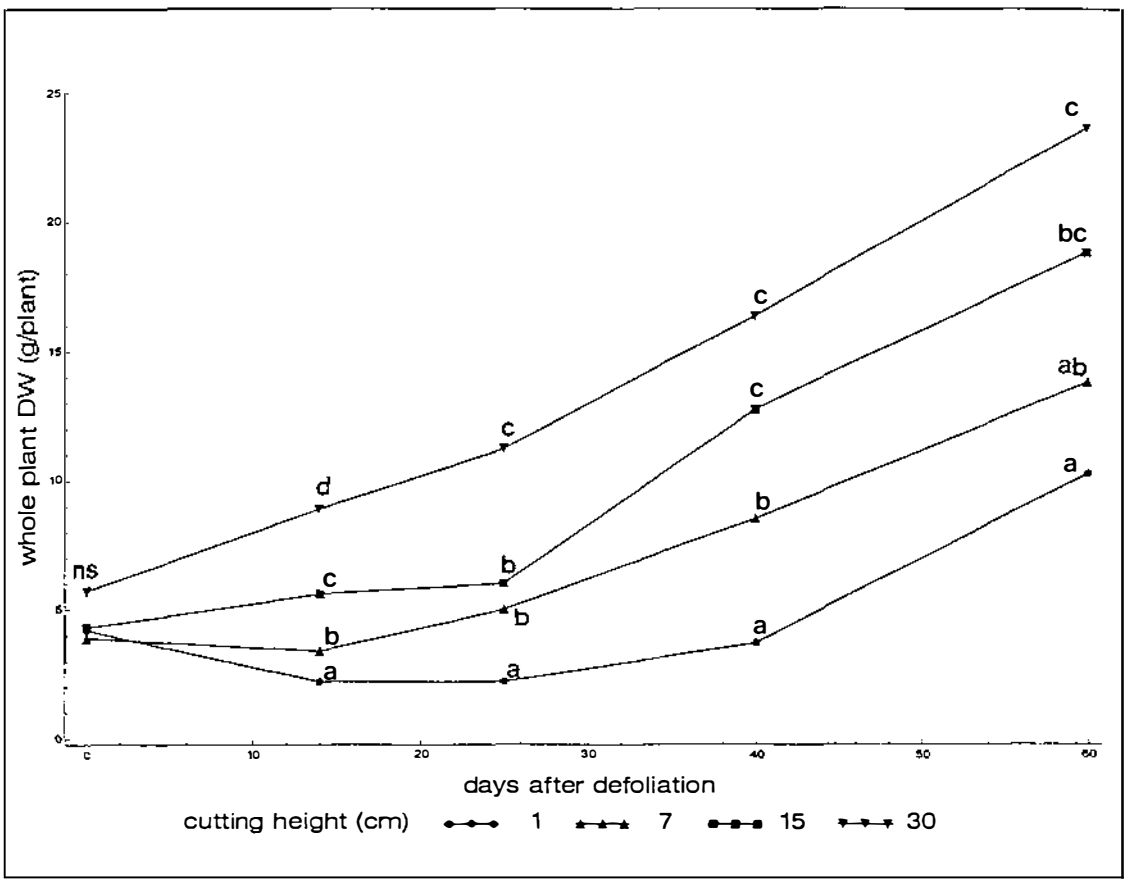


Fig 4.20 The effect of defoliation intensity on the whole-plant DW in sulla, over 60 days of regrowth. Data meaned over growth stages.

treatment were half the size of those in the 15 and 30 cm treatments. The mean weight in the 15 and 30 treatments was 21.1 g plant^{-1}.

4.3.11 RELATIVE GROWTH RATE

There was no significant ($P>0.05$) interaction between growth stage x cutting height x regrowth interval, in any of the growth analysis parameters measured.

When averaged over defoliation intensities, there was a significant ($P<0.001$) interaction between growth stage x sampling date in the mean RGR per plant (Table 4.3). In the early stages of regrowth, the mean RGR in the growth stages did not differ significantly and was negative at -0.02 g g^{-1} d^{-1}. However, in the subsequent interval, mean RGR in the LV treatment became positive and was high but

Table 4.3 The effect of plant growth stage at defoliation on the mean relative growth rate (RGR) (g g^{-1} d^{-1}) of sulla, in four intervals over the first regrowth cycle. Data meaned over defoliation intensities. The figures in parenthesis are with 1 removed to indicate negative values†.

Growth stage	Regrowth interval (in days)			
	0-14	14-25	25-40	40-60
LV	0.97 (-0.03)	1.09 (0.09)	1.04 (0.04)	1.03 (0.03)
MSE	0.99 (-0.01)	1.02 (0.02)	1.04 (0.04)	1.04 (0.04)
EF	0.98 (-0.02)	1.01 (0.01)	1.02 (0.02)	MD§

$LSD_{0.05}$=0.03

† Refer Section 4.2.4 for further explanation
§ Missing data

Table 4.4 The effect of defoliation intensity on the mean relative growth rate (RGR) (g g^{-1} d^{-1}) of sulla, in four intervals over the first regrowth cycle. Data meaned over growth stages. Refer Table 4.3 for explanation of figures in parenthesis.

Cutting height (cm)	Regrowth interval (in days)			
	0-14	14-25	25-40	40-60
1	0.93 (-0.07)	1.02 (0.02)	1.04 (0.04)	1.06 (0.06)
7	0.98 (-0.02)	1.07 (0.07)	1.02 (0.02)	1.03 (0.03)
15	1.00 (0.00)	1.04 (0.04)	1.05 (0.05)	1.02 (0.02)
30	1.02 (0.02)	1.04 (0.04)	1.03 (0.03)	1.02 (0.02)

$LSD_{0.05}$=0.03

decreased thereafter. Following the early stage of negative growth in the MSE and EF treatments, the RGR also became positive and plants grew at a similar rate of 0.02 g g^{-1} d^{-1} throughout regrowth.

When meaned over growth stages, there was a significant ($P<0.001$) interaction between defoliation intensity and sampling date in the mean RGR. From 0-14 days, the mean RGR was negative in the 1 and 7 cm treatments, whereas it was positive in the 15 and 30 cm treatments (Table 4.4). The relatively lower mean RGR was marked in the 1 cm treatment, which was 3.5 times less than in the 7 cm treatment. Over the remainder of the regrowth, plants in the 1 cm treatment grew exponentially, whereas those in the 7 cm peaked between 14-25 days and then decreased. Plants in the 15 and 30 cm treatments grew moderately throughout the regrowth period and meaned 0.03 g g^{-1} d^{-1}.

4.3.12 UNIT LEAF RATE

There was no significant ($P>0.05$) interaction between growth stage x regrowth interval in the mean unit leaf rate (ULR) per plant. Across growth stages however, there was a significant ($P<0.001$) interaction between defoliation intensity x regrowth interval on the ULR. From 0-14 days, the ULR in the 1 and 7 treatments was negative, whereas those in the 15 and 30 cm treatments were positive (Table 4.5). The decrease in ULR in the 1 cm treatment was 3.6 times greater than in the 7 cm treatment. Between 14-25 days, the ULR in all treatments became positive. The ULR was significantly higher in the 7 cm treatment, whereas the 1, 15 and 30 cm did not differ significantly. Between 25-40 and 40-60 days, the ULR in all treatments did not differ significantly and meaned 4.4×10^{-4} and 4.9×10^{-4} g cm^{-2} d^{-1} respectively.

4.3.13 LEAF AREA RATIO

Across defoliation intensities, there was significant ($P<0.001$) interaction between growth stage x regrowth interval on the leaf area ratio (LAR) per plant. The LAR was inversely proportional to the growth stage treatments (Table 4.6). There was gradual decrease in LAR in the LV treatment during regrowth. However, there was a decrease followed by an increase in LAR in the MSE treatment. Over the

Table 4.5 The effect of defoliation intensity on the mean unit leaf rate (g cm^{-2} d^{-1}) of sulla, in four intervals, over the first regrowth cycle. Data meaned over growth stages. Actual values are included in parenthesis.

Cutting Height (cm)	Regrowth interval (in days)			
	0-14	14-25	25-40	40-60
1	0.99217 (-0.00783)	1.00004 (0.00004)	1.00060 (0.00060)	1.00074 (0.00074)
7	0.99785 (-0.00215)	1.00153 (0.00153)	1.00017 (0.00017)	1.00049 (0.00049)
15	1.00049 (0.00049)	1.00038 (0.00038)	1.00069 (0.00069)	1.00029 (0.00029)
30	1.00012 (0.00012)	1.00045 (0.00045)	1.00031 (0.00031)	1.00042 (0.00042)

$LSD_{0.05}$=0.00092

regrowth, LAR in the EF treatment increased gradually.

When averaged across growth stages, there was a significant ($P<0.001$) interaction between defoliation intensity x regrowth interval. The LAR in the 1 cm treatment did not change significantly in the first two intervals (Table 4.7). However, there was a significant increase thereafter. The LAR in the 15 cm treatment remained unchanged throughout the regrowth, whereas there was a decreasing trend in the 30 cm treatment. In the final interval, the LAR in the 30 cm treatment was 38% less than in the 1 cm treatment.

Table 4.6 The effect of plant growth stage at defoliation on the mean leaf area ratio ($cm^2\ g^{-1}$) of sulla, in four intervals, in the first regrowth cycle. Data meaned over defoliation intensities.

Growth Stage	Regrowth interval (in days)			
	0-14	14-25	25-40	40-60
LV	149.4	113.2	76.9	78.9
MSE	67.1	52.3	69.2	66.1
EF	22.9	32.8	55.5	-

$LSD_{0.05}$=12.8

Table 4.7 The effect of defoliation intensity on the mean leaf area ratio ($cm^2\ g^{-1}$) of sulla, in four intervals, in the first regrowth cycle. Data meaned over growth stages.

Cutting Height (cm)	Regrowth interval (in days)			
	0-14	14-25	25-40	40-60
1	32.7	37.5	75.9	88.3
7	55.4	61.5	72.4	76.3
15	77.9	70.6	64.7	70.7
30	113.6	88.4	55.9	54.8

$LSD_{0.05}$=14.8

4.4 DISCUSSION

4.4.1 Effect of growth stage at defoliation and stubble leaf on net herbage production.

Over the period of regrowth examined, agricultural productivity as measured by leaf area and shoot DW, was markedly influenced by defoliation intensity and least affected by growth stage at defoliation. Nevertheless, plant vigour may be affected if defoliation occurs at an immature growth stage (LV and MSE), when starch status and root mass was lower. At the mature growth stage (EF) however, starch status and root mass was relatively higher, enabling the plant to withstand defoliation stress with least effect on root mass and starch status after cutting. In addition, there was the important advantage of greater herbage available in the EF treatment at defoliation. Plants severely defoliated had their root system impaired, and maintained lower starch levels at the end of the experiment. However, plants cut to 15 cm were able to recover from the stress of defoliation, and produced significantly higher net new leaf area relative to other treatments.

When averaged across growth stages, the leaf area retained on the stubble in the 1, 7, 15 and 30 cm treatments was 0, 84, 180 and 415 m^2 respectively. At the conclusion of the experiment, the net leaf area gained in the 1, 7, 15 and 30 cm treatments was 705, 752, 983 and 784 cm^2 respectively in the 60 days of regrowth. Evidently the 15 cm treatment produced the greatest increase in leaf area whereas the net production of leaf area in the 1, 7 and 30 cm was approximately similar.

Across growth stages and cutting heights, the increase in leaf number over the 60 days of regrowth suggested that plants in all treatments were able to regrow after defoliation. Across cutting heights and sampling dates, the reduction in leaf number in the 1 cm treatment indicated that plant vigour was affected. Moreover, across cutting heights and sampling dates, production of new leaves in the LV treatment was suppressed.

Complete removal of leaf area (1 cm) and the retention of too much leaf area (30 cm) on the stubble resulted in lower net production. The retention of greater than 200 cm^2 leaf area on the stubble accrued no extra production of new leaf tissue. Presumably, the older leaves retained in the 30 cm treatment were less efficient than the new leaves that were needed to replace the greater leaf area

removed in the 1 and 7 cm treatments. The ability of newly formed leaves to grow at a faster rate than the older leaves retained on the stubble, in the 30 cm treatment, implied that age and efficiency of the leaves were important considerations in the regrowth in sulla. In an erect species like sulla, older leaves are located near the base of the plant.

Brown et al., (1966) reported that older and less efficient leaves in lucerne may be more of a handicap than benefit during regrowth following partial defoliation. Moreover, leaves remaining after cutting or grazing a dense sward may be inefficient due to previous shading (Burnside & Bohning, 1957; Langer & Keoghan, 1970) or to advanced leaf age (Singh & Lal, 1935; Thorne, 1959). Fuess & Tesar (1968) found that the net photosynthetic activity of leaves decreased with age. Leaves more than three weeks old were less than one-seventh as active photosynthetically as 5-days old leaves.

The net production of approximately similar leaf area in the complete (1 cm) and near complete (7 cm) defoliation treatments, may be explained in terms of plant morphology and the consequent retention of leaf (petiole + lamina) area on the stubble following cutting. Compound leaves in sulla have a long petiole ranging from 10-20 cm at the LV growth stage, and even longer as the plant matures (See plates 4.5, 4.6 & 4.7). As all the shoots were lifted upright at cutting, the 7 cm treatment retained more leaf petiole than leaf lamina following defoliation, and hence the greater area measured at day 0. As a consequence, the leaf petiole devoid of lamina retained on the stubble subsequently shrivelled and dried down. Thus, essentially treatments 1 and 7 cm were similar in effect, except for the presence of dormant shoots in the leaf axil. Shoots were completely removed in the 1 cm treatment.

4.2.2 The effect of stubble leaf area and starch status at defoliation on the regrowth pattern in sulla.

The pattern of leaf area development after complete or partial defoliation reflects the rate of regeneration of the photosynthetic area of the plant. As leaf area accumulation and shoot mass were linearly correlated (r^2=0.75, P<0.001) in this experiment, they are discussed together.

Across growth stages, the effect of increased severity of defoliation on sulla was to depress shoot growth and leaf area formation for increasingly longer periods. The inability of the complete (1 cm) and near complete (7 cm) defoliated plants to produce new leaf area to the net amount in the 15 cm treatment, in the same regrowth period, was probably due to the early lag phase (0-14 days) experienced by these plants as indicated by their negative mean RGR and ULR (See Tables 4.4 & 4.5), suggesting the preponderance of respiration as new leaves were produced at the expense of root and stubble weights. Conversely, plants in the 15 cm treatments maintained or continued to gain weight in the same regrowth period. Langer & Keoghan (1970) working with severely defoliated 'Wairau' lucerne at an immature growth stage have shown negative growth rates in the first week following complete defoliation.

Across sampling dates, the interaction between growth stage and defoliation intensity on leaf area (See Fig 4.5) illustrated the importance of retaining stubble leaf area (lamina) in all growth stage treatments, for the production of new leaf area. On the whole, complete defoliation suppressed leaf area production in all growth stage treatments and more so in the LV treatment.

Physiologically the LV growth stage was in its juvenile phase of ontogeny and appeared dependent on stubble leaf area at defoliation to produce new leaf tissue. In addition, the carbohydrate status at defoliation was lower than in the MSE and EF treatments (See Figs 4.11 & 4.14), and may not have been sufficient to meet the current demands for the formation of new leaf tissue and to sustain root respiration after cutting. Thus, plants must rely on current photosynthate, otherwise growth is suppressed. Furthermore, the lower starch status suggested that plant vigour may have been affected (See Figs 4.13 & 4.16). Silva (1968) has demonstrated that the recovery growth in lucerne with low carbohydrate status at defoliation strongly depended on the amount of leaf area retained on the stubble.

In the MSE and EF growth stages however, that is at a more mature growth phase in their ontogeny when the initial carbohydrate status of the plants was higher, regrowth was more related to the absence or presence of leaf area on the stubble, as in the 15 cm treatments where new leaf area production were similar. This again may be related to the lesser leaf area (lamina) retained on the stubble,

that is plant morphology at defoliation, in these treatments. Conversely, with the retention of greater amounts of leaf area (lamina) in the 30 cm treatment in plants defoliated at the LV growth stage, production of new leaf area was higher than in the MSE and EF treatments. Presumably the leaves were younger and more efficient in the LV treatment (75 days), compared to the older leaves in the MSE (85 days) and EF (105 days) treatments respectively. These results and the linear relationship between leaf area and shoot DW (See Fig 4.8) thus emphasize the importance of the retention of stubble foliage in determining the rate and amount of recovery growth in sulla when defoliated at an early stage of growth.

Reserve energy status of perennial forage plants (based on concentration and content or quantity of starch) gives an indication of plant vigour, provided environmental stresses are absent. Starch content in storage tissue is considered the best basis for evaluating reserve energy level, as a small mass with high starch concentration may contain a smaller quantity of starch than a large mass with a relatively low starch concentration. Weight of starch, therefore, is a better criterion than concentration for determining the importance of reserves for regrowth (Smith, 1969a; Booysen & Nelson, 1975). Caldwell (1984) pointed out that to explain cutting or grazing responses, measurements must integrate total nonstructural carbohydrate (TNC) with fluctuations in biomass of the organ or tissue from which the TNC was obtained. As both measurements were obtained in this experiment, they will be discussed together.

Averaged across defoliation intensities, the pattern of fluctuation in starch concentration and content following defoliation was proportional to the initial starch status of the plant. When the plant was actively growing (LV growth stage), starch concentration and content were found to be lower. Presumably, the current photosynthate produced in this stage of exponential growth is used as an energy source for the actively growing meristem. After the rate of growth began to decline, there was a steady increase in the level of starch accumulated in the roots, as in the case of the MSE and EF growth stages treatments (Figs 4.11 & 4.14). Thus, the level of starch maintained immediately after defoliation and throughout the period of regrowth is primarily dependent on the starch status at defoliation. These results tend to support the hypothesis that carbohydrate reserve storage is inversely related

to growth. Numerous other researchers have suggested that carbohydrate reserve storage in herbaceous plants is inversely related to growth (Menke & Trlica, 1981; Deregibus et al., 1982)

Averaged across growth stages, completely and near completely defoliated (1 and 7 cm) plants showed a decrease in starch concentration and content in their roots. Also there was a corresponding decrease in shoot DW. Presumably this decrease in starch content of roots and shoot DW was as a consequence of the degradation and remobilisation of starch from taproot and crown (stubble), for the initiation of new shoot growth (Pearce et al., 1969; Smith & Silva, 1969; Smith & Marten, 1970) and for the sustenance of root respiration (May, 1960; Davidson & Milthorpe, 1965; Culvernor et al., 1989b). Hodgkinson (1969, 1970) has shown that the taproot in lucerne is the prime source of metabolizable compounds during the early stages of regeneration, and organic root compounds labelled with ^{14}C prior to herbage removal are used as respiratory substrate, and to a lesser extent translocated into new shoots for the first 20 days of regrowth.

Over the 40 days of regrowth, the completely defoliated plants did not regain their initial (pretreatment) starch concentration or content. This may have been due primarily to the exponential shoot growth during the period of regrowth examined (Deregibus et al., 1982). This is supported by the increase in S/R ratio during the period of regrowth (See Fig 4.17). Moreover, the lower starch status in the 1 and 7 cm treatments, relative to the other treatments, may indicate lower plant vigour.

The trends in starch concentration and content observed in the complete and near complete defoliated plants followed a cyclic pattern similar to that reported by other researchers in lucerne (Graber et al., 1927; Grandfield, 1935; Ueno & Smith, 1970), red clover (Smith, 1950; 1962), birdsfoot trefoil (Smith, 1962) and sainfoin (Cooper & Watson, 1968); decreasing initially, reaching a minimum level and then increasing. In contrast, the starch concentration or content in partially defoliated plants (15 and 30 cm) was not decreased, presumably because photosynthate produced by the stubble leaves was sufficient to meet current needs in the shoots and the roots, so root reserves were not used (Hodgkinson, 1972; 1974).

It is generally believed that accumulation of starch in taproots of perennial legumes is associated with the tolerance to stress related to defoliation and winter

survival (Graber et al., 1927; Grandfield, 1935; Smith, 1962; 1964; 1980).

4.4.3 Effect of growth stage and intensity of defoliation on the root system.

Changes in total root weight were largely a reflection of the loss or gain in root organic reserves, and the significance of these changes has been discussed. Averaged over defoliation intensities, the changes in root mass over the regrowth period were closely related to the quantity of root mass present at defoliation. Root mass was also directly proportional to growth stage. Resumption of new root growth in the LV and MSE treatments was evident at 40 days after defoliation.

When averaged over growth stages, the decrease in root mass in the first 14 days after defoliation in the 1 and 7 cm treatments did not reach statistical significance. Nevertheless, the complete removal of top growth caused a 32% reduction in root mass by day 14 (See plate 4.8), and the resumption of root growth was suppressed for greater than 40 days. This retardation of root growth in the 1 cm treatment, relative to the other treatments over the 60 days of regrowth, suggested that complete removal of top growth was detrimental to root regrowth. The subsequent decline of root weight in the completely defoliated plants was consistent with those reported by Langer & Steinke (1965) in lucerne, where plants were defoliated to 1 in (2.54 cm) and 5 in (12.7 cm) and left to regrow uninterrupted for 63 days. There was a decline and subsequent retardation of root weight in their experiment. The relatively rapid root recovery in the 7 cm treatment (< 40 days) may be due to the presence of dormant shoots at defoliation that resumed growth soon after defoliation, in contrast to the need to form new shoots in the 1 cm treatment for continued growth and development. This resulted in twice as much root mass in the 7 cm treatment as in the 1 cm treatment.

Similar root weights in the 15 and 30 cm treatments suggested that defoliation in this range (15-30 cm) will probably not impair root growth in sulla. Retention of stubble with sufficient leaf area (lamina) in these treatments caused minimum stress to the plant. The retardation of root growth in the completely defoliated plants agreed with that reported in lucerne (Mitchell & Denne, 1967), who assumed that after severe defoliation extension of the roots would cease similarly

Plate 4.8 The effect of cutting sulla to 1, 7, 15 & 30 cm (from right to left) on the root system, 14 days after defoliation.

to that reported in grasses. In addition, the slow increase in root weight in sulla agreed with findings by Troughton (1957) and Chapin & Slack (1979). They considered that the loss in weight by the roots in grasses is relatively small, the main effect of defoliation on roots being the retardation of their growth for sometime after defoliation. Numerous other researchers have also reported the detrimental effect of defoliation of herbaceous plants on root growth (Fulkerson, 1970; Langer & Keoghan, 1970).

4.4.4 Severity of defoliation and dry matter partitioning.

Over the course of the experiment, the overall effect of growth stage on the S/R ratio was significant. The decrease in S/R ratio, with increasing plant maturity at defoliation, implied that dry matter was partitioned relatively more into root growth and storage organs as the plant matures. The decrease in S/R ratio with increasing age has been shown in other plant species (Pearsall, 1927; Sprague, 1944).

Averaged across growth stages, with complete removal of top growth, the initial decrease and subsequent increase in the S/R ratio suggested that the plants were adjusting their S/R ratio in response to the sudden complete removal of photosynthetic tissue. Conversely, with the retention of stubble leaf, a relatively constant S/R in the 7, 15 and 30 cm treatments indicated adjustment of dry matter partitioning during the period of regrowth. Brouwer & de Wit (1975) and Szaniawski, (1981) considered that a functional equilibrium existed in the interdependence of shoot and roots. They stated that a rapid restoration of the original S/R ratio occurred after defoliation, as a consequence of the reduction in growth rate of the dependent organ (root) and relatively increased growth rate of the supplying organ (shoot).

The higher S/R ratio in the 1 cm treatment, at the end of the regrowth period, suggested that plants completely defoliated invested current photosynthate into the formation of new photosynthetic tissue in preference to root tissue. In addition, the S/R balance was upset, and the plant was unable to reestablish an equilibrium by day 60 relative to the other treatments (Luckwill, 1960; Brouwer, 1983). As a consequence, the exploitation of moisture and mineral nutrients may be reduced and plant vigour affected (Harris, 1978). External factors such as intensity of

defoliation affecting S/R ratios in a similar manner have been reported in other plant species (Troughton, 1963).

4.4.5 Severity of defoliation and its effect on plant size.

Across defoliation intensities the whole-plant DW, which is a measure of plant size, showed a progressive increase with time. The initial size of plants at defoliation, as determined by the growth stage, influenced the weight at each sampling. Variations in plant size were essentially due to variations in root mass. The lower weight in the LV growth stage was a result of its lower root weight (See Fig 4.9), although the final shoot weights were no different (Fig 4.6). Extrapolating, it would be expected that the root weight in MSE treatment may not have differed significantly from that of the EF growth stage treatment at the final harvest, although data is not available. This can be inferred from the rather stable root mass maintained in the EF treatment following defoliation (See Fig 4.9). Ueno & Smith (1970), working with different sized lucerne plants at defoliation, found that the whole-plant growth at each sampling was proportional to the initial plant size. Their experiment covered a period of 42 days. In addition, Langer & Keoghan (1970) in their study of severely defoliated lucerne, reported that the total plant weight was reduced due to the retardation of root growth.

Averaged over growth stages, complete defoliation resulted in smaller plants at the end of the regrowth period. The decrease in plant size in the 1 cm treatment was due to the decrease in both shoot and root (See Figs 4.7 & 4.10) and the weights suggested depressed plant vigour. Conversely, defoliation between 15-30 cm did not affect plant size. The deleterious effect of defoliation as one of the factors affecting plant size has been reviewed by McNaughton (1983).

4.4.6 Conclusions

1. The influence of growth stage at defoliation and defoliation intensity on the accumulation of starch, as measured by starch concentration and content, were similar. Starch concentration and content were relatively greater in the EF treatment at defoliation. In addition, cutting at 15 cm and above did not affect the starch status in sulla. However, at an immature growth stage, varying defoliation

heights varied starch accumulation.

2. Under a cutting regime, defoliation intensity appeared a more important determinant than growth stage on regrowth and productivity. Defoliation intensities above 15 cm did not contribute significantly towards further increases in productivity. Retention of leaf area was more sensitive to severe defoliation at an immature growth stage than at a mature growth stage. It would appear best to defoliate plants at the EF growth stage to a height between 7-15 cm, to ensure sufficient retention of leaf area on the stubble, and maintain greater root mass with corresponding high starch status for the rapid recovery in sulla.

