COMPETITIVE INTERACTIONS IN A DAIRY PASTURE CONTAINING PASPALUM (*PASPALUM DILATATUM* POIR.) FOLLOWING THE INTRODUCTION OF RYEGRASS (*LOLIUM PERENNE* L.)

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ABSTRACT

A series of trials investigated the contribution of introduced grasses (*Lolium perenne* and *Bromus catharticus*) to seasonal production of a high yielding dairy sward containing paspalum (*Paspalum dilatatum*). The persistence of the introduced species was also determined.

Autumn overdrilling improved (<500 kg DM/ha) herbage production in the following winter/spring and autumn, but thereafter differences between drilled and undrilled swards disappeared. The monitoring of individual plants showed that there were high summer losses of introduced plants; up to 56% were lost by one year after drilling. The contribution of *Bromus catharticus* to herbage mass was less than that for *Lolium perenne*, as summer losses of the former plants were higher than for the latter because of increased susceptibility to direct 'animal effects' (eg. 'pulling'). *Bromus catharticus* was therefore excluded from subsequent experiments. Summer growth of introduced plants was more restricted when they were closely associated with established paspalum than with other resident species, and large plants had better summer persistence than small plants.

Manipulation of the light environment of the introduced ryegrass plants by regular clipping (10 mm stubble) of surrounding resident herbage markedly improved their ability to survive summer management and environmental stresses. The introduced plants were able to attain a large average size (20 to 50 tillers per plant) before the onset of summer.

Summer losses of introduced plants were higher when grazed at a short (2-3 week) rather than a long (3-4 week) interval and if paspalum was a close neighbour. About 20% of total losses were related to direct cow damage, namely, severe grazing, 'pulling', dung and urine deposition, and trampling. The latter effects may be important where stocking densities are high. Other treatments such as late-winter/early-spring application of nitrogen fertiliser and irrigation during summer/autumn, failed to improve persistence of introduced ryegrass.

One of the various ecological strategies that gives paspalum a competitive advantage over ryegrass is its ability to accumulate large reserves of carbohydrate. Measurement of nonstructural carbohydrate accumulated in above-and below-ground organs indicated that these reached a maximum for both species towards the end of the period of their most active growth. At this time the nonstructural carbohydrate level for paspalum at 1050 kg/ha, was four times greater than that for ryegrass.

Possible practical methods for improving the persistence of ryegrass introduced into established swards are discussed.

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INTRODUCTION

About 90% of New Zealand's dairy production is obtained from North Island flat and rolling country, the main regions being Northland, Auckland, Waikato, Bay of Plenty and Taranaki. Dairy production has intensified over the past 20 to 30 years, the best farmers now achieving production of 700 to 800 kg of milkfat per grazed hectare, about double that of 30 years ago.

This production is generally achieved from pastures containing mixtures of grasses (predominantly ryegrasses, in particular *Lolium perenne*) and white clover (*Trifolium repens*) (Lancashire 1982). However, in northern New Zealand (Northland, Auckland, Waikato and Bay of Plenty) summer growing paspalum (*Paspalum dilatatum*) is widespread in dairy pastures (Percival 1977) and during its winter/spring dormancy, *Poa* spp. may occupy available niches (Bryant & Parker 1971).

High stocking rates, dry summers and insect damage have on occasions led to pasture deterioration. Volunteer paspalum has become dominant in some areas possibly because of the combined effect of high stocking rates and frequent dry, hot (daily screen maximum >25 °C) spells during summer. Paspalum dominance usually means poorer spring pasture production because of a reduced contribution from perennial ryegrass. This poses a serious feed supply problem on seasonal dairy farms since about 80% of total milkfat production can be achieved from July to January (Campbell & Bryant 1978).

The recent development in New Zealand of overdrilling equipment (Baker 1980) offers a relatively cheap method, compared to conventional cultivation, of renovating lowland pastures. Current costs are only 20 to 35% of the costs of conventional cultivation, depending on the seed and herbicide used. In a recent survey, Sangakkara et al. (1982) found many farmers used overdrilling on an annual basis to introduce improved cultivars into some of their pastures. *Lolium perenne* cultivars such as 'Grasslands Nui' and 'Ellett' are most often used, while of the other grasses, prairie grass (*Bromus catharticus*) is preferred (Sangakkara et al. 1982).

With adequate moisture, seedling emergence of autumn overdrilled grasses has generally been satisfactory. Of concern to many farmers is the poor persistence of the introduced species. Some believe it is necessary to drill each autumn. Suggestions have been made as to why the persistence of introduced species is poor (Baker 1980) but the problem has received little attention from agronomists.

The present investigation was initiated to obtain a measure of the seasonal extent of the persistence problem and to develop methods of achieving satisfactory persistence of grasses introduced into pasture containing paspalum. At the field experimental sites during summer paspalum comprised 45 to 55% of the herbage mass. Paspalum occupied 30 to 40%, and after dry summers, up to 60% of the area. Most but not all was located in areas that supported predominantly paspalum.

The first chapter reviews the literature on factors affecting the growth of perennial grasses and how competition for the various growth factors modifies their growth and persistence in mixed pastures.

Work reported in the second chapter describes the extent of the contribution of overdrilled *Lolium perenne* and *Bromus catharticus* to seasonal dry matter production of a paspalum pasture. The fate of the introduced species was monitored by periodic measurements on individual plants. Subsequently, the need for information on the growth strategies and morphological structures of potentially competitive species (*Lolium perenne* and *Paspalum dilatatum*) was identified and is described in chapter 3.

In the two field experiments described in chapter 4 the application of nitrogen fertiliser during winter/spring is used to modify the relative competitive abilities of the introduced and resident plants. The effects of nitrogen fertiliser on the persistence of introduced *Lolium perenne* plants located in areas with paspalum or other pasture species as close neighbours are described. In one experiment, contrasting grazing intervals were included as variables. A complementary glasshouse experiment (chapter 5) provides an opportunity to study competition between *Lolium perenne* and *Paspalum dilatatum* without interference from confounding factors (eg. grazing animal, periodic moisture stress).

In the final field experiment (chapter 6) the growth of resident species surrounding introduced ryegrass plants was controlled by clipping. The effects of this treatment on the growth and persistence of introduced ryegrass were studied using the experimental design as described for chapter 4. Other variables included contrasting grazing intervals with a 'crossover' of treatments in early summer, and irrigation during summer/autumn. The final chapter discusses the major findings of the experimental programme and suggests possible alternatives for future study.

CHAPTER 1

REVIEW OF LITERATURE

1.1 INTRODUCTION

Plant species and cultivars differ in their requirements for various growth factors and competition for these factors is an important determinant of pasture composition and species distribution (Grime 1979). The responses of plants to competition have been researched in depth and have been the subject of extensive reviews (Clements et al. 1929; Donald 1963; Black 1966; Risser 1969; Rhodes 1970; Etherington 1975; Haynes 1980).

This review is largely restricted to the environmental factors affecting the growth of perennial grasses; how growth is modified by competition between neighbours with particular emphasis on the nature of competitive stress; the characters associated with competitive ability and the effects of the environment on competitiveness. The factors affecting the contributions of perennial grass plants to the seasonal production of swards rotationally grazed by dairy cattle are emphasised. Particular reference is given to pasture in warm-temperate environments containing mixtures of grasses of temperate and subtropical origins, and to the management problems relating to the maintenance of an appropriate species balance.

1.2 GROWTH OF PERENNIAL GRASSES

1.2.1 Tillers - the units of growth

The grass seedling consists of a short stem bearing leaves at nodes. In the axil of each leaf are buds from which axillary shoots or tillers grow as the result of meristematic activity. Tillering or axillary bud development in grasses has been thoroughly researched and there are reviews of a general nature (Langer 1963, 1972) or that emphasise cutting for conservation (Dorrington Williams 1970) or plant factors controlling tillering during reproductive development (Jewiss 1972).

Intravaginal tillers grow upwards within the leaf sheath and emerge near the base of the parent lamina; this type of tillering is most common in tufted or tussock-forming grasses (eg. *Lolium perenne*). Extravaginal tillers may break through the base of the leaf sheath and give rise to rhizomes or stolons (eg. *Poa trivialis*) (Langer 1963, 1972; Jewiss 1972). Tiller abnormalities in *Lolium perenne* include 'aerial tillering', usually at the nodes of flowering stems (Simons et al. 1974; Davies 1978; Minderhoud 1978, 1980a,b) and stoloniferous growth (Harris et al. 1979; Minderhoud 1980b).

The number of tillers produced by the grass plant is the most important determinant of its size when plants are at a low density and before the sward is closed and is achieving full light interception (Luxmoore & Millington 1971; Kays & Harper 1974). Thereafter as tiller deaths begin to occur and tiller density stabilises, tiller weight becomes more important in governing yield response (Nelson & Zarrough 1981). The individual tiller is therefore viewed as the unit of plant growth. The abilities of grass species to produce tillers and to maintain tiller production is variable and their classification on the basis of persistence ranges from semi-annual to true perennial (Langer 1963).

1.2.2 Factors affecting tiller production

Environmental factors such as light, water, nutrients and temperature affect tiller growth in perennial grasses. The responses of plants to these factors are modified by interspecific and intraspecific competition between neighbouring plants and/or allelopathic secretions, defoliation management, animal damage during grazing and attack by insects and pathogenic diseases. Most research has concentrated on the responses of temperate grasses and in particular *Lolium perenne*.

1.2.2.1 **Light intensity**

Tiller production in perennial grasses is favoured by high light intensity (Mitchell 1953a b, 1955; Donald 1958; Langer et al. 1964; Spiertz & Ellen 1972; Hunt & Halligan 1981). Interactions with temperature have also been reported (Section 1.2.2.3).

Mitchell (1955) demonstrated an inhibitory effect of continuous shading on tiller formation in young *Lolium perenne*, *Dactylis glomerata* and *Paspalum dilatatum* plants with various defoliation regimes. The work of Mitchell (1953a,b) and Mitchell & Coles (1955) suggested that ryegrass plants were sensitive to current rather than previous light conditions, as plants transferred from shade to full sunlight resumed tillering at the same rate as unshaded plants. However, if shading was prolonged dormant buds were difficult to stimulate and tillers developing from such buds lacked vigour. Auda et al. (1966) also reported a reduced tillering rate for *Dactylis glomerata* in response to reduced light intensity and increased photoperiod.

In field experiments Langer et al. (1964), Spiertz & Ellen (1972) and Hebblethwaite (1977) have recorded mortality of vegetative tillers of *Lolium perenne*, *Phleum pratense* and *Festuca pratensis*, especially at the time of stem elongation in reproductive tillers. These workers invoked competition for light, and therefore the products of photosynthesis, to explain these results which the work of Ong et al.

(1978) confirmed. The tillers that died were small, suffered intense shading, and were unable to compete with the larger reproductive tillers for the available assimilates. Furthermore, the work of Woledge & Leafe (1976) and Woledge (1977, 1979) has shown the photosynthetic capacity of leaves of *Lolium perenne* developing in the shaded base of the canopy to be lower, and to decline at a faster rate, than in the flag leaf on reproductive tillers developing in full sunlight. Thus, illumination during leaf expansion is important for establishing a high photosynthetic rate.

Rhodes (1968b) showed that grasses may respond to variation in their light environment during regrowth by changing tiller number or leaf size and leaf area production per tiller. Plasticity in tiller number or leaf area production per tiller was also partly attributed to the selection pressures to which the species had been subjected.

1.2.2.2 **Leaf area and light interception**

Many reviewers have emphasised the importance of rate of accumulation of leaf area in pasture production (Donald & Black 1958; Cooper & Tainton 1968; Brown & Blaser 1968). Interception of light energy is dependent on the leaf area developed by the pasture plants. The concept of leaf area index (LAI), defined as the ratio of leaf area to the area of ground it occupies (Watson 1947) has been widely adopted to aid the description of light interception by pastures.

At a LAI of 5.0, Brougham (1956) found about 95% of light energy was intercepted by the canopy and in a later publication (Brougham 1958) he referred to it as the 'critical' LAI. As the LAI of the pasture increased above the critical or optimum value the pasture growth rate was reduced (Stern & Donald 1962), due to the leaves lower in the canopy losing dry matter as their photosynthetic capacity declined because of shading.

Light interception and distribution within sward canopies is influenced by factors such as angle of elevation of the sun; whether radiation is direct or diffuse; the reflection, absorption and transmission characteristics of the foliage and the extent to which gaps in the foliage or its movement allows sunflecks to penetrate (Stern 1962). The influence of leaf arrangement on the light profile of the sward was demonstrated by Monsi & Saeki (1953) using an adaption of Beer's Law:

$I_L = I_o e^{-kL}$ where I_L = light energy penetrating through a leaf area L

I_o = incident light energy

k = extinction coefficient

The extinction coefficient k ranges from 0.3 to 0.5 in communities with erect leaves such as grasses and from 0.5 to 1.0 in communities with horizontal leaves such as clovers. Grasses therefore require a greater LAI than do clovers to intercept a given amount of light (Brown & Blaser 1968).

The effects of leaf orientation and LAI are illustrated by the following examples. Stern & Donald (1962) found that the grass in grass/clover pastures fertilised with nitrogen became dominant because its rapid growth caused shading of clovers. Harris (1970) found that deaths of *Lolium* (*multiflorum* x *perenne*) and *Lolium perenne* plants were greater with infrequent rather than frequent cutting, mainly due to competition for light excluding the more prostrate individuals. In an experiment incorporating various degrees of shading of *Poa trivialis* and *Lolium perenne* grown in 50:50 mixtures in simulated swards, the competitive ability of prostrate *Poa trivialis* was less than for the erect form (Vartha 1973). The difference was attributed to lower tillering ability of the prostrate compared to the erect form of *Poa trivialis*.

Sward characteristics affect both photosynthetic and tillering activity (Hodgson et al. 1981). At a low LAI high tiller densities can be maintained. However, at a high LAI, any advantages in photosynthetic efficiency and herbage growth are partially counterbalanced by increased losses of mature tissues.

1.2.2.3 **Temperature**

In general, the optimum ambient temperature for growth of temperate species is in the range of 18 to 25 °C (Langer 1972; McWilliam 1978) with a minimum of about 5 °C and a maximum of 30 to 35 °C (McWilliam 1978). The optimum temperature for growth of subtropical species is higher (35 °C) (Langer 1972; McWilliam 1978) with lower and upper limits of 15 and about 45 °C (McWilliam 1978).

The experiment of Mitchell (1956) illustrates that temperature optima for tiller production vary with genotype. He grew young *Lolium perenne*, *Lolium* (*multiflorum* x *perenne*), *Dactylis glomerata*, and *Paspalum dilatatum* plants in a controlled-climate laboratory at a range (7 to 35 °C) of constant (day and night) temperatures, and a light intensity of about 29 000 lux for a 12 hour day. The respective temperature optima for tillering were 12.8 and 18.3 °C, 18.3 and 23.9 °C, and 23.9 and 29.4 °C for *Dactylis glomerata* and *Paspalum dilatatum*. Tillering in *Paspalum dilatatum* continued at a high rate as the temperature was increased to 35 °C.

Lowering of the ambient temperature increased tillering in some grasses (Mitchell 1956; Alberda 1957; Ryle 1964) but the response was affected by genotype and physiological age of the plant (McWilliam 1978). High temperature tends to increase the rate of leaf appearance and leaf area expansion (McWilliam 1978). In some species (*Lolium perenne*, *Dactylis glomerata* and *Agrostis tenuis*), tillering was increased by lowering the night temperature from 7.2 °C to 1.7 °C after the plants had been grown at 15.6 °C during the day (Mitchell & Lucanus 1960). Alberda (1957) showed tiller numbers were reduced in *Lolium perenne* plants grown at 25 °C during the day if the night temperature was increased from 10 °C to 15 °C or 25 °C, a finding consistent with that of Mitchell & Lucanus (1960).

Tillering responses of *Lolium perenne*, *Bromus unioloides* and *Paspalum dilatatum* were influenced by the interaction of temperature and light intensity (Mitchell 1955; Langer 1972; Hunt & Halligan 1981). When light intensity was low tillering was greatest at low temperatures, but when light intensity was high, tillering was greatest at high temperatures.

The growth of axillary buds to form tillers largely depends on the availability of adequate carbohydrates as determined by the relative rates of photosynthesis and respiration (Langer 1963). Any restriction of light energy along with high night temperature may produce an unfavourable carbon balance and thus reduce tillering, particularly in young plants (Langer 1963; McWilliam 1978).

1.2.2.4 **Water**

The physiological and morphological responses of plants to water deficits have been extensively reviewed (Hsiao 1973; Boyer & McPherson 1975; Turner & Begg 1978, 1981; Ritchie 1981). However, there is a paucity of information in the literature on pasture species (Turner & Begg 1978) and especially C_4 species.

Water stress has generally been shown to reduce tillering in temperate grasses such as *Lolium perenne*, *Phalaris tuberosa* and *P. minor* (Luxmoore & Millington 1971; Sheehy et al. 1975; Owen 1977; Norris & Thomas 1982a,b; Korte & Chu 1983) and increase leaf death (McWilliam 1968; Sheehy et al. 1975), as was also found for the subtropical species *Panicum maximum* (Ng et al. 1975). With *Lolium perenne* tiller dry weight may be affected before tiller production, but then if drought persists the reverse effect may occur. Work in the field by Korte & Chu (1983) and in a glasshouse by Owen (1977) showed these effects. Garwood (1969) reported a negative tiller density response to irrigation by *Lolium perenne* while Hebblethwaite (1977) found a positive response to irrigation in terms of increased total tillers (vegetative plus reproductive) for the same species.

Cell enlargement is considered to be more sensitive to water deficits than is cell division (Turner & Begg 1978). An important consequence of the sensitivity of cell enlargement to small water deficits is reduced leaf area and plant growth rate. Since rate of evapotranspiration is influenced by leaf area, the sensitivity of leaf expansion to water deficits is a mechanism of limiting the evaporative surface and delaying the development of further stress. Other morphological and physiological adaptions of plants to water stress (eg. leaf shedding, leaf re-orientation, stomatal control of water loss, osmotic adjustments) have been reviewed by Hsiao (1973) and Turner & Begg (1978, 1981), and will not be discussed further in this review.

1.2.2.5 **Nutrients**

The effects on tillering of perennial grasses of the addition of the most commonly applied fertiliser nutrients, namely, nitrogen (N), phosphorus (P) and potassium (K) are discussed in this Section.