3. Root weight decreased as a result of complete removal of shoots in the 1 cm treatment, leading to reduced plant size and depressed herbage production. However, the presence of some leaf area in the 7 cm treatment did not affect root regrowth over the regrowth period examined, but production was lower than in the 15 and 30 cm treatments.

CHAPTER 5. THE EFFECT OF VARIOUS GRAZING MANAGEMENT SYSTEMS ON THE PRODUCTION AND PERSISTENCE OF SULLA (*Hedysarum coronarium* L.) cv. NECTON.

5.1 INTRODUCTION

The ability of sulla to provide good quality non-bloating forage throughout the year is an important advantage over conventional forages used in New Zealand. Preliminary grazing studies in the Manawatu have shown that the herbage production of sulla ranged between 10000-19000 kg DM ha^{-1} (Chapter 3). Herbage accumulation rates were highest in summer and relatively lower in winter, and ranged between 30-60 kg DM ha^{-1} d^{-1} (Chapter 3). However, the detrimental effect of grazing sulla in late autumn-winter on the subsequent spring production could pose management problems, especially in view of its autumn-winter activity.

The effect of grazing or cutting winter active lucerne in late autumn is currently of interest. White & Lucas (1989, 1990) demonstrated the negative effect of cutting and grazing of winter active lucerne cultivars in autumn on the subsequent spring production in Canterbury. They also found that the reduction in herbage accumulation in spring was probably due to low levels of nonstructural carbohydrate reserves in the roots of winter active cultivars used.

Moreover, perennial forage legumes like birdsfoot trefoil and lucerne differ with respect to several growth responses. When cut or grazed, regrowth in birdsfoot trefoil comes from axillary buds on the remaining stubble, and this explains the importance of leaving a high stubble to maintain stands (Smith, 1966). In contrast, lucerne can be grazed boldly to the ground, as this stimulates regrowth which predominantly originates on crowns (Iversen, 1967; Langer & Keoghan, 1970). Therefore, a more thorough knowledge of the morphological responses of sulla is needed to develop its grazing management.

Although the preliminary grazing trial estimated herbage production over a year, the results reported (Chapter 3; Krishna et al., 1990) were as a consequence of N application and under severe weed infestation. The application of N is unrealistic, as sulla is a legume and is capable of fixing N. In addition, the problems identified in the husbandry of sulla in the preliminary trial and their possible solutions

needed to be tested under more realistic field conditions. Furthermore, the loss of potential production in spring following the late autumn grazing also needed further investigation. The objectives of the trial were thus to examine:

1. the effects of plant growth stage at grazing and grazing intensity on the production and persistence of sulla over one year;
2. the effect of late autumn-winter grazing on the subsequent spring production, and
3. the effect of plant growth stage at first grazing and grazing intensity on the early regrowth characteristics in sulla.

5.2 MATERIALS AND METHODS

5.2.1 SITE INFORMATION

The trial site of 0.72 ha was located at Frewens 3, Massey University (See plate 5.1) and the experiment was conducted from October 1989 to October 1990. The soil type was similar to that of the first experiment (See chapter 3 for site information). Soil and foliar analysis was carried out, to guide decisions on nutrient requirements (See appendices 5.1, 5.2 & 5.3). The soil was ploughed in early spring 1989 and agricultural lime at 4 t ha^{-1} was incorporated to raise the pH to 6.0. A single dose mixture of 40 kg urea, 500 kg single superphosphate and 200 kg muriate of potash ha^{-1} was top dressed at sowing. Dehulled sulla cv. Necton at 15 kg ha^{-1} was drilled to 2-3 cm soil depth in 15 cm rows on the 26 October 1989. Seeds were inoculated with peat slurry containing the reisolate ICMP 10149. 10% sugar solution was added to the mixture as a seed adherent (Vincent, 1970), then air dried in a cool area and sown within 24 hours. A preemergent herbicide Stomp 330 E a.i pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine], selected by NZ Agriseed Limited (G. Kerr, pers comm) as suitable for sulla, was sprayed at 4 l ha^{-1}. Sodium molybdate (70 g) was added to the herbicide to correct any molybdenum deficiency in sulla (Ratera et al., 1977; During, 1984). Plant tissue analysis in the previous trial had indicated low molybdenum levels in the soil type. By early January 1990, a healthy, effectively nodulated and relatively weed free stand was established. Postsowing plant tissue analysis indicated acceptable levels

Plate 5.1 General view of established sulla plots located at Frewens 3, Massey University.

of molybdenum in the herbage sampled (See appendix 5.2).

5.2.2 DESIGN AND TREATMENTS

The experimental design was a randomised complete block, comprised of a factorial combination of three growth stages (late vegetative, midstem elongation, early flowering) at grazing and two grazing intensities (severe grazing, less severe grazing), resulting in 6 treatments. The trial was replicated 4 times, plot size was 192 m^2 (29 x 6.6 m), and was grazed with sheep. Individual plots were electric fenced with separate access, to facilitate the movement of sheep in and out of the plots as and when desired (See appendix 5.4 for field layout).

Combinations of six grazing management treatments are presented in Table 5.1. There were two grazing intensity managements at each growth stage i.e at the late vegetative (LV), midstem elongation (MSE) and early flowering (EF) (See plates 5.2, 5.3 & 5.4). The grazing intensity treatments at the LV growth stage began when the plants reached the commencement of early stem elongation. The plots were either severely grazed, i.e 70-80% of the stem and leaf material eaten, leaving stubble equivalent to 400-700 kg DM ha^{-1} (See plate 5.5) or less severely grazed, i.e 60-70% of the stem and leaf material eaten, leaving stubble equivalent to 900-1100 kg DM ha^{-1} (See plate 5.6). The grazing intensity treatments at the midstem elongation (MSE) growth stage began when the plants were at the mid to late stem elongation, and the early flowering grazing commenced when the plants were at the late stem elongation to 10% flowering, and plots were either grazed severely or less severely as described above.

Plate 5.2 Sulla sward at the late vegetative growth stage

Plate 5.3 Sulla sward at the midstem elongation growth stage

Plate 5.4 Sulla sward at the early flowering growth stage

Plate 5.5 Severe grazing treatment

Plate 5.6 Less severe grazing treatment

Plate 5.7 Summer grazing in progress. Note green herbage on offer compared to surrounding pasture.

Table 5.1 A flow chart showing grazing intensity management treatment imposed at the late vegetative (LV), midstem elongation (MSE) and early flowering (EF) growth stages, at each grazing, over 365 days.

Growth Stage Treatment	Grazing intensity treatments†				Total Number of Grazings	Resultant grazing management
	§1	2	3	4		
LV	H	H	H	H	4	LVHHHH
	L	L	L	L	4	LVLLLL
MSE	H	H	H	H	4	MSEHHHH
	L	L	L	L	4	MSELLLL
EF	H	H		H	3	EFHHH
	L	L		L	3	EFLLL

† H= severe grazing.
L= less severe grazing.
§ Grazing sequences are fitted based on nearest chronology of grazing.
Note: Only three grazings occurred in the EF growth stage and its final grazing is included in the final sequence.

Thus, the first grazing in the LV, MSE and EF growth stage treatments occurred on 17 January, 1989 (83 DAS), 24 January 1990 (90 DAS) and 14 February 1990 (111 DAS) respectively. Subsequent grazings in the severely and less severely grazed treatments within each growth stage treatment were determined by growth stage i.e when the plants reached similar physiological maturity to when they were first grazed. The severely and less severely grazed treatments within each growth stage treatment were grazed at the same time and a grazing schedule is presented in Table 5.2. This was possible as the residual plant material after the first and subsequent grazings at both intensities within each growth stage treatment disappeared, and the criteria based on growth stage at each grazing could be carried out. Thus, a total of four grazings eventuated in the LV and MSE treatments, and three grazings in the EF treatments over 365 days. About 30-

Table 5.2 Grazing schedule as determined by plant growth stage at grazing in sulla at each grazing over 365 DAS.

Grazing sequence	Late vegetative			Midstem elongation			Early flowering		
	Grazing date	DAG†	DAS§	Grazing date	DAG	DAS	Grazing date	DAG	DAS
1	17/01/90	-	83	24/01/90	-	90	14/02/90	-	111
2	14/03/90	56	139	28/03/90	63	153	18/04/90	63	174
3	22/06/90	100	239	04/07/90	98	251			
4	26/10/90	126	365	26/10/90	114	365	20/09/90	155	329

Sowing date: 26 October 1989
† Days after grazing
§ Days after sowing

40 sheep, equivalent to 1500-2000 sheep ha^{-1}, were used to effect quick grazing (See plate 5.7). The duration of the grazing was normally between 1-2 days depending on the feed on offer. The grazing was closely monitored and once the desired residual herbage, determined visually was reached, sheep were removed from the plots.

At the late autumn-winter grazing in the LV and MSE growth stage treatments, the plots were split and subplots were either grazed or left ungrazed. The ungrazed control subplots were caged to prevent access to herbage by sheep. Plant counts were monitored before grazing and on 20 September 1990 in the grazed and ungrazed subplots.

5.2.3 MEASUREMENTS

Three 0.2 m^2 quadrats per plot were used to estimate herbage mass (kg DM ha^{-1}) before and after grazing, and to monitor plant density. Pre and post grazing herbage samples were cut to ground level using a sickle. Samples were thoroughly washed, separated into leaf, stem, flower (if any) and weed fractions, and the fractions were weighed. Then subsamples were forced draught oven dried at 70-75°C for 24 hours and weighed for DM determination. The herbage accumulated (leaf + stem + flower) and its components, herbage accumulation rate, plant density, individual plant dry-weight (DW), leaf-to-stem mass ratio and weed accumulated were calculated from the DM and plant density data. The pregrazing herbage mass at the second and subsequent grazings of sulla was mostly new growth, as the herbage mass after each grazing in all the growth stage treatments subsequently died and decayed, and thus was excluded from the DM calculations, as in Chapter 3.

Five grazed plants from the severely and less severely grazed treatments in each LV and MSE plot were removed, at 15 days after the first grazing (DAG) and the plants were then thoroughly washed and soaked in water to maintain turgor. Individual plants were then dissected and the origin (primary stem, secondary stem(s) and crown) and number of shoots on each origin, shoot length, number of leaves, petiole length, leaf area and taproot diameter were measured. The crown was cut at the position where the crown meets the taproot and the longest distance

across the top of the severed taproot was measured as the taproot diameter. Area of leaves was measured with a Li-Cor Area Meter Model 3100, and the cumulative area was recorded. Roots for DW determination were trimmed to 50 mm from the crown. The dissected shoots and roots were then oven dried and weighed. Whole plants harvested from the EF treatment plots, kept in a cool room for measurement at a later time, decayed unexpectedly and had to be discarded.

5.2.4 STATISTICAL ANALYSIS

Statistical analysis (ANOVA) was conducted using Statistical Analysis System General Linear Model (GLM) procedure guide (Steel & Torrie, 1981; SAS, 1989) on all the measurements over 365 DAS. Comparison on total flower accumulation was possible because flowering occurred in the LV and MSE treatments only once, as this was allowed irrespective of growth stage at the final grazing with the intention to conclude the trial at 365 DAS. The sources of variation were partitioned into block, growth stage, grazing intensity and the relevant interactions. Analysis of variance was also conducted on each harvest individually. As grazings in the growth stage treatments were not synchronised, comparisons were made on the basis of nearest chronology.

Regrowth studies were analyzed as a randomised complete block, including: regrowth site as a classification variable or a source of variation to study the effect of growth stage, grazing intensity, regrowth site and relevant interactions on the regrowth site characteristics in sulla.

The effects of winter grazing on plant density were analyzed for statistical significance as a split plot design where the main plot effects were severe and less severe grazing, and subplots effects were grazed or ungrazed control. Treatment means were compared using Fisher's protected least significant difference (LSD) procedure (Carmer & Walker, 1985). Unless otherwise stated, the 0.05 level of probability was used to determine differences.

5.3 RESULTS

5.3.1 CLIMATE

The climate data during the trial are summarised in Table 5.3. Adequate

rainfall fell over the trial site during the course of the experiment. The total precipitation received was close to the Palmerston North average of 1000 mm. Lower than average rainfall fell in November 1989 to January 1990 with January receiving the lowest rainfall. Above average rainfall that fell in October 1989 at the time of sowing provided a conducive soil moisture status, and coupled with a soil temperature (100 mm depth) of 13°C resulted in favourable germination and

Table 5.3 Summary of climate data at the trial site from October 1989 to October 1990, recorded at the DSIR climate station (40°23′S 175°37′E, 34 m asl).

Month	Total Rain (mm)	Air temperature °C			Soil Temp °C	Sun-shine hours	RH%
		Mean	Max	Min			
Oct	123	13.8	18.0	9.6	13.0	130	78
Nov	23	16.0	20.0	12.0	16.2	192	70
Dec	59	15.7	20.1	11.3	16.1	158	71
Jan	18	20.1	24.9	15.2	19.8	223	84
Feb	104	17.6	23.0	13.0	17.8	201	78
Mar	184	17.9	22.2	13.6	17.1	172	79
Apr	66	14.4	18.6	10.2	13.6	111	80
May	92	11.9	15.8	8.0	10.7	113	83
Jun	125	9.4	13.1	5.6	8.2	67	88
Jul	85	9.0	12.8	5.1	7.3	84	88
Aug	111	10.1	13.7	6.4	8.4	103	86
Sept	17	10.1	14.4	5.7	9.5	132	73
Oct	84	13.4	17.4	9.4	13.1	153	80

establishment of the forage. The cumulative sunshine hours received were above average which, with a relative humidity of 80%, led to advantageous growing conditions throughout the trial. The average maximum and minimum temperatures over the year were slightly higher than expected.

5.3.2 HERBAGE AND COMPONENTS OF HERBAGE ACCUMULATION

There was no significant interaction between plant growth stage at grazing and grazing intensity management, and the overall effect of grazing intensity was not significant on the herbage and components of herbage accumulated over 365

DAS. As a consequence only the effect of plant growth stage at grazing is discussed.

The total herbage and herbage components accumulated over 365 DAS are presented in Table 5.4. There was a significant ($P<0.01$) difference between the growth stage treatments in the total herbage accumulated over 365 DAS. The total herbage accumulated in the EF treatment was 13% greater than in the LV and MSE treatments. The LV and MSE treatments did not differ significantly and averaged 21941 ± 507 kg DM ha^{-1} y^{-1}.

There was a significant ($P<0.001$) effect of growth stage at grazing on the

Table 5.4 The effect of plant growth stage at grazing on the total herbage and components of herbage accumulated (kg DM ha^{-1}) in sulla, over 365 days. Data meaned over all intensities.

Growth Stage	Total Herbage Accumulated	Components of total herbage accumulated		
		Leaf	Stem	Flower§
LV (4)	21865	14167	7609	89
MSE (4)	22016	14956	6935	124
EF (3)	24705	13150	10682	873
$LSD_{0.05}$†	1987	955	1310	219

† LSD at the 0.05 level of significance.
§ Flowering occurred in the LV and MSE treatments at the final grazing on 26 October 1990 as all treatments were intended to be grazed then irrespective of growth stage as a conclusion to the trial.
Numbers in brackets are the total number of grazings that occurred in each growth stage treatment.

total leaf accumulated over 365 DAS. The total leaf accumulated in the EF treatment was 10% less than in the LV and MSE treatments, which meaned 14561 ± 243 kg DM ha^{-1} y^{-1}. Moreover, there was also a significant ($P<0.001$) difference between the growth stage treatments in the total stem accumulated over 365 DAS.

The total stem accumulated in the EF treatment was 47% greater than in the LV and MSE treatments. There was no significant difference between the LV and MSE treatments and the total stem accumulated was 7272 ± 334 kg DM ha^{-1} y^{-1}. Moreover, the total flower accumulated was also significantly ($P<0.001$) different between the growth stage treatments. The total flower accumulated in the EF treatment was eight times greater than in the LV and MSE treatments. The LV and MSE treatments did not differ significantly and averaged 107 ± 56 kg DM ha^{-1} y^{-1}.

5.3.3 HERBAGE MASS AT EACH GRAZING

At the time of the first grazing in January/February, there was no significant interaction between growth stage at grazing and grazing intensity, and there was no significant overall effect of grazing intensity on the pregrazing herbage mass (Fig 5.1). However, there was a significant ($P<0.001$) effect of growth stage at grazing. The pregrazing herbage mass in the LV, MSE and EF growth stage treatments was 3724 ± 248, 5128 ± 248 and 7067 ± 248 kg DM ha^{-1} equivalent to 45 ± 7, 57 ± 7 and 64 ± 7 kg DM ha^{-1} d^{-1} respectively.

At the second grazing in March/April however, there was a significant ($P<0.001$) interaction between growth stage and grazing intensity in the pregrazing herbage mass. The pregrazing herbage mass in the severely grazed treatment was greater than in the less severely grazed treatment within the MSE growth stage treatment, whereas it was vice versa within the EF treatment. The herbage accumulation rate (HAR) in the severely grazed treatment was 26% greater than in the less severely grazed treatment, within the MSE treatment (Table 5.5). However, within the EF treatment, the HAR in the severely grazed treatment was 15% less than in the less severely grazed treatment. Grazing severity did not affect the pregrazing herbage mass significantly within the LV treatment.

Moreover, at the third grazing in June/July, there was no significant interaction between growth stage and grazing intensity nor an overall effect of growth stage or grazing severity on the pregrazing herbage mass. Across all growth stages and intensities, that is over the LVH, LVL, MSEH and MSEL treatments, the pregrazing herbage mass was 6189 ± 201 kg DM ha^{-1} which was equivalent to 63 kg DM ha^{-1} d^{-1}.

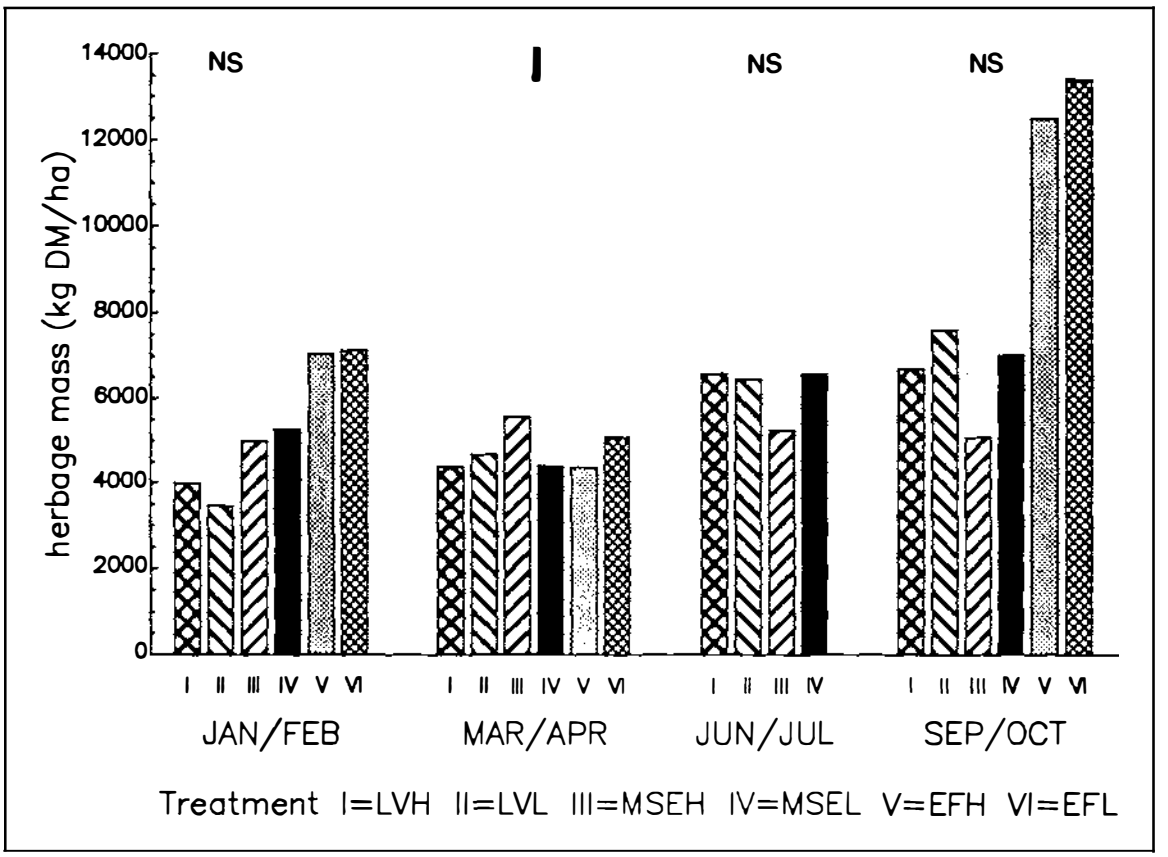


Fig 5.1 The effect of plant growth stage at grazing and grazing intensity on the pregrazing herbage mass in sulla, at each grazing over 365 DAS. Bar represents least significant difference at the 0.05 level of probability and NS=not significant at the same level. KEY: LV=late vegetative, MSE=Midstem elongation and EF=early flowering growth stages, H=severe grazing and L=less severe grazing.

Table 5.5 The effect of plant growth stage at grazing and grazing intensity on herbage accumulation rate (kg DM ha^{-1} d^{-1}) at each grazing in sulla, over 365 days.

Growth Stage	Grazing† Intensity	Grazing sequence			
		Jan/Feb	Mar/Apr	Jun/Jul	Sept/Oct
LV	H	48	78	66	53
	L	42	83	64	60
MSE	H	55	88	53	45
	L	59	70	67	61
EF	H	63	69	-	80
	L	64	81	-	86
$LSD_{0.05}$		NS	11	NS	NS

† H=severe grazing
L=less severe grazing
- Grazing did not occur in the EF treatment in winter.

At the final grazing in September/October, there was also no significant interaction between growth stage and grazing intensity nor an overall effect of grazing intensity on the pregrazing herbage mass. However, there was a significant ($P<0.001$) effect of growth stage at grazing. The pregrazing herbage mass in the LV, MSE and EF treatments was 7128 ± 663, 6029 ± 663 and 12921 ± 663 kg DM ha^{-1} which was equivalent to 57 ± 5, 53 ± 5 and 83 ± 5 kg DM ha^{-1} d^{-1} respectively, even though the period of growth was substantially greater.

5.3.4 LEAF MASS AT EACH GRAZING

At the commencement of the first grazing in January/February, there was no significant interaction between growth stage at grazing and grazing intensity nor an overall effect of grazing intensity on the pregrazing leaf mass (Fig 5.2). However, there was a significant ($P<0.001$) effect of growth stage at grazing on leaf mass. The pregrazing leaf mass in the LV, MSE and EF treatments was 3122 ± 144, 3786

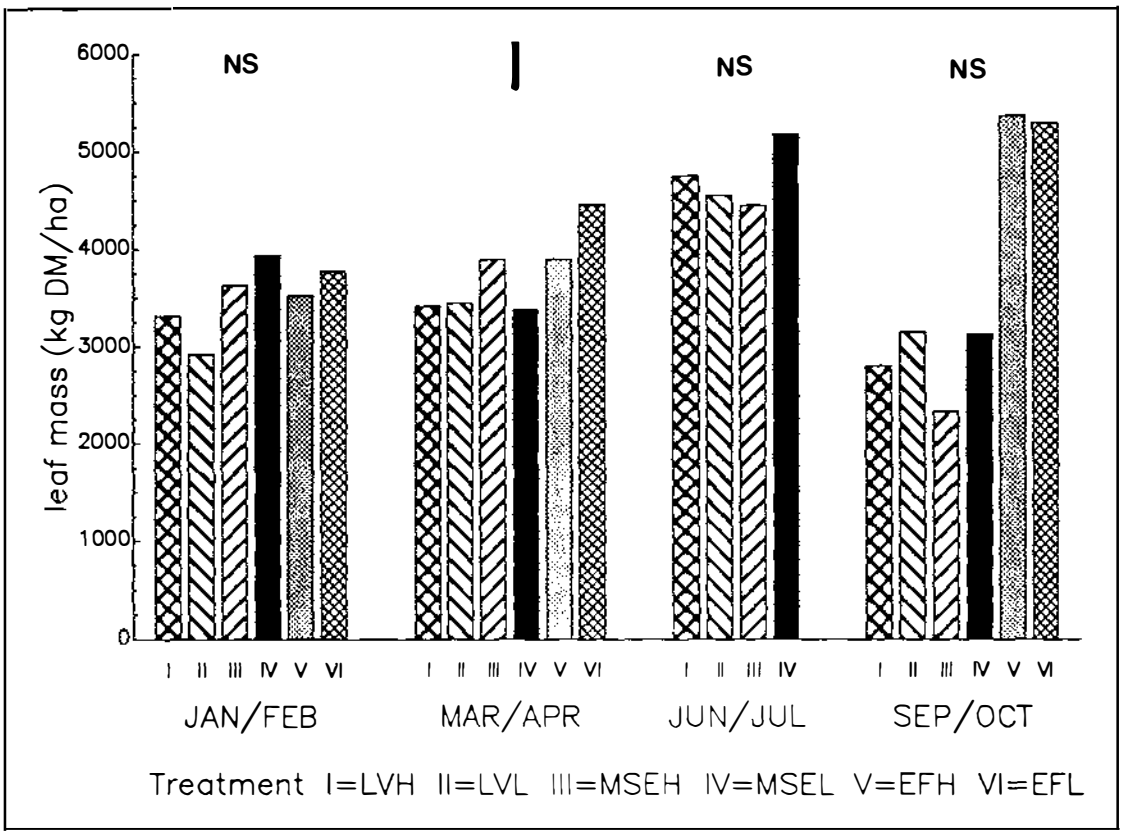


Fig 5.2 The effect of plant growth stage at grazing and grazing intensity on the pregrazing leaf mass in sulla, at each grazing over 365 DAS. Refer Fig 5.1 for key to treatments.

± 144 and 3653 ± 144 kg DM ha^{-1} respectively. The pregrazing leaf mass in the LV treatment was significantly lower than in the MSE and EF treatments, whereas it did not differ significantly between the MSE and EF treatments.