(a) *Nitrogen*: The application of nitrogen fertiliser increases the tiller density, tillering rate and tiller size of many pasture species including *Lolium perenne*, *Festuca arundinacea*, *Dactylis glomerata* and *Paspalum notatum* (Auda et al. 1966; Huokuna 1966; Beaty et al. 1970; Harris 1973; Ishida 1975; Sampio & Beaty 1976; Wilman et al. 1976; Bartholomew & Chestnutt 1977, 1978; Hebblethwaite & Ivins 1978; Hunt & Field 1979; Wilman 1980; Wilman & Mohamed 1980).

High nitrogen levels or the resultant high herbage mass may also promote the formation of 'aerial tillers'. These and other tiller abnormalities can suppress the normal basal tillering in grasses (Simons et al. 1974; Minderhoud 1980a,b) primarily by shading of tiller buds (Hayes, 1971; Jewiss 1972). This type of tillering is also prevalent around dung pats because of the reluctance of cattle to graze over or near them and the presence of nitrogen and other elements in dung (Hayes 1971; Davies 1978; Wolton 1979). 'Aerial tillers' (Section 1.2.1) are more susceptible to physical removal by cattle and sheep (Kydd 1966; Simons et al. 1974; Minderhoud 1978) and may also be susceptible to frost damage resulting in reduced tiller density and the appearance of bare patches in the sward (Minderhoud 1978, 1980a).

(b) *Potassium and phosphorus*: McAllister et al. (1971) associated stoloniferous growth in ryegrass swards and a predisposition to uprooting by the grazing animal, with excessively high levels of soil nutrients, particularly potassium. Hayes (1971), however, considered that the abnormal pattern of growth was the result of aerial tillering stimulated by the shading of basal buds, not to a high nutrient level *per se*. The shallow rooting noted by McAllister et al. (1971) may have been due directly to the high soil nutrient concentrations which often reached toxic levels (Hayes 1971).

1.2.3 **Photosynthetic capacity and shoot growth rates**

Temperate species such as *Lolium perenne* produce carbohydrates using the Calvin or C_3 photosynthetic pathway (Evans 1971). Those of subtropical origins such as *Paspalum dilatatum* possess the Hatch and Slack or C_4 photosynthetic pathway (Hatch & Slack 1970). Uptake of carbon dioxide by leaves of C_4 plants is continuous as light intensity increases to full sunlight and ranges from 50-100 mg/dm^2/hour. C_3 species, however, assimilate only 10-35 mg of carbon dioxide/dm^2/hour and light saturates at about 20-30% of full sunlight (Black et al. 1969; Downton 1971; Gifford 1971).

The above physiological differences are reflected in the efficiency of use of environmental resources in biomass production. The water use efficiency (biomass production per unit of water used in evapotranspiration) of C_4 species is about twice that of C_3 species (Slatyer 1970; Bjorkman 1971; Downton 1971). This arises from the higher photosynthetic and growth rates of C_4 plants, especially with high light intensities and temperatures, and their higher stomatal resistance to water loss compared to C_3 species. Some C_4 species (eg. *Paspalum dilatatum* and *Pennisetum clandestinum*) have become adapted to temperate areas which has further increased their water use efficiency because their potential evapotranspiration losses are lower in these environments (Turner & Begg 1978). In growth rooms at a range of day temperatures (17.5 to 35 °C) Forde et al. (1977) showed that the mean transpiration rate (grams water/grams dry weight of leaf/hour) of *Lolium perenne* was significantly greater than that of *Paspalum dilatatum* (4.74 vs 2.74). Brown (1978) reviewed data supporting his hypothesis that nitrogen use efficiency (biomass production per unit of nitrogen in the plant) for C_4 plants was greater than for C_3 plants.

High shoot growth rates have been reported for C_4 species grown in monocultures in northern New Zealand (Taylor et al. 1976). Of the large number of species and cultivars tested, *Seteria anceps* cv. Narok produced the highest mean shoot growth rate over three consecutive summers (November to April/May, 158 days) of 74 kg DM/ha/day for the dryland plots. This increased to 106 kg DM/ha/day for irrigated plots at the same site and was highest (250 kg DM/ha/day) during December/January (Sithamparanathan 1979). Summer growth rates of 38 to 46 kg DM/ha/day have been reported for dryland plots of *Paspalum dilatatum* by Baars (1976) and Taylor et al. (1976). These increased to 63 kg DM/ha/day for irrigated plots (Taylor et al. 1976) and were highest (160 kg DM/ha/day) in January (Sithamparanathan 1979). Maximum growth rates for *Lolium perenne* cv. Grasslands Nui during October/November/December of 65 kg DM/ha/day were reported by Sithamparanathan (1979), while for irrigated plots Taylor et al. (1976) measured a mean growth rate of 33 kg DM/ha/day over three summers for the same cultivar. Without irrigation 50% of the plants were lost by the third year.

Growth rates of C_4 grasses are reduced when exposed to low night temperatures (<15 °C). This is associated with the accumulation of starch in *Paspalum* and *Digitaria* spp. (McWilliam 1978) because of its slow rate of mobilisation (Lush & Evans 1974) which leads to a depression in photosynthesis caused by chloroplast instability (McWilliam 1978). Hacker et al. (1974) have shown that cold tolerant C_4 grasses like *Paspalum dilatatum* have the ability to harden which reduces damage after exposure to frost. C_3 grasses are physiologically adapted to withstand frost which causes little physical damage but markedly reduces winter growth (McWilliam 1978).

Induction of summer dormancy in C_3 grasses such as *Lolium perenne* and *Phalaris tuberosa* aid their survival of heat and moisture stress. Regrowth occurs from dormant buds in response to a reduction in temperature and moisture stress at the end of summer (McWilliam 1978).

1.2.4 Plant reserves

Competitive ability and the utilisation of environmental resources for maintenance, growth and reproduction requires an adequate energy source. Photosynthesis provides this energy source in the form of carbohydrate which when not completely used for immediate plant requirements, may become part of a reserve which can be used during stress period (Trlica & Singh 1979). Reserve substances consist largely of nonstructural carbohydrate (Cook 1966) but may include fats, oils and some proteins (Dilz 1966; Trlica & Singh 1979). The maintenance of critical levels of other elements such as potassium, sodium, magnesium and phosphorus is also essential for plant growth and development (Weinmann 1948).

Species of temperate origins 'store' carbohydrates in the form of sucrose and fructosans while species of subtropical origins 'store' carbohydrates as sucrose and starch (White 1973; Smith 1973). Organs that actively 'store' reserves (or sinks) may vary with growth habit (Rodel & Boultwood 1981) and are above-ground in non-rhizomatous species such as *Lolium perenne* (young leaves and stems) and below-ground in rhizomatous species like *Paspalum dilatatum* (rhizomes) (White 1973; Vartha & Bailey 1980). The carbohydrate concentrations in herbage of temperate species were usually higher than in the herbage of subtropical species (Smith 1973; Wilson & Ford 1973; Noble & Lowe 1974; Forde et al. 1976). Seasonal carbohydrate levels in temperate grasses were highest in winter and late-spring and were lowest in summer and autumn (Noble & Lowe 1974; Vartha & Bailey 1980). In subtropical species, seasonal carbohydrate levels were highest in autumn and were lowest in the late-spring/early-summer (Cook 1966; Humphreys & Robinson 1966).

Carbohydrate reserves can be used for respiration and limited growth during winter and for the initiation of early spring growth. They may also be required for regrowth after foliage removal and at any time that photosynthesis cannot meet the demands of the plant (Cook 1966; Trlica & Singh 1979; Menke & Trlica 1981). Nitrogen reserves may also be mobilised and translocated to growing points during periods of high demand (Trlica & Singh 1979). Many experiments have investigated the effects of defoliation on regrowth; most researchers have emphasised the interaction of reserve carbohydrates, the photosynthetic capacity of the remaining stubble, and the size of the root system (Section 1.2.5).

There are conflicting reports on the role of carbohydrate reserves in regrowth after defoliation (Harris 1978). From a review of below-ground development and reserves in grasses, Weinmann (1948) suggested defoliation by cutting or grazing reduced the level of carbohydrate reserves in below-ground parts. The degree of reduction depended on the intensity of defoliation, the species concerned and the environmental conditions. May & Davidson (1958) and May (1960) doubted this interpretation; they considered the reduction in carbohydrate present in roots and stems was largely due to its continued use as a respiratory substrate. Carbohydrate reserves were thought to be of minor importance as a substrate for synthesis of new growing points. Other workers also support the latter viewpoint (Jameson 1963; Humphreys & Robinson 1966; Marshall & Sagar 1965; Harris 1978). For example, Humphreys & Robinson (1966) considered a minimal residual leaf area to be of greater importance than reserve carbohydrates in the regrowth of *Panicum maximum* and *Cenchrus ciliaris* in a subtropical environment. On the contrary, Adegbola (1966) found a positive correlation between reserve carbohydrate and regrowth in *Panicum maximum* and *Cynodon plectostachyus* in a similar environment. Harris (1978) considers reserve carbohydrate to be unimportant in the regrowth of temperate ryegrass/white clover pastures in New Zealand. Nevertheless in a recent review, Dorrington Williams (1970) suggested reduced growth rate and sward deterioration under frequent and intense cutting was probably caused by depletion of carbohydrate reserves because of excessive use of nitrogen fertiliser under conditions of high temperature and water stress. Recent findings of Ennik et al. (1980) and Alberda and Simba (1982) support this conclusion.

The experiments of Pearce et al. (1969) and Smith & Marten (1970) using radiocarbon assays have provided direct evidence for the use of carbohydrate reserves in the regrowth of *Medicago sativa*, but Marshall & Sagar (1965) were unable to demonstrate this effect using similar assays of seedlings of *Lolium multiflorum*. However, Watson & Ward (1970) showed for small *Paspalum dilatatum* plants that total nonstructural carbohydrate levels in roots and stem bases (including any rhizome development) were reduced by clipping all tillers to 25 mm. If 10% or more tillers were left intact reserve levels were unaffected. Bommer (1966) has also reported a reduction in total nonstructural carbohydrate reserve levels in stubble and roots of *Lolium perenne*, *Festuca pratensis* and *Arrhenatherum elatius* for frequently compared to infrequently cut plots. It seems that both reserve carbohydrates and residual leaf area contribute to regrowth in grasses. Reserves are important to tiller and plant survival (Alberda 1966; Leafe et al. 1974; Ennik et al. 1980) when a negative carbon balance exists as determined by severe defoliation (no residual leaf area) or rapid growth conditions (eg. with excessive use of nitrogen fertilisers). If photosynthetic tissue remains after defoliation, the involvement of reserves in regrowth is likely to be smaller.

Harris (1978) considered involvement of reserves in regrowth and persistence to be more important where growth has been previously retarded by periods of climatic extremes such as low temperature and drought. Storage organs for accumulation of reserves are an adaptation of perennial plants to these environments (Harris 1978). If a severe defoliation reduces reserves before the onset of a stress period, survival and regrowth when favourable conditions return may be hindered. For example, Jones (1969) reported variation in the ability of *Panicum* and *Paspalum* spp. to over-winter following severe defoliation, whereas invading plants of *Paspalum dilatatum* and *Pennisetum clandestinum* showed no mortality under the conditions of the experiment. The most frost resistant grasses in terms of carrying green leaves through or into severe frosts were *Chloris distichlophylla*, *Paspalum dilatatum*, *Seteria sphaelata* and *Pennisetum clandestinum*. With a frost temperature of -2.5 °C, Hacker et al.

(1974) demonstrated that ranking order for frost tolerance was not associated with differences in concentrations of alcohol soluble carbohydrates in leaves of *Setaria* and *Paspalum* spp. However, *Paspalum dilatatum* had the highest frost tolerance of all tropical grasses tested which is similar to the finding of Jones (1969).

1.2.5 Root growth

This section briefly reviews the morphology and function of graminaceous root systems, then discusses factors affecting the growth and distribution of roots in soils.

1.2.5.1 Function and morphology

The functions of the root system are anchorage, water and nutrient absorption, and storage of metabolisable reserves such as soluble sugars and proteins (Troughton 1957).

Grass root systems consist of seminal or primary roots which arise from primordia present in the embryo contained in the seed, and nodal or secondary roots, produced after seminal roots, usually from stelar tissue of nodes on the true stem, rhizome or stolon (Troughton 1957; Brouwer 1966). Seminal roots are usually fine (diameter less than 3 mm), consist of profusely branched main roots, and function for a variable length of time in providing water and nutrients for the seedling. Nodal roots are thin, fibrous and profusely branched, and are thought to have a lesser water and nutrient absorbing capacity than the seminal roots (Troughton 1957; Brouwer 1966).

Nodal root growth in temperate grasses reaches a peak in spring and declines over summer probably because of high soil temperatures in surface layers (Stuckey 1941; Jacques & Edmond 1952; Garwood 1967). Root growth increases again in autumn and these roots live for a few days or for several months. Some roots produced in spring and some of those surviving from the autumn continue to grow in the lower soil horizons during early summer, and probably function in water absorption (Garwood 1967). Information is scant for subtropical grasses but Ueno & Yoshihara (1967) suggested for *Paspalum dilatatum*, *P. notatum* and *Chloris gayana* that root growth was greater during summer than for temperate grasses (eg. *Lolium perenne*). This finding suggests the optimum temperature for root growth of subtropical grasses is higher than that for temperate grasses.

1.2.5.2 Factors affecting root growth and distribution

According to the extensive review of Troughton (1957), root depth increases rapidly during seedling growth of the grass plant and reaches a maximum during the second year's growth. Plant species with greater total root length generally show a deeper penetration and spread of roots, although evidence is scanty. Roots are not equally distributed throughout the soil profile and tend to occur mostly in the upper layers of soil (Troughton 1957; Evans 1978). Their actual distribution, however, is affected by many environmental factors including surface applied fertiliser, defoliation management, soil physical conditions (Cornish 1981) and plant species. The following examples illustrate some of these effects.

Doss et al. (1960) observed that in a fine sandy loam soil the rooting depths of *Paspalum dilatatum*, *P. notatum* and *Cynodon dactylon* were greater in soils with low compared to high moisture levels. Root length for *Paspalum dilatatum* varied from 100 cm to 75 cm at the respective moisture levels. Evans (1978) found the roots of *Dactylis glomerata* to be at a greater depth than *Lolium perenne* in a free-draining sandy loam soil during a dry summer, the former being the more drought tolerant species (Langer 1973). From 59 to 81% of the roots (length per 1000 g of dry soil) of all species tested were in the upper 20 cm of soil and the numbers of roots decreased down to 100 cm depth. Using labelled (P^{32}) superphosphate placed at various depths in a virgin sand, Burton et al. (1954) reported the rooting depths of *Paspalum notatum*, *P. dilatatum* and *Cynodon dactylon* to be 60, 120 and 240 cm, respectively, after 15 months growth. Root penetration was increased in the first but not the second year by the surface application of 224 kg N/ha. After 23 months growth about 90% of the roots (dry weight basis) of drought susceptible species were located in the upper 60 cm of soil while drought tolerant species such as *Cynodon dactylon* had only 65% of its roots in this region.

Jacques (1941) traced root penetration of autumn (March) and spring (August) sown perennial ryegrass and white clover in paddocks rotationally grazed by sheep. Root penetration by the following February had reached 198 and 115 cm (autumn sown) and 150 and 103 cm (spring sown), respectively. In summarising the literature, Troughton (1957) reported that perennial ryegrass roots had been found to penetrate to depths of 58-143 cm after 4-18 months growth in diverse European environments.

Most workers (eg. Jacques 1941; Burton et al. 1954; Troughton 1980) emphasise the importance of deeply penetrating roots to keep the plant adequately supplied with water and possibly nutrients during dry weather. Deeply penetrating roots usually confer a competitive advantage over shallower rooting species (Haynes 1980). The volume of soil within the cylinder formed by the root hair tips may also be important in determining the plant's ability to compete for water and nutrients. In this respect, Evans (1977) found the root morphology of grasses (eg. *Lolium perenne*, *Dactylis glomerata*) to be superior to that of clovers (eg. *Trifolium repens*, *T. pratense*).

Since root extension is very sensitive to changes in carbohydrate supply from the shoots (Brouwer 1966; Evans 1971), factors causing reduced supply, such as periods of shading (Black 1957) and defoliation (Weaver 1930; Jacques 1937; Lovvorn 1944, 1945; Baker 1957a,b; Brouwer 1966; Evans 1971, 1972), can rapidly reduce root growth. Black (1957) cites a number of experiments including that of Watkins (1940) where 'root' and 'rhizome' fractions of shaded *Bromis inermis* were reduced by 70% compared with unshaded plants. Above-ground fractions ('hay' and 'stubble') were reduced 35% due to shading. It also has been demonstrated (Lovvorn 1945; Davidson & Milthorpe 1966; Evans 1971) that the more frequent and severe the defoliation, the less the root elongation and the greater root death.

Increased nitrogen supply can also result in a reduction in root mass. Ennik et al. (1980) reported that herbage yield of a perennial ryegrass sward increased and root mass decreased with increased nitrogen supply at two, four or six week cutting intervals. Nevertheless, in summarising early experimental results, Troughton (1957) considered defoliation effects on root mass to be greater than the effects of supplying extra nitrogen fertiliser.

Underground rhizomes or stolons of some perennial grasses favour persistence when plants are subjected to severe or continuous defoliation regimes (Weaver 1930; Weinmann 1948; Jones et al. 1969; Harris 1978) or heavy treading (Edmond 1966; Hunt 1979). Surviving periods of environmental stress such as frosting or drought is also aided by the possession of rhizomes (Harris 1978; Davies & McNaughton 1980) (Section 1.2.5). Examples of rhizomatous (or stoloniferous)

C_3 species are *Agropyron repens*, *Agrostis tenuis* and *Poa trivialis*, while C_4 species are *Paspalum dilatatum*, *Pennisetum clandestinum* and *Cynodon dactylon*. Rhizomes function as storage organs for carbohydrate, nitrogen and elemental reserves (Troughton 1957), and as a means of vegetative reproduction (Evans & Ely 1935).

1.3 PLANT COMPETITION

1.3.1 Definition

There are varying interpretations or disagreements with the usage of the term 'competition' in plant ecology. The classical definition of plant competition (Donald 1963; Etherington 1975) is that of F.E. Clements as reported by Clements et al. (1929):

> 'Competition is purely a physical process. With few exceptions, such as crowding of tuberous plants when grown too closely, an actual struggle between competing plants never occurs. Competition arises from the reaction of one plant upon the physical factors about it and the effect of the modified factors upon its competitors. In the exact sense, two plants do not compete with each other as long as the water content, the nutrient material, the light and the heat are in excess of the needs of both. When the immediate supply of a single necessary factor falls below the combined demands of the plants competition begins.'

Recently (Hall 1974a, 1978) pointed out that Clement's definition of competition does not include other mutual influences (eg. allelopathy) which may largely determine the success or failure of a species. Some researchers have also included symbiotic relationships where the interference effects are positive in nature. Hall does not accept the latter inclusion and prefers Harper's broader definition (Harper 1961), substituting 'plant interference' for 'plant competition'. Plant interference may be defined as 'the response of an individual plant or plant species to its total environment as this is modified by the presence and/or growth of other individuals or species'. Hall (1974a) considers competition to be a facet of interference but concedes that often it may be the one having the most influence on the plant response. Furthermore, Hall (1974a) divides 'interference' into 'competitive interference' whereby one species directly affects the growth of the other by competing for resource(s) potentially available equally to both; and 'non-competitive interference' whereby associated plants mutually benefit from their association, for example, grasses and legumes.

De Wit (1960) refers to 'competition for space' between species, where space is interpreted in a biological sense representing a composite of growth factors and resources. He argues that 'space' embraces all factors and they should not be referred to individually as it is probably impossible to isolate one factor without affecting the whole system. The evidence reviewed by Harper (1977) (Section 1.3.2) supports this assertion. Nevertheless, both Donald (1963) and Hall (1974a) have argued against the use of the term 'space' as it evades the need to recognise the actual factor for which competition is occurring. Thus, when a single limiting factor can be identified de Wit's approach precludes the possibility of rectifying the situation.

Grime (1979) prefers not to dispense with the term 'competition' but suggests a precise definition of competition which relates to its mechanisms rather than its effects. He defines competition as 'the tendency of neighbouring plants to utilise the same quantum of light, ion of a mineral nutrient, molecule of water, or volume of space'. This clarifies the definition of competition as it refers solely to the acquisition of essential resources by plants. Other processes such as allelopathy or symbiosis which may also influence vegetation composition and distribution are excluded. Competition is therefore viewed as only part of the mechanism whereby a plant may reduce the fitness of a neighbour by modifying its environment. Emphasis on the classification of mechanisms whereby certain plants are successful in pastures should increase agronomic understanding of the reasons for the observed changes in botanical composition. Thus the definition of competition given by Grime (1979) is considered appropriate to this study.

1.3.2 Competition for environmental factors

Plants may compete for any environmental growth factor for which they have a common requirement. Competition may be for light, carbon dioxide, nutrients, water, oxygen and space (Harper 1961; Donald 1963; Risser 1969; Rhodes 1970; Etherington 1975; Grime 1979). Competition in pastures is generally for light, nutrients (especially nitrogen) and water, as these are most often deficient (Donald 1941, 1956, 1963; Milthorpe 1961). Environmental factors like temperature and humidity may also influence the outcome of competition (Donald 1963; Harris et al. 1981a,b) by modifying competitive ability.

As competition commonly involves more than one factor at a time (Donald 1958, 1963; Harper 1977) problems of interpretation arise. For example, if a particular plant is able to obtain a greater share of a limiting nutrient the resultant increased growth and stature may suppress competing species secondarily by shading. Furthermore, Harper (1977) states bluntly (p. 348) that 'the analysis of which particular factors act in any one effect of neighbour on neighbour is bound to be extremely difficult ..... the establishment of causation is usually barred to the scientist, who has to be content with correlation'.

This situation has forced experimenters to examine the growth of associated species (usually two) in environments which provide control over particular variables allowing others to be studied in isolation. In pot studies, partitioning of above- and below-ground environments of the test plants have been widely used (Donald 1958; Aspinall 1960; King 1971; Eagles 1972; Remison & Snaydon 1978) with the aim of quantifying the relative roles of competition for light or nutrients. The limitations of this approach have been discussed by Harper (1977) and Hall (1978). A number of researchers have used the de Wit model of competition to quantify competitive effects (de Wit 1960; van den Bergh & Elberse 1962; de Wit & van den Bergh 1965; de Wit et al. 1966; van den Bergh 1968; Harris 1970, 1973; Harris & Thomas 1970, 1972, 1973; Hall 1974a,b; Harris et al. 1981a,b; Gillard & Elberse 1982; Sangakkara & Roberts 1982). In these experiments two species are deliberately arranged in artificial swards or pots so that the overall density in all treatments remains the same, that is, a 'replacement species' experimental design. The growth of each species in the mixtures is then compared with its growth in a pure stand where the 'degree of competition' or aggressiveness of one species towards another can be described mathematically. This approach was used in one experiment described here and theoretical considerations in the use of the de Wit model of competition are discussed in Section 1.3.6.

All the above testing procedures involve a degree of artificiality. Harper (1977) in discussing interactions between species (p. 349) states: 'There is room for much scepticism in the interpretation of competition experiments, particularly when they are applied to the field.' Hall (1978), however, concludes his review by suggesting that despite these limitations, the potential for species to compete with one another under the conditions of these experiments had been forcefully demonstrated.

Interest in plant competition in pastures has been stimulated since the 1920's with the widespread practice of sowing mixtures. Furthermore, the suggestion from theoretical studies that mixtures of grasses might be more efficient at utilising the available environmental resources than monocultures, gave impetus to studies of competition between pasture plants (Rhodes 1970). However, there have been few studies of competitive stress in pasture plants under cutting or grazing (Rhodes 1970), probably because the agronomic requirement has been for data on area yield and mean plant response (Etherington 1975).

Various authors (Donald 1963; Harper 1964; Black 1966) have emphasised that competition operates essentially at the individual plant level. The phenomenon involves (a) the modification of the environment by the presence of a plant and (b) the effect of these modifications upon surrounding plants. However, results of interactions at the plant level may be expressed in terms of higher levels (eg. dry matter yield per hectare of a pasture or plant population). Harris (1970, 1971) has also recognised the need for development of techniques whereby individual pasture plants and their component parts can be studied in a mixed sward, thus allowing for full expression of their competitive characteristics which determine their yield contribution to the sward.

There are few published reports of plant competition studies in warm-temperate, subtropical or tropical environments. Competitive interactions between species of temperate and subtropical origins have also received scant attention despite advocacy of combinations of species with different growth rhythms (Harris & Lazenby 1974; Harris et al. 1981a,b) as a possible means of increasing annual yields in warm-temperate regions.

1.3.2.1 Competition for light

Competition for light is a common occurrence in pastures. Donald (1963) considers that even if supplies of water and nutrients were limited, plant growth would have to be severely reduced before competition for light did not occur. Interference with the supply of light is considered by Harper (1964) to be the most effective means by which one species may succeed at the expense of another. He suggests the roles of water and nutrients in competitive interactions may often be in modifying the timing and extent of competition for light.

Competition for light is least during early stages of plant establishment and immediately following defoliation (Rhodes & Stern 1978). Donald (1961) considers competition for light to be independent of light intensity as plant canopies will develop to a point where competition for light is so intense that some leaves begin to senesce. The extent of senescence depends on the depth of canopy rather than the degree of competition. Thus a dense healthy sward resulting from adequate water and nutrient supplies may give rise to intense competition for light (Donald 1963). It is obvious that light cannot be considered as a factor for which competition occurs in isolation, since it often finds expression through interactions with other factors (Donald 1963; Rhodes & Stern 1978).

Donald & Black (1958) noted the importance of leaf position in a canopy and that 'overtopping' usually confers a competitive advantage for light. Mitchell & Calder (1958) found that plant height and growth habit influenced the proportion of light penetrating to various depths in the sward canopy. For example, with erect ryegrass pastures much light penetrated a considerable depth into the canopy while 85% of the incident light was intercepted by the upper surfaces of a clover canopy. Monsi & Saeki (1953) using a 'stratified clip' technique, whereby competing plants were harvested in successive layers from the surface downwards, demonstrated the importance of plant height in competition for light. According to Clements et al. (1929) difference in height of only 1 mm may be significant in competition for light as it may cause a particular leaf to overlap another. Variation in clover petiole length also has considerable influence on growth of clovers (Black 1958; Brougham 1958).

One of the few studies of competition in grazed swards was conducted by Norman (1960). He compared 'competition' plots (normal growth of test species like *Dactylis glomerata* and *Festuca rubra*) over the experimental period, with 'no competition' plots (herbage trimmed to ground level around the same test species). The plots were grazed by cattle or sheep. Competition from surrounding species reduced the yield of all test species and also increased their height and susceptibility to the effects of grazing. Although Norman emphasised competition for light in explanation of his results, the technique used did not separate shoot and root competitive interactions.

1.3.2.2. **Competition for water and nutrients**

Root morphology and the distribution of roots in soil (Section 1.2.5) strongly influences competition between plants for water and nutrients. For one plant to gain an advantage over another in competition for water and nutrients, a faster growing root system (greater length of root) is required (Trenbath 1974). Since root competition is probably more important than shoot competition during establishment (see below) this evidence suggests a correlation between seedling competitive ability and early root production (Rhodes 1970; Cook 1980). For plants with similar root lengths, the one with the most widespread root system will be advantaged. This early competition by the root systems will modify the timing and extent of the development of competition for light (Rhodes 1970).

Differences in root hair production can have an important influence on competition for available nutrients (Trenbath 1974; Evans 1977, 1978). As grasses possess longer and greater numbers of root hairs than do clovers, Evans (1977) postulated that in grass/clover pastures, these differences could disadvantage clovers in water and nutrient uptake, especially for immobile nutrients such as phosphorus. Levels of mycorrhizal infection of roots also influence uptake of phosphorus (Powell 1979).

(a) *Water*

Most pastures depend largely on rainfall for their source of water, and where rainfall is irregular, water deficits develop which can severely limit productivity and persistence of perennial plants (Lucanus et al. 1960; Baars & Coulter 1974; Turner & Begg 1978). The ability of plants to compete for water depends on the rate and completeness with which they can make use of water stored in the soil (Haynes 1980) and this capacity is influenced by many genotypic attributes (Donald 1963).

It has been recognised that grasses vary in their ability to take up water during dry periods and that drought tolerance appears largely to be determined by the volume of the soil exploited by the roots for water (Garwood & Sinclair 1979). Garwood & Sinclair (1979) showed that the drought tolerant *Festuca arundinacea* could obtain water from a depth greater than 100 cm whereas the less tolerant *Lolium perenne* was able to utilise water from an 80 cm soil depth. Hebblethwaite & McGowan (1977) grew *Lolium perenne* on a clay soil which was subject to waterlogging in winter to a level of about 50 cm from the surface. During the spring of two years, roots extracted water from about 105 cm depth in the soil profile which roughly agrees with the findings of Garwood & Sinclair (1979). Turner & Begg (1978) indicated that although plants may have roots penetrating the deeper and wetter parts of the soil profile, growth may be limited more by the relative lack of nutrients in the subsoil and the unavailability of nutrients in the dry surface soil, than by the soil water deficit *per se*. Surface dryness curtailed production of new *Lolium perenne* roots in the experiment of Troughton (1980) and deep roots were necessary to keep plants alive during dry periods. There was a rapid resumption in root production when soil surfaces received further moisture. Milthorpe (1961) and Hoen (1968) showed that the production of an extensive root system, ability to obtain water, and drought resistance, were associated with the attainment of a large leaf area. Smaller plants experienced a shortage of water at a lower water deficit and the water shortage itself lead to further decreases in growth and death of many roots (Milthorpe 1961).

Turner & Begg (1978) concluded there were insufficient data comparing morphological and physiological responses of different species grown under the same conditions. It was therefore not possible to predict either the effects of water deficits on mixed communities, or the effects deficits would have on competition between species.

(b) *Nutrients*

To enable the separation of competition for nutrients and water (root competition) from competition for light (shoot competition), Donald (1958) grew plants in pots allowing for various partitionings of the shoot and root environments. This technique has since been modified (Rhodes 1968c; Snaydon 1971; King 1971; Eagles 1972; Remison & Snaydon 1978, 1980a,b) and used to study the nature of competition between pasture plants including *Lolium perenne*, *Festuca* spp., *Dactylis glomerata*, *Holcus lanatus*, *Anoxanthum odoratum* and *Trifolium repens*. The experiments indicate that root competition is usually greater than shoot competition especially during the few months following planting. Surface concentration of roots hastens the overlap of depletion zones around individual roots and leads to an overestimation of the agronomic effect (eg. reduced yield) of competition for nutrients (Trenbath 1974). Donald (1958) and Milthorpe (1961) have also shown that interactions between shoot and root competition can occur.

Application of fertiliser (nitrogen and phosphorus) generally increased the root competitive ability of the aggressor species over the suppressed species (King 1971; Remison & Snaydon 1980a). Dominant species (eg. *Lolium perenne*) were able to inhibit responses of suppressed species (eg. *Festuca rubra*) to nitrogen and phosphorus fertiliser applications (King 1971; Harris 1973). King (1971) suggests, therefore, that the dominance of established species should be reduced by the use of mechanical or chemical treatments to improve the chances of survival of establishing seedlings. Similar experiments concerned with mixtures of subtropical, tropical or subtropical and temperate species have not been reported. However, Cook (1980) has published a general review of the major factors affecting establishment of oversown pasture species in the subtropics and tropics of Australia. He considered that root competition between the resident vegetation and establishing seedlings was the major factor limiting seedling growth and survival.

Most published reports have been concerned with competition for major elements such as nitrogen, phosphorus, potassium and sulphur. Bray (1954) has hypothesised that competition is likely to be greatest for the relatively soil-mobile elements such as nitrogen and sulphur rather than the relatively immobile elements such as phosphorus. A zone of depletion around roots for mobile elements is likely to develop earlier in growth than for immobile elements, thus competition between root systems may occur during early growth (see above).

On a worldwide basis more crops are deficient in nitrogen than in any other element (Viets 1965). Competition for this nutrient therefore most often arises (Donald 1963). Most agricultural plants, particularly grasses, have been selected for their high vegetative or reproductive yields and can be demanding nutritionally (Donald 1958; Etherington 1975). Productive grasses like *Lolium perenne* were able to respond to nitrogen fertiliser and dominate less productive grasses like *Poa trivialis*, *P. annua*, *Dactylis glomerata*, and *Festuca pratensis* (Castle & Holmes 1960; Haggar 1971; Charles et al. 1979). This was achieved provided high levels of phosphorus and potassium were also available (Castle & Holmes 1960; van den Bergh & Elberse 1962; Hopkins & Green 1979).

Some authors consider nutrient competition to be an important factor in the process of pasture degeneration. The succession occurring during degeneration is commonly associated with depletion of soil fertility and pasture management. Blaser and Brady (1950) showed that the application of nitrogen fertiliser to grasses increased their growth and their uptake of potassium, thus increased competition for potassium also reduced the growth of the legume associate. Cook et al. (1978a,b) showed that high annual inputs of superphosphate were required for sown *Lolium perenne* to persist in pastures in the Northern Tablelands of New South Wales. Fertiliser level influenced the ability of the sown grass to develop its potential vigour and competitive ability, and was therefore an important determinant of botanical composition. This finding agrees with the suggestions of King (1971). For seedling establishment and development in an existing grass sward, nutrient competition may help maintain the existing pasture composition, unless the dominance of the established species can be reduced by some means (King 1971).

1.3.3 **Competition and genetic composition of survivors**

Most of the considerable mortality that occurs during pasture establishment when competition is intense may be non-selective in nature (Snaydon 1978). An extensive series of experiments in Britain by A.H. Charles, however, has demonstrated substantial changes after a few years in the genetic composition of survivors in populations of *Lolium* spp., *Dactylis* spp., *Phleum* spp., *Trifolium repens* and *T. pratense* (Charles 1961, 1964, 1966, 1968, 1970, 1971, 1972). Changes in herbage accumulation, tillering, flowering date, leaf size, plant height and other characteristics were observed, all of which were modified by grazing management, fertiliser treatment and the presence of other species. Brougham and co-workers in New Zealand reported similar findings for ryegrass cultivars under various grazing managements (Brougham et al. 1960; Brougham & Harris 1967; Harris &

Brougham 1970). Snaydon (1978) concluded that competition is probably the most important factor accelerating the rate of change in genetic structure of established swards. The work of Charles (1971, 1972) indicates that the surviving *Lolium* genotypes were generally more productive than the original cultivar, and they survived better in swards under the particular conditions where they had persisted, namely, high nitrogen fertiliser inputs and intensive grazing management.

1.3.4 **Allelopathy**

Competition (Section 1.3.1) is the mechanism by which one plant interferes with the growth of another by depleting some essential growth factor to a level that is limiting to the growth of the second plant sharing the habitat. Allelopathy is the inhibition of plant growth caused by the release of phytotoxic substances from neighbouring plants (Tukey 1969; Bell & Koeppe 1972; MacFarlane et al. 1982a). The effects of competition and allelopathy are often confused (MacFarlane et al. 1982a) and the contributions of competitive versus allelopathic attributes to interactions between plants have rarely been studied (Putnam & Duke 1978).

Reviews of allelopathic interactions between plants include Bonner (1950), Woods (1960), Garb (1961), Tukey (1969), Etherington (1975) and Haynes (1980). Emphasis here is on the results of experiments with plants used in agriculture.

Substances potentially involved in allelopathy are liberated from plants by (a) leaching of foliage by rain or dew (b) abscission and litter fall (c) volatilisation from foliage (d) and root exudation (Tukey 1969). Patrick (1971) concluded that there is a high probability that phytotoxic substances are produced during decomposition of plant residues in soil. Allelopathic substances include phenolic acids, flavonoids, terpenoid substances, alkaloids and organic cyanides (Whittaker 1971; Whittaker & Feeney 1971), compounds which remain in the soil for varying lengths of time depending on microbial activity (Börner 1971).

Plants may also exhibit autotoxic effects, whereby substances produced by some species are toxic to themselves. Newman & Rovira (1975) reported this effect for *Lolium perenne* while a similar effect has been demonstrated for *Trifolium repens* (Scott 1975; MacFarlane et al. 1982a,b). Some workers consider the 'sod-bound' condition often found in old brome-grass paddocks to be due to the accumulation of a toxic substance excreted by the roots or produced during decomposition of root tissue (Benedict 1941; Myers & Anderson 1942).