However, at the second grazing in March/April, there was a significant ($P<0.01$) interaction between growth stage at grazing and grazing intensity in the pregrazing leaf mass. The pregrazing leaf mass, within the MSE treatment, in the severely grazed treatment was 15% greater than in the less severely grazed treatment, whereas within the EF treatment it was 13% less in the severely grazed treatment than in the less severely grazed treatment. Grazing severity did not affect the pregrazing leaf mass significantly within the LV treatment.

At the time of the third grazing in June/July, there was no significant

interaction between growth stage at grazing and grazing intensity or an overall effect of growth stage or grazing intensity on the pregrazing leaf mass. Across all growth stages and grazing intensities, that is over the LVH, LVL, MSEH and MSEL, the pregrazing leaf mass was 4726 ± 132 kg DM ha^{-1}.

Moreover, at the final grazing in September/October, there was also no significant interaction between growth stage and grazing intensity nor an overall effect of grazing intensity on the pregrazing leaf mass. However, there was a significant ($P<0.001$) effect of growth stage at grazing. The pregrazing leaf mass in the LV, MSE and EF treatments was 2968 ± 242, 2727 ± 242 and 5323 ± 242 kg DM ha^{-1} respectively. The pregrazing leaf mass in the EF treatment was 87% greater than in the LV and MSE treatments. There was no significant difference between the LV and MSE treatments and the pregrazing leaf mass averaged 2848 ± 172 kg DM ha^{-1}.

5.3.5 STEM MASS AT EACH GRAZING

When the first grazing commenced in January/February, there was no significant interaction between growth stage and grazing intensity nor an overall effect of grazing severity on the pregrazing stem mass (Fig 5.3). However, there was a significant ($P<0.001$) effect of growth stage at grazing. The pregrazing stem mass in the LV, MSE and EF treatments was significantly different from each other and was 579 ± 122, 1242 ± 122 and 2541 ± 122 kg DM ha^{-1} respectively.

However, at the second grazing in March/April, there was a significant ($P<0.001$) interaction between growth stage at grazing and grazing intensity on the pregrazing stem mass. Within the MSE treatment, the pregrazing stem in the severely grazed treatment was 62% greater than in the less severely grazed treatment. Grazing severity did not affect the pregrazing stem mass significantly within the LV and EF treatments.

At the third grazing in June/July, there was no significant interaction between growth stage at grazing and grazing intensity nor an overall effect of grazing intensity on the pregrazing stem mass. However, there was a significant ($P<0.001$) effect of growth stage at grazing. The pregrazing stem mass in the LV and MSE treatments was 1847 ± 123 and 1077 ± 123 kg DM ha^{-1} respectively.

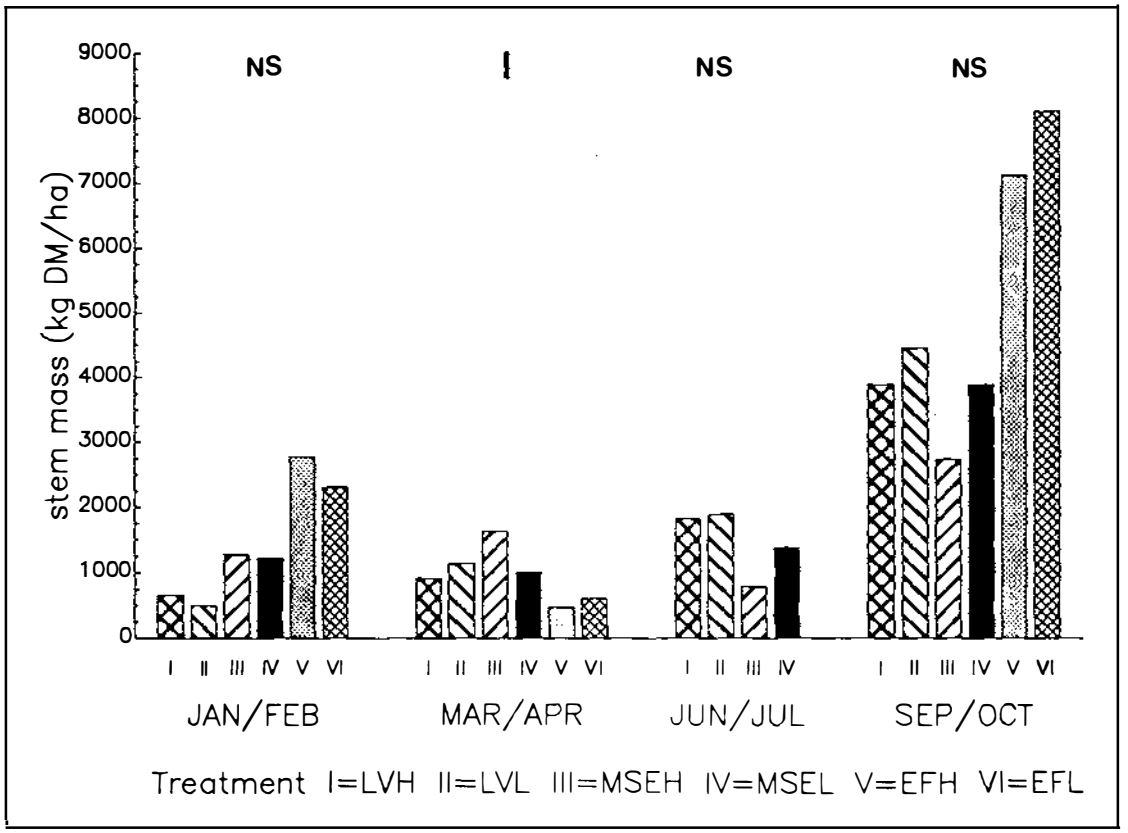


Fig 5.3 The effect of plant growth stage at grazing and grazing intensity on the pregrazing stem mass in sulla, at each grazing over 365 DAS.

When the final grazing commenced in September/October, there was no significant interaction between growth stage at grazing and grazing intensity nor an overall effect of grazing intensity on pregrazing stem mass. There was however, a significant ($P<0.001$) effect of growth stage at grazing. The pregrazing stem mass in the LV, MSE and EF treatments was 4159 ± 456, 3302 ± 456 and 7598 ± 456 kg DM ha^{-1} respectively. The pregrazing stem mass in the EF treatment was more than double that in the LV and MSE treatments, although this was over a substantially longer period of accumulation. However, the LV and MSE treatments did not differ significantly and averaged 3731 ± 323 kg DM ha^{-1}.

5.3.6 PLANT DENSITY

Over the duration of the trial, plant density declined gradually after each grazing. There was a significant ($P<0.05$) interaction between growth stage at

Table 5.6 The effect of plant growth stage at grazing and grazing intensity on the final plant density in sulla, at 365 DAS.

Grazing management		Plant density (plant m^{-2})
Growth stage	Grazing Intensity	
LV	HHHH	16
	LLLL	13
MSE	HHHH	13
	LLLL	18
EF	HHH	36
	LLL	28
$LSD_{0.05}$		6

grazing and grazing intensity on the final plant density at 365 DAS (Table 5.6). Within the EF treatment, the final plant density in the less severely grazed treatment was 22% less than in the severely grazed treatment. Grazing severity did not affect plant numbers in the LV and MSE treatments. Averaged over all intensities, the plant density in the LV and MSE treatments was 14 ± 2 and 16 ± 2 plants m^{-2} respectively. Over all intensities, the decline in plant numbers relative to the start of the trial was 79, 74 and 29% in the LV, MSE and EF treatments respectively. There was a decline in plant numbers in all growth stages over the 365 DAS, but it was very marked in the LV and MSE treatments.

When the first grazing commenced in January/February, there was no significant interaction between growth stage at grazing and grazing intensity nor an overall effect of grazing intensity on the pregrazing plant density (Fig 5.4). However, there was a significant ($P<0.001$) effect of growth stage at grazing and the pregrazing plant density in the LV, MSE and EF treatments was 67 ± 3, 62 ± 3 and 45 ± 3 plants m^{-2} respectively. There was significantly lower plant density in the EF treatment and this may have been due to self-thinning. The LV and MSE treatments did not differ significantly.

Moreover, at the second grazing, there was no significant interaction between

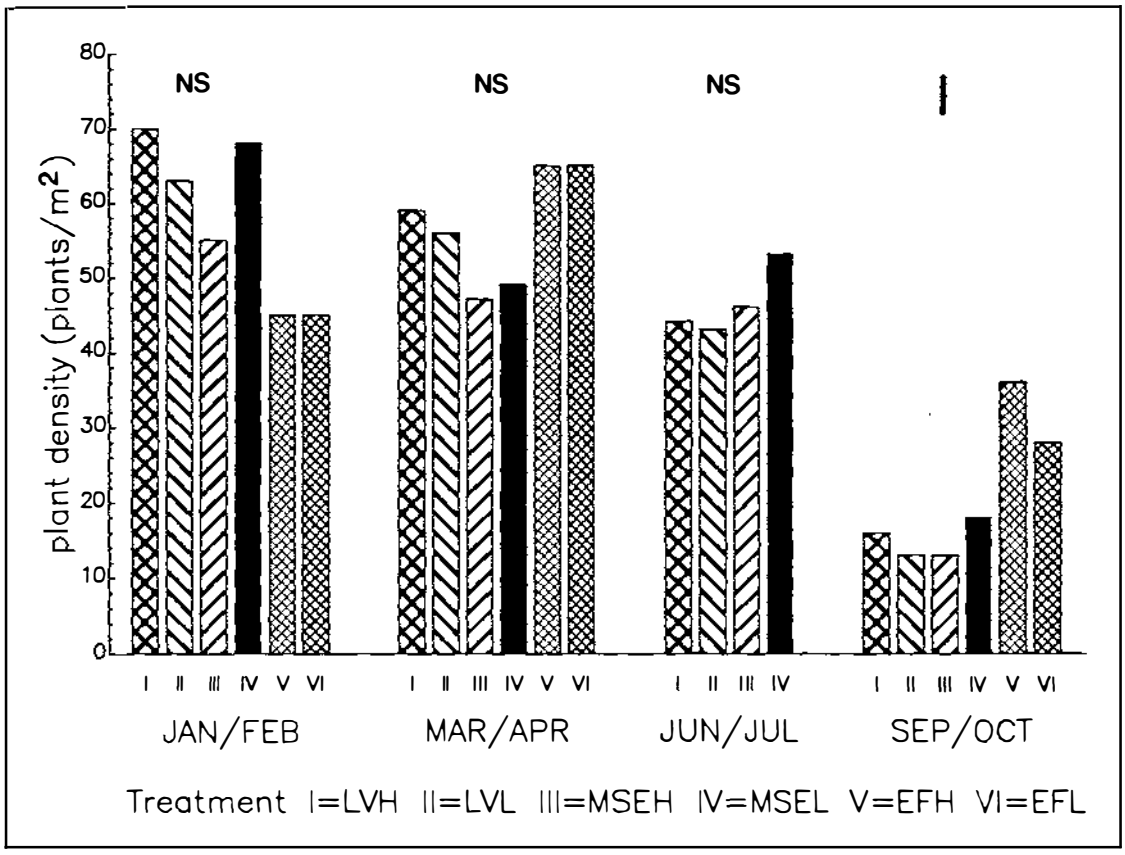


Fig 5.4 The effect of plant growth stage at grazing and grazing intensity on the pregrazing plant density in sulla, at each grazing over 365 DAS.

growth stage at grazing and grazing intensity nor an overall effect of grazing intensity on the pregrazing plant density. However, there was again a significant ($P<0.001$) effect of growth stage at grazing. The pregrazing plant numbers in the LV, MSE and EF treatments were 58 ± 3, 48 ± 3 and 65 ± 3 plants m^{-2} respectively and differed significantly from each other. A greater density than at the previous grazing in the EF treatment may have been a consequence of staggered germination or seed shatter at the preceding grazing.

At the time of the third grazing in June/July, there was again no significant interaction between growth stage at grazing and grazing intensity nor an overall effect of grazing severity on the pregrazing plant density. However, there was again a significant ($P<0.05$) effect of growth stage at grazing. Averaged over all intensities, the pregrazing plant density in the LV and MSE treatments was 44 ± 2 and 49 ± 2

plants m^{-2} respectively. At the final grazing commenced in September/October, there was a significant ($P<0.05$) interaction between growth stage at grazing and grazing intensity on the final plant density as was discussed.

At the winter grazing in June/July, there was a significant ($P<0.01$) decrease of 59% in plants m^{-2} in the grazed subplots, compared to in the ungrazed subplots within the LV and MSE treatments (Table 5.7). The grazed and ungrazed subplots clearly demonstrated the detrimental effect of grazing in the wet early winter months (See plates 5.8 & 5.9).

5.3.7 INDIVIDUAL PLANT DRY-WEIGHT

There was no significant interaction between growth stage at grazing and grazing intensity nor an overall effect of grazing intensity or growth stage at grazing on the final individual plant dry-weight (DW) at 365 DAS. Although the effect of growth stage at grazing was not significant, plants in the LV treatment weighed 48%

Table 5.7 The effect of grazing sulla in winter at the late vegetative and midstem elongation growth stages on plant density, in grazed and ungrazed subplots (means of treatments LV and MSE), on 20 September 1990.

Treatment	Plant density (plants m^{-2})	
	Late vegetative	Midstem elongation
Winter grazed	14	16
Ungrazed (control)	34	39
$LSD_{0.05}$	4	4

Note: Grazing in the EF treatment did not occur in winter.

Plate 5.8 Winter grazing in progress in the midstem elongation growth stage treatment.

Plate 5.9 The consequence of winter grazing on plant productivity in spring. Plants in the background were ungrazed.

more than in the MSE and EF treatments (Table 5.8). Over the duration of the trial, plants increased in weight and when compared to the initial weight at the start of the trial, the increase was twelve times in the LV treatment, five times in the MSE treatment and three times in the EF treatment. When averaged over all growth stages and grazing intensities the final individual plant DW was 52.9 ± 4.5 g plant^{-1}.

Table 5.8 The effect of plant growth stage at grazing on the final individual plant dry-weight (DW) in sulla, at 356 days. Data meaned over all intensities.

Growth stage	Plant DW (g plant^{-1})
LV (4)	68.0
MSE (4)	46.2
EF (3)	45.0
$LSD_{0.05}$	NS

Compensation for the loss of plant numbers by an increase in individual plant DW was evident at each grazing (Fig 5.5). At the time of the first grazing in January/February, there was no significant interaction between growth stage and grazing intensity nor an overall effect of grazing severity on the pregrazing individual plant DW. However, there was a significant ($P<0.001$) effect of growth stage at grazing. The pregrazing plant DW in the LV, MSE and EF treatments were significantly different from each other and were 5.8 ± 0.8, 9.2 ± 0.8 and 16.7 ± 0.8 g plant^{-1} respectively.

At the second grazing in March/April, there was a significant ($P<0.05$) interaction between growth stage at grazing and grazing intensity in the pregrazing plant DW. Within the MSE treatment, the pregrazing plant DW in the severely grazed treatment was 30% greater than in the less severe grazing treatment. Grazing severity had no significant effect on plant DW within the LV and EF treatments.

At the early winter grazing in June/July in the LV and the MSE treatment,

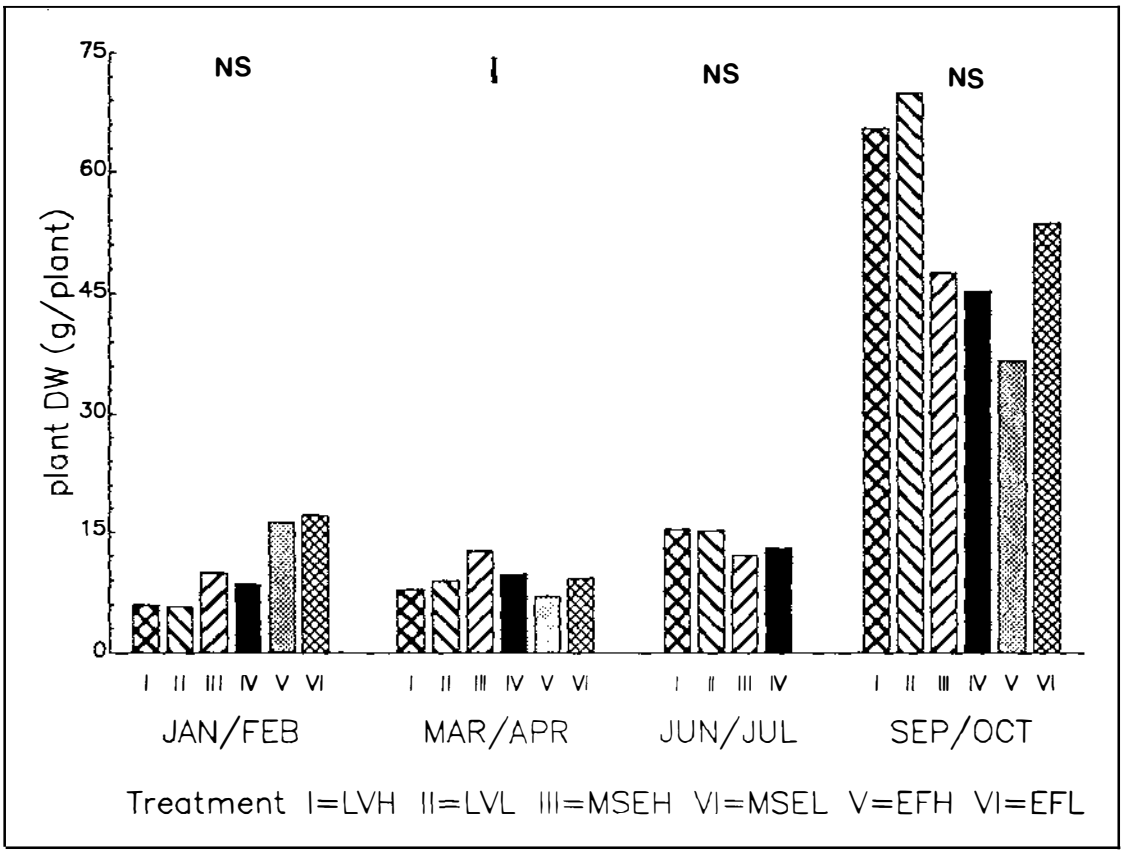


Fig 5.5 The effect of plant growth stage at grazing and grazing intensity on the pregrazing individual plant dry-weight (DW) in sulla at each grazing over 365 DAS.

there was no significant interaction between growth stage and grazing intensity nor an overall effect of grazing intensity on the pregrazing plant DW. However, there was a significant ($P<0.05$) effect of growth stage at grazing and the pregrazing plant DW in the LV and MSE treatments was 15.2 ± 2.5 and 12.5 ± 2.5 g plant^{-1} respectively.

No interaction was significant between growth stage and grazing intensity, and there was no significant overall effect of grazing severity or growth stage at grazing on the pregrazing plant DW at the final grazing in September/October, and the overall results were as discussed at 365 DAS.

5.3.8 INDIVIDUAL PLANT DRY WEIGHT VERSUS PLANT DENSITY

The relationship between individual plant DW and plant density at the Jan/Feb, Mar/Apr, Jun/Jul, Sept and Oct grazings is represented in Figures 5.6a,

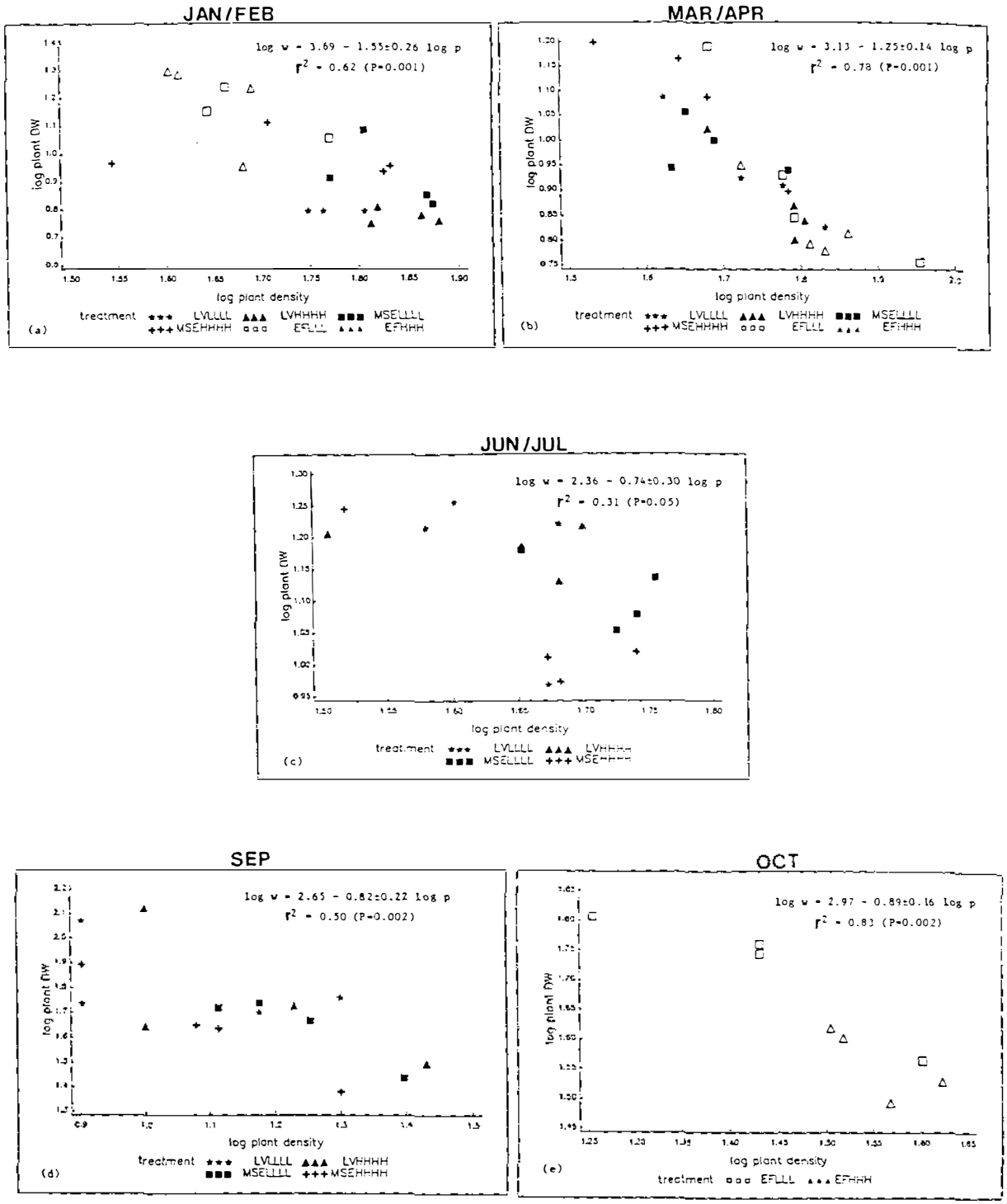


Fig 5.6 a, b, c, d & e. Scatterplots showing the relationship between $\log_{10}$ plant dry weight (w) and $\log_{10}$ plant density (p) at each grazing over 365 days. Points represent four replicates in each treatment combination. KEY: LV=late vegetative growth stage, MSE=midstem elongation growth stage, EF=early flowering growth stage, L=less severe grazing and H=severe grazing. Note that no grazing occurred in the EF treatment in June/July. Thus the regression for the EF treatment is plotted separately at its final grazing in October.

b, c, d & e respectively. Points on the scatterplot represent four replicates in each treatment combination. There was a gradual change in the slope of the regression over time in all treatment combinations. At the first grazing in Jan/Feb, the relationship between individual plant DW and plant density is represented by the regression equation log w=3.69 - 1.55±0.26 log p (r^2=0.62, P<0.001) where p is the density of plants and w their corresponding individual plant DW. The slope of the equation was close to the expected -1.55 value. At the second grazing in Mar/Apr, the decline of plant density was compensated by a corresponding increase in plant DW as shown by the equation log w=3.13 - 1.25±0.14 log p. The equation explained 78% of the variation (P<0.001). At the Jun/Jul grazing however, the relationship between w and p became poor, with only 31% (P<0.05) of the variation explained by the regression equation. The slope of the regression decreased to 0.74±0.30. At the final grazing in September (Fig 5.6d), the density/size relationship in the LV/MSE treatment remained poor (r^2=0.50, P<0.002) with a slope of 0.82±0.22. The points on the scatterplot tended towards a horizontal plane with more variation in p than variation in w. In the EF treatment in October (Fig 5.6e) however, the relationship remained strong with 83% of the variation explained by the equation. The slope of the equation was close to that of the regression in the LV/MSE treatments.

5.3.9 LEAF-TO-STEM MASS RATIO

Over the 365 DAS, there was no significant interaction between growth stage at grazing and grazing intensity nor an overall effect of grazing intensity on the leaf-to-stem mass ratio (LSR) of the total herbage accumulated. However, there was a significant effect of growth stage at grazing. The LSR in the EF treatment was 37% less than in the LV and MSE treatments (Table 5.9). The LSR in the LV and MSE treatments did not differ significantly.

When the first grazing commenced in January/February, there was no interaction between growth stage and grazing intensity nor an overall effect of grazing severity on the pregrazing LSR (Fig 5.7). However, there was a significant (P<0.001) effect of growth stage at grazing. The pregrazing LSR in the LV, MSE

Table 5.9 The effect of plant growth stage at grazing on the total accumulated leaf -to-stem mass ratio in sulla, over 365 DAS. Data meaned over all intensities.