Most evidence for allelopathic interactions between plants has come from laboratory experiments involving applications of plant extracts or exudates to test plants (Hoveland 1964; Grant & Sallans 1964; Overland 1966; Scott 1975; MacFarlane et al. 1982a). The phytotoxic substances affect germination and often the subsequent growth of the plants. This type of experiment demonstrates the possibilities of different sorts of effects and increase the likelihood of field recognition (Harper 1977; MacFarlane et al. 1982a,b).

Demonstration of allelopathic interactions between plants in the field is difficult (Kershaw 1964; Harper 1977). This is because competitive interactions for limiting environmental factors may occur at the same time (Kershaw 1964; Harper 1977; Young & Bartholomew 1981). For example, Donald (1946) was unable to reproduce the findings of Ahlgren & Aamodt (1939) of an interaction between clovers (*Trifolium hybridum* and *T. repens*) and *Poa pratensis*.

Harper (1977) criticised many experiments cited by Rice (1974) as evidence for toxic interactions in nature. Two reasons suggest toxic interactions may be uncommon in higher plants: (i) higher plants have shown rapid ability to evolve tolerances to environmental toxins such as lead and zinc (ii) there is a high probability that compounds regularly released from plants are rapidly broken down by the soil microbial population (Harper 1977).

Poor germination and growth of seedlings following renovation of pastures by direct drilling, especially if herbicide band-spraying is incorporated, may be a result of the release of allelopathic substances from trash (Field 1979; Habeshaw 1980).

Trenbath (1974) suggests that due to the extreme experimental difficulties encountered in studying allelopathy under field conditions, workers have been cautious in assigning allelopathy as the cause of neighbour effects. So called effects of competition could be the result of combinations of effects of competition and allelopathy, especially if competition for nutrients is being investigated.

1.3.5 **Competitive ability**

Competitive ability depends on a combination of plant characteristics. It is a function of the area, the activity, and the distribution in space and time of plant surfaces through which resources are absorbed (Grime 1979). The physiological and morphological characteristics of plants influencing their competitive abilities have been discussed above; emphasis here is given to the contribution of seed and seedling characteristics.

Seed size has often been assumed to be a sound predictor of success of establishment and vigour of a sward (Chippindale 1932; Davies 1960; Milthorpe 1961; Hayes 1975; Cook 1980), and therefore of importance to interspecific competition (Blaser et al. 1956). For example, Hayes (1975) found plants derived from large seeds of *Lolium perenne*, *Festuca arundinacea* and *Holcus lanatus* produced a greater number of tillers, more leaves, greater leaf area and greater dry weight than plants derived from small seeds, especially up to four weeks from planting. Cook (1980) also implicated large seed size in the success of some subtropical species. Plants grown from large seeds of *Lolium* (*multiflorum* x *perenne*) and *Phalaris coerulescens* were found by Rhodes (1968a) to be more competitive and larger than plants grown from small seeds. In contrast, Naylor (1980) considered individual seed size was a poor predictor of emergence time, subsequent tillering and production in a *Lolium perenne* cultivar. Furthermore, as Troughton (1963) demonstrated a positive relationship between tillering and nodal root production in *Lolium perenne*, Rhodes (1970) suggested that the effect of seed size on tillering may merely reflect differences in nodal root production, which in turn is reflected in competitive ability.

Many authors consider rapid germination and the prior occupation of the soil by one species to be an important factor affecting competitive ability (Blaser et al. 1956; Mouat & Walker 1959; Milthorpe 1961; King 1971). Rapidly germinating species usually become increasingly dominant over competitors (Milthorpe 1961).

Rapid tillering during establishment improves the competitive ability of the plant by rapidly providing sufficient leaf area for complete light interception (Jewiss 1972). Although competitive ability may change with growth stage and age (Charles 1961; Rhodes 1968b), the work of Charles (1961) demonstrates the importance of competitive ability during the establishment phase. At two and 12 months from sowing, surviving seedlings of *Lolium*, *Dactylis* and *Phleum* cultivars represented only 20 and 10%, respectively, of the viable seed sown. Similar high losses of plants during establishment has been reported by Langer et al. (1964) for *Phleum* and *Festuca* swards and by Harris (1973) for ryegrass cultivars. Generally, plant numbers declined dramatically during establishment and populations changed from many plants with few tillers to few plants with many tillers. High plant losses occur when seed or small plants are introduced into established swards (Snaydon & Bradshaw 1962; Harper 1967; Davies & Snaydon 1976).

Plants which dominate a particular community (often expressed as a larger size than its associates) depend on a superior competitive ability to suppress the fitness of its neighbours. The attainment of a large size has been shown to be advantageous in many interactions which occur between species or between individuals of the same species (Langer et al. 1964; Hoen 1968; Harris 1973; Grime 1979). Dominance is recognised as part of the mechanism controlling the composition of plant communities and the differentiation of vegetation types (Grime 1979). The impact of the dominant plant (eg. by shading or nutrient depletion) can occur at any stage of the life cycle of neighbouring plants but its greatest affect is at the seedling stage (Milthorpe 1961; Grime 1979). The dominant plant is able to expand during the growing season and produce larger zones which are depleted of the resources required by the smaller neighbours. The subordinate neighbours display high rates of mortality with low rates of reproduction, until the growth of the larger species, if unchecked, continues the exclusion process and the community tends towards a monoculture (Grime 1979).

1.3.6 Competition models

Models have been developed to study the population dynamics of various plant species (eg. Antonovics 1972; Sarukhán & Harper 1973; Watkinson & Harper 1978; Turkington & Harper 1979). These take the plant demographic approach or the description and interpretation of plant numbers in consecutive phases of the plant's life cycle. A second approach, that of competition, analyses plant interference during the phase of active growth (de Wit 1960). Others have developed formulations describing the effects of density on intraspecific competition (eg. Kira et al. 1953; Koyama & Kira 1956) in populations of plants undergoing increasing levels of competitive stress. Emphasis is given here to the de Wit (1960) approach to aid the description of competitive interactions in mixed populations of pasture grasses.

There are two experimental designs most used to analyse interactions between species in mixtures. The first is the diallel arrangement and the many developments in the statistical analysis of this design are summarised by Trenbath (1978). Test species are grown in monoculture and all possible binary combinations. All plots (or containers) are sown with a constant overall density of plants, and 1:1 proportions are used in the mixtures (Trenbath 1974). The second is the replacement series experimental design introduced by de Wit (1960). This design includes a range of species proportions and has been shown (Trenbath 1978) to provide a more accurate assessment of the observed behaviour of species in mixtures than does the simpler 1:1 diallel design. Analyses of the replacement series have been identified as 'empirical' (eg. Hill & Shimamoto 1973) and 'rational' (eg. Hall 1974a, Trenbath 1974). Trenbath (1978) favours the rational model which assumes species yield will be non-linear with species frequency, as opposed to the simpler model of Hill & Shimamoto (1973) which predicts a linear relationship.

When a replacement series experimental design is used, 'competitive power' is measured by the relative crowding coefficient (de Wit 1960). The relative crowding coefficient (k) for species 'i' grown in association with species 'j' in a two-component mixture is:

$$k_{ij} = \frac{0_{ij}z_j}{(M_i - 0_{ij})z_i}$$

where M_i is the per area yield of species i in its monoculture, 0_{ij} is the per area yield of species i in a mixture with species j, and z_1 and z_j are relative frequences of the species. The values of k for each species, k_{ij} and k_{ji} (and therefore the shapes of the curves derived from these coefficents), and their product are used to describe the level and type of interference occurring between two species (Hall 1974a). A constraint in the use of the relative crowding coefficient is that it remains constant over all species frequencies.

The de Wit model assumes that the limiting growth factor(s) is evenly distributed over the land surface but is unevenly shared between the components of a mixture (Hall 1974a; Trenbath 1974). It is also assumed that the response to increased uptake of the limiting factor is linear over the range of uptakes encountered. Thus the yield of each component of a mixture is strictly proportional to the share of the environmental factor it can acquire. When sharing is uneven, the yield of one component will be larger in mixture than in monoculture, while the yield of the other will be correspondingly smaller.

The relative crowding coefficient may not be appropriate if the combined yields of species in mixtures are not predictable from the monoculture yields (Harper 1977). In these cases it could be preferable to use the concept of 'Relative Yield' (R) where $R_i = \frac{O_{ij}}{M_i}$ is the relative yield of species i using symbols previously defined (de Wit & van den Bergh 1965). If the plant relative yield (based on this concept) of a component is defined as the ratio of the per plant yield in mixture to that in monoculture, then in such a mixture, the plant relative yield of the aggressor will be greater than unity while that of the subordinate will be less than unity (Trenbath 1974).

The sum of the relative yields for the two species in a mixture gives the 'Relative Yield Total' (RYT). A theoretical consideration of this concept is given by van den Bergh (1968). If the value of RYT is close to unity, it implies the two species are making demands on the same limiting resources of the environment. Alternatively, if RYT is greater than 1.0, the species make different demands on resources, avoid competition with each other, or are showing some form of symbiotic relationship. Values of RYT of less than 1.0 imply a mutual antagonism. In the situation where RYT = 1.0 the product of the crowding coefficient ($k_{ij} \times k_{ji}$), based on the yields per unit area for the mixture, is also unity. This situation is of particular ecological interest as Trenbath (1974) reported the mean RYT of 512 experimental mixtures of predominantly graminaceous species to be 1.027 ± 0.006, indicating that competition for the same resources is a common occurrence.

Trenbath (1974) provides a detailed review of possible interpretations when the yield of mixtures of the two species in a replacement design is above or below the mean yield of their monocultures.

1.4 PASTURE PRODUCTION AND PERSISTENCE

In this section pasture persistence and herbage mass responses to defoliation, the application of nitrogen fertiliser and the supply of irrigation water are briefly discussed. The effects of damage caused by insects, diseases and cow grazing on the competitive ability of pasture grasses are then discussed followed by a description of overdrilling procedures for the renovation of established dairy pastures. Finally, as the experiments described here are concerned with dairy pasture containing sown *Lolium perenne* and volunteer *Paspalum dilatatum*, a description is given of the origins of these species and of their management and productivity in mixed pastures, with particular reference to New Zealand.

1.4.1 Defoliation

Defoliation is normally defined in terms of three parameters (i) frequency - the time interval between successive grazings (ii) intensity - the proportion of herbage harvested at each defoliation (iii) timing - in relation to the season and stage of growth of the plants (Donald 1941; Harris 1978). Defoliation generally changes the competitive environment of the sward since it changes the structure of the sward (Hughes & Jackson 1974; Davies 1977). Thus defoliation interacts with environmental stresses in determining the botanical composition of the sward (Harris 1978).

Intensive and frequent defoliation of both temperate and tropical pastures generally results in a reduction in herbage mass (Hedrick 1958; Jameson 1963; Harris 1978). Paddocks intensively grazed by cattle usually develop a patchwork of contrasting areas (Hodgson 1973) ranging from severely to laxly grazed, which may reduce sward persistency for different reasons (Hughes & Jackson 1974).

Depending on the frequency and intensity of defoliation imposed on the sward, the effect of natural selection can determine sward structure. Kydd (1966) found intensive grazing by sheep lead to about 90% of perennial ryegrass plants having a prostrate growth habit. Charles (1970) showed that plants derived from seed harvested from grazed leys were generally more prostrate with a higher tillering capacity than plants grown from breeders seed. A similar situation has been reported for survivor plants of perennial ryegrass cut to a uniform height in six to 11 year old swards (Pike et al. 1979). Frequent defoliation caused the adaption to a prostrate growth habit while less frequent defoliation intervals greater than six weeks encouraged a more erect habit. Presumably the prostrate habit reduced the proportion of herbage harvested with the consequence that defoliation has a less profound effect on plant growth.

Long defoliation intervals generally increase herbage yield from ryegrass/clover pasture (Brougham 1959, 1960; Agyare & Watkin 1967). It is not the most appropriate method of utilisation for maintaining the sward as leaf and tiller death increases at higher leaf area indices (Langer et al. 1964; Hunt 1971; Woledge 1972). Similarly, hard grazing during a dry summer can weaken or kill ryegrass plants (Brougham 1960, 1961) while similar management during winter, spring and autumn has little effect. Brougham (1961) found a single defoliation in mid-summer of a *Lolium* (*multiflorum* x *perenne*) sward to about a 1 cm stubble height (previously defoliated to about an 8 cm stubble height), reduced its tiller density by 86% over a 69 day period. Such losses can have a detrimental effect on late-winter/ spring pasture production (Lancashire 1982). Dorrington Williams (1970) cites several instances of a high leaf area index causing a decrease in tiller density or complete failure to grow following defoliation. Increased leaf death at the base of the sward reduced tiller numbers because of severe shading (Section 1.2.2.1), a situation which is compounded in flowering crops shut up for hay or silage. Spaces left in the sward are rapidly invaded by weeds and weed grasses (Haggar 1971). Defoliation also rapidly reduces root growth (Section 1.2.5.2).

Genotypic persistency, like yielding ability, is a plant characteristic which can be strongly influenced by prevailing environmental and managerial factors such as soil conditions, defoliation regimes and the ability to withstand animal treading (Breese 1979). Breese (1979) points out that consistency of yield and persistency are often in conflict although both are to do with resistence to environmental stresses. For example, ryegrasses and clovers often avoid cold winter or dry summer conditions by invoking dormancy or restricted growth (Section 1.2.3). This may allow them to persist but prolonged seasonal production requires a different mechanism of cold and drought tolerance. The best survivors are not necessarily the most productive in any particular grassland system.

1.4.2 **Nitrogen fertiliser**

Many European reports (eg. Reith & Inkson 1961; Minderhoud et al. 1974; Prins et al. 1980; Laidlaw 1980; MacKenzie & Daly 1982) indicate a positive seasonal yield response to high rates of nitrogen fertiliser (up to 500 kg N/ha). Pure *Lolium perenne* swards with intensive cutting or grazing management were often involved.

Large herbage production responses to high rates of nitrogen fertiliser have also been reported for pastures containing species of subtropical or tropical origins (Evans et al. 1959; Ashley et al. 1965; Beaty et al. 1970; Cassidy 1971; Colman et al. 1974; Goold 1979). For example, Cassidy (1971) recorded a highly significant production response to spring and early-summer applications of 224 kg N/ha by *Paspalum dilatatum* growing in nitrogen deficient dairy pastures. Goold (1979) observed a linear response to nitrogen fertiliser increments up to 480 kg/ha for a sward dominated by *Pennisetum clandestinum*. The effect was greatest during winter and spring when *Poa* spp. made the largest contribution to herbage mass and in autumn when *Pennisetum clandestinum* was dominant. Bryant & Parker (1971) have also noted a similar influence of *Poa* spp. in swards containing *Paspalum dilatatum*. Garwood et al. (1980) showed the utilisation of nitrogen fertiliser by *Lolium perenne* was enhanced by irrigation when this was sufficient to account for soil water deficits at the time of cutting or grazing and application of fertiliser.

Nevertheless, detrimental effects of high nitrogen applications on sward persistency have been reported (Dorrington Williams 1970; Ishida 1975; Wilman et al. 1976; Bartholomew & Chestnutt 1977; Ennik et al. 1980; Alberda & Simba 1982), especially in combination with infrequent defoliation. Alberda & Simba (1982) suggested the increased herbage mass response to increased nitrogen and reduced defoliation frequency increased the risk of sward deterioration because of excessive mutual shading leading to tiller and plant mortality (Section 1.2.2.1).

In New Zealand, nitrogen fertiliser is not used extensively on ryegrass/white clover swards. Single tactical applications to improve the immediate feed supplies are made when soil mineralisation or supply from clovers does not meet the needs of the usually dominant grass component. The literature covering the use of nitrogen fertiliser on well developed pastures and under intensive grazing management has been recently reviewed (Field & Ball 1978; Ball & Field 1982; O'Connor 1982). Substantial reliable responses to nitrogen fertiliser can be obtained in late-winter/early-spring (July to September) to applications up to 50 kg N/ha. This is because mineralisation of nitrogen from soil organic matter is low and moisture levels and temperatures are usually adequate during this period for growth of *Lolium perenne*. Autumn response may be reduced by a previous dry period or lack of sufficient autumn rains, while responses in summer are often limited by periods of soil moisture deficit. The level of response depends on local weather conditions and the timing of the application and may range from three to 24 kg DM/kg N for 25 kg N/ha applied over the period June to October (O'Connor 1982). For predominantly dairying areas (eg. Waikato), small spring responses of 210 and 300 kg DM/ha to applications of 24 and 50 kg N/ha, respectively, were measured by O'Connor (1982) at the first cut after the application.

1.4.3 **Irrigation**

Irrigation studies in New Zealand have been concentrated in the drought prone areas of the South Island such as north and central Otago and the MacKenzie country (Radcliffe & Cossens 1974; Sheath et al. 1977; Scott & Maunsell 1981). Annual herbage mass increases of 200 to 300% over dryland pastures have been achieved. Similar results were obtained by Korte & Chu (1983) in the southern North Island (Manawatu).

Hutton (1978) in the Waikato reported positive herbage mass responses to irrigation during dry summers for pastures dominated by *Paspalum dilatatum*. In the same region during summer, irrigated ryegrass cultivars outyielded unirrigated cultivars by 60% (Baars et al. 1976). Hopewell (1958) and Baars et al. (1976) suggested that paspalum could be successfully combined with ryegrass and white clover in the Waikato, and that these pastures would be likely to respond to irrigation. Hopewell (1960) reported on average for an 11 year period, a 22 to 99% increase in annual herbage accumulation and a 37 to 575% increase in summer herbage accumulation for irrigated compared to unirrigated pastures in the Waikato. McAneney et al. (1982) have also reported responses to irrigation in the Waikato. They found the ratio of herbage accumulation on unirrigated relative to irrigated plots was 0.73 for the period November to April.

1.4.4 Plant damage and competitive ability

The competitive ability and survival of grass species can be profoundly influenced by its susceptibility to attack by insects, fungal and viral pathogens, and the influences of the grazing animal (mainly by defoliation of individual plants, treading action and excretion of dung and urine).

The most important diseases of ryegrass cultivars in New Zealand are caused by crown rust (*Puccinia coronata*) and stem rust (*Puccinia graminus*) fungal infections. The former is the most common and damaging especially in summer and autumn, while the latter assumes importance in seed crops (Latch 1980a). Barley Yellow Dwarf virus infection is also widespread in pastures in New Zealand (Latch 1980b). The presence of fungal and viral infections in grasses can result in a reduction in tillering and pasture production (Lancashire & Latch 1969; Latch 1980a), which ultimately reduces host competitiveness (Carr 1979). The two most widely preferred perennial ryegrass cultivars at present, 'Grasslands Nui' and 'Elletts', are both susceptible to rust attack (Latch 1980a). By comparison, subtropical species such as *Paspalum dilatatum* are relatively disease free and probably the most important pathogen attacking this species is the ergot fungus (*Claviceps paspali*), which interferes with its seed production (Latch 1980a).