Growth stage	Leaf-to-stem mass ratio
LV(4)	2.0
MSE (4)	2.1
EF(3)	1.3
$LSD_{0\,05}$	0.2

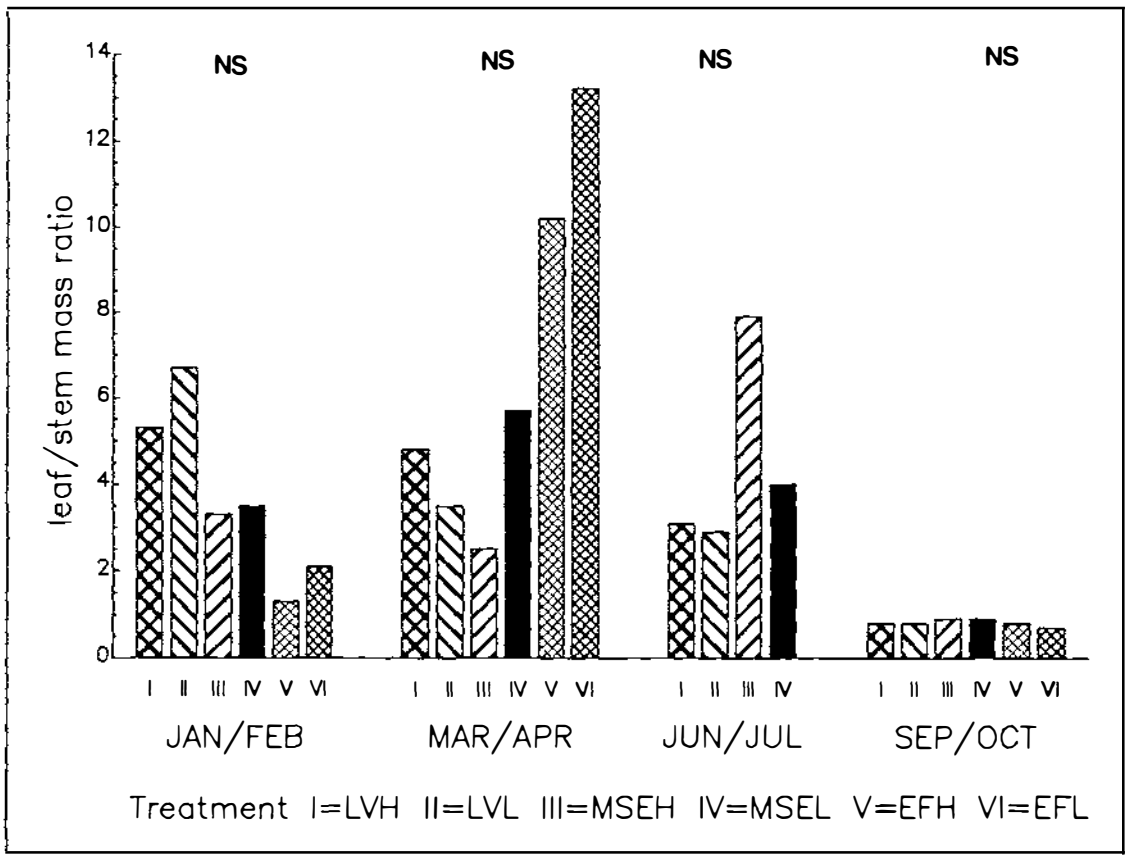


Fig 5.7 The effect of plant growth stage at grazing and grazing intensity on the pregrazing leaf-to-stem ratio in sulla, at each grazing, over 365 DAS.

and EF treatments was significantly different to each other and averaged 6.0 ± 0.3, 3.4 ± 0.3 and 1.7 ± 0.3 respectively.

At the second grazing in March/April, interaction between growth stage and grazing intensity was not significant nor was there an overall effect of grazing intensity. The effect of growth stage at grazing, however was significant ($P<0.01$). The pregrazing LSR in the LV, MSE and EF treatments was 4.1 ± 1.7, 4.1 ± 1.7 and 11.7 ± 1.7 respectively. The pregrazing LSR in the EF treatment was three times greater than in the LV and MSE treatments.

At the winter grazing in June/July, no interaction was again significant between growth stage and grazing intensity nor was there an overall effect of grazing severity on the pregrazing LSR. The effect of growth stage at grazing was again significant ($P<0.01$) and the pregrazing LSR in the LV and MSE treatment was 3.0 ± 0.7 and 6.0 ± 0.7 respectively. However, at the final grazing, there was no significant interaction between growth stage and grazing intensity nor an overall effect of grazing intensity or growth stage at grazing on the pregrazing LSR. Across all growth stages and intensities, the pregrazing LSR was 0.81 ± 0.03.

5.3.10 WEED ACCUMULATION

Over the 365 DAS, there was a significant interaction between growth stage and grazing intensity on the total weed accumulated (Table 5.10). Within the MSE treatment, the total weed accumulated in the severely grazed treatment was 81% greater than in the less severely treatment. Grazing severity did not affect the total weed accumulated in the LV and MSE treatments and averaged 1269 ± 133 and 802 ± 133 kg DM ha^{-1} y^{-1} respectively.

At the time of the first grazing in January/February, there was no significant interaction between growth stage and grazing intensity nor an overall effect of grazing intensity on the pregrazing weed mass (Fig 5.8). However, the effect of growth stage at grazing was significant ($P<0.001$). The pregrazing weed mass in the LV, MSE and EF treatments was 233 ± 86, 405 ± 86 and 788 ± 86 kg DM ha^{-1} respectively. The pregrazing weed mass in the EF treatment was 147% greater than in the LV and MSE treatments. The LV and MSE treatments did not differ significantly, and averaged 319 ± 61 kg DM ha^{-1}.

Table 5.10 The effect of plant growth stage at grazing and grazing intensity on the total weed accumulated (kg DM ha^{-1}) in sulla, over 365 DAS.

Grazing management		Total weed accumulated
Growth stage	Grazing intensity	
LV	HHHH	1018
	LLLL	1519
MSE	HHHH	1803
	LLLL	996
EF	HHH	803
	LLL	773
$LSD_{0.05}$		520

When the second grazing commenced in March/April, interaction between growth stage and grazing intensity, and the overall effect of growth stage at grazing was not significant on the pregrazing weed mass. However, there was a significant ($P<0.05$) overall effect of grazing severity. Pregrazing weed mass in the severely and less severely grazed treatments was 26 ± 30 and 126 ± 30 kg DM ha^{-1} respectively.

No pregrazing weed mass was estimated at the third grazing in June/July, as herbage samples were free of weeds. However, at the final grazing in September/October, there was a significant ($P<0.01$) interaction between growth stage and grazing intensity on the pregrazing weed mass. Within the MSE treatment, the pregrazing weed mass in the severely grazed treatment was 153% greater than in the less severely grazed treatment. Grazing intensity did not affect the pregrazing weed mass in the LV treatment, and herbage samples in the EF treatment were weed free.

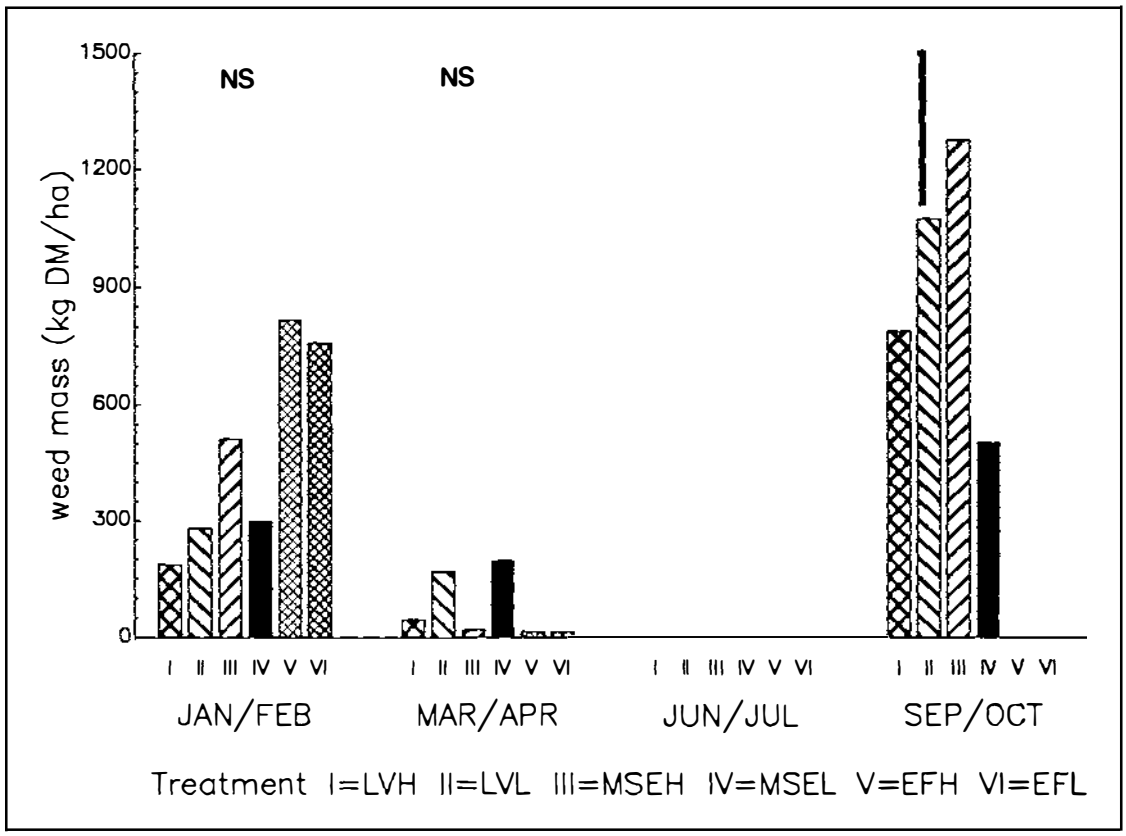


Fig 5.8 The effect of plant growth stage at grazing and grazing intensity on the pregrazing weed mass in sulla, at each grazing, over 365 DAS. Note no estimate is available at the winter grazing in the LV and MSE treatments, and in the EF treatment at its final grazing.

5.3.11 HERBAGE CONSUMPTION

The amount of herbage and herbage components consumed by sheep and percentages of the total herbage and herbage components consumed, included in parenthesis, over 365 DAS are presented in Table 5.11. Over the 365 DAS, there was no significant interaction between growth stage at grazing and grazing intensity, and there was no significant overall effect of grazing intensity or growth stage at grazing on the total herbage consumed by sheep. Across all growth stages and grazing intensities, the total herbage consumed by sheep was 16097 ± 355 kg DM ha^{-1} y^{-1}. However, there was a significant ($P<0.01$) interaction between growth stage at grazing and grazing intensity on the percent total herbage consumed. The percent herbage consumed in the severe grazing management treatments, in the

Table 5.11 The effect of plant growth stage at grazing and grazing intensity on herbage, herbage components and weeds consumed (kg DM ha^{-1}) in sulla, over 365 days. Figures in brackets are percentages (%) of total accumulation grazed by sheep.

Grazing management	Herbage consumed	Herbage components consumed			Weeds consumed
		Leaves	Stems	Flowers	
LVHHHH	16287 (75)	12576 (88)	3642 (50)	69 (100)	976 (94)
LVLLLL	14345 (65)	11452 (81)	2784 (33)	109 (100)	1420 (93)
MSEHHHH	16139 (77)	12906 (90)	3126 (49)	128 (100)	1794 (99)
MSELLLL	16184 (70)	12891 (82)	3152 (41)	143 (100)	945 (95)
EFHHH	16314 (69)	12077 (94)	3524 (35)	713 (100)	804 (98)
EFLLL	17314 (67)	12263 (91)	4018 (34)	1033 (100)	710 (90)
$LSD_{0.05}$	NS (5)	NS (2)	NS (NS)	NS (NS)	517 (NS)

LV and MSE treatments, was significantly higher than in the less severe grazing management treatments. The severe and less severe grazing management in the EF treatment did not differ significantly. Nevertheless, the percent herbage consumed was higher in the severely grazed treatment.

There was no significant interaction between growth stage and grazing intensity nor an overall effect of grazing severity or growth stage at grazing on the total leaf tissue consumed over 365 DAS. The mean across all growth stages and grazing intensities was 12361 ± 195 kg DM ha^{-1} y^{-1}. However, there was a significant ($P<0.05$) interaction between growth stage and grazing intensity in the percent total leaf tissue consumed. Within all growth stages, the percent leaf tissue consumed in the severe grazing management treatment was greater than in the less severe grazing management treatment.

For the total stem tissue consumed by sheep over 365 DAS, interaction between growth stage and grazing intensity, the overall effect of grazing intensity and of growth stage at grazing were not significant. Moreover, there was also no significant interaction between growth stage and grazing intensity on the percent stem tissue consumption. However, there was a significant ($P<0.05$) overall effect of growth stage at grazing and grazing intensity. The percent stem tissue consumed in the LV, MSE and EF treatments was 42 ± 3, 45 ±3 and 34 ± 3 respectively. Sheep consumed significantly less stem tissue in the EF treatment than in the LV and MSE treatments. The LV and the MSE treatments did not differ significantly. Across all growth stages, the percent stem tissue consumed in the severely and less severely grazed treatments was 44 ± 2 and 36 ± 2 respectively.

There was no significant interaction between growth stage and grazing intensity nor an overall effect of grazing intensity on the total or percent flower tissue consumption over the 365 DAS. However, there was a significant ($P<0.001$) effect of growth stage at grazing. The total flowers consumed in the LV, MSE and EF treatments was 89 ± 80, 136 ± 80 and 873 ± 80 kg DM ha^{-1} y^{-1} respectively. Consumption of flowers in the EF treatment was significantly higher than in the LV and MSE treatments. The flowers consumed in the LV and MSE treatments did not differ significantly. There was no significant interaction nor an overall effect of growth stage or grazing intensity on the percent flowers consumed, as sheep

consumed all flowers on offer.

Significant ($P<0.01$) interaction occurred between growth stage and grazing intensity on the total weeds consumed over the 365 DAS. Within the MSE treatment, sheep consumed 90% more weeds in the severely grazed treatment than in the less severely grazed treatment. Grazing severity did not affect weeds consumption significantly in the LV and EF treatments. No significant interaction occurred between growth stage and grazing intensity, and there was no significant overall effect of growth stage at grazing or grazing intensity on the percent weeds consumed. Across all growth stages and grazing intensities the weeds consumed by sheep was 95%. Herbage, herbage components and weeds consumed by sheep at each grazing over 365 DAS are included in appendix 5.5.

5.3.12 REGROWTH SITE CHARACTERISTICS

5.3.12.1 SHOOT NUMBER

There was a significant ($P<0.001$) interaction between plant growth stage x grazing intensity x regrowth site in the number of shoots produced over the 15 days after first grazing (Table 5.12). As data in the EF treatment was not obtained, only the LV and MSE treatments are presented. Within the MSE growth stage, plants less severely grazed, produced three times more shoots on the secondary stem(s) than plants severely grazed on the same regrowth site. Grazing intensity did not significantly affect the number of shoots produced on the primary stem (PS), secondary stem(s) (SS) and crown (CR) in the LV growth stage, and on the PS and CR within the MSE growth stage. Across all intensities, the number of shoots produced on the PS, SS and CR in the LV growth stage was 0.3 ± 0.5, 3.1 ± 0.5 and 5.7 ± 0.5 respectively. The number of shoots produced on the CR was significantly greater that on the PS and SS. Moreover, in the MSE growth stage, the PS and CR produced 1.5 ± 0.5 and 5.4 ± 0.5 shoots respectively. The number of shoots produced on the CR in the LV growth stage, did not differ significantly from those produced on the CR in the MSE growth stage.

Table 5.12 The effect of plant growth stage at grazing and grazing intensity on the regrowth site characteristics of sulla, at 15 days after the first grazing.

Growth Stage	Grazing Intensity	Regrowth Site	Shoot Number	Shoot Length (mm)	Leaf Number	Petiole Length (mm)	Leaf Area (cm^2)	Shoot DW (g)
	H	Primary	0.5	0.9	1.4	12.3	9.3	0.05
	L	Stem	0.1	0.2	0.3	4.8	3.9	0.02
LV	H	Secondary	3.9	5.3	9.7	42.4	30.7	0.25
	L	Stem	2.2	1.8	5.2	34.5	21.1	0.14
	H	Crown	5.3	5.2	14.1	75.8	87.2	0.59
	L		6.1	7.2	14.7	101.6	148.1	1.04
	H	Primary	1.0	1.4	2.7	18.3	19.2	0.15
	L	Stem	2.1	3.0	5.4	38.5	44.9	0.30
MSE	H	Secondary	3.5	4.0	9.4	51.3	57.4	0.34
	L	Stem	9.5	6.6	25.5	64.7	140.0	0.96
	H	Crown	5.5	8.5	15.8	83.0	121.0	0.87
	L		5.2	8.7	14.9	76.8	142.0	1.02
$LSD_{0.05}$			1.9	2.8	5.2	20.1	42.6	0.30

5.3.12.2 SHOOT LENGTH

A significant ($P<0.05$) interaction between plant growth stage x grazing intensity x regrowth site had an influence on the length of shoots produced over the 15 days of regrowth (Table 5.12). Grazing intensity did not affect the length of shoots produced in all the regrowth sites within the MSE and LV growth stages, except on the secondary stem(s) in the LV growth stage. The shoot length on plants grazed severely was significantly greater than those on the less severely grazed plants. Moreover, the shoot length on the CR, of plants severely grazed at the MSE growth stage, was 1.6 times longer than those on the CR of plants grazed severely at the LV growth stage.

5.3.12.3 LEAF NUMBER

There was a significant ($P<0.001$) interaction between plant growth stage x grazing intensity x regrowth site on the number of leaves produced in the plant, after 15 days of grazing (Table 5.12). In the MSE growth stage, the secondary stem(s) in the less severely grazed plants, produced about three times the number of leaves than in the severely grazed plants. However, grazing intensity did not affect the other regrowth sites in the LV and MSE growth stage treatments. Across all intensities, within the LV growth stage, the number of leaves produced on the PS, SS and CR was 0.8 ± 1.3, 14.8 ± 1.3 and 14.4 ± 1.3 respectively. Also, within the MSE growth stage, the number of leaves produced on the PS and CR was 4.0 ± 1.3 and 15.4 ± 1.3 respectively. Between the LV and MSE growth stages, the number of leaves produced on the CR did not differ significantly in either grazing severity.

5.3.12.4 PETIOLE LENGTH

A significant ($P<0.01$) interaction occurred between plant growth stage x grazing intensity x regrowth site on the petiole length of leaves produced on the plant, after 15 days of grazing (Table 5.12). The petiole length on the crown in the LV growth stage was affected by grazing severity, with the petiole length on the CR in plants severely grazed being significantly shorter than those less severely grazed. Moreover, petiole length on the PS, within the MSE growth stage treatment, was

also affected by grazing severity. The petiole length in plants severely grazed was half as long as those on the less severely grazed plants. The petiole length produced on the CR, in plants less severely grazed within the LV treatment, was significantly longer than that on the CR in plants treated similarly within the MSE treatment, whereas those severely grazed did not differ significantly between the MSE and LV treatments.

5.3.12.5 LEAF AREA

There was a significant ($P<0.01$) interaction between plant growth stage x grazing intensity x regrowth site on the leaf area produced over the 15 days of regrowth, after the first grazing (Table 5.12). Within the LV growth stage, the leaf area of the shoots arising on the CR, in plants less severely grazed, was almost twice as great at that in the severely grazed plants, whereas it was not significantly different within the MSE growth stage. However, in the MSE growth stage, the leaf area produced on the SS, in plants less severely grazed, was twice that of the severely grazed plants. Between growth stages, grazing severity did not affect leaf area production on the CR significantly, in the 15 days of regrowth, although the severely grazed plants at the LV growth stage produced 28% less leaf area than plants severely grazed at the MSE growth stage.

5.3.12.6 SHOOT DRY WEIGHT

The interaction between growth stage x grazing intensity x regrowth site had a significant ($P<0.01$) effect on shoot dry-weight (DW), 15 days after grazing (Table 5.12). Shoots arising on the CR, in plants less severely grazed at the LV growth stage, were 76% heavier than shoots on plants severely grazed, but there was no significant effect at the MSE growth stage. Nevertheless, the shoot DW on the SS was affected in plants severely and less severely grazed at the MSE growth stage. Shoots were more than three times heavier in the less severely grazed plants than in the severely grazed plants. Between growth stages, grazing intensity did not affect shoot DW production on the CR significantly, although the severely grazed plants at the LV growth stage produced 32% less shoot DW than plants severely grazed at the MSE growth stage.

5.3.13 TAPROOT DIAMETER

A significant ($P<0.01$) interaction between plant growth stage and grazing intensity had an effect on taproot diameter of plants harvested at 15 days after grazing (Table 5.13). The diameter of the taproot of the less severely grazed plants was significantly larger than those of plants grazed severely in the MSE treatment. However, the taproot diameter in the severely and less severely grazed plants in the LV treatment was not significantly different.

5.3.14 ROOT DRY WEIGHT

There was a significant ($P<0.001$) interaction between growth stage and grazing intensity on root dry-weight (DW) (Table 5.13). The root DW of the severely grazed plants was significantly lower than in the less severely grazed plants, in the MSE treatment. Moreover, the root DW in the severely grazed treatment was 26% less than in the less severely grazed treatment, at the MSE growth stage. Grazing intensity did not influence root DW significantly at the LV growth stage.

Table 5.13 The effect of plant growth stage at grazing and grazing intensity on taproot diameter and root dry weight in sulla, 15 days after first grazing.

Growth Stage	Grazing Intensity	Taproot Diameter (mm)	Root DW (g)
LV	H	16.5	2.5
	L	15.7	2.4
MSE	H	18.1	3.0
	L	24.4	5.9
$LSD_{0.05}$		3.1	1.0

Note: No data available in the EF treatment.

5.4 DISCUSSION

5.4.1 Herbage production.

The annual herbage production of sulla grown under effectively nodulated and relatively weed free conditions ranged between 22000-25000 kg DM ha^{-1} in the growth stage treatments. This was higher than the DM reported in Experiment 1 where sulla was grown with applied N and under severe weed competition (Chapter 3). Gurfel et al. (1982) in Israel have shown that the DM of effectively nodulated sulla was significantly higher than when the same plants were grown with 100 kg N and 300 kg N ha^{-1} under cutting in field and greenhouse conditions respectively. Other researchers in Finland (Ropenen & Virtanen, 1964), Australia (Casella et al., 1984) and Spain (Rodriquez-Navarro et al., 1991), working under controlled environment conditions, demonstrated the greater herbage production potential of effectively nodulated sulla.

The herbage DM's obtained in the various growth stage treatments were unaffected by the grazing intensity management imposed, which was most probably due to the subsequent death and decay of the remaining stubble, more so in the less severely grazed treatments (See plate 5.10). At both grazing intensities the regrowth originated from the crown (See plates 5.11 & 5.12), which confirmed the findings in Chapter 3.

5.4.2 Effect of growth stage at grazing on herbage production.

The higher DM obtained in the mature EF treatment in three grazings, compared to the four grazings in the LV and MSE treatments, suggests plant maturity at grazing is important to the maximisation of herbage production by sulla. These findings were in accordance with those of Rys et al., (1988) who found that sulla under a cutting regime produced more herbage at the mature (5-10% flowering) plant growth stage than at the more mature (70-80% flowering) growth stage.

Keoghan (1967) reviewed the effect of cutting height and cutting frequency, or cutting based on plant maturity, on lucerne, and stressed the importance of plant maturity at cutting as an important determinant in the management of lucerne swards. He concluded that cutting at immature growth stages or at frequent

Plate 5.10 Stubble decaying after grazing

Plate 5.11 Crown shoots emerging after first grazing

Plate 5.12 Early regrowth in the LV growth stage treatment, 10 days after first grazing

intervals will nearly always reduce herbage production significantly, compared to cutting at mature growth stages or less frequently. He also concluded that the height of cutting was for all practical purposes unimportant, unless lucerne was being cut frequently.

5.4.3 Seasonal pattern of herbage accumulation.

Herbage accumulation rates in sulla under grazing were remarkably high throughout the year. The overall HAR was 66 kg DM ha^{-1} d^{-1} over the duration of the trial. The HAR peaked in summer (January to April) and was relatively lower in the late autumn/winter. However, continued accumulation of herbage was evident throughout winter, with HAR ranging from 50-60 kg DM ha^{-1} d^{-1} indicating an advantage of sulla in providing green herbage in early spring, especially in the EF growth stage management. Also, the bulk of the herbage produced throughout winter remained green and did not appear to show signs of frost injury (See plates 5.13 & 5.14). Cowling (1954) expressed the opinion that sulla could be of value in view of its autumn activity. Conversely, under the relatively drier conditions experienced in the summer of 1989, with low rainfall in January (See Table 5.3), HAR were relatively high despite the lack of moisture suggesting the inherent ability of sulla to withstand drier conditions and obtain moisture, with its deeply taprooted system. The usefulness of sulla in the subhumid and humid bioclimates (rainfall >600 mm) is well known overseas (Le Houerou, 1984).

Higher temperatures combined with sulla's morphological adaptation to recover moisture resulted in rapid regrowth in the 8-14 days after grazing. Leach (1971) and Singh & Winch (1974) have indicated that lucerne may be particularly responsive to higher temperatures when the new leaf canopy is being established immediately after cutting or grazing.

5.4.4 Effect of winter grazing and stocking density on plant density.

Though there was a steady decline in plant numbers after each grazing, after the first grazing the remaining plants were able to compensate for the loss by an increase in plant DW. However, the grazing in late-autumn severely affected plant density, to the extent that the remaining plants could not further compensate for the

Plate 5.13 The effect of frost (0627 hrs) on sulla, in late winter

Plate 5.14 The same sward in spring, showing no signs of frost damage

decline in density, resulting in a decrease in plant DW. Visual observations suggested that the effects of trampling, compounded by wet soil conditions, could be a major factor contributing to mechanical injury and subsequent death of plants. The stocking densities ranged from 1500-2000 sheep ha^{-1} and were used for 1-2 days in the wet winter soil conditions, which may have contributed to the substantial decline of plant density by trampling and probable damage to growing points and crown.

Rys et al., (1988) reported the loss of sulla plants and resultant decrease in production through damage to the crown by the loss of growing points. Thompson et al., (1976) in New South Wales showed that the decrease in plant density in lucerne was related to stocking density. In a comparison of stocking densities ranging from 8 to 21 ewes ha^{-1}, a greater decline in lucerne stands occurred with densities above 12 ewes ha^{-1}. Furthermore, Reeve & Sharkey (1980) showed that lucerne stands were maintained at 7.4 and 9.9 ewes ha^{-1}, but declined at 12.4 and 14.8 ewes ha^{-1}.