The most important insect pests affecting New Zealand pastures include grass grub (*Costelytra zealandica*), Argentine stem weevil (*Listronatus bonariensis*), black beetle (*Heteronychus arator*), black field crickets (*Teleogryllus commodus*), Australian soldier fly (*Inopus rubriceps*) white fringed weevil (*Graphognathus lecucoloma*) and porina (*Wiseana cervinata*). *Lolium perenne* is generally susceptible to some degree to all of the above (Gerard & Parr 1977), and in some instances establishment (Dixon & Davison 1976; Blank & Bell 1982) and persistence (Hunt & Gaynor 1982; Kain et al. 1982) have been seriously reduced. The major insect pest affecting the competitive ability and persistence of *Paspalum dilatatum* in northern New Zealand is black beetle (Watson & Wrenn 1980), and sporadic outbreaks have reduced the paspalum content of affected areas (Percival 1977; King et al. 1982). Insects such as porina, Australian soldier fly and grass grub may be controlled by increased grazing intensity and/or stock trampling at critical periods of their life cycles within the constraints of such factors as weather, and the detrimental effects of hard grazing and trampling on pasture production (East & Pottinger 1983).

The extensive literature covering the variety of effects grazing animals have on swards has been summarised in a number of reviews (Sears 1956; Moore & Biddiscombe 1964; Barrow 1967; Marsh & Campling 1970; Frame 1971; Spedding 1971; Wolfe 1972; Hodgson 1973; Brown & Evans 1973; Watkin & Clements 1978; Charles 1979). The effects of defoliation *per se* on plant and sward persistence are discussed in Section 1.4.1. This Section discusses the extent to which physical damage, caused by cattle grazing and the excretion of dung and urine, affects the competitive ability, productivity and persistence of pasture grasses.

Activities such as sitting, lying, scratching and pawing are considered to be of minor importance in causing damage to pasture plants (Spedding 1971), but treading has been shown to influence the growth and botanical composition of pastures (Edmond 1966, 1970; Campbell 1966; Brown 1968; Gillard 1969; Harris & Brown 1971; Harris et al. 1973; Mullen et al. 1974), with a large variation in response being recorded.

The variable dry matter yield responses to treading are related to differences in soil type and its moisture content at grazing, the quantity of herbage present, the grass species or cultivars used and their stage of development (Charles 1979). Treading causes injury to the growing points, leaves, stems and roots of herbage plants and the effects generally increase with increasing stocking rate (Frame 1971; Watkin & Clements 1978). Since plant numbers and tiller density may be reduce by treading (Edmond 1966; Campbell 1966) and the botanical composition may change towards plants most resistant to hoof action, competition between plants in swards is also modified by treading (Watkin & Clements 1978).

Tiller loss due to uprooting by cattle during grazing (Spedding 1971; Hodgson 1973; Boswell 1977; Charles 1979), is an action which can contribute to the development of bare areas in the sward. Plant or tiller losses from 'pulling' are often observed in swards subjected to intensive grazing (Hodgson 1973) and on occasions where severe treading has destroyed soil structure causing poor root development (Charles 1979). Further research is required to determine its importance as a factor affecting sward persistency.

Smothering of pasture plants with dung and the occurrence of urine scorch can cause damage or death of pasture plants (Doak 1954; MacDiarmid & Watkin 1971; Richards & Wolton 1975; Wolton 1979). Urine scorch is intensified in hot, dry weather and clovers are more susceptible to burn than are grasses (Frame 1971). However, Richards & Wolton (1975) observed scorch by cattle urine of 'S23' perennial ryegrass under wet conditions. The scorched areas represented up to 2% of the plot areas but only 15% of the urinations caused scorch. Regrowth replenished losses where only a few grass tillers had been killed, but colonisation by flatweeds and annual grasses occurred where whole plants had been killed (Richards & Wolton 1975). The scorching effect has been attributed to the occasional voiding of urine of high osmotic potential and the susceptibility to this of grasses with a high nitrogen content (Wolton 1979). The main effect of the urine appeared to be on the root system and not the foliage (Wolton 1979).

The high nitrogen concentration in cattle urine can stimulate the growth of grasses at the expense of clovers and can also cause a decline in nitrogen fixation by clovers (Ledgard et al. 1982). Under intensive dairy farming (three cows per hectare) where urine may affect 40% of the grazed area (Richards & Wolton 1976), nitrogen fixation may be reduced by at least 10% per annum (Ledgard et al. 1982). Urine stimulates herbage growth to a greater extent than does dung because of its higher nitrogen concentration. Since the area affected by urine approximates to that affected by dung, the stimulating effect of urine nitrogen on herbage production usually outweighs the reduction in herbage utilisation caused by the presence of dung pats (MacLusky 1960).

1.4.5 Pasture renovation by overdrilling

Established pastures in intensive production systems often need renovation or reseeding because of sward deterioration caused by many factors, some of which have already been discussed. Direct drilling (overdrilling or sod seeding) and 'one-pass' seeding offer less costly alternatives to conventional ploughing and reseeding (Haggar 1978; Kunelius et al. 1982). These techniques involve placement of seed into untilled soils and the creation of a suitable environment for seedling germination and growth. This is facilitated by the type of groove made by the coulter, band-spraying of herbicide to reduce competition from surrounding herbage, and the application of fertilisers and pesticides (Baker 1980).

Blackmore (1955, 1958) first suggested direct drilling of seed as a method of improving deteriorating or low producing pastures. In a recent series of papers Baker and co-workers have studied the effects of coulter type (Baker 1976; Choudhary & Baker 1980, 1981a,b; Baker & Mai 1982a,b). They found moisture retention for seed germination was best for the chisel coulter. Further modifications (Baker & Badger 1979; Baker et al. 1979a,b,c) allow for the handling of trash, the application of fertiliser, and herbicide band-spraying. Similar work in Britain has lead to the development of a 'slot seeder' (Squires et al. 1979) with similar capabilities. The successful introduction of *Lolium perenne* into an existing *Festuca-Agrostis* sward using the slot seeder has been recently reported (Haggar & Squires 1982).

Direct drilling equipment has been used in New Zealand and parts of Australia as a means of introducing newly released cultivars into swards or to maintain a desirable balance of pasture species. For example, temperate grasses and legumes have been autumn overdrilled into dairy pastures containing summer growing species like *Paspalum dilatatum* (Crofts et al. 1957; Read 1978; Martin 1979; Baker et al. 1979c). Other New Zealand overdrilling experiments have produced variable results with respect to grass and legume seedling establishment (Ryan et al. 1979; Kunelius et al. 1982; Betteridge & Baker 1983; Campbell et al. 1983). Even though renovation of pastures by overdrilling grasses is a common occurrence (Sangakkara et al. 1982), there have been no published reports of the persistence and contribution of introduced cultivars to seasonal herbage production.

Recommendations for the grazing management of overdrilled pastures are contradictory. Early reports (Blackmore 1958; Robinson & Cross 1960) suggested lenient grazing following overdrilling. Miller (1973), however, based on farm observations in Taranaki, suggested regular severe grazing of the renovated dairy pasture was necessary for at least three months after drilling of *Lolium perenne* seed, to reduce competition from resident species. Researchers (Robinson &

Cross 1960; Baker 1980) have noted the importance of post-drilling management as a determinant of the success or failure of renovation by overdrilling, but there have been no published reports of research on this subject.

1.4.6 Description and origin of *Lolium perenne*

Lolium perenne belongs to the subfamily Festucoideae and the tribe Hordeae in the grass family Gramineae (Evans 1964). It is a true perennial (Corkill 1949) and produces many tillers in a tufted growth habit (Langer 1972) with limited ability to spread by vegetative means (Harris et al. 1979; Minderhoud 1980a). Perennial ryegrass growth is greatest in spring and although a number of strains are available in New Zealand for use in different environments and farming systems (Langer 1972), its growth is enhanced under conditions of high soil fertility (Lancashire & Harris 1978; Corkill et al. 1981). Perennial ryegrass is the most widely sown grass in New Zealand (Lancashire et al. 1979).

Perennial ryegrass became established in New Zealand in the 1880-1890 period from introductions made by English immigrants (Frankel 1954). Distinct ecotypes have subsequently arisen. In Hawke's Bay and Poverty Bay persistent leafy strains evolved under permanent grassland farming while under arable farming (eg. Canterbury), short-lived stemmy strains developed (Levy & Davies 1929, 1930; Corkill 1949). The former were referred to as 'true perennials' and from these a 'pedigree strain' was bred which was superior to the best uncertified strains in production, persistency and resistance to crown rust fungus (*Puccinia coronata*) (Corkill 1949; Lancashire et al. 1979). The main seed producing areas of New Zealand were Auckland, Sandon, Hawke's Bay, Canterbury, Otago and Southland (Cockayne 1914). The 'pedigree strain' was certified as New Zealand perennial ryegrass and the first breeder's seed became available in 1936; this strain was renamed 'Grasslands Ruanui' in 1964 (Lancashire 1978).

Another distinct ecotype of perennial ryegrass was identified by T.R. Ellett at Mangere near Auckland. This ecotype has developed over about 60 years of lax dairy cattle grazing with the opportunity for reseeding. The climate in the area is mild with some light frosts in winter and a mean annual rainfall of 1200 mm with moisture deficits common in summer. The Mangere ecotype is more erect with larger leaves and tillers than the Hawke's Bay 'Ruanui' type. It also has a higher winter production and tolerance to summer drought with a superior response to autumn rains than does 'Grasslands Ruanui' (Corkill et al. 1981). These characteristics of 'Grasslands Nui' perennial ryegrass (Armstrong 1977) (derived from the Mangere ecotype) have been shown to be favoured by infrequent mowing or grazing (Lancashire et al. 1979). In 1972, a commercial seed firm began a regional-strain breeding programme (Duder 1978) using the Mangere ecotype as a basis which culminated in the release of Ellett perennial ryegrass in the late 1970's.

1.4.7 Description and origin of *Paspalum dilatatum*

Paspalum dilatatum is a perennial grass which belongs to the subfamily Panicoideae and the tribe Paniceae in the grass family Gramineae (Burton 1940; Percival 1977). The morphology of the plant has been variously described in the literature (Hamblyn 1937; Arnold 1953; Anonymous 1954; Griffith Davies & Hutton 1970; Bennett 1973).

Morphology under New Zealand conditions (Hamblyn 1937; Arnold 1953) resembles that described for Australian conditions (Anonymous 1954; Griffith Davies & Hutton 1970) probably because the plant has been naturalised in both countries under intensive dairy cow grazing. Arnold (1953) describes paspalum as a 'strong growing deep-rooted perennial' which grows in clumps but due to the development of short underground rhizomes is able to spread and eventually form a dense sward of leafy shoots. Both Hamblyn (1937) and Arnold (1953) recognised that the exceptional colonising ability of paspalum in many northern New Zealand areas of variable soil fertility and soil types, coincided with a marked increase in dairying and sheep production. Controversy over the fertility requirements of paspalum is evident since Whyte et al. (1959) considered it to have a high fertility requirement while Karlovsky (1959) reported an intolerance to higher fertility.

Paspalum dilatatum is a native of South America with its main distribution in the humid subtropics in Argentina, Uruguay and southern Brazil (Whyte et al. 1959). It has been introduced into a number of warm-temperate and subtropical areas of the world including New Zealand where it was first recorded in 1892 (Kirk 1895), Australia in 1881 (Griffiths Davies & Hutton 1970) and the south eastern United States of America in about 1840 (Tabor 1963). Paspalum has become naturalised in these countries in areas with annual rainfalls greater than 750 mm and where mild winters are experienced. In New Zealand, it is widely distributed throughout the northern half of the North Island (especially in association with dairying in Northland, South Auckland, Waikato and Bay of Plenty districts) and is found to a lesser extent in coastal areas of the North Island and the north-western corner of the South Island (Percival 1977). In Australia, the most important areas of paspalum occur under dairying in southern Queensland and northern New South Wales, especially in association with *Trifolium repens* (Griffiths Davies & Hutton 1970).

Paspalum is difficult to establish from seed because of its extremely low seed viability and poor germination capacity (Ray & Stewart 1937; Burton 1962; Owen 1977). Seed production can also be affected by infection with the ergot fungus (Section 1.4.4).

In northern New Zealand the growing season for paspalum is from about late October until April/May (Allo 1953; Owen 1977; Percival 1977; Lambert 1968) and because of winter dormancy it contributes little to winter/spring herbage production. Paspalum displays vigorous summer growth and has the ability to exclude other species such as perennial ryegrass (Sturme 1977). It is therefore necessary to develop specialised management to control its growth (Hamblyn 1937; Arnold 1953; Karlovsky 1959) and prevent the development of unpalatable feed in late summer/autumn and sod-bound pastures (Hamblyn 1937; Karlovsky 1959). Cutting or hard grazing are suggested means of controlling the excess summer growth (Allo 1952a; Karlovsky 1959; Bryant & Parker 1971) as paspalum has generally displayed tolerance to hard grazing and treading over summer (Whyte et al. 1959; Hunt 1979; Baars et al. 1980).

The ability of paspalum to survive periods of drought has often been recognised and is related to its deep rooting system (Section 1.2.5.2). Paspalum has also become acclimatised to severe frosts and can survive -7 °C without loss of leaf, although the colder the winter the slower is its subsequent growth (Hamblyn 1937).

Until recently no certified cultivar was available in New Zealand and paspalum seed was imported from eastern Australia (Lancashire et al. 1979; Percival & Couchman 1979). A New Zealand bred cultivar *Paspalum dilatatum* Poir. 'Grasslands Raki', derived originally from a bulk seed sample from Uruguay has recently become available but has yet to make an impact on commercial farms (Lancashire et al. 1979). 'Grasslands Raki' originally referred to as 'G15' was markedly superior to unselected New Zealand populations and overseas lines in summer/autumn dry matter accumulation in mixed pastures under sheep grazing in Northland (Percival et al. 1979).

1.4.8 *Lolium perenne/Paspalum dilatatum* pasture mixtures

Early reports (Hamblyn 1937; Allo 1953; Arnold 1953; Karlovsky 1959) recommended pasture combinations of perennial ryegrass, white clover and paspalum as a means of achieving high seasonal production in the warm zone of New Zealand. These recommendations were based on few data. Lynch (1953) obtained a yield of 16 700 kg DM/ha (range 12 500 to 21 300 kg DM/ha) from a rotationally grazed dairy pasture in Northland which was dominated by perennial ryegrass in winter and spring, and by paspalum in summer/autumn. In an unreplicated experiment over two years in the Waikato, Karlovsky (1959) showed that pastures containing paspalum, ryegrass and white clover outyielded those with no paspalum, especially in summer and autumn. The work of Baars et al. (1976) confirmed this finding. As found by Lynch (1953), ryegrass production in winter/spring was more or less replaced by that from paspalum in summer. Brougham (1979) noted that *Lolium*, *Trifolium* and *Paspalum* species combinations in pastures generally produce high yields in the region of 16 000 to 18 000 kg DM/ha.

Hutton (1973) measured a maximum annual yield of 22 800 kg DM/ha for a pasture containing paspalum at the Ruakura Agricultural Research Station while Bryant & Parker (1971) obtained very high milk fat production from cows grazing similar pastures.

Overdominance by paspalum during summer can result in loss of ryegrass and clover and the consequent poor winter/spring pasture production may seriously effect feed supplies on seasonal dairy farms (Hamblyn 1937; Arnold 1953; Karlovsky 1959). This overdominance may then lead to lower soil fertility and sod-bound pastures. Thus, frequent introductions of ryegrass and white clover are required to renovate paspalum dominant pastures (Allo 1953; Arnold 1953).

Since precise management of pastures containing paspalum is required to prevent overdominance by this species, workers in the Waikato and Northland examined this problem further in three experiments (Baars et al. 1980). Two were conducted in the Waikato and used dry cattle and sheep respectively as defoliators while the third study was conducted under sheep grazing in Northland and has since been the subject of a more detailed report (Percival & McClintock 1982). In these experiments an increased proportion of paspalum in the pasture was generally favoured by hard grazing the previous spring. This treatment was associated with a decrease in the ryegrass content. Lax grazing in spring reduced the paspalum content in the subsequent summer. Hard grazing in summer increased the paspalum content under cattle grazing, with a corresponding decline in the ryegrass content, but the reverse occurred under sheep grazing.

Even though the work of Baars et al. (1980) may provide adequate guidelines for farmers to successfully manipulate the species balance in ryegrass/paspalum pastures, in practice many failures have been reported, especially under intensive dairying systems. In these cases the ryegrass component has been reduced to the point where renovation by overdrilling or other means is necessary (Baker et al. 1979c; Martin 1979; Baker 1980) to provide adequate late-winter/spring feed on seasonal dairy farms.

CHAPTER 2

RENOVATION OF PASTURES CONTAINING PASPALUM

2.1 INTRODUCTION

In the warm-temperate regions of New Zealand, paspalum (*Paspalum dilatatum* Poir.) is often an important component of dairy swards (Percival 1977; Brougham 1979). However, where this species represents a high proportion of the sward and where high stocking rates are maintained, dairy farmers have found difficulty in retaining sufficient perennial ryegrass (*Lolium perenne* L.) for the provision of adequate late-winter/spring feed (Hamblyn 1937; Karlovsky 1959). Researchers have also recognised the need for specialised management to maintain the appropriate species balance (Hamblyn 1937; Arnold 1953; Karlovsky 1959; Baars et al. 1980). Farmers have also attempted to improve the species balance in paspalum dominant swards by introducing improved cultivars of perennial ryegrass (Baker 1980). Direct drilling (overdrilling, sodseeding) of seed is often used as it is a relatively cheap procedure compared to conventional cultivation practices (Haggar 1978; Kunelius et al. 1982).

The development and testing of direct drilling equipment in New Zealand is well advanced (eg. Baker 1976, 1980; Baker et al. 1979a,b,c). The performance of various coulter assemblies in relation to seedling emergence under various soil moisture conditions, and in association with band-spraying along the drill lines, has been determined in many environments including dairy pastures in northern New Zealand (Baker et al. 1979c; Baker 1980).

Emergence and establishment of grass and clover seedlings has been variable when seed was overdrilled into pastures treated with herbicide to reduce competition from resident species (Ryan et al.

1979; Kunelius et al. 1982; Betteridge & Baker 1983; Campbell et al. 1983). Despite widespread overdrilling of grass seed (Sangakkara et al. 1982) into deteriorated pastures, data describing the persistence and contribution of the introduced species to seasonal herbage production have not been reported.

In this experiment, seed of commercial lines of certified first generation *Lolium perenne* L. 'Grasslands Nui' perennial ryegrass and second generation *Bromus catharticus* Vahl. 'Grasslands Matua' prairie grass were overdrilled into a sward containing paspalum. Their persistence and contributions to sward production were followed over a two year period from autumn 1978. Both Nui ryegrass and Matua prairie grass represent recently released improved perennial cultivars which are considered suitable for use on high fertility dairy farms (Rumball 1974; Armstrong 1977). The practical objective of this experiment was to measure the effect of the introduction of temperate grasses on seasonal dairy pasture production, in particular, from July to January when about 80% of total milkfat production can be produced (Campbell & Bryant 1978).

2.2 GENERAL DESCRIPTION OF EXPERIMENTAL AREA

The field experiments described in this chapter and those in chapters three, four and six, were conducted at No. 5 Dairy, Ruakura Agricultural Research Station, Hamilton, New Zealand (latitude 37° 47' S, longitude 175° 19' E, altitude 40 m above sea level). The region is classified as warm-temperate (Brougham 1979) with an average air temperature of 13° C.

Ground frosts (grass minimum temperature less than -1 °C) are common during the cool season (May, June, July, August), average occurrence being 28% of the cool season days (Appendix 1). Dry periods are also common during the warm season (December, January, February, March) often being accompanied by high day temperatures (screen maxima of 25 °C or greater). For example, over 13 consecutive warm seasons from 1969/70 to 1981/82, dry spells averaged 21 days (range, 14 to 42 days) while high screen temperatures (excluding 1975/76) occurred on an average of 38 days (range, 22 to 61 days). An exception was 1975/76 when temperatures reached the above criterion on only seven days.

The pastures in the experimental area had previously received annual maintenance dressings of about 98, 49 and 49 kg/ha of potassium, phosphorus and sulphur, respectively, as potassic superphosphate but no lime had been applied for at least 10 years. Soil quick tests (Cornforth 1980) taken over the whole experimental area in July 1977, indicated a high soil fertility status with respect to available potassium, phosphorus and magnesium. The average pH in the upper 75 mm of soil was 5.6.

From 1969 to 1975 the pastures in the experimental area were included in farmlet-scale studies (Bryant & Parker 1971; Hutton 1978) and were rotationally grazed at high stocking rates (4.1 to 5.6 cows/ha). Irrigation treatments were imposed from 1972 to 1975 along with a nitrogen fertiliser treatment (490 kg N/ha/annum) from 1973 to 1975. High stocking rates were also used during 1975 to 1978. A feature of the pastures was the influence of summer growing paspalum (Table 2.1).

Table 2.1 Botanical composition (% of pre-grazing herbage mass) of the pastures in the experimental area. (Source: Dairy Science Group experimental records 1972 to 1975)

	Species				
Season	Perennial ryegrass	Paspalum	*Poa* spp.	White[a] clover	Other grasses, dead matter, weeds
Winter	40	4	15	31	5
Spring	34	4	32	23	7
Summer	8	47	1	19	25

[a] *Trifolium repens* L.

The experimental area is flat to gently undulating and its soils range from well drained to imperfectly drained with rare flooding (Singleton 1981). Te Kowhia silt loam (Haplic Andaquept), a gley soil, predominates in the poorer draining lower regions while in the better drained raised regions Bruntwood silt loam soils (Aquic Dystrandept) are found. These soils are derived from similar parent material, namely, alluvially deposited pumiceous sands (Singleton 1981).

2.3 EXPERIMENTAL DESIGN AND TREATMENTS

A split-plot experimental design was used with treatments randomly located within five block replicates. Each block was represented by a 0.12 ha paddock (40 m x 31 m) and five main treatment plots were arranged at random in 40 m strips of varying widths across each block. These treatments were:

(i) Nui ryegrass sown (11.7 kg/ha) through a triple disc coulter in a 5 m wide strip (TN).

(ii) Nui ryegrass sown (11.7 kg/ha) through a chisel coulter in a 7.4 m wide strip (CN).

(iii) A combination of Nui ryegrass (11.2 kg/ha) and Matua prairie grass (12.2 kg/ha) sown through a triple disc coulter in a 5 m wide strip (TNM).

(iv) The same seed combination as for (iii) sown through a chisel coulter in a 7.4 m wide strip (CNM). As for treatment (iii), the seed was mixed with a small amount of untreated sawdust to improve the sowing of the large, awned, prairie grass seed.

(v) A 6.3 m wide control strip where no drilling took place (C).

Half the width of each of the above main plot treatments received paraquat (1,1'dimethyl-4,4'bypridinium ion) in 40 mm bands covering the drill lines. The side to receive herbicide was chosen at random before drilling. The paraquat was applied at the rate of 5 l in 500 l water/ha. The appropriate coulter assemblies were arranged on a 'Duncan 30 Multiseeder' drill to sow at 150 mm drill widths. In all treatments, grooves were harrowed with a bar harrow (Baker 1970) allowing two hours after drilling for the herbicide to dry. In the sprayed subplots, 27% of their area received herbicide.

The experimental plots were hard-grazed to a visually estimated residual herbage mass (Hodgson 1979) of 800-1000 kg DM/ha before overdrilling during 20-21.4.78. No pesticides were applied at drilling. Soil moisture levels were high since 77 mm of rain fell over the four days preceding drilling, and the mean screen maximum, recorded at the Ruakura Climatological Station located approximately 1 km from the experimental site, for the period 20.4.78 to 30.4.78, was 20.5 °C.

2.4 EXPERIMENTAL PROCEDURES AND TECHNIQUES

2.4.1 Grazing management

During the two year experimental period the plots were subjected to 20 grazings by dairy cows (Table 2.2). The first grazing was 69 days after drilling and then at about 60 day intervals during the 1979 winter. Thereafter they were grazed at intervals of 26-36 days.

Visual estimates of herbage mass were used to determine the number of cows per block required to complete the grazing in three to five hours. Grazing of all blocks was usually complete over a two day period. The sequence in which blocks were grazed was the same throughout the study period. All blocks were grazed to similar levels of residual herbage mass, but this level varied with season. Averaged over the experimental period for spring, summer, autumn and winter, herbage mass for pre- and post-grazing assessments were 3200 and 1800, 4300 and 2700, 4000 and 2200, and 2100 and 1200 kg DM/ha, respectively.

2.4.2 Fertiliser policy

Each of the 0.12 ha experimental blocks received regular maintenance dressings of potassium (K), phosphorus (P) and sulphur (S) as potassic superphosphate. In April and again in October 1978, 10.1 kg K, 2.1 kg P and 2.1 kg S was applied. A further 2.5 kg K, 1.3 kg P and 1.3 kg S was applied in April 1979 followed by 5.8 kg K, 1.2 kg P and 1.2 kg S in November 1979. No lime was applied during the experimental period.

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■ = Measurement date)■ = Measurement period

an. p.	Tiller density		Grazing	Tiller no. and length	Herb. mass	Tiller no.	Botan. comp.	Tiller density
		1979 3 Jan. 9 10 11		)■	■		■	
		Jan. 12–13	■					
		15			■			
		16		■				
		24				■		
		7 Feb. 8 9		)■	■			
		12–13	■					
		14 15 16		)■	■			
		26				■		
		7 Mar. 8 9		■	■			
	■	12 13	)■		■			
		14–16		■				
		19						■
		27				■		
		4 Apr. 5 6		)■	■			
		9					■	
		10	■		■			
		11–12		■				
		26				■		
		9 May 10 11		)■	■			
		14	■					
		15 16 17		)■	■			
		1 Jun.				■		
		19				■		
		8 Jul. 9 10		)■	■		■	
		11	■					
	■	12 13 26		)■	■	■		■

	Grazing	Tiller no. and length	Herb. mass	Tiller no.	Botan. comp.	Tiller Density
1979 16 Aug.				■		
29				■		
Sept. 9–10 11		)■	■			
12	■					
13 14–15		)■	■			
27				■		
7 Oct 8 9		)■	■		■	
10–12	■					
13 14 15		)■	■			
17						■
29				■		
4 Nov. 5 6		)■	■			
7–8	■					
9 10 11		)■	■			
28				■		
3 Dec.	■					
4				■		
1980 3 Jan.	■					
4				■		
1 Feb.					■	
3	■					
4				■		
9 Mar.	■					
10				■		
7 Apr.	■					
8				■		
12 May					■	
13	■					
14				■		

Table 2.2. Schedule of major events

	Grazing	Tiller no. and length	Herb. mass	Tiller no.	Botan. comp.	Tiller density
1978 Jun. 21-25		■				
26					■	
27			■			
29 30 1 Jul. 2	■	)■				
3			■			
10				■		
25				■		
7 Aug.				■		
22-27		■				
28			■		■	
30	■					
31			■			
Sept. 4-6		■				
12						■
14				■		
25 26		)■				
27			■			
28-1 Oct.	■					
2			■		■	
3 4		)■				
16				■		
31 1 Nov.		)■				
2			■			
3-4	■					
6			■			
7		■				
24				■		
3 Dec. 4 5			■	)■		
6 7	)■		■			
9-11				■		
19						■
20				■		
1979 8 Jan. 9 10 11		)■	■		■	
Jan. 12-13	■					
15			■			
16		■				
24				■		
7 Feb. 8 9		)■	■			
12-13	■					
14 15 16		)■	■			
26				■		
7 Mar. 8 9		■	■			
12 13	)■		■			
14-16		■				
19						■
27				■		
4 Apr. 5 6		)■	■			
9					■	
10	■		■			
11-12		■				
26				■		
9 May 10 11		)■	■			
14	■					
15 16 17		)■	■			
1 Jun.				■		
19				■		
8 Jul. 9 10		)■	■		■	
11	■					
12 13 26		)■	■	■		■
1979 16 Aug.				■		
29				■		
Sept. 9-10 11		)■	■			
12	■					
13 14-15		)■	■			
27				■		
7 Oct 8 9		)■	■		■	
10-12	■					
13 14 15		)■	■			
17						■
29				■		
4 Nov. 5 6		)■	■			
7-8	■					
9 10 11		)■	■			
28				■		
3 Dec.	■					
4				■		
1980 3 Jan.	■					
4				■		
1 Feb.					■	
3	■					
4				■		
9 Mar.	■					
10				■		
7 Apr.	■					
8				■		
12 May					■	
13	■					
14				■		

2.4.3 Sward measurements

2.4.3.1 Visual estimation of herbage mass

Herbage mass (Hodgson 1979) in this series of experiments includes living and dead plant material above ground level but excludes soil, dung and other contaminants, which were removed by washing.

The following calibration, grading and cutting procedures were used to estimate pre- and post-grazing plot herbage mass (Table 2.2).

(i) *Calibration*: For each assessment one of the five blocks were selected at random and 30 calibration quadrats (three per plot, each 0.25 m^2) were identified. Quadrats were chosen to cover block variability in herbage mass (Campbell & Arnold 1973) and were assumed to be representative of the herbage mass on the other blocks. Quadrats were not sited in areas where measurement were being made on individual plants (Section 2.4.3.2), where dung and/or urine had been deposited and where quadrats had previously been cut. Post-grazing estimates were made using quadrats located in one of the remaining blocks. For each assessment, nine visual estimates were made on quadrats before cutting but as observers gained experience, this number was reduced to five. At the same time (12.2.79) the number of quadrats were reduced from 30 to 10 (one per plot).

(ii) *Grading*: Each calibration quadrat was given a visual grade (grade 1 = 300 kg DM/ha, grade 7.5 = 2250 kg DM/ha) by consensus of three observers, one of whom had at least 10 years experience in grading similar pastures. The two less experienced observers then graded each plot in each block by recording 20 estimates of herbage mass (each for about 0.25 m^2 of pasture) at two to three step intervals over the plot length. After each block of 10 treatments were assessed each observer returned to the calibration quadrats and independently estimated their herbage mass. Thus nine visual estimates were made on quadrats before cutting and 40 visual estimates of herbage mass were made on each plot.

(iii) *Cutting*: On the completion of grading the herbage contained in each calibration quadrat was cut to ground level using a motorised shearing handpiece, and after washing was dried in a forced draught oven at 100 °C for 36 hours.

The mean herbage mass estimate for each treatment plot was adjusted using the regression of visual grade on herbage mass for the quadrat assessments. The correlations between the dependent variable (mean visual grade) and the independent variable (herbage mass per quadrat) for each grazing are presented in Appendix 2. All were significant ($P<0.01$) (28 degrees of freedom, for grazings from 29.6.78 to 12.1.79, eight degrees of freedom for grazings from 12.2.79 to 13.5.80).

Seasonal accumulations of herbage for periods roughly equivalent to winter, spring, summer and autumn were obtained by summing successive growths between grazings, over these periods. In the case of the first winter after drilling, the first pre-grazing herbage mass estimate was included plus the growth from post-grazing one to pre-grazing two; thus the total for this season overestimated the actual growth. Also, the period for the 1979 spring (49 days) was curtailed by about one month compared to the 1978 spring (87 days). In calculating seasonal herbage accumulations no account was taken of pasture growth over the period between pre- and post-grazing assessments at a particular grazing.

2.4.3.2 Identification of individual plants

During May 1978, 240 Nui ryegrass and 120 Matua prairie grass seedlings were permanently identified allowing sequential growth measurements during each plant's life cycle. In each block, six random diagonals were located by means of matched pegs on opposite sides of the block. Within each treatment single ryegrass and prairie grass seedlings resulting from overdrilling were selected at random along the diagonals. Coloured telephone wire was placed around the base of each of these seedlings and formed into a loop by twisting the ends together and inserting this portion into the ground to act as an anchor. The ring size was periodically enlarged to prevent damage to the plant as it grew. Thus in each block, 48 Nui ryegrass and 24 Matua prairie grass plants were identified (six per drilled treatment). When a marked plant died, or was removed by the grazing animal, or as on a few occasions, could not be positively identified at the appropriate site (eg. because the identifying ring was missing or had been covered by soil as the result of animal trampling or earthworm activity), the frequency of the plot mean was reduced by one. Dead plants were visually identified as those consisting of brown, necrotic, tissues with no green tissue.

2.4.3.3 Measurements on individual plants

Nui ryegrass and Matua prairie grass seedlings had emerged by 1.5.78, nine days after drilling. In mid-May counts were made in 300 mm of drill row beginning at the location of previously ringed seedlings. Six estimates were therefore made in each treatment plot and these were converted to a density measurement (plants/m^2) by dividing the number of seedlings of each species by a factor (0.045 =

0.3 m x 0.15 m), representing the area potentially available to the introduced plants.

Tiller counts were made on ringed plants in association with the 20 grazings during the experimental period and also at intervals between grazings (Table 2.2). All emerged tillers on each plant were counted at each time and records were kept as to whether they were alive or dead or undergoing vegetative or reproductive growth. From grazing one (29.6.78) to 14 (7.11.79) (with the exception of grazing five) the length of the longest vegetative tiller on ringed plants was also recorded before and after grazing (Table 2.2). The measurement was made from the base of the plant to the tip of the longest leaf, fully extended.

Dung deposited during grazing on or near ringed plants was removed using a small shovel.

2.4.4 Botanical composition

Samples for botanical dissection (Table 2.2) were obtained from random ground level clips throughout the length of each plot. The fresh weight of a subsample consisting of 100 representative pieces of herbage was determined for each plot. A further subsample four times this weight was then taken for dissection into component species. Dissected material was dried at 100 °C for 36 hours and then weighed. The proportion of the herbage mass made up by each species was represented by the ratio of the species dry weight over the total dry weight of the 400 piece sample.

2.4.5 Tiller density measurements

Cores (50 mm diameter) were taken (Mitchell & Glenday 1958) on five occasions (Table 2.2). On each occasion four cores were taken at random from each plot. Live tillers and rooted clover nodes were counted on each core.

2.5 STATISTICAL METHODS

For this and the field experiments described in chapters 4 and 6, analysis of variance models provided by the statistical package 'Genstat V' (Lawes Agricultural Trust, Rothamsted Experimental Station) were used to test for treatment differences at each measurement date. Standard errors are given as follows:

(i) *SED - standard error of mean differences*

When a covariate was included in the model the SED cited represents an average standard error of mean differences. Plots of residual variances against fitted values for the model indicated when transformations of the data were required to obtain errors resembling the normal distribution with constant variance. When a log transformation was used the error term associated with geometric means (back transformed) was given as a LSR.

(ii) *LSR - least significant ratio*

LSR ($P<0.05$) = e^{2s} where s = SED of log transformed means. In comparing treatment means, if the ratio of the larger to the smaller exceeds the stated LSR, a significant difference exists between the treatments for the measured parameter.

The following symbols are used to indicate levels of significance:

$P<0.001$ = ***; $P<0.01$ = **; $P<0.05$ = *; $P<0.10$ = (†);

ns = not significant

In this experiment a split-plot analysis of variance model was used to test for treatment differences. Treatment means and standard errors were adjusted using a covariate to account for the proportion of each plot previously drilled with Matua prairie grass before this trial. The botanical composition data (proportions) were analysed as such and when arcsin transformed to check for non-normality in the distribution of the data and stability of the variance. Both approaches were satisfactory as indicated by plots of residuals, against fitted values for the models. The analysis of untransformed data was preferred for ease of interpretation although only approximate standard errors associated with differences between means can be cited. However, when arcsin transformation improved the precision of the analysis, significance levels from this analysis are presented. As the tiller density data covered a wide range of values and included some zero values a log (x+1) transformation was used to equalise the variances. The effects of treatments on plant losses were tested using analysis of deviance (log-likelihood ratios) (Nelder & Wedderburn 1972).

2.6 CLIMATIC DATA

A summary of monthly averages for selected variables over the study period (April 1978 to May 1980), is presented in Appendix 1. Comparisons with data averaged over an extended period (up until 1970) are also presented.

January and June 1979 were very dry months (Appendix 1), and during January reduced pasture production was likely because of moisture deficits (Appendix 3). However, there was a higher summer (December, January, February) rainfall in 1979/80 (374 mm) than in 1978/79 (287 mm), the former rainfall being greater than 100 mm above the long term average (241 mm).