In conventional pasture, trampling is an important consideration in the management for productivity. Frame (1976) considered that stocking densities of 1100-1600 sheep ha^{-1} adversely affected productivity due to trampling. Moreover, an interaction between high stocking densities and wet soil conditions may have accentuated plant death in sulla. Whitear et al. (1962) concluded that grazing lucerne in a wet season had a greater negative effect on subsequent lucerne vigour than similar treatments applied under drier conditions. Presumably this death of plants and reduction in plant numbers, with subsequent decrease in herbage production may also be accentuated by low levels of nonstructural carbohydrates in the taproots of the actively growing sulla (See Chapter 4), although this parameter was not measured in the current trial. White & Lucas (1990), reported that grazing winter active lucerne in mid July resulted in a significant decrease in herbage production at the end of September, and attributed this reduction to low levels of nonstructural carbohydrates in the roots of the winter active cultivars used.

5.4.5 Relationship between plant dry weight and plant density.

The relationship between $\log_{10}$ plant DW (w) and $\log_{10}$ plant density (p) at each grazing demonstrated the phenotypic plasticity of sulla. With the course of time, the slope of the regression line decreased from the expected -1.55, suggesting that with each grazing, the decline in plant density was not fully compensated by an increase in plant DW (See Figs 5.6a, b, c, d & e), especially in the MSE treatment combinations. Furthermore, the poor relationship between w and p at the third (r^2=0.31) and final (r^2=0.50) grazing in the LV and MSE treatments, indicated that factors other than grazing, such as the prevailing environmental conditions, may be responsible for the poor compensation in plant DW that occurred.

The reduction in plant density in the LV and EF growth stages was compensated for, by an increase in individual plant DW, to greater extent than at the MSE growth stage. The plants in the grazing intensity combinations at the MSE growth stage however, did not appear to compensate fully with an increase in plant DW, although the plant density in these treatments was not significantly different from those in the LV growth stage. Presumably, the grazing at the MSE growth stage, which occurred well into winter (4 July), compared to the earlier grazing (22 June) in the LV growth stage, affected the ability of plants in the MSE growth stage to compensate by an increase in plant DW, resulting in reduced plant vigour. Regrowth of the weakened plants in the MSE growth stage was disadvantaged, as the environmental conditions were becoming increasingly unfavourable for regrowth following defoliation in late winter. Changes in plant density and plant dry weight with time have been shown in other taprooted plants, such as *Medicago sativa* L. and *Trifolium pratense* L. (White & Harper, 1970).

5.4.6 Weed encroachment.

Weed infestation was minimal during the establishment phase in the current trial, compared to the previous trial (Chapter 3). The total weed accumulation in the preliminary trial was 5476 ± 213 compared to 1137 ± 77 kg DM ha^{-1} in the current trial. The successful use of the preemergent herbicide Stomp 330 E at 4 l ha^{-1} suppressed weed growth and competition. However, the decline of plant numbers, particularly after the autumn/winter grazing, in the LV and the MSE treatments

encouraged an increase in weed invasion. The weakened sulla plants were unable to compete with the vigorously growing weeds, and following the final grazing, recovery of sulla plants was poor in all the treatments. Moreover, grazing sulla at an immature growth stage increased competition from weeds, clovers and grasses. Increased weed ingress with grazing at an immature growth stage or frequent defoliation has been shown by many researchers in lucerne (Weir et al., 1960; Peters & Linscott, 1988).

5.4.7 Efficiency of grazing.

Herbage consumption of sulla ranged from 65-77% of the total herbage on offer in the grazing management treatments. The consumption of herbage by sheep was primarily a function of grazing intensity. As the grazing intensity increased, herbage consumed increased. Sheep grazed leaves in preference to stems, as the percent leaf tissue consumed ranged from 81-94% compared to 33-50% for stem tissue consumption. The consumption of stems in the more mature EF growth stage was less than in the less mature LV and MSE growth stages. Much of the lower stems portions of plants in the EF growth stage treatment appeared highly lignified, and were avoided by sheep. Practically all flowers on offer was eaten by sheep. Weed tissue consumption in the grazing management treatments was high, and ranged between 90-98%. The significantly higher consumption of weeds in the MSE treatment was related to the initialy greater amount of weeds on offer paticularly in the severely grazed treatment combination (See Table 5.11)

5.4.8 Regrowth sites and their contribution to herbage accumulation.

Release of apical dominance, with the removal of the stem apex by grazing, caused the axillary buds to commence elongation on the various potential regrowth sites. There was an influence of grazing intensity on the regrowth sites in the two maturity stages examined. However, under the conditions of the experiment, the effects were small, and suggested that grazing intensity was not of major importance in regrowth. The greater number of shoots on the secondary stem(s), in the less severely grazed treatment, was largely the result of there being more axillary buds the greater the stubble height.

The stage of maturity (LV and MSE) of plants, when first grazed, had an influence on the total number of shoots produced on the various regrowth sites in the plant. The contribution of shoots on the crown to regrowth, was no different between the maturity stages studied, suggesting that the number of shoots produced on the crown is independent of the stage of maturity at the time of first the grazing. However, severe grazing at the LV growth stage, had an effect by decreasing shoot extension rate and leaf area produced on the crown in the early stages of regrowth, indicating the importance of less severe grazing at an immature growth stage in sulla. The origin of shoots on the crown in defoliated sulla is illustrated in plates 5.15, 5.16 & 5.17.

Cowett & Sprague (1962), concluded in their study on the factors affecting branching in lucerne, that the stage of maturity had only a small influence on the number of stems produced per plant. They also found that lucerne in pots, cut to 7.62 cm (3 in.), produced more stems and buds on the entire plant, but maintained the same number of stems and buds on the crown, compared with those cut to 2.52 (1 in.) or 5.08 cm (2 in.). The shoots on the crown dominated growth and development, in the 15 days of regrowth. Nelson & Smith (1968a), compared the morphological development and DM distribution in lucerne and birdsfoot trefoil under a cutting regime, reported that the crown or basal shoots were more vigorous in growth than axillary shoots on the stubble, in the two species studied. Furthermore, the subsequent death of the remaining stubble, after sulla was grazed, limited possible contribution to regrowth on the primary stem or secondary stem(s).

At both growth stages, it was observed that many shoots that commenced extension after grazing, failed to elongate and produce stems at a later stage of regrowth. Singh & Winch (1974), found with lucerne that many buds were present that failed to expand and produce stems, and many stems present soon after cutting died before the next cut with the losses often exceeding 50% of the maximum numbers of shoots. They concluded that under sward conditions, only a fraction of the potential production of each plant is achieved. Shoot development in lucerne swards has been reported to be controlled by environmental factors such as soil moisture, light intensity, temperature, mineral nutrition and photoperiod; management factors such as cutting height and stand density; and physiological

Plate 5.15 The origin of shoots on the crown in defoliated sulla

Plate 5.16 Shoots dissected from a single crown

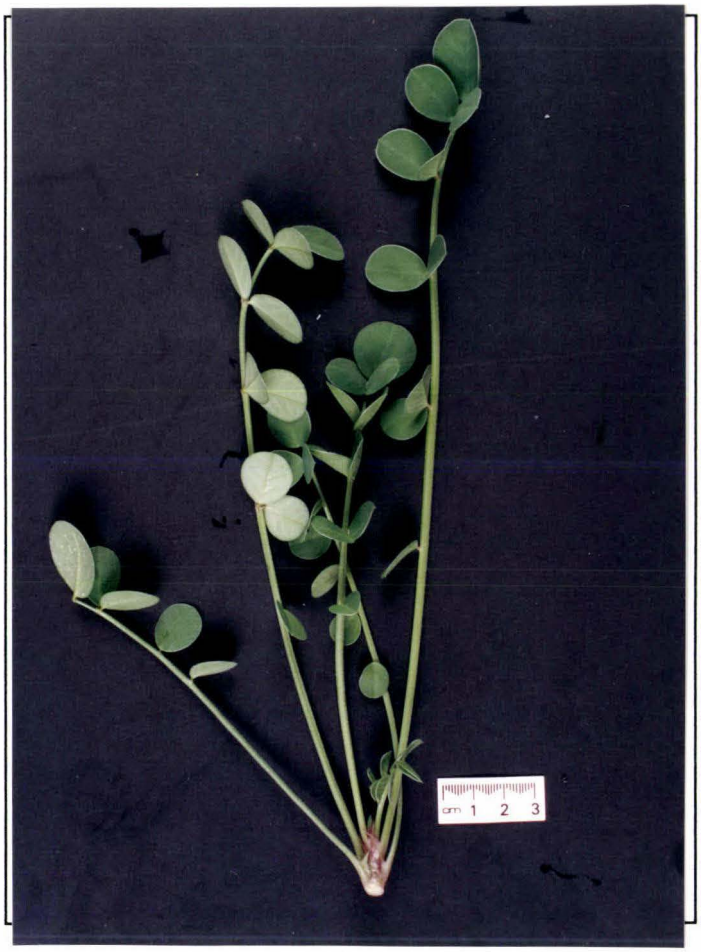


Plate 5.17 A typical sulla shoot

factors such as stage of maturity, apical dominance and plant growth regulators (Cowett & Sprague, 1962).

5.4.9 Effect of grazing on the root system.

As total nonstructural carbohydrates (TNC) and root DM are highly correlated (Wolf, 1978), any changes in root size reflects changes in TNC levels. Taproot diameter and root DM in plants grazed at the MSE growth stage was sensitive to grazing intensity (See Table 5.13). Presumably, at the time of grazing, the taproot diameter and root mass in plants in the MSE treatment was greater than that in the LV treatment. As growth and TNC status of roots are inversely related (Deregibus et al., 1982), one would expect a corresponding greater taproot size in the MSE treatment, where growth slowed down as the plant was rapidly approaching early flowering. With most of the stubble removed in the severely grazed treatment at the MSE growth stage, the reduction in taproot diameter and root DM may be as a result of remobilisation of TNC reserves for shoot initiation and to sustain root respiration. In the less severely grazed treatment, however, remaining stubble leaves may have been sufficient to replenish lost leaf tissue, and root reserves may not have been used, resulting in little change in root size.

In contrast, the remaining stubble leaves, in plants grazed in both intensities at the LV growth stage, may have been sufficient to replenish lost leaf tissue and reserves were not used. Ueno & Smith (1970), found that in defoliated lucerne plants, there was a loss of TNC from larger roots than from smaller roots.

5.4.10 Grazing management and persistence of sulla.

The complete disappearance of sulla, following the final grazing in all the grazing managements, showed that sulla behaved more like an 'annual' rather than a biennial or short-lived perennial, as commonly categorised (Kernick, 1978; Watson, 1982; Douglas, 1985). In contrast, sulla cultivated in the Mediterranean basin is known to persist up to three years under a cutting regime (Whyte et al., 1953; Kernick, 1978; Corleto & Magini, 1985). That sulla flowered more than once in the EF treatment suggested, strictly speaking, that it should be referred to as a polycarpic perennial (Grime et al., 1988) or a semi-perennial (Le Houerou, 1984).

When sulla was first introduced into New Zealand in 1949, for evaluation at the Botany Division, DSIR, it behaved more like an annual and consequently was not released for commercial use. However, in a recent autumn sown evaluation in Hawke's Bay (Rys et al., 1988), complete disappearance of undefoliated plants was reported by the second year. Furthermore, in another trial on the same location, the second year total herbage accumulation, under cutting, was only 27% of what was achieved in the first year. This reduction in herbage production was attributed to a marked decline in plant population. Also, a spring sown stand of sulla in the Wairarapa persisted only for a year under a cutting regime for hay and silage, with complete disappearance of plants after the final cut in the following spring (T. Phelps, pers comm).

5.4.11 Conclusions and management implications.

1. The herbage production in sulla can be more fully realised when grown under effectively nodulated and relatively weed free conditions.

2. Severe grazing, between the late stem elongation and early flowering growth stage, remains the optimum grazing management for maximum production and utilisation. Also, grazing at the more mature growth stage gave similar leaf DM production compared to grazing at an immature growth stages.

3. Late autumn/winter grazing, particularly with high stocking densities in wet soil conditions should be avoided.

4. The steady decline of plants over the year, and complete disappearance following the final grazing in spring, suggested the semi-perenniality of sulla. Grazing at early flowering however, resulted in a slower decline in plant density.

CHAPTER 6. GENERAL DISCUSSION

6.1 Introduction

The attributes desirable in evaluating a forage species for potential use in animal production systems include its ability to establish easily, to withstand climatic stresses and adapt to a wide range of management systems, to produce large quantities of nutritious forage free from toxic constituents, maintenance of nutritive value, to resist pests and diseases and to produce adequate quantities of seed (Rogers, 1975; Hodgson, 1981b; Wheeler, 1981). Lack of moisture, low or high temperature, the onset of the reproductive phase in grasses, and other factors combine to cause marked variation in growth and availability of herbage on grassland. Forage plants that will grow better in winter or in summer than conventional pasture species have been sought for centuries (Beddows, 1965), as have plants that will serve to fatten stock more rapidly. The concept of complementary forage production is to exploit the benefits of cultivating and fallowing soil, to exploit the physiological differences between species and/or to use the capacity of some species to retain accumulated dry matter with less deterioration of nutritive value than is the case of pasture (Wheeler, 1981; Hodgson, 1990).

The three separate experiments reported in Chapters 3, 4 and 5 evaluated some of these desirable characteristics outlined above in sulla. In this chapter, the focus is on the general results and observations in the form of an integrated discussion. The general results and observations are used to formulate an optimum grazing and cutting management for sulla, with the objective of maximising DM production, utilisation and persistence. The potential role of sulla in animal production systems in New Zealand and its limitations as a complementary forage species are also considered.

6.2 Comparative annual production and seasonal distribution of herbage.

The herbage production of sulla on a well drained, medium fertility silt loam soil with an annual precipitation of 1000 mm in Palmerston North ranged between 19000-25000 kg DM ha^{-1} y^{-1} (Tables 3.4 & 5.4). The annual DM production of sulla,

Table 6.1 Annual herbage production of some forage species used for complementing pasture in the Manawatu.

Species	Herbage production (kg DM ha^{-1})	Source
'Puna' chicory	25070	Hare et al., 1987
'Pawera' red clover	13200	Anderson, 1973
'Wairau' lucerne	12500	Janson, 1978
'Necton' sulla	24705	Chapter 5
Ryegrass/white clover pasture	11923	McCrone (unpublished)

compared with other forage species currently used in complementing pasture, is given in Table 6.1. It is apparent that the DM production of sulla is close to that of 'Puna' chicory in comparable environmental conditions and soil fertility.

The lower production attained (See Table 3.4) in the preliminary trial was probably due to establishment problems experienced. Nodulation failure, a critical factor in legume establishment, and weed infestation contributed to reduced herbage production. Several studies overseas have shown that successful inoculation consistently resulted in higher herbage production, and the application of artificial N may not be sufficient to realise the full production potential in sulla (Gurfel et al., 1982). The problems identified in Chapter 3 as critical to the successful establishment of sulla resulted in the reisolation of an effective *Rhizobium* strain ICMP 10149 suitable for sulla, and concurrent herbicide trials in Canterbury by Agriseed Ltd. (G. Kerr, pers comm) resulted in the satisfactory use of Stomp 330 E as a suitable preemergent herbicide in the subsequent grazing trial. Consequently, there was a marked decrease in weed content (Tables 3.11 vs 5.10) in the herbage sampled, and an increase in herbage production in the large-scale trial.

In many pastoral farming systems in New Zealand where year round grazing is the rule, major importance is attached to improvements in forage production or nutritive value at critical times of the year (Willoughby, 1971), and in many situations the seasonal distribution of herbage growth is likely to be more important than absolute amount grown (Hodgson, 1981b). The preliminary (Figs 3.1a & 3.1b) and the large-scale grazing trials (Fig 5.1) have shown that sulla possesses high herbage accumulation rates throughout the year (See Tables 3.5, 3.6 & 5.5), notably during summer and autumn/winter when pasture deficits are critical to animal production. A seasonal comparison of herbage accumulation rates of different forages grown in the Manawatu are presented in Table 6.2.

It is seen from Table 6.2, in the Manawatu, forage species commonly employed in complementary forage systems are adequate to meet summer deficits but have their limitations in late autumn and winter, when pasture accumulation rates are low.

6.3 Managing sulla for maximum productivity, utilisation and persistence.

The defoliation management of sulla is essentially similar to the management of winter active lucerne. Once an effectively nodulated and weed free stand of sulla is established, the productivity, utilisation and persistence of the forage will depend on several management factors.

Under a grazing regime, growth stage at defoliation influenced productivity and persistence in the two seasonal grazing studies conducted. Of the two and three growth stages compared in Chapters 3 & 5 respectively, the optimum growth stage to maximise production and persistence was shown to be between the late stem elongation and early flowering (Tables 3.4 & 5.4). Grazing at an immature growth stages i.e at the late vegetative (LV), early reproductive (ERP) or midstem elongation (MSE) growth stages resulted in lower herbage production in the two grazing trials conducted. This decrease in herbage production may be due to the interaction between physiological status of the sward at defoliation, high stocking density used and the prevailing environmental conditions.

The carbohydrate status at the LV and MSE/ERP was low, presumably due

Table 6.2 Seasonal herbage accumulation rates of different forage species used in complementing pasture in the Manawatu.

Species	Seasonal herbage accumulation rate (kg DM ha^{-1} d^{-1})				Source
	Spring	Summer	Autumn	Winter	
'Puna' chicory	115	225	107	-	Hare et al., 1987
'Pawera' red clover	38	90	58	-	Krishna & Kemp (unpublished)
'Wairau' lucerne†	102	161	111	-	Janson, 1978
'Necton' sulla	51	80	63	55	Chapter 5
Ryegrass/white clover pasture	42	44	27	18	McCrone (unpublished)

† A winter dormant lucerne cultivar.

to photosynthate partitioned to new growth in the actively growing plants (See Figs 4.11 & 4.14). As a consequence, grazing at these growth stages resulted in reduced taproot starch status, and the impaired root system (Fig 4.10) resulted in lower plant vigour and depressed production. On account of the criteria of grazing, the LV and MSE/ERP treatments (all immature growth stages) were grazed in autumn/winter. The high stocking density used in the prevailing environmental conditions accentuated the decline in plant density and subsequent herbage production in spring. The seasonal total nonstructural carbohydrate (TNC) fluctuation in sulla was not measured. Nevertheless, in other taprooted forages like lucerne, there is a rapid build up of TNC in the roots with the onset of shorter days and lowering temperatures in autumn. The accumulation of TNC in autumn is however, only true for winter dormant lucerne cultivars such as 'Wairau' and 'Saranac' (White & Lucas, 1990). In contrast, it has been shown that in winter active lucerne cultivars like 'Rere' and 'Matador', TNC levels were low in autumn through to winter. Grazing when TNC levels were low affected production in spring (White & Lucas, 1990). The lower TNC status was presumably related to continued growth in autumn/winter.

In all probability, the actively growing sulla in autumn/winter may have had low TNC levels, and grazing when TNC levels were low affected recovery growth and vigour, more so in unfavourable environmental conditions. In addition, grazing in wet soil conditions with high stocking densities may have also caused mechanical damage to the crown. Consequently, the invasion of crown diseases may have caused death to plants (Carr, 1971). Plants that survived the winter grazing were not able to compensate for the decrease in plant density (See Figs 3.6, 5.6c & 5.6d). Although plant density decreased gradually after each grazing, the decrease was marked after the autumn/winter grazing in the LV and MSE treatments (Table 5.7). In the preliminary experiment (Chapter 3) however, plants grazed less severely at the ERP in autumn were able to compensate for the decline in plant numbers. This was probably due to the early autumn grazing that occurred at the end of May in the ERP treatment, when prevailing environmental conditions were not severe enough to affect regrowth. This was in contrast to the late grazing in autumn/winter (Jun/Jul) that eventuated in the LV and MSE treatments in Chapter 5.

The intensity of grazing examined in the two grazing trials did not influence

productivity or persistence. This was attributed to the senescence of residual herbage after grazing. Senescence of residual herbage may be due to two factors namely, selective grazing and trampling. The height of the sward at grazing in the MSE and EF treatments ranged from 60-100 cm high. Approximately 30-40 sheep were used in the 200 m^2 plots and this led to herbage being trampled prior to intake. This may have caused mechanical damage to stem tissue, especially close to the crown, where the primary stem elongated in the MSE and EF growth treatments. Mechanical damage by trampling and resultant lodging of plants may have injured the vascular system resulting in death of the stubble after grazing (See plate 5.10). In the LV treatment, the damage may have been more to leaf laminae, petiole tissue and crown. In addition, the herbaceous nature of the plant offered no resistance to trampling damage.

The sheep used in these trials selectively grazed leaves in preference to stem. The preference of leaf to stem has been observed in other forages such as lucerne (Arnold, 1960; McKinney, 1970). Devoid of photosynthetic tissue, and compounded by mechanical damage to structural tissue, death of the stubble was inevitable, and regrowth must originate from the crown (See plate 5.11 & 5.12). This argument is further supported by visual observations in the greenhouse cutting trial, where there was no apparent death of stubble following defoliation, suggesting that death and decay of stubble in the field was related to mechanical injury to the plants.

The results from the greenhouse trial (Figs 4.13 & 4.16) suggest that retention of leaf area on the stubble is critical, if any attempts are made to defoliate sulla in autumn. Retention of some leaf tissue on the stubble will ensure that, at the time of low TNC reserves, the presence of leaf lamina will enable the plant to continue photosynthesis and replenish any loss of tissue. In contrast, the absence of leaf lamina by complete defoliation, may require the plant to draw from its already low TNC reserves which may not be sufficient to sustain new growth and root respiration. In view of selective grazing by sheep, it may be best to defoliate sulla by cutting in autumn/winter rather than grazing so that sufficient leaf area can be retained on the stubble.

In practice, an increase in DM production is often associated with a decrease

in efficiency of utilisation and in nutritive value of the forage (Hodgson, 1982). Although, the optimum defoliation management to maximise herbage production and persistence is between the late stem elongation and early flowering, this growth stage was not associated with poor utilisation (See Tables 3.12 & 5.11) or low digestibility (Table 3.10). Presumably, the high digestibility is related to the herbaceous nature of the forage. Furthermore, the leaf production at early flowering was no different from the immature growth stages treatments.

Under a cutting regime, both growth stage at defoliation and defoliation intensity influenced dry matter accumulation. The influence of plant growth stage on subsequent DM accumulation was however, more limited (Fig 4.6). Severe defoliation with the complete removal of leaf tissue at an immature growth stage should be avoided, as it weakens the root system as indicated by the poor increase in root mass (Fig 4.10), low starch status (Figs 4.12 & 4.15) and subsequent reduction in DM production (Fig 4.7) after defoliation. The smaller root system may lead to poor exploitation of soil moisture and nutrients which ultimately affects plant vigour. Although the greenhouse experiment studied the defoliation effects in one growth cycle, it would be safe to extrapolate that any subsequent severe defoliation will result in further suppression of root growth and lower starch reserves, which may lead to death of plants. In contrast, the root system in the less severe defoliations was not impaired (Fig 4.10), suggesting that defoliation heights between 7-15 cm may not reduce vigour and exploitation of soil moisture and nutrients may not be restricted. Although root measurements were not made after defoliation in the grazing trials, there is an indication that the root system may not have been severely affected in the ERP/MSE or EF treatments (Table 5.13), as there was sufficient stubble retained in the two intensity treatments. This was because sheep avoided the lower portions of the stem.

The importance of root reserves in the management of taprooted forage plants is unequivocally accepted (Smith, 1980) and its association with environmental and management stresses is widely acknowledged (Deregibus et al., 1982). The high starch status and the relatively large root mass of sulla plants at the EF growth stage (Figs 4.11 & 4.14), suggested that defoliation to a height of 15 cm should allow for the rapid recovery, provided any subsequent defoliation

occurred at the same growth stage. However, should defoliation occur at immature growth stages, the retention of leaf area is crucial to the maintenance of plant vigour.

Although an interaction occurred between growth stage and cutting height in the greenhouse trial, extrapolation of this information to the field was not possible because of confounding factors, such as selective grazing and herbage trampling, which caused unexpected senescence of residual tissue.

6.4 The potential role of sulla in animal production systems in New Zealand.

There is a continuing search for different plant species with complementary patterns of growth or utilisation for subsequent incorporation into farming systems (Hodgson, 1981a). The complementary role of sulla in forage systems during critical periods of the year when pasture quantity or quality is low is thus evident.

In a deer farming enterprise, summer is the most critical period of the year for hinds and their fawns. It is the quality and quantity of feed available which largely determines the milk production of hinds and hence the growth of suckling fawns. Hinds will produce higher milk yields only when feed quality is high and their voluntary intake is not restricted. This requires a vegetative, leafy pasture. Preventing flowering and seedhead production in conventional pasture is important, but may not be possible (Fennessy & Milligan, 1987). In such a situation, sulla can provide large quantities of high quality herbage over summer without apparent deterioration of quality (Rys et al., 1988).

In a sheep enterprise, summer is one of the seasonal management priorities. Lambs for sale are a high priority and require high pasture intake to maintain liveweight gains. Also, replacement ewe lambs should achieve liveweight gains of 80-100 g d^{-1} over the summer (Rattray et al., 1987). Specialist high quality forage may be used to ensure target liveweight gains are met, and there is a need to prepare the forage in spring. The role of sulla in such a situation is again evident. In addition, the use of drenches in the control of parasites can be reduced by using forages containing tannins. Preliminary research at the AgResearch Grasslands Palmerston North, has indicated that lambs with moderate to high parasite burdens can still grow quickly when fed with tannin-containing pasture like sulla. Undrenched

lambs, with high parasite counts, grew at 230 g d^{-1} on sulla compared to 27 g d^{-1} on lucerne. This increase in liveweight in lambs carrying high parasite counts may be related to the tannin content in sulla (Waghorn & Niezen, 1992).

Sulla, with its better winter production than some alternative special-purpose forages, can play an important role in a dairy enterprise, by providing nonbloating forage during crucial times (summer and autumn/winter) when supply from conventional pastures cannot meet demands (Holmes, 1987). Moreover, the high quality herbage provided by sulla can also be used to finish cattle in time for the autumn sale in a beef cattle enterprise (Nicol & Nicoll, 1987).

6.5 Limitations

Although sulla may have many desirable characteristics and has potential use in animal production systems in New Zealand, its use may currently be limited. Sulla is an erect growing species reaching to about 1 m at early flowering. The height and density of the sward at grazing can pose difficulties in ease of prehension. There may be considerable wastage of herbage through trampling and fouling, especially if grazing occurred in wet soil conditions. It may, however, be more suitable for cattle where feed is rationed through break fencing (Hodgson, 1990).