A feature of the 1978 and 1979 cool seasons was the incidence of ground frosts. In 1978 there was a total of 54 ground frosts and in 1979 another 47 from May 1 to August 31 compared to a long term average of 34. However, the 1978 cool season was generally colder with 22 frosts of -4 °C or less compared to 17 for the same period in 1979. The colder 1978 winter contributed to a lower mean spring (September, October, November) 10 cm earth temperature than the long term average (12.5 vs 13.4 °C). The equivalent figure for 1979 was 13.3 °C. During the warm seasons of 1978/79 and 1979/80, daily screen maxima reached 25 °C or greater on 30 and 22 days, respectively.

2.7 RESULTS

2.7.1 Establishment of overdrilled grasses

Emergence of Nui ryegrass was significantly affected by treatment and there was a highly significant treatment x herbicide interaction (Table 2.3). Herbicide increased the number of ryegrass seedlings emerging in the CN but not the TNM treatment. However, the TN

Table 2.3 Interaction between coulter and herbicide treatment for emergence of Nui ryegrass (seedlings/m^2) in May 1978.

Herbicide (H) treatment	Coulter treatment CN	 CNM	 TN	 TNM
+H	527	462	416	461
-H	455	448	367	522

SED = 25.1, comparing means within coulter treatments
= 31.0, otherwise

treatment gave a lower density at emergence than did other treatments, regardless of whether or not herbicide had been applied. No significant interactions or differences between treatments were revealed by the analysis of the Matua prairie grass emergence data. These data are not presented. The number of Matua prairie grass seedlings in 300 mm row lengths was only 15% of the number of Nui ryegrass seedlings.

2.7.2 **Survival of introduced grasses**

For most of the study period, generally similar reductions in the numbers of survivors of ringed plants occurred across all treatments (Table 2.4). This trend was maintained until the beginning of the second summer (December 1979) after which more variable reductions occurred, especially for Matua prairie grass. The pattern of survival

Table 2.4 Numbers of survivors after the first summer (March 1979), at the beginning (December 1979) and end (March 1980) of the second summer, and at the end of the study (May 1980).

	Treatment							
	CN		CNM		TN		TNM	
	+H	-H	+H	-H	+H	-H	+H	-H
(a) Nui ryegrass:								
Initial n (May 1978)	30	30	30	30	30	30	30	30
1979								
March	21	23	19	23	22	21	19	19
December	18	15	16	19	19	15	12	16
1980								
March	16	12	12	16	16	13	12	16
May	12	5	10	12	14	10	9	11
(b) Matua prairie grass:								
Initial n (May 1978)			30	30			30	30
1979								
March			18	16			14	14
December			9	13			9	11
1980								
March			2	11			6	7
May			1	10			6	4

for both plant species was strongly influenced by season (Fig. 1, 2). The second curve situated above the 'total loss' curve (Fig. 1, 2) represents the survivorship pattern when losses ascribed to obvious 'animal effects' were excluded. The difference between these curves and the 'total loss' curves largely represents plant losses due to animal 'pulling' (removal of plants) from the pasture and sometimes

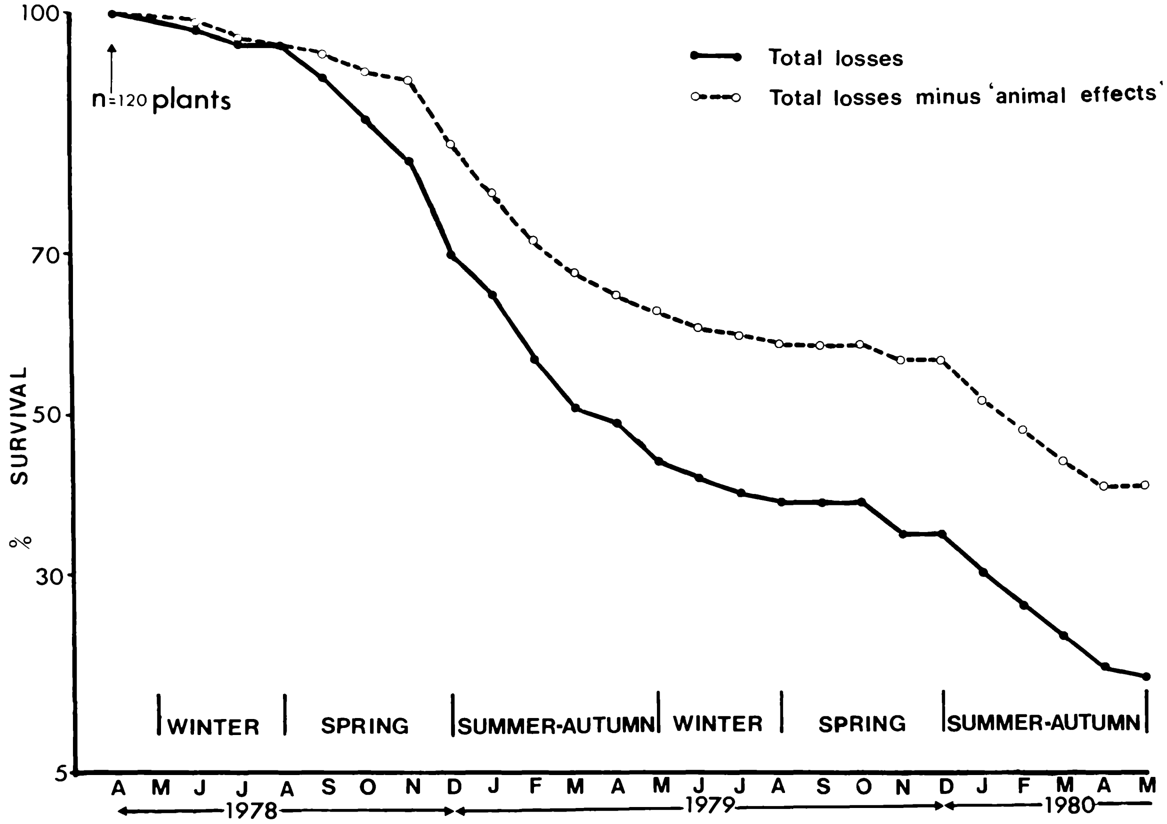

Fig. 1 Seasonal survival of overdrilled Matua prairie grass over a two year period.

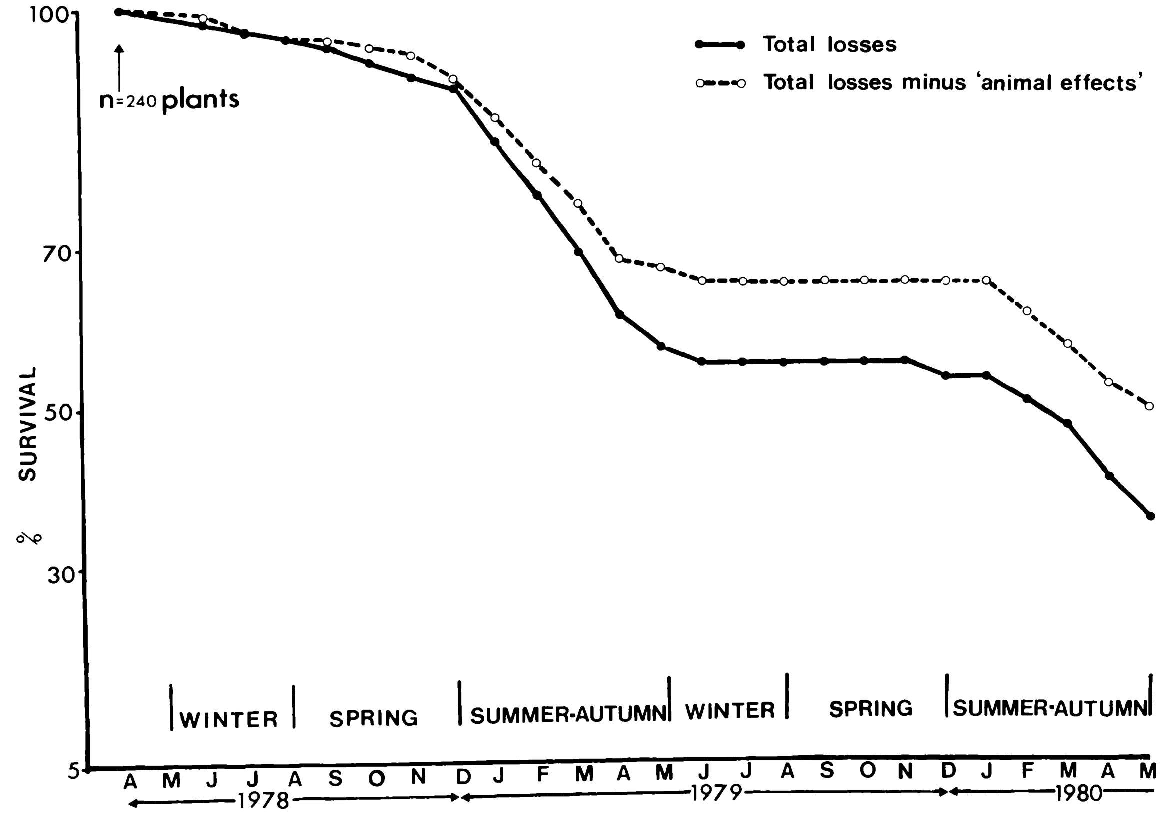

Fig. 2 Seasonal survival of overdrilled Nui ryegrass over a two year period.

loss or occasional burying of ring labels by the action of the grazing animals or earthworms, precluding positive identification of study plants. Total losses after two years were on average greater for Matua prairie grass (about 83%) compared to about 65% for Nui ryegrass. Heavy losses were evident in the spring following drilling for Matua prairie grass and in the following summer/autumn for Nui ryegrass. Loss rates levelled off over the 1979 winter/spring for Nui ryegrass but continued at a high rate for Matua prairie grass, because of higher losses of the latter plants during this period caused by animal pulling (Fig. 1, 2).

As survival of individual Nui ryegrass and Matua prairie grass plants was strongly affected by seasonal changes (Fig. 1, 2), log transformation to linearise the data was considered inappropriate. Instead, because losses were largely confined to the summer/autumn periods comparisons were made of the growth of plants from all treatments, when grouped as follows:

Group 1 - survived the study period (21.4.78 to 14.5 80)
    2 - survived until December 1979; lost over the second summer/autumn (1.12.79 to 14.5.80) after drilling
    3 - survived until December 1978; lost over the first summer/autumn (1.12.78 to 1.5.79) after drilling

Since unequal numbers of survivors were present in each group and each treatment at any particular time, data were analysed using a least squares analysis of variance model with group x treatment interaction terms included. However, on no occasions were significant interactions detected for any variable so these were then excluded from the model. Least squares means for pre-grazing tiller numbers and pre- and post-grazing tiller lengths for Nui ryegrass and Matua prairie grass plants in the above groups are presented in Fig. 3 and Tables 2.5 and 2.6. As least squares means for post-grazing tiller

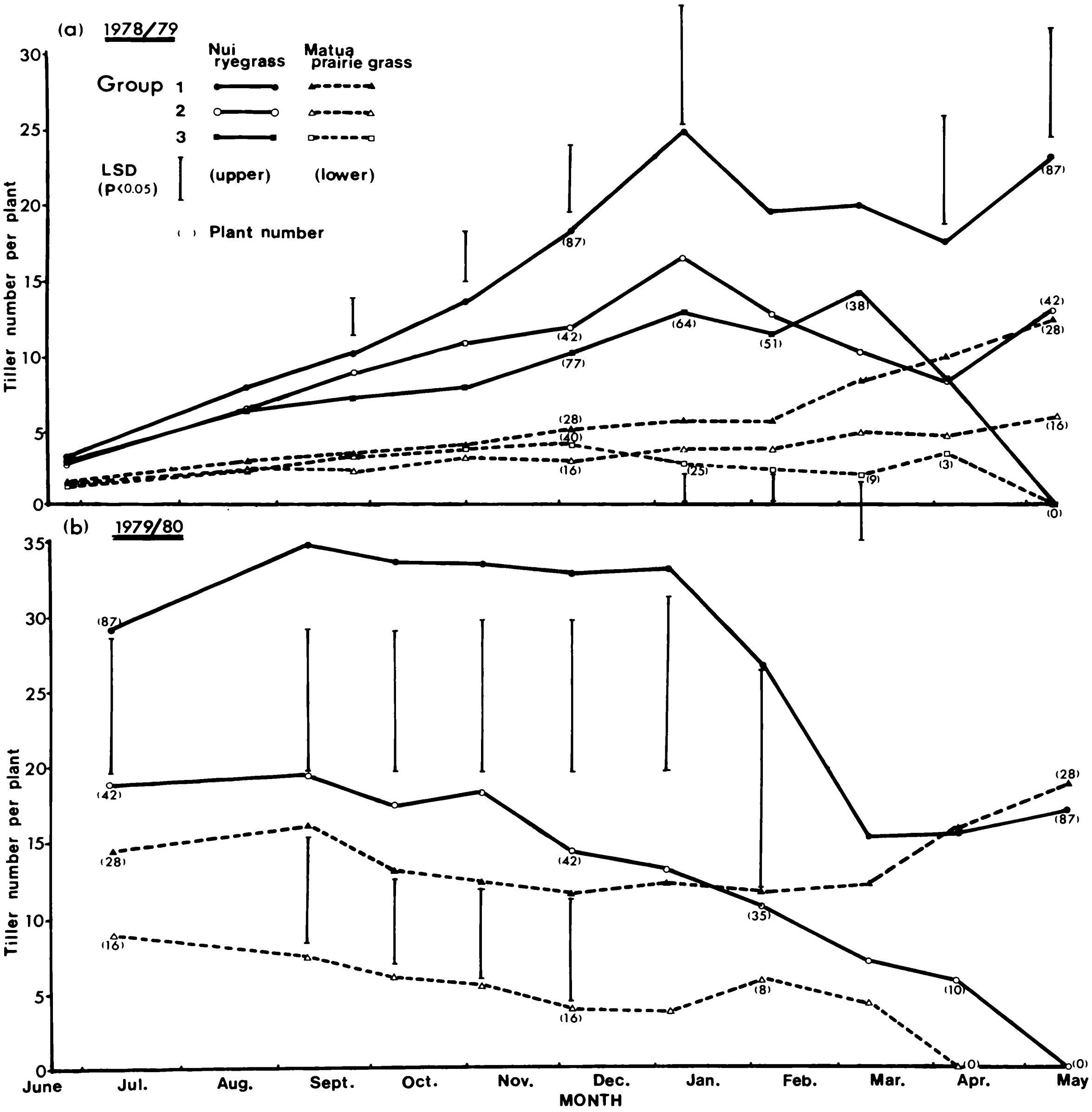

Fig. 3 Pre-grazing tiller numbers for Nui ryegrass and Matua prairie grass plants classified into survival Groups 1, 2 and 3 (see text).

Table 2.5 Pre- and post-grazing tiller lengths (mm) for Nui ryegrass plants from 21.6.78 to 17.5.79 classified into Groups 1, 2 and 3 (see text).

	PR1 21.6.78	PT1[d] 29.6.78	PR2 22.8.78	PT2 4.9.78	PR3 25.9.78	PT3 4.10.78	PR4 31.10.78	PT4 7.11.78	PR6[c] 9.1.79	PT6 16.1.79
Group										
1	[b](87) 145	93	145	106	200	107	284	119	226	151
2	(42) 128	81	130	100	203	108	274	123	220	149
3	(77) 134	74	134	87	186	90	[b](77) 260	95	(64) 204	124
SED[a]	6.7	8.4	8.1	12.0	15.2	9.3	14.5	10.2	13.3	13.1
Sig.	*	*	ns	ns	ns	ns	ns	**	ns	ns

	PR7 7.2.79	PT7 15.2.79	PR8 7.3.79	PT8 14.3.79	PR9 4.4.79	PT9 11.4.79	PR10 9.5.79	PT10 17.5.79
Group								
1	146	108	180	125	239	125	242	109
2	146	98	171	102	227	98	214	98
3	(51) 156	77	(38) 146	75	(20) 182	50	(0) -	-
SED[a]	10.6	8.8	12.3	12.9	17.0	22.8	-	-
Sig.	*	**	*	*	**	**		

[a] average standard error of mean differences
[b] () number of plants in each group
[c] no measurements made at pre- and post-grazing five
[d] PR = pre-grazing measurement; PT = post-grazing measurement

Table 2.6 Pre- and post-grazing tiller lengths (mm) for Matua prairie grass plants from 21.6.78 to 17.5.79, classified into Groups 1, 2 and 3 (see text).

	PR1 21.6.78	PT1[d] 29.6.78	PR2 22.8.78	PT2 4.9.78	PR3 25.9.78	PT3 4.10.78	PR4 31.10.78	PT4 7.11.78	PR6[c] 9.1.79	PT6 16.1.79
Group										
1	[b](28) 172	77	167	87	222	82	267	104	303	153
2	(16) 149	77	166	78	211	64	195	70	247	102
3	(39) 174	81	181	92	251	89	[b](39) 242	86	(25) 262	110
SED[a]	15.9	18.4	19.3	11.6	25.0	10.1	27.6	11.2	29.1	22.6
Sig.	ns	ns	ns	ns	ns	ns	ns	*	ns	*

	PR7 7.2.79	PT7 15.2.79	PR8 7.3.79	PT8 14.3.79	PR9 4.4.79	PT9 11.4.79	PR10 9.5.79	PT10 17.5.79
Group								
1	187	103	263	89	298	81	289	85
2	155	90	175	73	206	66	214	81
3	(18) 156	79	(9) 180	92	(3) 165	87	(0) -	-
SED[a]	22.4	20.1	27.7	12.7	45.9	41.1	-	-
Sig.	ns	ns	***	**	ns	ns		

[a] average standard error of mean differences
[b]() number of plants in each group
[c] no measurements made at pre- and post-grazing five
[d] PR = pre-grazing measurement; PT = post-grazing measurement

numbers were similar to pre-grazing measurements, analyses of these data are not presented.

By mid-spring (25.9.78), about five months after drilling, tiller numbers for Group 1 Nui ryegrass plants were superior to those for Group 3 plants (Fig. 3a). This trend continued over the summer/autumn as the number of plants in Group 3 were reduced to zero, although in February and March 1979 differences were only significant at the 10% level. Tiller numbers for Group 2 plants (all of which were lost from the pasture during the 1979/80 summer/autumn) were not significantly different to those for Group 3 plants over the 1978/79 summer/autumn. From July 1979 tillering for Group 1 and 2 plants were compared (Fig. 3b). Markedly superior tillering occurred in the former Group from this date and over the second summer/autumn, although in March and April 1980 differences failed to reach significance.