In addition, the optimum growth stage for maximum production and persistence, lies between late stem elongation and early flowering. The nutritive value at this optimum growth stage is high with digestibilities of various plant components ranging from 70-88% (See Table 3.10). There is however, a rapid deterioration of nutritive value as the plant passes early flowering (Kernick, 1978), and the huge quantities of standing forage must be utilised quickly if maximum nutrient yields are to be exploited. One possible solution to this problem is to graze part of the standing forage, and the rest may be conserved as hay or silage.

Under the environmental and management conditions imposed in these trials, sulla proved to be short-lived. It is however, known to persist under cutting for 2-3 years in the Mediterranean basin (Sarno & Stringi, 1981). The lack of persistence may be inherent in the erect hay-type cultivar used. It is known in other forage plants that erect growing hay-type genotypes are less persistent than their prostrate counterparts (Hodgkinson & Willams, 1983). In addition, there is evidence that

winter-active genotypes are less persistent than winter-dormant ones (Wassermann et al., 1992). The perenniality of the accessions that were used to breed 'Necton' sulla is unknown. It may be possible to incorporate perenniality in future breeding programmes as variability exists for perenniality in populations currently used in the Mediterranean basin, especially in the more prostrate genotypes (Mathison, 1983).

The current cost of seed, establishment costs, limited availability of suitable post-emergent herbicides coupled with poor persistence may hinder the acceptability of sulla. Although sulla has the potential to produce large quantities of high quality nonbloating herbage, and possesses good seasonal distribution of herbage, further research is needed to reduce its cost of production, and improve its perenniality before farmer enthusiasm can be expected.

6.6 CONCLUSIONS

1. The management of sulla is similar to that of a winter growth active lucerne. Sulla is capable of providing good quality herbage in spring, summer, autumn/winter with its high herbage accumulation rates ranging from 60-80 kg DM ha^{-1} d^{-1}, but adequate forage production in sulla requires effective nodulation and minimum weed competition.

2. The optimum growth stage for grazing to ensure total production potential, utilisation and digestibility lies between late stem elongation and early flowering. Leaf mass in the EF growth stage is comparable to that in the less mature growth stages.

3. Defoliation at the early flowering growth stage encouraged vigorous shoot extension and rapid recovery within 8-14 days. This appeared associated wth the maintenance of high starch status and a larger root mass, which enable the sward to withstand the stresses of defoliation.

4. Loss of production in spring can result if grazing occurs in late autumn/winter, especially during wet conditions with high stocking densities ranging from 1500-2000 sheep ha^{-1}. High stocking densities can cause mechanical injury to the

crown complex and consequent death of plants. A lower stocking density, perhaps between 100-200 lambs ha^{-1} d^{-1}, may be attempted to benefit from the winter production in sulla (T. Phelps, pers comm), but care should be taken to retain sufficient leaf area by less severe grazing for continued winter growth.

5. Under cutting, sulla should be defoliated at the EF growth stage to about 15 cm, for the maintenance of maximum productivity without weakening of the stands. Defoliation at an immature growth stage should be avoided. However, should sulla be defoliated at an immature growth stage, care should be taken to allow for sufficient retention of leaf area (>200 cm^2) on the stubble.

6. Under grazing, selective grazing and trampling imposed by the grazing animal can cause senescence of residual herbage, especially in less severely grazed treatment. Thus under field conditions, selective grazing can pose problems in the control of sufficient residual leaf area.

7. Sulla is strongly apical dominant, and only at flowering are new shoots released in leaf axils of undefoliated plants. In defoliated plants however, regrowth originates from the crown. It is recommended that summer grazing should be severe for maximum utilisation, but care should be taken to minimize crown damage. Prevailing environmental conditions must be taken into consideration before severe grazing can be imposed in autumn/winter.

8. The rapid decline in plant population is compensated by an increase in individual plant dry weight. Nevertheless, maximum compensation is soon reached and plants are not able to compensate for the further decline in plant density, especially in late autumn, which can result in decreased herbage production in spring.

9. The rapid decline in plant density under a grazing regime suggested that sulla should be managed more like an annual forage species. Allowing a seed crop to shatter periodically may be a useful management tool for the maintenance of

stands.

10. To benefit from the autumn/winter growth, an autumn sowing (Feb/Mar) for early spring utilisation may be considered as a management advantage.

11. Sulla has potential for use in animal production systems in New Zealand - deer, sheep, beef cattle and dairy cattle enterprises - as a special purpose forage utilised *in situ* or conserved as hay or silage in summer, autumn and winter when feed supply is restricted in conventional pastures.

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Appendix 3.1 Site soil pedology - Marton silt loam

MARTON SILT LOAM

PEDOLOGY

LOCATION: Meteorological enclosure, Marton Experimental Farm, Marton. N143/900689. SLOPE: Flat. ASPECT: On undulating wide coastal plain. ALTITUDE: 480 ft.

VEGETATION OF SITE: Yorkshire fog, sweet vernal, ryegrass, flatweeds.

PROFILE:

A_1 0–9 in. very dark greyish brown (10YR 3/2) silt loam; friable; moderately developed fine granular structure grading into nutty below 3 in.; very many roots; bluish black fine concretions at about 8 in.; distinct irregular boundary,

A_{3g} 9–13 in. pale brown (10YR 6/3) clay loam; friable; many distinct fine strong brown mottles and greyish brown casts; weakly developed fine nutty structure; many roots; indistinct boundary,

B_{1g} 13–18 in. pale and strong brown mottled clay loam (heavier); firm; weakly developed fine to medium blocky structure; few roots; distinct boundary,

18–20 in. white sandy loam with prominent yellowish red mottling; structureless,

C_{1x} 20–30 in. pale grey (10YR 7/1) clay loam; many medium distinct strong brown mottles forming a reticulate pattern; very firm; weakly developed medium blocky structure; diffuse boundary,

C_2 on yellowish brown to brownish yellow (10YR 5/8 – 6/8) clay loam with many pale grey veins; firm and massive.

PARENT MATERIAL: Moderately weathered drift (loess plus volcanic ash).

NATIVE VEGETATION: Broadleaved-podocarp forest. RAINFALL: 40 in.

CLASSIFICATION: (a) Weakly leached gleyed net-gammate central yellow-grey earth.
(b) Weakly enleached gleyed net-gammate pallic soil.

MAIN USE OF SOIL: Pastoral land for breeding and fattening sheep.

MONOLITH: See Plate 41.

THE SAMPLES for the analysis of Marton silt loam are registered in Soil Bureau records as follows:
SB 7537 A 0–3 in. 7537 B 3–8 in. 7537 C 10–13 in. 7537 D 13–18 in. 7537 E 18–20 in. 7537 F 21–29 in. 7537 G 30–36 in.
No numbers have been given to undisturbed cores.

SOIL PHYSICS

Depth (in.)	0–3	3–8	10–13	13–18	18–20	21–29	30–36
Horizon	A_{11}	A_{12}	A_{3g}	B_{1g}	B_{1g}	C_{1x}	C_2
Mechanical analysis							
% Sand (2–.02 mm)	41	44	38	31		35	35
% Silt (.02–.002 mm)	31	29	32	32		34	34
% Clay (< .002 mm)	27	24	30	37		31	31
Texture	sil	sil	cyl	cyl		cyl	cyl
Moisture							
Est. field cap. % w/w							
<2 mm	44.0	30.5	28.5	32.0		33.0	44.5
Wilting point % w/w	19.7	15.3	18.5	27.9		21.1	23.0
Avail. moisture % v/v	23.3	17.2	11.9	12.5		17.5	28.1
Undisturbed cores							
Depth (in.)	1–3	4–7	10–13	14–17		23–26	31–34
Dry bulk density g/cc	0.96	1.13	1.32	1.13		1.4	1.49
Total porosity %	61.0	55.1	49.7	57.0		44.0	43.2
Macroporosity %	13.9	14.9	8.4	12.2		1.9	0.6
Stones(> 2mm) % v/v							
Density							
Stones g/cc							
Particles(<2mm) g/cc	2.46	2.52	2.63	2.63		2.63	2.63

SOIL ENGINEERING

Depth (in.)	0–3	3–8	10–13	13–18	18–20	21–29	30–36
Horizon	A_{11}	A_{12}	A_{3g}	B_{1g}	B_{1g}	C_{1x}	C_2
On site 10 / 9 / 59							
Dry bulk dens. lb/ft³	58.8	70.4	82.2	70.4		91.6	92.5
Water content %	38	29.9	25.0	37.0		28.6	30.0
Penetr. resist. lb/in²	205	285	260	175		230	395
Compaction							
Max. dry bulk density lb/ft³			92.5	83.3		94	88.2
Opt. water content %			26	34		26	30
Penetr. resist. lb/in²			270	190		250	400
Size analysis							
<0.076 mm	85	84	92	94		96	97
<0.422 mm	96	92	98	100		100	100
<2 mm	99	97	100				
<60 mm	100	100					
Effective size d10 mm							
Unif. coeff. d60/d10							
Plasticity							
Liquid limit	77	53	57	77		51	65
Plastic limit	39	31	26	31		24	28
Activity	1.41	0.92	1.03	1.30		0.87	1.19
Class. symbol	MH	MH	CH	CH		CH	CH

SAND MINERALOGY

Frequency of mineral species in sand (2 to 0.02 mm)

Depth (in.)	0–3	3–8	10–13	13–18	18–20	21–29	30–36
Horizon	A_{11}	A_{12}	A_{3g}	B_{1g}	B_{1g}	C_{1x}	C_2
Sand %, of soil	49	47	45	40	42	43	48
Quartz	A	A	A	A	S	A	A
Feldspars							
Acid	A	A	A	A	R	A	A
Andesine							
Glass	R	A	A	A	A	R	C
Micas							
Muscovite	R	R	R	R		S	R
Biotite							
Chlorite	R		R	S		S	R
Amphiboles							
Hornblende A	S	C	S	S	R	S	S
Hornblende B							
Glaucophane							
Actinolite							
Pyroxenes							
Augite	R	C	R				
Diopside							
Hypersithene	C	C	S	R			R
Enstatite	C	C	C	S			R
Epidotes							
Epidote	C	R	C	C	R	R	S
Zoisite, clinozoisite	C	R	C	C		C	C
Saussurite							
Pumpellyite			R	R		R	R
Sericitic aggregates				S			
Quartz aggregates							
Chert	R	R	R	S	R	S	R
Plant opal	C	C	R	R		S	S
Lignite							
Calcite							
Apatite							
Accessory oxides							
Cristobalite							
Tridymite							
Rutile							
Brookite							
Ilmenite							
Magnetite							
Accessory silicates							
Zircon	R	R	R	R		R	R
Tourmaline	R			R		R	
Sphene							
Kyanite							
Garnet							
Kaolinite							

SOIL CHEMISTRY

Depth (in.)	0–3	3–8	10–13	13–18	18–20	21–29	30–36
Horizon	A_{11}	A_{12}	A_{3g}	B_{1g}	B_{1g}	C_{1x}	C_2
pH (moist soil, H_2O)	5.9	5.8	5.6	5.9	5.4	5.2	5.4
(dried soil, H_2O)	4.9	5.4	5.4	6.2	6.1	5.9	5.7
(dried soil, N KCl)	4.3	4.2	4.1	4.2	4.3	4.0	3.9
$CaCO_3$ %							
Cation exchange							
CEC me %	17.5	13.1	11.5	14.5	14.7	13.2	13.9
TEB me. %	9.7	8.3	6.6	11.3	11.0	8.5	8.5
BS %	55	40	58	78	75	64	61
Ca me %	5.9	4.0	5.7	5.2	5.8	4.6	1.9
Mg me. %	2.4	1.3	2.4	5.5	4.2	3.4	5.6
K me. %	0.31	0.09	0.05	0.08	0.10	0.08	0.11
Na me %	0.5	0.1	0.2	0.7	1.0	0.5	0.7
Organic matter							
C %	4.5	2.8	0.9	0.7	0.5	0.3	0.3
N %	0.36	0.23	0.10	0.09	0.06	0.04	0.03
C/N	12	12	9	8	8	8	10
Phosphorus (P)							
Total mg %	70	53	27	21	19	16	14
Organic mg %	43	32	11	6	6	3	2
Inorganic mg %	27	21	16	13	13	13	12
N H_2SO_4 mg %	10	8	2	2	1	1	2
Truog mg %	1	0.7	0.5	1	0.7	0.5	0.2
Citric mg %	1	1	0.5	0.5	0.2	0.2	0.2
P retention %	31	32	32	41	42	25	28
N/Organic P	8	7	9	11	10	13	15
Potassium (K)							
Total me. %	20	22	19		22	23	
Exch. (moist) me. %	0.37	0.11	0.11	0.11			
K_r	0.11	0.10					
Magnesium (Mg)							
Acid-sol me. %	8.4	7.9					
Sulphur (S)							
Total mg %	63	52	30				26
Adsorbed mg %	1	0.5	1	0.5	1	4	7
Tamm oxalate							
Al %	0.28	0.28	0.28	0.40	0.34	0.19	0.15
Fe %	0.88	0.84	0.67	0.70	0.56	0.69	0.39
Horizon weights							
Thickness (in.)	3	6	4	5	2	10	
Weight, lb/ac × 10^6	0.7	1.5	1.2	1.3	0.5	3.3	

CLAY MINERALOGY

Constituents as % of minerals (< 2 μ) identified

Depth (in.)	0–3	3–8	10–13	13–18	18–20	21–29	30–36
Horizon	A_{11}	A_{12}	A_{3g}	B_{1g}	B_{1g}	C_{1x}	C_2
Clay % of soil	18	20	25	34	34	26	31
Free Fe_2O_3 % of soil	2.8	3.5	3.6	2.6	2.3	2.9	3.6
Chlorite			14	10			
Interlayered chlorite			32	25			10
Mica							
Illite	3				40		
Interlayered hydrous mica						44	40
Clay-vermiculite 1	36	37	12	26	5		
Clay-vermiculite 2	37	41	30	27	30	30	20
Montmorillonite					5		
Kaolin							
Quartz	2						
Feldspar	2	2				1	
Hydrous feldspar							
Allophane							
Halloysite	20	20	12	12	20	25	30
Gibbsite							
Cristobalite							

SPECTROGRAPHIC ANALYSIS (APPROX.)

Depth (in.)	0–3	3–8	10–13	13–18	18–20	21–29	30–36
Horizon	A_{11}	A_{12}	A_{3g}	B_{1g}	B_{1g}	C_{1x}	C_2
Macroelements %							
Al	8	11	12	13	13	10	11
Fe	3.5	4	4.2	4.1	4	4	5
Ca	1.5	1.5	1.3	1	1	1	0.9
Mg	0.7	0.9	0.9	0.8	0.65	0.65	0.65
Na	1.2	1.3	1.5	1.2	1.3	1.4	1.3
K	0.8	0.8	0.8	0.8	1	0.8	0.9
Microelements p.p.m							
Zr	270	250	300	300	300	350	300
Cr	18	20	20	30	20	20	20
Ni	4	6	6	6	8	6	4
Co	4	4	3	3	4	2	2
Mn	980	1200	250	150	150	150	200
Mo	2	2	3	2	3	2	3
Ga	9	10	12	12	12	12	15
V	80	100	100	100	100	100	100
Cu	15	15	15	20	20	20	20
Ba	600	900	600	800	1000	900	600
Sr	530	500	400	200	150	300	300
Ti	2500	3000	3500	3500	4000	3000	3000
Loss on ign. %	11	7	4	5	6	3	3

Appendix 3.2 Site soil pedology - Matapiro silt loam

MATAPIRO SILT LOAM

PEDOLOGY

LOCATION: Hatuma, ½ mile north-east from railway crossing and between old road and railway line. N146/930738.

SLOPE: Flattish. ASPECT: Crest in easy rolling landscape. ALTITUDE: 450 ft.

VEGETATION OF SITE: Crested dogstail.

PROFILE:

A_{11} 0–3 in. very dark greyish brown (10YR 3/2) silt loam; friable; moderately developed fine granular structure; many roots; indistinct boundary,

A_{12} 3–7 in. very dark brown (10YR 2/2) silt loam; friable; moderately developed fine nutty structure with much cast granular; many roots; distinct irregular boundary,

A_2 7–14 in. yellowish brown to pale yellow (10YR 5/4 – 2.5Y 7/4) silt loam; friable; many fine pores; massive; distinct irregular boundary,

B_{2x} 14–32 in. yellowish brown (10YR 5/4) clay loam; very firm; many pale grey and greyish brown fine mottles, which increase downward and join into a network of veins; moderately developed coarse blocky structure; few roots; indistinct boundary,

C_{1x} on pale yellowish brown (10YR 6/4) clay loam; massive; with few pale grey streaks extending vertically downward.

PARENT MATERIAL: Moderately weathered drift of Pleistocene silts over siltstone.

NATIVE VEGETATION: Broadleaved forest or fern. RAINFALL: 33 in. and unevenly distributed.

CLASSIFICATION: (a) Moderately leached central yellow-grey earth.
(b) Moderately enleached clay illuvial net-gammate pallic soil.

MAIN USE OF SOIL: Pastoral land used mainly for fattening sheep and cattle. Pastures tend to dry out in summer.

MONOLITH: See Plate 40.

THE SAMPLES for the analysis of Matapiro silt loam are registered in Soil Bureau records as follows:

SB 7604 A 0–3 in. 7604 B 3–7 in. 7604 C 9–13 in. 7604 D 16–22 in. 7604 E 24–30 in. 7604 F 37–42 in. 7604 G at 15 in.

No numbers have been given to undisturbed cores.

SOIL PHYSICS

Depth (in.)	0 / 3	3 / 7	9 / 13	16 / 22	24 / 30	37 / 42
Horizon	A_{11}	A_{12}	A_2	B_{2x}	B_{2x}	C_{1x}
Mechanical analysis						
% Sand (2–.02 mm)	46	44	52	36	49	26
% Silt (.02–.002 mm)	30	33	30	24	25	46
% Clay (<.002 mm)	23	23	17	40	26	28
Texture	sil	sil	sil	cyl	sil	sil
Moisture						
Est. field cap. % w/w <2 mm	33.5	29.6	20.3	27.7	25.7	
Wilting point % w/w	13.0	11.1	7.9	15.1	16.1	
Avail. moisture % v/v	24.3	21.5	17.5	19.1	14.6	
Undisturbed cores	0 / 3	4 / 7	10 / 13	19 / 22		36 / 39
Dry bulk density g/cc	1.09	1.16	1.41	1.52		1.51
Total porosity %	56.4	53.0	46.1	42.6		43.1
Macroporosity %	15.5	15.7	14.6	5.1		3.2
Stones (>2mm) % v/v						
Density						
Stones g/cc						
Particles (<2mm) g/cc	2.47	2.47	2.62	2.66		2.66

SOIL ENGINEERING

Depth (in.)	0 / 3	3 / 7	7 / 13	16 / 22	24 / 30	37 / 42
Horizon	A_{11}	A_{12}	A_2	B_{2x}	B_{2x}	C_{1x}
On site 11 kg / 60						
Dry bulk dens. lb ft³	67.3	72.3	87.8	94.7		94.0
Water content %	24.7	20.0	12.5	16.1	16.0	23.2
Penetr. resist. lb/in²	190	230	340	>600	>600	570
Compaction						
Max dry bulk density lb ft³			106.4	102	101	
Opt. water content %			15.8	20.5	21	
Penetr. resist. lb/in²			850	270	350	
Size analysis						
<0.076 mm	81	81	91	96	89	95
<0.422 mm	99	100	100	100	100	100
<2 mm	100					
<60 mm						
Effective size d10 mm						
Unif. coeff. d60/d10						
Plasticity						
Liquid limit	54	45	25	48	38	40
Plastic limit	33	30	20	21	21	23
Activity	0.91	0.65	0.29	0.97		
Class symbol	MH	MI	ML – CL	CI	CI	CI

SAND MINERALOGY

Frequency of mineral species in sand (2 to 0.02 mm)

Depth (in.)	0 / 3	3 / 7	9 / 13	16 / 22	24 / 30	37 / 42	
Horizon	A_{11}	A_{12}	A_2	B_{2x}	B_{2x}	C_{1x}	A_3
Sand % of soil	63	64	65	57	56		
Quartz	A	A	A	C	A	A	A
Feldspars							
Acid	A	A	A	c	A	A	A
Andesine	c	c	c	S	S	R	R
Glass	C	C	C	S	S	R	c
Micas							
Muscovite				R	S		
Biotite							
Chlorite			R	R	R	R	R
Amphiboles							
Hornblende A	R	S	R	R	R	R	R
Hornblende B	R	R	R				
Glaucophane							
Actinolite							
Pyroxenes							
Augite							
Diopside		S		R	R		R
Hypersthene	c	c	c	S	R	R	S
Enstatite							
Epidotes							
Epidote	R		R	R	R		
Zoisite, clinozoisite	R	c	S		R	R	S
Saussurite							
Pumpellyite							
Sericitic aggregates	c	c	c	c	C	c	c
Quartz aggregates	S			S			
Chert							
Plant opal	c	c	S		R	R	R
Lignite	R						
Calcite							
Apatite	R						
Accessory oxides							
Cristobalite							
Tridymite	R						
Rutile							
Brookite	R						
Ilmenite							
Magnetite							
Accessory silicates							
Zircon	R	R	R		R		R
Tourmaline							
Sphene						R	
Kyanite							
Garnet	R						
Kaolinite							

CLAY MINERALOGY

Constituents as % of minerals (<2μ) identified

Depth (in.)	0 / 3	3 / 7	9 / 13	16 / 22	24 / 30	37 / 42	
Horizon	A_{11}	A_{12}	A_2	B_{2x}	B_{2x}	C_{1x}	A_3
Clay % of soil	15	14	13	24	21	22	14
Free Fe_2O_3 % of soil	0.8	1.1	0.9	1.6	1.6	1.9	0.9
Chlorite	5	5			3		
Interlayered chlorite	10	16	9	5	4		
Mica							
Illite	15	11	15	19	17		
Interlayered hydrous mica	30	24	22	31	27		
Clay-vermiculite 1	11	17	10	7	7		
Clay-vermiculite 2	18	11	27	25	30		
Montmorillonite			3	6	6		
Kaolin							
Quartz	3	8	5	2	3		
Feldspar	8	8	9	5	3		
Hydrous feldspar							
Allophane			*				
Halloysite							
Gibbsite							
Cristobalite							

* Allophane 0% of whole soil

SOIL CHEMISTRY

Depth (in.)	0 / 3	3 / 7	7 / 13	16 / 22	24 / 30	37 / 42	
Horizon	A_{11}	A_{12}	A_2	B_{2x}	B_{2x}	C_{1x}	A_3
pH (moist soil, H_2O)	5.8	5.9	6.3	6.0	5.7	5.6	
(dried soil, H_2O)	5.4	5.5	5.9	5.6	5.3	5.2	
(dried soil, N KCl)	4.3	4.3	4.2	3.6	3.3	3.3	
$CaCO_3$ %							
Cation exchange							
CEC me %	14.9	12.7	9.2	20.2	20.6	23.2	
TEB me %	6.5	5.3	5.3	11.3	10.6	15.3	
BS %	44	42	58	56	52	66	
Ca me %	5.0	4.0	3.4	6.0	5.3	7.5	
Mg me %	1.4	1.3	1.7	4.2	4.1	6.3	
K me %	0.24	0.13	0.09	0.21	0.21	0.23	
Na me %	0.2	0.1	0.2	0.7	0.7	0.6	
Organic matter							
C %	4.0	3.7	0.6	0.4	0.3	0.3	
N %	0.26	0.20	0.06	0.04	0.04	0.03	
C/N	15	14	10	10	8	10	
Phosphorus (P)							
Total mg %	61	51	20	16	16	21	
Organic mg %	44	39	12	5	4	4	
Inorganic mg %	17	12	8	11	12	17	
N H_2SO_4 mg %	4	4	2	3	5	7	
Truog mg %	0.7	0.5	0.2	0.5	0.5	1	
Citric mg %	4	4	1	0.5	0.5	2	
P retention %	24	25	14	29	25	22	
N/Organic P	9	5	5	6	10	8	
Potassium (K)							
Total me %	31	32	34	38	41	42	
Exch. (moist) me %	0.25	0.18	0.13				
Ke	0.30	0.30					
Magnesium (Mg)							
Acid-sol. me %	7.6	7.0					
Sulphur (S)							
Total mg %	42	30		7		5	
Adsorbed mg %	1.0	0.9	0.2	0.2	0.2	0.2	
Tamm oxalate							
Al %	0.24	0.24	0.16	0.26	0.17	0.18	
Fe %	0.36	0.40	0.27	0.24	0.15	0.15	
Horizon weights							
Thickness (in.)	3	4	7	15			
Weight, lb/ac × 10⁶	0.7	1.1	2.2	6.2			

SPECTROGRAPHIC ANALYSIS (APPROX.)

Depth (in.)	0 / 3	3 / 7	7 / 13	16 / 22	24 / 30	37 / 42	
Horizon	A_{11}	A_{12}	A_2	B_{2x}	B_{2x}	C_{1x}	A_3
Macroelements %							
Al	8.5	10	8	9	8	7	8
Fe	2.4	2.5	3.5	3	3.5	3	3.5
Ca	1.1	1.5	1.2	1.5	1.1	0.9	0.9
Mg	0.4	0.4	0.55	0.65	0.85	0.55	0.55
Na	1.1	1.5	2	1.5	2	1.5	1.5
K	1.3	1.5	1.9	1.9	2.3	1.5	1.5
Microelements p.p.m.							
Zr	250	270	300	200	300	150	200
Cr	20	13	20	20	20	15	25
Ni	2	2	2	2	2	3	5
Co	<1	<1	<1	<1	1	1	<1
Mn	300	270	200	150	150	150	150
Mo	<1	<1	1	<1	1	<1	<1
Ga	8	7	10	10	12	10	10
V	40	45	50	40	50	30	30
Cu	12	9	4	10	12	15	15
Ba	1000	1300	1500	1000	1000	800	1000
Sr	250	270	300	250	400	300	500
Ti	1400	1000	2000	2500	1500	1500	
Loss on ign. %	9	11	2	2	3	2	2

Appendix 3.3 Presowing site soil analysis (Frewens 7)

FERTILIZER & LIME RESEARCH CENTRE
Massey University, Palmerston North, New Zealand.
Telephone (063) 69-099, Telex 30974-Mas Uni.

LABORATORY REPORT

NAME: SALLY NEWTON	
ADDRESS: AGRONOMY DEPARTMENT	Type of material: SOIL
	Date analysis completed: 17-6-88

SAMPLE	ANALYSIS									
	OLSEN P	pH	Ca	Mg	K	Na		TEB	CEC	
SAMPLE 1	14	5.5	5.9	1.0	0.53	0.1		7.6	9.3	

COMMENT: Exchangeable cations expressed as meq/100g

SIGNED: _____ _____ (for Director)

Appendix 3.4 Postsowing site soil analysis (Frewens 7)

FERTILIZER & LIME RESEARCH CENTRE
Massey University, Palmerston North, New Zealand.
Telephone (063) 69-099, Datex 30974-Mas Uni.

LABORATORY REPORT

NAME: HARI KRISHNA

ADDRESS: AGRONOMY DEPARTMENT
MASSEY UNIVERSITY

Type of material: SOIL

Date analysis completed: 6-06-89

SAMPLE	ANALYSIS									
	pH	Olsen P	SO_4	Exch. K	Exch. Ca	Exch. Mg	Exch. Na		TEB	CEC
HK 1	5.9	10	11	0.22	10.0	1.1	0.07		11	10

COMMENT: Sulphate and phosphate values are expressed as micrograms per gramm (air-dry).
Exchangeable cations are expressed as meq/100g (air-dry).

SIGNED: _____ _____ (for Director)

Appendix 3.5 Leaf nutrient analysis

ANALYTICAL SERVICES LTD
SOIL ▲ PLANT ▲ WATER ANALYSIS
Cambridge
85 Queen St, Private Bag, Cambridge, New Zealand
Telephone (071) 274-409
Fax (071) 274-495.
Telex NZ2474.

CLIENT: Massey University
ADDRESS: Private Bag
PALMERSTON NTH
Hari Krishna
CROP GROWN: Sulla

LABORATORY REPORT

JOB No: 51324
PAGE: 1 OF 1
RECEIVED: 22/09/89
COMPLETED: 27/09/89
SUBMITTED BY: Massey University

SOIL TEST RESULTS

SAMPLE NAME	SAMPLE NO	BULK DENSITY g/ml	pH	PHOSPHORUS ug/ml	EXTRACTABLE CATIONS: POTASSIUM me/100g	CALCIUM me/100g	MAGNESIUM me/100g	SODIUM me/100g	CAT. EXCH CAPACITY me/100g	PERCENTAGE SATURATION: POTASSIUM %	CALCIUM %	MAGNESIUM %	SODIUM %

SAMPLE NAME	SAMPLE NO	ORGANIC MATTER %	AVAILABLE NITROGEN kg/ha	LIME REQUIREMENT kg/ha	SALTS (SAT. EXT.) mS/cm	PHOSPHATE RETENTION %	RESERVE MAGNESIUM me/100g	SALTS (1:5 EXT.) mS/cm	SULPHATE-SULPHUR ug/g	EXTRACTABLE ALUMINIUM ug/g	TOTAL NITROGEN %	BORON ug/g	RESERVE POTASSIUM me/100g

PLANT TISSUE ANALYSIS

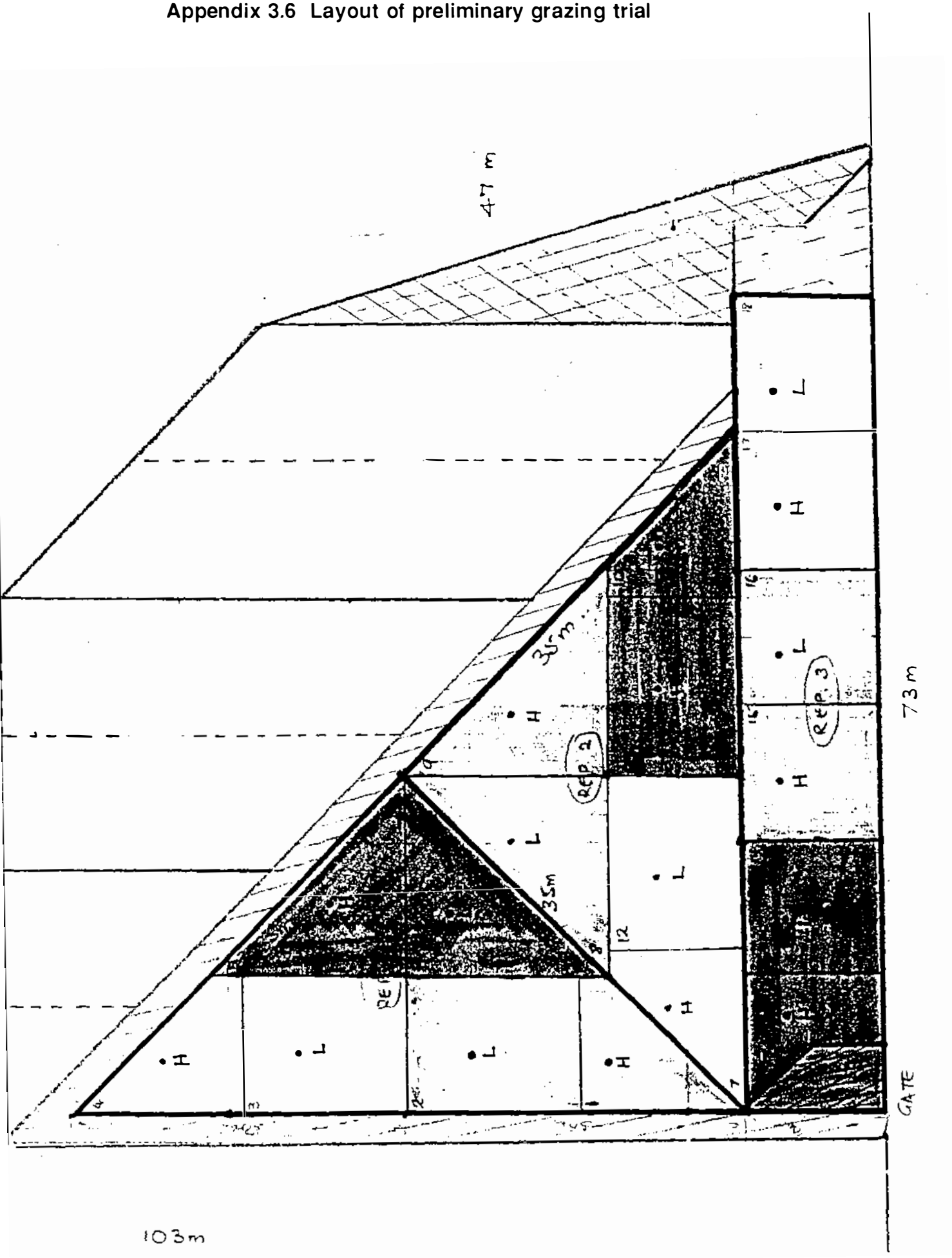
SAMPLE NAME	SAMPLE NO	NITROGEN %	PHOSPHORUS %	POTASSIUM %	SULPHUR %	CALCIUM %	MAGNESIUM %	SODIUM %	IRON ppm	MANGANESE ppm	ZINC ppm	COPPER ppm	BORON ppm
1	1	3.0	0.19	1.6	0.59	1.05	0.32	0.98	46	59	20	7	36

SAMPLE NAME	SAMPLE NO	MOLYBDENUM ppm	COBALT ppm	SELENIUM ppm	IODINE ppm	SULPHATE-SULPHUR %	CHLORIDE %	ALUMINIUM ppm					
1	1	0.11											

Samples are analysed as received at the laboratory using Analytical Services in-house methods. These are summarised on the reverse of this report and further

TELARC
This laboratory is registered by the Testing Laboratory Registration Council of New Zealand. The tests reported herein have been performed in

Appendix 3.6 Layout of preliminary grazing trial



Appendix 3.7 50 years climate data for Palmerston North

*E05363 PALMERSTON NTH D S I R GRID REFS NZMS 1. 1:63360 N149104323
NZMS 260. 1:50000 T24317885 LAT 40 23S LONG 175 37E HT 34 M.

	PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
RAINFALL MILLIMETRES														
HIGHEST MONTHLY/ANNUAL TOTAL	1928-1980	245	192	216	155	222	263	245	204	165	187	191	219	1298
90 PERCENTILE VALUE	1928-1980	141	126	128	130	151	190	140	150	126	141	133	173	1140
MEAN	1928-1980	79	67	69	81	89	97	89	89	75	88	78	94	995
10 PERCENTILE VALUE	1928-1980	32	18	21	36	33	37	38	47	31	39	34	40	823
LOWEST MONTHLY/ANNUAL TOTAL	1928-1980	10	8	14	19	13	15	29	30	13	15	27	24	713
AVERAGE RAIN DAYS. 1 0MM OR MORE	1928-1980	9	7	8	10	12	12	12	12	11	12	11	10	126
MAXIMUM 1-DAY RAINFALL	1928-1980	82	92	85	69	74	98	59	51	46	39	47	63	98
MAXIMUM 2-DAY RAINFALL	1928-1980	136	92	117	72	84	103	63	73	70	59	66	69	136
TEMPERATURE OF THE AIR DEGREES CELSIUS														
HIGHEST RECORDED	1918-1980	30 0	30 6	29 5	27 8	23 4	20 9	19.3	22 8	22 1	26.2	27.7	31 7	31.7
AVERAGE MONTHLY/ANNUAL MAXIMUM	1918-1980	27 1	27 4	25 9	23 1	19 5	16 9	15.9	17.2	19.2	21.2	23 4	25.7	28.3
AVERAGE DAILY MAXIMUM	1928-1980	21.9	22 3	20 9	18.2	15 0	12 6	11.9	13 1	14.7	16.6	18.5	20.6	17.2
MEAN	1928-1980	17 3	17 6	16 4	13 9	10 9	8 6	8 0	9 0	10 6	12 4	14 2	16.1	12.9
AVERAGE DAILY RANGE	1928-1980	9 1	9.5	9 2	8.6	8.2	7.9	7.9	8 1	8.1	8 3	8 7	9.0	8.6
AVERAGE DAILY MINIMUM	1928-1980	12.8	12 8	11 7	9 6	6 8	4 7	4 0	5 0	6 6	8.3	9 8	11.6	8 6
AVERAGE MONTHLY/ANNUAL MINIMUM	1918-1980	6.3	6 4	4 1	2 4	-0.3	-1.7	-1.9	-1 4	0 1	1 7	3 3	5.3	-2.7
LOWEST RECORDED	1918-1980	1.7	1.4	0 0	-3.3	-3.9	-5 0	-5.3	-6.0	-3.9	-2.0	0 6	0.0	-6.0
TEMPERATURE OF THE GROUND DEGREES CELSIUS														
LOWEST GRASS MINIMUM RECORDED	1918-1980	-4 4	-3.8	-5.6	-7 7	-7 6	-10.0	-9 4	-9 4	-8.3	-7.7	-5.0	-4 4	-10.0
AVERAGE GRASS MINIMUM	1928-1980	9 4	9 4	8 2	6 1	3.3	1.3	0.5	1 5	3 1	5.0	6.7	8.3	5.2
AVERAGE AT 10 CM DEPTH	1939-1980	18.5	18 1	16.3	13.2	10 1	7.7	6 7	7.6	9.9	12.5	15 1	17.3	12.8
AVERAGE AT 30 CM DEPTH	1928-1980	19.2	19.1	17.6	14.9	11.7	9.3	8.1	8.8	10.8	13.2	15 7	18.0	13.9
AVERAGE AT 1 M. DEPTH	1928-1980	18.1	18.6	17.9	16.1	13.7	11.3	9.8	9.7	10.9	12.7	14.7	16.8	14.2
FROST														
AVERAGE DAYS OF GROUND FROST	1928-1980	0.2	0.3	0.8	2 4	6.5	10.6	13.1	10.4	6.0	3.0	1.0	0 1	54.4
AVERAGE DAYS OF AIR FROST	1928-1980	.	.	.	.	1.2	3.8	4.8	2.6	0.9	0.2	.		13.5
RELATIVE HUMIDITY (%)														
AVERAGE AT 9 A.M.	1928-1980	73	74	77	81	83	85	85	81	78	75	73	73	78
VAPOUR PRESSURE MILLIBARS														
AVERAGE AT 9 A.M.	1941-1980	15.2	15.3	14.6	12 8	10.9	9.3	8.9	9 4	10.6	11.7	12.7	14.0	12.1
EVAPORATION MILLIMETRES														
RAISED PAN AVERAGE	1975-1980	168	143	115	66	40	24	25	42	65	98	129	154	1069
SUNSHINE TOTAL HOURS														
HIGHEST	1935-1980	302	262	229	190	161	133	147	182	223	236	263	280	2020
MEAN	1935-1980	209	186	170	136	112	94	104	122	133	158	177	193	1794
% OF POSSIBLE	1935-1980	48	50	46	43	38	35	37	39	39	40	43	43	42
LOWEST	1935-1980	139	124	108	91	62	59	54	69	75	101	111	129	1387
WIND														
MEAN DAILY WINDRUN. KILOMETRES	1928-1980	275	260	238	224	214	201	200	221	258	270	282	267	243
SPECIAL PHENOMENA AVERAGE DAYS OF														
SNOW	1972-1980	.	.	.	.	0 1	0.1	0.2	.	.	.	.	.	0.4
HAIL	1928-1980	0.1	.	.	.	0.2	0.3	0.3	0.3	0 4	0.2	0.2	0 1	2 1
THUNDER	1971-1980	0.6	.	0.2	0.3	0.7	0.2	0.5	0.6	0.1	0.8	0 4	0 4	4.8
GALE	1929-1980	0.3	0.1		0.1		0.1	.	0.1	0.2	0 1	0.1	0.1	1.2
FOG	1928-1980	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.1	.	.	.	.	1.2

Appendix 3.8 The effect of plant growth stage (ERGS) at grazing and grazing intensity on herbage, herbage components and weeds consumed (kg DM ha^{-1}), and percent herbage consumed (%), at each grazing, over 365 DAS.

Parameter Estimated	Grazing Intensity	22/12/88 85 DAS	16/2/89 140 DAS	29/5/89 240 DAS	28/9/89 365 DAS
Herbage Consumed	HHHH	1427	1627	2953	1163
	HLLL	1698	1317	2053	3233
	LHHH	1152	2320	2797	983
	LLLL	1760	2976	2313	2480
$LSD_{0.05}$		NS	NS	NS	1580
Leaves Consumed	HHHH	1373	1390	2617	913
	HLLL	1583	963	1873	2423
	LHHH	1007	1580	2350	807
	LLLL	1603	2217	2000	1860
$LSD_{0.05}$		NS	NS	NS	947
Stems Consumed	HHHH	53	143	337	250
	HLLL	118	293	180	810
	LHHH	145	540	447	177
	LLLL	157	657	313	620
$LSD_{0.05}$		NS	NS	NS	NS
Weeds Consumed	HHHH	950	263	140	973
	HLLL	253	720	346	586
	LHHH	530	720	177	1037
	LLLL	120	980	77	887
$LSD_{0.05}$		395	NS	157	NS
Percent Herbage Consumed	HHHH	66	70	77	62
	HLLL	71	43	60	77
	LHHL	43	72	81	54
	LLLL	63	66	59	73
$LSD_{0.05}$		NS	NS	18	NS

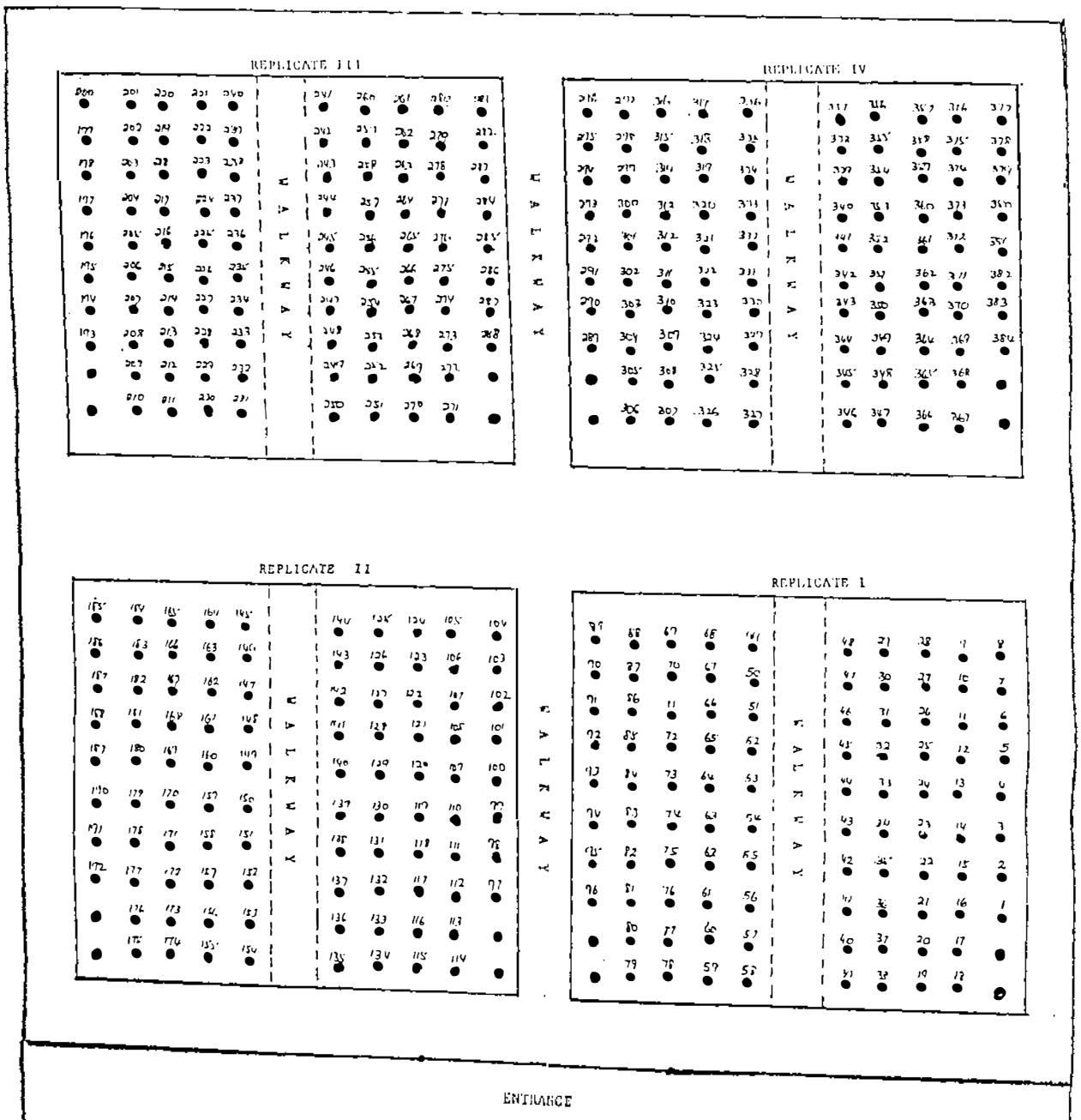
Appendix 3.9 The effect of plant growth stage at grazing (LRGS) and grazing intensity on herbage, herbage components and weeds consumed (kg DM ha^{-1}), and percent (%) herbage consumed, at each grazing, over 365 DAS.

Parameter Estimated	Grazing Intensity	11/1/89 106 DAS	18/3/89 172 DAS	28/9/89 365 DAS
Herbage Consumed	LLL	3973	3077	9641
	HHH	2043	2417	11207
$LSD_{0.05}$		NS	646	NS
Leaves Consumed	LLL	3653	2603	5343
	HHH	1657	2063	6597
$LSD_{0.05}$		NS	NS	NS
Stems Consumed	LLL	320	340	4298
	HHH	387	200	4610
$LSD_{0.05}$		NS	NS	NS
Weeds Consumed	LLL	1233	1813	756
	HHH	900	733	449
$LSD_{0.05}$		NS	NS	NS
Percent Herbage Consumed	LLL	85	80	88
	HHH	80	71	80
$LSD_{0.05}$		NS	NS	NS

Appendix 3.10 The effect of grazing sulla under different intensity management treatments at the early reproductive growth stage on pregrazing plant morphology -stem density (stems plant^{-1}), stem node number (number stem^{-1}) and stem height (mm) n=15.

Parameter Estimated	Grazing Intensity	22/12/88 85 DAS	16/2/89 140 DAS	29/5/89 240 DAS
Stem Density	HHHH	1.3	2.6	5.3
	HLLL	1.0	2.5	6.2
	LHHH	1.3	1.3	5.3
	LLLL	0.3	2.0	4.3
$LSD_{0.05}$		-	NS	NS
Node Number	HHHH	1.0	5.0	3.9
	HLLL	1.0	5.4	3.7
	LHHH	1.1	7.1	3.8
	LLLL	0.5	6.7	3.9
$LSD_{0.05}$		-	1.4	NS
Stem Height	HHHH	38.4	491.6	256.9
	HLLL	40.3	904.7	183.4
	LHHH	32.9	574.0	238.9
	LLLL	16.7	634.8	214.5
$LSD_{0.05}$		-	NS	NS

Appendix 4.1 Layout of greenhouse cutting trial



REMARKS: Sowing Date- 28th. August, 1989

No. of polythene bags per replicate - 100

No. of replicates - 4

No. of plants per bag - 4

Total no. of plants - 1600

● polythene bag

TREARMENT COMBINATIONS:

(1) LV-1
(2) LV-7
(3) LV-15
(4) LV-30
(5) MSE-1
(6) MSE-7
(7) MSE-15
(8) MSE-30
(9) FBI-1
(10) FBI-7
(11) FBI-15
(12) FBI-30

APPENDIX 4.2 PROCEDURE FOR CARBOHYDRATE DETERMINATION

(Department of Plant Science, Massey University)
(As described by Dr. R. Haslemore, DSIR Biochemistry, P.North)

Section I describes the steps involved in **SOLUBLE SUGAR** analysis. The reagents required are listed in Appendix II. Section II describes the steps involved in STARCH analysis. The reagents required are listed in Appendix III and the equipment required in Appendix IV.

NOTE:

- All chemicals should be analytical grade reagents (AnalaR)
- All water should be distilled
- All tubes should be absolutely clean and dust free
- Always work through the tubes in a set order. In this way, if labels wash off, samples can still be identified.
- All samples should be freeze dried and finely ground to pass a 0.5 mm mesh size.

I SOLUBLE SUGARS

Step 1 : Dried plant material (100 mg) is extracted with 10 ml of 62.5% methanol for 30 min at 55°C using screw-capped culture tubes (16x125 mm) with teflon-faced caps.

(a) Weigh about 100 mg of dry, finely-ground plant material to an accuracy of 4 decimal places.

(b) Place plant material in carefully labelled culture tubes. Add exactly 10 ml 62.5% methanol (extracting) solution.

(c) Place tubes in waterbath at 55°C for 30 min.

Step 2 : The samples are centrifuged then 4 ml aliquot are transferred to a second series of capped culture tubes each containing 0.1 ml lead acetate. (Standards are prepared by making up stock solutions containing 4, 8 12, 16 and 20 mg sucrose in total volume of 10 ml 62.5% methanol.

Aliquot of 4 ml are removed and treated in the same manner as the plant samples to give standards equivalent to 4, 8, 12, 16 and 20% (mg) soluble sugars on dry weight basis respectively. A blank of 4 ml 62.5 % methanol is treated similarly. Lead acetate is added to the blank and standards).

(a) Tighten caps well and centrifuge at about 2000 rpm for 5 min to obtain a clear extract, from which the aliquot may be removed.

(b) Label six more tubes clearly with standard numbers (i.e. 0, 4, 8, 12, 16 and 20% soluble sugar). Prepare standards as follows from sucrose standard stock solution.

Standard % soluble sugars (mg)	Stock solution (ml)	62.5% methanol (ml)
0	0	10
4	2	8
8	4	6
12	6	4
16	8	2
20	10	0

(c) Take aliquot of exactly 4 ml from standards and from upper, clear portion of samples. Place aliquot into another set clearly labelled culture tubes, each containing 0.1 ml lead acetate. The same pipette may be used to take all aliquot, provided the standards are sampled first. (The lead acetate causes precipitation from the solution of unwanted phenols).

Step 3 : After 10 min standing with occasional shaking, 5 ml chloroform is added and the tubes are capped securely and shaken vigorously. They are then briefly centrifuged to aid phase separation.

(a) Vortex mix the aliquot, allow to stand for 10 min, then vortex mix again.

(b) **IF** chlorophyll pigments, and therefore galactolipids, are present, a liquid-liquid extraction with chloroform is necessary. 5 ml chloroform is

added to each aliquot. Cap tubes tightly and vortex mix. Centrifuge at about 2000 rpm for 5 mins. The upper, aqueous phase now contains the carbohydrate, and the lower, chloroform phase contains the unwanted lipids.

Step 4 : Aliquot of 50 µl are removed from the upper, aqueous phase and added to 0.95 ml in culture tubes (16x125 mm).

Step 5 : 5% Phenol (1 ml) is added, with mixing, followed by 5 ml of sulphuric acid by pipette taking care to direct the stream of acid directly on to the surface of the liquid to aid mixing.

(a) Wearing safety glasses and gloves, add 1 ml phenol to each tube.

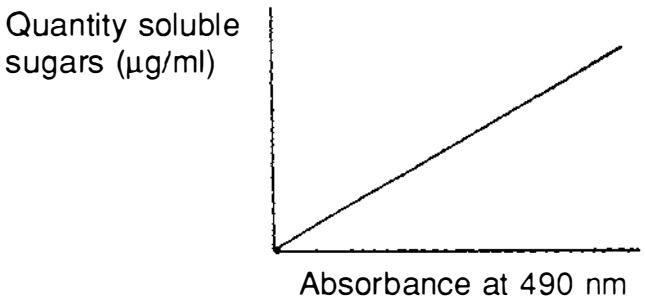
(b) Using pipette and pipetting aid, add 5 ml concentrated sulphuric acid to each tube, taking care to direct stream of acid onto surface of liquid.

Step 6 : Samples are stood to cool for 60 min then absorbances read at 490 nm.

(a) Vortex mix, then leave to stand for 60 min.

(b) Pour each sample into the cuvette and read absorbances at 490 nm on spectrophotometer. Hold cuvette by upper rim, and take care not to smear sides. Drain cuvette well between readings, and begin with standards.

Analysis : A standard curve is formed by plotting relationship between soluble sugar concentration and absorbance of standards. As absorbances of samples are known, soluble sugar concentrations can then be interpolated from this curve. The curve is usually linear from 0-70 µg soluble sugar, and gradient should remain fairly constant between tests. Standards must be used every time the test is run.



$$\% \text{ soluble sugar} = \frac{\text{slope x absorbance x 100}}{\text{sample weight}}$$

Note: Sucrose standards of 50 µl aliquots made up to 1 ml contain 0, 20, 40, 60, 80 and 100 µg sucrose per ml.

APPENDIX II

Reagents for soluble sugar analysis

1. Methanol, 62.5 (v/v) in water
2. Neutral lead acetate (0.5 mol/l) solution
3. Phenol (0.05 mol/l) in water. (5 g phenol in 100 ml water).
4. Concentrated sulphuric acid (sp.gr. 1.84)
5. Sucrose standard. 2 mg/ml in 62.5% methanol. Made up weekly and stored at 4°C
6. Chloroform - IF samples contain chlorophyll

Equipment for soluble sugar analysis.

Vortex mixer

Pressure cooker with tube holder (for use without pressure as low temperature water bath)

Water bath

Micropipette

Zipette dispenser

Pipettes

Pipette bulb
Timer
Centrifuge
2 test-tube holders
4 decimal place balance
"Kimax" culture tubes (16x125 mm) with teflon-lined caps
(2 per sample + standards)
Spectrophotometer

II STARCH

Note:

- Reagents required are described in Appendix III
- Extreme care must be taken when handling dianisidine HCL as it has carcinogenic properties.
- The amyloglucosidase preparation is obtained from Boeringer Mannheim or Sigma.
- The amyloglucosidase preparation must be tested before use by running the test with starch standards until full recovery is obtained. 95-105% recovery is acceptable within the limits of experimental error.
- The test provides a linear determination of starch concentration between 0-100 μg in the final aliquot.
  Samples with higher concentrations may require sampling in larger aliquot.
- On removal from fridge of freezer, all finely powdered chemicals must be brought to room temperature before opening.
- Glucose oxidase reagent will store for several weeks in an amber bottle at 4°C. It will darken in colour, but the colour difference between standards will remain constant.

Step 1 : The residual plant material following soluble sugar extraction is treated with 4 ml methanol at 100°C for 5 min. This is repeated and washings aspirated and discarded after centrifugation.

(a) Using water pump, aspirate methanol off tubes of residual plant

material used in first stages of sugar assay. Check tubes are still labelled clearly.

(b) Add 4 ml pure methanol to each tube, vortex mix and cap tightly. Place tubes in a water bath at 80-100°C for 5 min. **CHECK** tubes for signs of leaking. If a tube appears to be leaking, mark it for further reference, check tube is not damaged, replace lost methanol and cap with a new lid.

(c) Remove tubes from water bath and centrifuge at about 2000 rpm for 5 min. Aspirate off methanol with water pump.

(d) Add 4 ml clean methanol to each tube, vortex mix and cap tightly again. Place tubes in waterbath at 80-100°C for 5 min.

(e) Remove tubes from waterbath and centrifuge at about 2000 rpm for 5 min. Aspirate off methanol with water pump.

Step 2 : Starch standards of appropriate size (generally 4.0-8.0 mg starch) are prepared at this stage.

(a) Starch standards are prepared in the same type of culture tube as samples, and must be clearly labelled. The starch standard stock solution is used as shown below:

Standard (mg)	Stock solution (ml)	Water (ml)
4.0	2.0	2.0
8.0	4.0	0.0

Step 3 : The culture tubes are firmly capped and the samples heated with 4 ml water for 60 min at 100°C to gelatinise the starch (including starch standards).

(a) 4 ml distilled water is added to each test sample only, then all tubes (test samples and standards) are placed in a water bath at 100°C for 60 min.

(b) This gelatinises the starch by breaking hydrogen bonds, enabling complete enzymatic hydrolysis later.

Step 4 : After cooling, 2 ml sodium acetate buffer and 0.1 ml amyloglucosidase preparation are added and the samples incubated for 60 min at 55°C.

(a) Tubes are removed from water bath and allowed to cool.

(b) 2 ml sodium acetate buffer solution is added to each tube, followed by 0.1 ml amyloglucosidase preparation. These amounts are critical and any dispensers used must be calibrated by measuring at least 10 measures into a measuring cylinder.

(c) Vortex mix tubes and place in water bath (or incubator) at 55°C for at least 60 min. Caps are not required for this step.

Step 5 : Samples are finally diluted to 10 ml with water, thoroughly mixed and centrifuged.

(a) Dilute the contents of each tube to 10 ml by adding 3.9 ml of distilled water.

(b) Vortex mix tubes, cap tightly and centrifuge at about 2000 rpm for 5 min.

Step 6 : Glucose is determined by incubating 0.05-0.50 ml aliquot of the diluted hydrolysate in a final volume of 1 ml water with 2 ml glucose oxidase reagent at 37°C for 60 min. A blank of water only and standards of 25, 50, 75 and 100 µg glucose are treated similarly.

(a) an aliquot must now be taken form the hydrolysate. For most agronomic samples, an aliquot of the hyrolysate of 0.25 ml is acceptable. Measure aliquot precisely and place in a new set of clearly marked culture tubes. It may later be found that some aliquot sizes must be changed in order to give a central reading within the range 0-100 µg starch (final aliquot).

(b) Add distilled water to tubes to bring volume to 1 ml, i.e. 0.75 ml for a 0.25 ml aliquot.

(b) Prepare glucose standards of 25, 50, 75 and 100 µg in 1 ml distilled water from a stock standard solution of glucose as follows:

Standard (µg/ml)	Stock solution (µl)	Water (µl)
0	0	1000
25	25	950
50	50	950
75	75	925
100	100	900

(d) Add exactly 2 ml glucose oxidase reagent to each tube (including all standards), vortex mix well, cap tightly and place in a water bath at 37°C for 60 min. (To cool water bath to 37°C, remove water, fill with ice and reset temperature). At this point, if sample is significantly darker than the top standard, a dilution should be made and the factor noted. If a sample is significantly lighter in colour than the lowest standard, return to step 12 and take a larger aliquot, noting the different aliquot size.

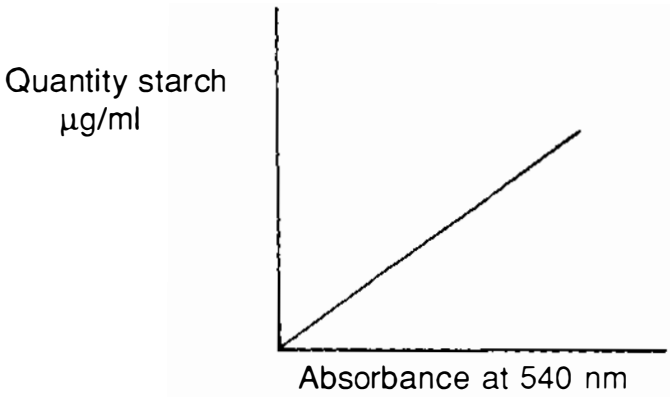
Step 7 : Hydrochloric acid (5 ml, 5 mol/l) is added, samples thoroughly mixed and absorbances read at 540 nm.

(a) Remove tubes from water bath, add exactly 5 ml of 5 mol/l HCL to each tube, and vortex mix well.

(b) Pour each sample into the cuvette and read absorbances at 540 nm on the spectrophotometer. Hold the cuvette by the upper rim, and take care not to smear the sides. Drain the cuvette well between readings, and begin with the standards.

Analysis : Spectrophotometer readings for glucose standards are used to plot a standard curve relating absorbance and starch concentration. Starch present in the aliquot of samples with known absorbances can be read off this curve. The starch standards are used as a check to ensure complete hydrolysis is occurring. Quantity of glucose recovered from starch

standards should be between 95 and 105% that of the original starch standard.



Once the standard curve is plotted, % starch in sample may be determined by:

$$\% \text{ starch} = \frac{\text{slope x absorbance x 0.9 x dilution factor x 100}}{\text{sample weight}}$$

The figure 0.9 is a correction factor for the hydrolysis of 1 g starch to 1.1 g glucose and water.

n.b

$$\text{Dilution factor} = \frac{\text{original sample volume}}{\text{aliquot volume}}$$

e.g. as described $\frac{10}{0.25} = 40$

Ensure units are kept constant in these equations - µg or mg not both.

Appendix III

Reagents for starch analysis

1. Sodium acetate buffer solution (0.25 mol/l, pH 4.5). Glacial acetic acid (7.15 ml) made up to 450 ml with water and adjusted to pH 4.5 with 5 mol/l sodium hydroxide. Dilute to 500 ml and store at 4°C. **MUST** be accurate to pH 4.5 ± 0.1.

2. Amyloglucosidase (from *Aspergillus niger*). Preparation obtained from Boehringer Mannheim or Sigma suspension in ammonium sulphate solution, 3.2 mol/l, pH ca. 6.

3. Tris-glycerol buffer (pH 7.0). 30.2 g Tris is dissloved in 400 ml water. The pH is adjusted to 7.0 with conc. hydrochloric acid and the solution diluted in to 500 ml. Add 330 ml glycerol and store at 4°C.

4. Glucose oxidase reagent. Sigma glucose oxidase (from *Aspergillus niger*) 180 mg; Sigma peroxidase (Horseradish) 18 mg; Sigma o-dianisidine dihydrochloride 120 mg; in a final volume of 600 ml Tris-glycerol. The dianisidine HCL is best dissolved in 150 ml of the buffer with warming. Dilute to 600 ml and glucose oxidase and peroxidase stirring until dissolved. Store in amber bottle at 4°C.

5. Hydrochloric acid (5 mol/l). Add 515 ml conc. hydrochloric acid to 485 ml water and mix well.

6. Starch standard. 100 mg soluble starch (AR) (BDH; corrected for moisture) is suspended in 10 ml water and placed in a boiling water bath until the suspension becomes translucent. This is diluted to 50 ml with water. Make up weekly and store at 4°C.

7. Glucose standard. 1 mg/ml in water stored at 4°C

APPENDIX IV

Equipment for starch analysis:

Vortex mixer

Pressure cooker with tube holder (for use without pressure as low temperature water bath)

pH meter

Water bath

Micropippette

Zipette dispensers

Pipette (1, 2 and 5 ml)

Pipette bulb

Timer

Centrifuge

vacuum pump (aspirator)

2 test-tube holders

4 decimal place balance

Magnetic stirrer

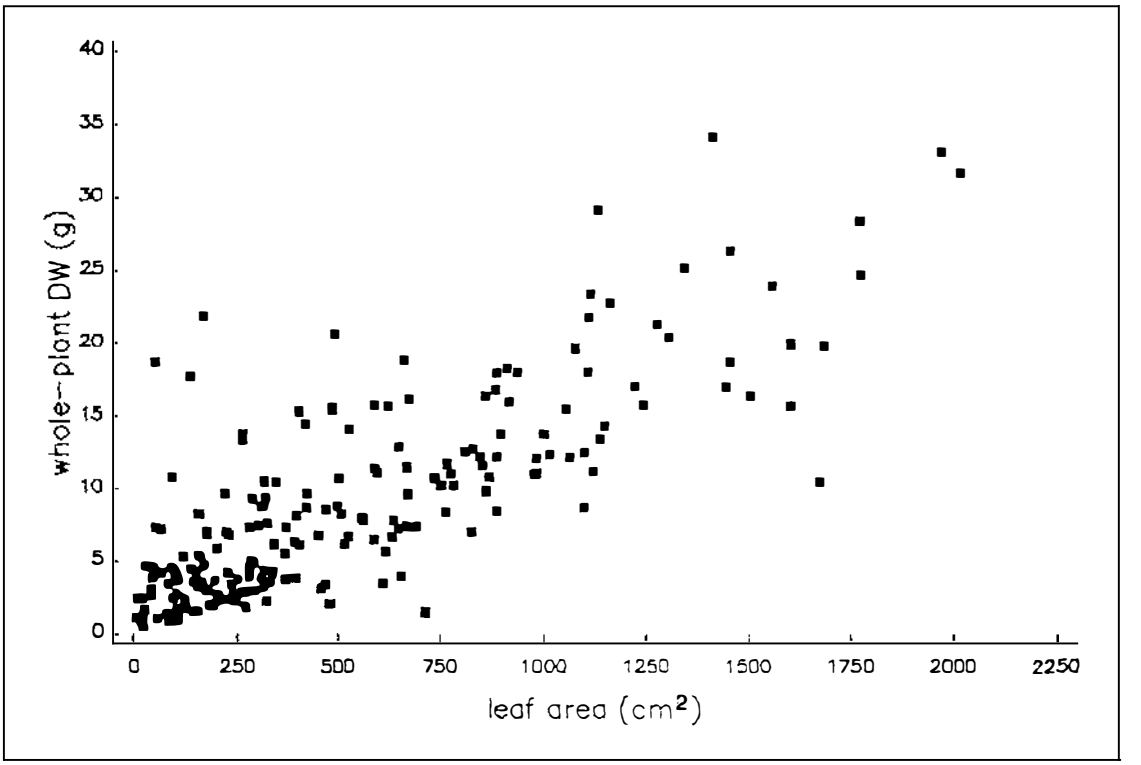
"Kimax" culture tubes (16x125 mm) with teflon-lined caps

(2 per sample + standards)

Spectrophotometer

METHOD REVISED AUGUST 1990

Appendix 4.3 The relationship between whole-plant DW (W) and leaf area (A) throughout the experiment.



Appendix 5.1 Presowing site soil analysis (Frewens 3)

FERTILIZER & LIME RESEARCH CENTRE
Massey University, Palmerston North, New Zealand.
Telephone (063) 69-099, Datex 30974-Mas Uni.

LABORATORY REPORT

NAME: HARI KRISHNA

ADDRESS: DEPARTMENT OF AGRONOMY

MASSEY UNIVERSITY

Type of material: SOIL

Date analysis completed: 2-08-89

SAMPLE	ANALYSIS									
	pH	Olsen P	Exch. K	Exch. Ca	Exch. Mg	SO_4				
HK 1 0-20cm	5.6	10	0.20	6.9	1.08	6.9				
HK 2 20-50cm	5.9	7	0.10	6.2	1.13	5.5				

COMMENT: Phosphate and sulphate values are expressed as micrograms per gram(air-dry).

Exchangeable cations are expressed as meq/100g (air-dry).

SIGNED: _____ _____ (for Director)

Appendix 5.2 Postsowing soil and plant analysis

ANALYTICAL SERVICES LTD
SOIL ▲ PLANT ▲ WATER ANALYSIS
Cambridge
85 Queen St. Private Bag, Cambridge, New Zealand
Telephone (071) 274-409.
Fax (071) 274-495
Telex NZ2474

CLIENT: Massey University
ADDRESS: Private Bag
PALMERSTON NTH
Hari Krishna
CROP GROWN: Sulla

LABORATORY REPORT

JOB No: 54841
PAGE: 1 OF 1
RECEIVED: 27/07/90
COMPLETED: 01/08/90
SUBMITTED BY: Massey University

SOIL TEST RESULTS

					EXTRACTABLE CATIONS					PERCENTAGE SATURATION			
SAMPLE NAME	SAMPLE NO	BULK DENSITY g/ml	pH	PHOSPHORUS ug/ml	POTASSIUM me/100g	CALCIUM me/100g	MAGNESIUM me/100g	SODIUM me/100g	CAT. EXCH CAPACITY me/100g	POTASSIUM %	CALCIUM %	MAGNESIUM %	SODIUM %
HKS 1	1	1.06	6.0	9	0.29	8.5	1.34	0.17	16	1.8	54	8.5	1.1

SAMPLE NAME	SAMPLE NO	ORGANIC MATTER %	AVAILABLE NITROGEN kg/ha	LIME REQUIREMENT kg/ha	SALTS (SAT. EXT.) mS/cm	PHOSPHATE RETENTION %	RESERVE MAGNESIUM me/100g	SALTS (1:5 EXT.) mS/cm	SULPHATE-SULPHUR ug/g	EXTRACTABLE ALUMINIUM ug/g	TOTAL NITROGEN %	BORON ug/g	RESERVE POTASSIUM me/100g
HKS 1	1								18				

PLANT TISSUE ANALYSIS *

SAMPLE NAME	SAMPLE NO	NITROGEN %	PHOSPHORUS %	POTASSIUM %	SULPHUR %	CALCIUM %	MAGNESIUM %	SODIUM %	IRON ppm	MANGANESE ppm	ZINC ppm	COPPER ppm	BORON ppm
HKL 2	2	2.8	0.18	1.9	0.54	1.29	0.26	1.53	83	72	33	17	41

SAMPLE NAME	SAMPLE NO	MOLYBDENUM ppm	COBALT ppm	SELENIUM ppm	IODINE ppm	SULPHATE-SULPHUR %	CHLORIDE %	ALUMINIUM ppm					
HKL 2	2	0.21											

Samples are analysed as received at the laboratory using Analytical Services in-house methods. These are summarised on the reverse of this report and further details are available on application.
I/S = insufficient sample for analysis.

TELARC NEW ZEALAND
This laboratory is registered by the Testing Laboratory Registration Council of New Zealand. The tests reported herein have been performed in accordance with its terms of registration. This document should not be

for ANALYTICAL SERVICES LTD

Appendix 5.3 Soil analysis at the conclusion of the trial

ANALYTICAL SERVICES LTD
SOIL ▲ PLANT ▲ WATER ANALYSIS
Cambridge
85 Queen St, Private Bag, Cambridge, New Zealand
Telephone (071) 274-409.
Fax (071) 274-495
Telex NZ2474.

CLIENT: The Registrar
ADDRESS: Massey University
Private Bag
PALMERSTON NTH
CROP GROWN:

LABORATORY REPORT

JOB No: 56861
PAGE: 1 OF 1
RECEIVED: 07/12/90
COMPLETED: 11/12/90
SUBMITTED BY: Massey University

SOIL TEST RESULTS

SAMPLE NAME	SAMPLE NO	BULK DENSITY g/ml	pH	PHOSPHORUS ug/ml	EXTRACTABLE CATIONS: POTASSIUM me/100g	CALCIUM me/100g	MAGNESIUM me/100g	SODIUM me/100g	CAT EXCH CAPACITY me/100g	PERCENTAGE SATURATION: POTASSIUM %	CALCIUM %	MAGNESIUM %	SODIUM %
Sulla SS1	1	1.06	6.0	12	0.31	9.1	1.28	0.27	16	2.0	58	8.1	1.7
Red Clover RCS1	2	1.03	6.0	10	0.28	9.2	1.44	0.13	16	1.8	58	9.1	0.8

SAMPLE NAME	SAMPLE NO	ORGANIC MATTER %	AVAILABLE NITROGEN kg/ha	LIME REQUIREMENT kg/ha	SALTS (SAT EXT) mS/cm	PHOSPHATE RETENTION %	RESERVE MAGNESIUM me/100g	SALTS (1:5 EXT) mS/cm	SULPHATE-SULPHUR ug/g	EXTRACTABLE ALUMINIUM ug/g	TOTAL NITROGEN %	BORON ug/g	RESERVE POTASSIUM me/100g
Sulla SS1	1								13				
Red Clover RCS1	2								12				

PLANT TISSUE ANALYSIS

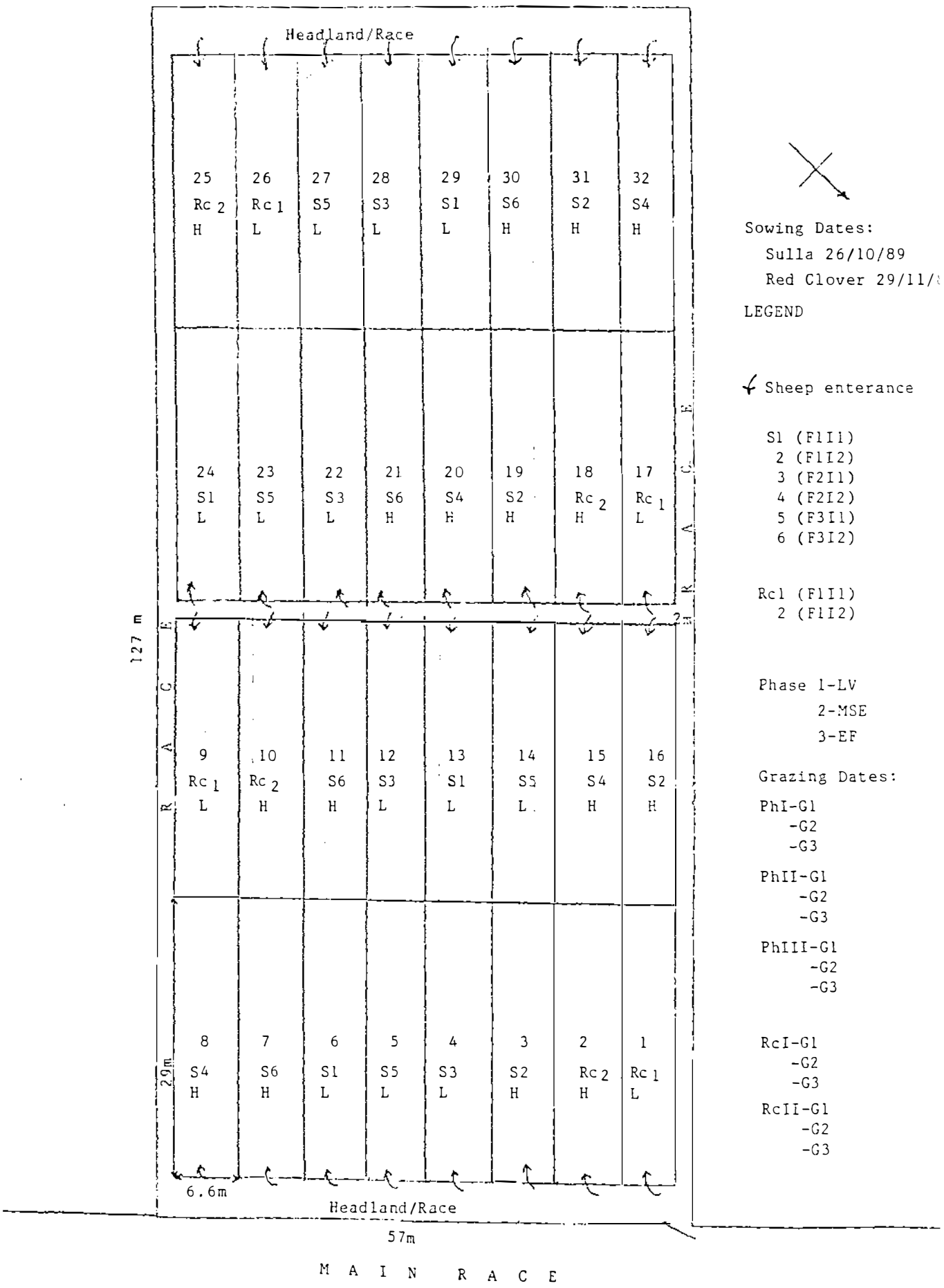
SAMPLE NAME	SAMPLE NO	NITROGEN %	PHOSPHORUS %	POTASSIUM %	SULPHUR %	CALCIUM %	MAGNESIUM %	SODIUM %	IRON ppm	MANGANESE ppm	ZINC ppm	COPPER ppm	BORON ppm

SAMPLE NAME	SAMPLE NO	MOLYBDENUM ppm	COBALT ppm	SELENIUM ppm	IODINE ppm	SULPHATE-SULPHUR %	CHLORIDE %	ALUMINIUM ppm					

Samples are analysed as received at the laboratory using Analytical Services in-house methods. These are summarised on the reverse of this report and further

TELARC
This laboratory is registered by the Testing Laboratory Registration Council of New Zealand. The tests reported herein have been performed in

Appendix 5.4 Layout of large-scale grazing trial



Appendix 5.5 The effect of plant growth stage at grazing and grazing intensity on herbage, herbage components and weed consumed (kg DM ha^{-1}), and percent (%) herbage consumed, at each grazing, over 365 DAS.

Parameter Estimated	Grazing Intensity	Jan/Feb (1)	Mar/Apr (2)	Jun/Jul (3)	Sept/Oct (4)
Herbage Consumed	LV-HHHH	3590	3653	4284	4759
	LV-LLLL	2561	3508	3816	4460
	MSE-HHHH	4263	4475	3896	3505
	MSE-LLLL	4310	3227	4278	4370
	EF-HHH	5484	3488	-	7341
	EF-LLL	5749	3578	-	7986
$LSD_{0.05}$		NS	671	NS	NS
Leaves Consumed	LV-HHHH	3238	3082	3465	2791
	LV-LLLL	2251	2969	3087	3146
	MSE-HHHH	3374	3778	3424	2330
	MSE-LLLL	3422	2798	3547	3124
	EF-HHH	3528	3188	-	5360
	EF-LLL	3778	3199	-	5286
$LSD_{0.05}$		584	522	NS	NS
Stems Consumed	LV-HHHH	335	519	819	1968
	LV-LLLL	280	461	729	1314
	MSE-HHHH	812	667	473	1175
	MSE-LLLL	766	408	732	1246
	EF-HHHH	1243	300	-	1981
	EF-LLLL	939	379	-	2700
$LSD_{0.05}$		NS	NS	NS	NS
Weeds Consumed	LV-HHHH	146	43	-	786
	LV-LLLL	228	120	-	1072
	MSE-HHHH	503	20	-	1272
	MSE-LLLL	277	167	-	502
	EF-HHH	790	14	-	0
	EF-LLL	697	14	-	0
$LSD_{0.05}$		NS	NS	-	407

	LV-HHHH	90	83	64	74
Percent	LV-LLLL	74	75	58	59
Herbage	MSE-HHHH	85	80	73	70
Consumed	MSE-LLLL	81	72	65	62
	EF-HHH	77	80	-	60
	EF-LLL	81	70	-	58
$LSD_{0.05}$		6	NS	NS	NS