For Matua prairie grass differences in tillering between plant groups were not evident until the first summer after drilling (9.1.79) (Fig. 3a). Tiller numbers for Group 1 plants were consistently superior to those in Group 3 in January, February, March and April. As found for Nui ryegrass, tillers on Group 2 plants were not significantly different from Group 1 plants over this period. For the comparison of Group 1 and 2 plants (Fig. 3b), tiller production was consistently greater for the former plants at all measurement times, reaching significance from September to December.

During late-spring (7.11.78) and summer/autumn, Nui ryegrass plants in Group 3 were grazed more severely, as demonstrated by tiller length, than those in Groups 1 or 2 (Table 2.5). This trend was also associated with a significantly lower pre-grazing tiller length for Group 3 plants from mid-summer (7.2.79) until autumn (4.4.79) as plant numbers were reduced to zero. As no tiller length data were collected over the 1979/80 summer, this precluded a comparison of Group 1 and 2 plants over the period when plants in the latter group were lost from the pasture. The pattern of treatment differences for tiller lengths was less distinct for Matua prairie grass then for Nui ryegrass. Generally over summer (16.1.79 to 14.3.79), the Group 3 plants were grazed slightly harder than Group 1 plants (Table 2.6). However, pre-grazing tiller lengths of Group 3 plants were also less than Group 1 plants over the summer/autumn, especially during March and April, when numbers in the former Group reached a low level.

A second approach was used to examine the relationship between tiller number and length and summer survival. All marked Nui ryegrass and Matua prairie grass plants surviving until the 2.11.78 and the 5.11.79 (pre-grazing measurement dates immediately before the 1978/79 and 1979/80 summers) were classified into groups based on their tiller numbers on those dates (Table 2.7). Similarly, divisions were made dependent on post-grazing tiller lengths on the 7.11.78 and the 9.11.79 (Table 2.8). The numbers of plants within each group subsequently lost over the summers were calculated and expressed as a percentage of the total plants (losses plus survivors) within each group (Table 2.7, 2.8). Losses during summer were much higher for ryegrass plants with 10 tillers or less at the beginning summer, than they were for larger plants (Table 2.7). Narrower divisions were used for prairie grass because of its low tillering capacity compared to ryegrass (Fig. 3). In the first summer no trend was evident but in the second losses of small prairie grass plants (three tillers or less) were much higher than for larger plants, but generally only small numbers of plants were involved in each tiller category at the commencement of the 1979/80 summer (Table 2.7). A similar analysis of post-grazing tiller lengths for Nui ryegrass and Matua prairie grass

Table 2.7 Tillers per plant for Nui ryegrass and Matua prairie grass at the beginning of the 1978/79 (2.11.78) and the 1979/80 (5.11.79) summers, and losses over these seasons.

	(a) 1978/79 Summer (7.11.78 to 14.3.79)			(b) 1979/80 Summer (4.12.79 to 10.3.80)		
Tillers per plant	Losses (L)	Survivors (S)	% Lost (100 L/L+S)	Losses (L)	Survivors (S)	% Lost (100 L/L+S)
(i) RYEGRASS						
1-5	22	62	26	7	13	35
6-10	17	38	31	6	14	30
11-20	6	46	11	1	24	4
21+	2	30	6	3	60	5
(ii) PRAIRIE GRASS						
1	3	8	27	4	2	67
2	6	13	32	3	4	43
3	8	18	31	2	3	40
4	8	13	38	2	5	29
5	1	3	25	0	1	0
6-9	5	9	36	0	5	0

suggests that plants grazed the hardest at the beginning of summer were most likely to be lost from the pasture during the summer, although small numbers of plants were often involved in the 0-40 mm category (Table 2.8).

The effects of the treatments on plant losses were determined for five seasonal groupings over the study period (Table 2.9). Means across herbicide, coulter and plant species treatments were obtained for Nui ryegrass and Matua prairie grass and were subjected to analysis of deviance. Since no significant treatment effects were detected for Matua prairie grass these data are not presented. There were also no herbicide or coulter effects on plant losses detected for Nui ryegrass. However, during the winter/spring period following drilling, losses of ryegrass plants were significantly greater in treatments where only its seed was sown (CN and TN) than when it was sown in mixtures with Matua prairie grass (CNM and TNM). The reverse was true during the succeeding summer (Table 2.9). There were no significant interactions between treatments for this analysis.

Table 2.8 Post-grazing tiller lengths (mm) for Nui ryegrass and Matua prairie grass at the beginning of the 1978/79 (7.11.78) and the 1979/80 (9.11.79) summers, and losses over these seasons.

Tiller lengths	(a) 1978/79 Summer (7.11.78 to 14.3.79) Losses (L)	Survivors (S)	% Lost (100 L/L+S)	(b) 1979/80 Summer (4.12.79 to 10.3.80) Losses (L)	Survivors (S)	% Lost (100 L/L+S)
(i) RYEGRASS						
0-40	5	6	45	2	6	25
41-80	21	42	33	10	28	26
81-120	14	65	18	4	42	9
121+	7	66	10	2	35	5
(ii) PRAIRIE GRASS						
0-40	4	3	57	2	2	50
41-80	13	25	34	4	10	29
81-120	13	22	37	5	10	33
121+	3	15	17	2	10	17

Table 2.9 The effect of herbicide (H), coulter and species mixture on seasonal losses of Nui ryegrass plants. Data are ratios of number of plants lost over the season(s) to the total plants available at the beginning of the season(s).

Treatment	Season Win./Spr. (29.6.78-6.11.78)	Sum. (6.11.78-14.3.79)	Aut./Win./Spr. (14.3.79-9.11.79)	Sum. (9.11.79-10.3.80)	Aut. (10.3.80-14.5.80)
Herbicide:					
+H	6/120	28/114	23/86	10/63	12/53
-H	12/120	19/108	24/89	8/65	14/57
Sig.	ns	ns	ns	ns	ns
Coulter:					
Chisel	9/120	19/111	23/92	11/69	14/58
Triple disc	9/120	28/111	24/83	7/59	12/52
Sig.	ns	ns	ns	ns	ns
Species:					
Nui	13/120 (11)[a]	16/107 (15)	25/91	9/66	12/57
Nui-Matua	5/120 (4)	31/115 (27)	22/84	9/62	14/53
Sig.	*	*	ns	ns	ns

[a] ratio expressed as a percentage

2.7.3 Reproductive development

Reproductive tillers (seedhead visible) on marked Nui ryegrass (240) and Matua prairie grass (120) plants were first recorded in October 1978. Over the period October 1978 to January 1979, 86% of the 101 ryegrass plants that produced reproductive tillers did so in the months of November and December. In spring 1979 (October, November, December) 62 ryegrass plants possessed reproductive tillers, 95% of these in November 1979. Matua prairie grass flowered slightly earlier than Nui ryegrass. Ninety-five prairie grass plants bore reproductive tillers over the period October 1978 to December 1978 of which 77% did so in October 1978. In spring 1979, 89 prairie grass plants bore reproductive tillers, 76% in October 1979. Thus the majority of the marked ryegrass plants remained totally vegetative during the study period.

2.7.4 **Growth of introduced grasses**

Treatment effects on the growth (tillers per plant, tiller length) of marked plants were summarised on a seasonal basis (Table 2.10). The only consistent treatment effect was the superior tiller length for Nui ryegrass sown through the chisel rather than the triple disc coulter, over the winter, spring and summer following drilling. Herbicide effects on tillering were small and restricted to the first winter after drilling and no effects on tiller length were recorded. Coulter type used at drilling had no effect on tillering of Nui ryegrass and Matua prairie grass. No significant interactions between herbicide, species mixture and coulter were revealed by the analyses.

2.7.5 **Sward botanical composition**

Overdrilling of Nui ryegrass substantially increased the ryegrass content of the sward above that of undrilled plots (Table 2.11a). A strong effect was detected during the winter/spring after drilling and early-summer (January 1979). A positive effect was still evident by the following spring but this had disappeared by mid-summer 1980 (February). The less frequent tiller density measurements also indicate a strong response to overdrilling during the spring and early-summer immediately following drilling (Table 2.11b). In plots where a mixture of Nui ryegrass and Matua prairie grass was drilled,

Table 2.10 Treatment effects on tiller number per plant and pre-grazing tiller length (mm) for marked Nui ryegrass and Matua prairie grass plants.

	Tillers per plant[a]												Tiller length							
	Nui				Matua				Nui				Nui				Matua			
	+H	-H	LSR	Sig.	+H	-H	LSR	Sig.	N	NM	LSR	Sig.	Chisel	Triple disc	SED	Sig.	Chisel	Triple disc	SED	Sig.
Winter I (21.6-22.8.78)	5.3	4.0	1.18	**	2.1	1.8	1.17	(†)	4.8	4.5	1.20	ns	144.4	132.9	4.15	*	174.0	168.8	10.13	ns
Spring I (4.9-4.12.78)	10.7	9.3	1.24	ns	3.4	3.0	1.20	ns	10.8	9.2	1.23	ns	252.1	216.0	7.11	***	234.1	231.9	12.63	ns
Summer I (11.12.78-7.3.79)	17.9	16.3	1.34	ns	4.1	4.6	1.31	ns	18.2	16.1	1.34	ns	194.7	159.0	11.26	**	241.2	211.3	12.70	(†)
Autumn I (14.3-9.5.79)	15.3	15.7	1.40	ns	6.0	8.1	1.62	ns	16.6	14.5	1.30	ns	242.3	227.0	12.32	ns	269.3	262.8	22.59	ns
Winter II (17.5-10.9.79	23.8	25.6	1.35	ns	10.2	11.0	2.00	ns	27.3	22.3	1.30	ns	190.5	177.5	9.60	ns	210.1	221.1	18.19	ns
Spring II (14.9-4.12.79)	27.5	30.1	1.55	ns	9.2	9.7	2.21	ns	35.7	23.3	1.44	*	257.9	253.2	15.58	ns	236.3	239.0	20.49	ns
Summer II (9.1-10.3.80)	23.8	23.4	1.37	ns	10.5	8.6	1.81	ns	28.1	19.8	1.64	ns	-	-	-	-	-	-	-	-
Autumn II (8.4-14.5.80)	15.3	20.8	1.76	ns	18.2	21.3	1.78	ns	20.4	15.6	1.65	ns	-	-	-	-	-	-	-	-

[a] data are means across pre- and post-grazing counts; H = herbicide; N = Nui ryegrass only, NM = mixture of Nui ryegrass and Matua prairie grass

Table 2.11 The effect of overdrilling[a] Nui ryegrass and Matua prairie grass on the ryegrass content (% of herbage mass) and tiller density (tillers/dm^2) of the sward.

Date	Treatment Drilled	 Control	SED[b]	Sig.
(a) Ryegrass content:				
28.6.78	38.9	25.9	3.38	**
28.8.78	41.9	20.0	2.11	***
2.11.78	46.7	26.4	4.20	***
8.1.79	37.6	19.7	3.20	***
9.4.79	34.3	25.7	3.88	*
10.7.79	64.1	53.1	3.98	*
9.10.79	51.6	40.3	3.29	**
1.2.80	24.3	21.3	3.14	ns
12.5.80	39.3	37.8	3.10	ns
(b) Ryegrass tiller density[c]:				
			LSR[d]	
12.9.78	40.1	5.9	2.63	**
19.12.78	35.8	6.8	2.63	**
19.3.79	28.8	24.0	1.86	ns
13.7.79	28.3	9.9	2.33	*
17.10.79	16.9	18.5	1.90	ns

---

[a] plots were drilled on the 20-21.4.78
[b] approximate standard error of mean differences
[c] treatment data are geometric means
[d] least significant ratio

their ryegrass contents from June 1978 until October 1979 were consistently below (range 0.7 to 7.6% of herbage mass) those for plots receiving only Nui ryegrass. Application of herbicide suppressed the growth of ryegrass in the sward until early-summer (8.1.79) but the effect was greatest nearer to the time of application (Table 2.12a). In addition, a consistent trend for ryegrass tiller densities to be higher in plots receiving no herbicide compared to those receiving herbicide was revealed for the samplings on the 12.9.78, 19.12.78 and the 19.3.79, although significant differences were found only at the latter dates (Table 2.12b). The application of herbicide at drilling did not significantly affect the sward content or tiller densities of other species in the sward.

The overdrilling of Matua prairie grass initially had only a small effect on its proportion in the sward (Table 2.13). However, by January 1979, overdrilled plots supported a higher proportion of prairie grass than did control plots and this trend continued until summer 1980 (1.2.80), but the prairie grass content of the sward never exceeded 20% of herbage mass (Table 2.13). As very little or no prairie grass was recorded in many tiller density core samples, it was not possible to statistically analyse these data.

Table 2.12 The effect of band-spraying herbicide (H) at drilling on the ryegrass content (% of herbage mass) and tiller density (tillers/dm^2) of the sward.

Date	Treatment +H	Treatment -H	SED[a]	Sig.
(a) <u>Ryegrass content</u>:				
28.6.78	33.3	39.4	2.85	*
28.8.78	35.4	39.7	2.12	(†)
2.11.78	41.3	43.9	3.81	ns
8.1.79	33.6	34.4	2.68	ns
9.4.79	35.0	30.1	3.66	ns
10.7.79	62.6	61.1	2.59	ns
9.10.79	48.1	50.6	3.12	ns
1.2.80	25.6	21.8	1.79	*
12.5.80	39.6	38.4	2.25	ns
(b) <u>Ryegrass tiller density</u>[b]:				
			LSR[c]	
12.9.78	24.9	30.0	1.45	ns
19.12.78	19.5	33.7	1.78	(†)
19.3.79	22.2	34.8	1.51	*
13.7.79	25.1	21.2	2.05	ns
17.10.79	16.5	17.9	1.79	ns

[a] approximate standard error of mean differences
[b] treatment data are geometric means
[c] least significant ratio

Table 2.13 The effect of overdrilling Nui ryegrass and Matua prairie grass on the prairie grass content (% of herbage mass) of the sward.

Date	Treatment Drilled	 Control	SED[a]	Sig.
26.6.78	16.9	12.7	3.13	(†)
28.8.78	17.4	15.2	3.70	ns
2.11.78	12.7	7.0	3.36	(†)
8.1.79	10.3	1.8	2.11	***
9.4.79	12.0	3.6	3.17	***
10.7.79	19.5	9.5	3.46	**
9.10.79	13.2	2.8	3.01	**
1.2.80	4.7	1.3	0.82	**
12.5.80	6.1	4.6	2.30	ns

[a] SED = approximate standard error of mean differences (significance levels taken from analysis of arcsin transformed data)

The paspalum, *Poa* spp. and white clover contents (% of herbage mass) of swards in overdrilled plots were generally significantly lower than in undrilled plots from June 1978 until October 1979. These results reflect increases in the ryegrass content (Table 2.11) after overdrilling ryegrass into the sward. The proportions of dead material in the swards were highest in summer and autumn and reached a maximum of 15% of herbage mass.

Overdrilling had no effect on tiller densities of paspalum or *Poa* spp., but rooted nodes per dm^2 of white clover were reduced in spring 1978 compared with the levels in swards of undrilled plots. Coulter type did not significantly affect the proportions and densities of all species in the sward.

2.7.6 Herbage accumulation

Herbage accumulation in overdrilled plots was greater than in the control plots (undrilled sward) during the first winter and spring after drilling (Table 2.14). However, over summer drilled plots yielded below undrilled plots. Table 2.14 indicates that this negative effect was from 6.11.78 to 9.3.79, being more marked from 15.1.79 to 9.3.79. By growth 8, drilled plots again outyielded the control plots and in subsequent growth periods during winter and spring, no significant differences were detected (Table 2.14).

Table 2.14 The effect of overdrilling Nui ryegrass and Matua prairie grass on seasonal herbage accumulation (kg DM/ha).

Season	Growth periods within seasons	Treatments		SED	Sig.
		Drilled[c]	Control		
WINTER I (123 days)	P[a] (21.4 -27.6.78)	2086	1803	59.9	***
	1 (3.7 -28.8.78)	1047	873	32.9	***
	TOTAL[b]	3133	2676	85.8	***
SPRING I (87 days)	2 (31.8 -27.9.78)	1515	1429	48.3	ns
	3 (2.10 -2.11.78)	2533	2385	36.6	**
	4 (6.11 -5.12.78)	1909	1911	109.7	ns
	TOTAL	5957	5725	116.0	(†)
SUMMER I (82 days)	5 (7.12.78-10.1.79)	3014	2985	100.8	ns
	6 (15.1 -8.2.79)	1422	1705	62.2	***
	7 (14.2 -9.3.79)	782	974	82.6	*
	TOTAL	5218	5664	169.6	*
AUTUMN I (55 days)	8 (13.3 -6.4.79)	1334	1108	82.4	*
	9 (10.4 -11.5.79)	607	544	40.5	ns
	TOTAL	1941	1652	92.3	**
WINTER II (117 days)	10 (15.5 -10.7.79)	899	850	28.2	ns
	11 (12.7 -11.9.79)	1335	1369	48.4	ns
	TOTAL	2234	2219	56.3	ns
SPRING II (49 days)	12 (13.9 -9.10.79)	1050	1054	43.9	ns
	13 (15.10-6.11.79)	1608	1534	68.5	ns
	TOTAL	2658	2588	90.0	ns

[a] the first pre-grazing herbage mass estimate
[b] overall seasonal herbage accumulation
[c] means across all overdrilled plots

A consistently greater herbage accumulation in all seasons resulted from sowing the seed through the chisel coulter than through the triple disc coulter (Table 2.15). These differences were small and only reached significance ($P<0.05$) in Autumn I.

Table 2.15 Effect on seasonal herbage accumulation (kg DM/ha) of drilling plots with chisel or triple disc coulters.

	Treatments			
Season[a]	Chisel	Triple disc	SED	Sig.
Winter I	3186	3080	76.5	ns
Spring I	6053	5861	103.5	(†)
Summer I	5318	5118	151.2	ns
Autumn I	2049	1832	82.3	*
Winter II	2268	2200	50.2	ns
Spring II	2698	2618	80.3	ns

[a] see Table 2.14

Band-spraying of herbicide at drilling reduced herbage mass in the first winter (Table 2.16). This effect was largely due to a highly significant reduction at the first pre-grazing estimate, 67 days after drilling. No significant interactions between grass species mixtures, coulter type and herbicide treatments were detected by the analysis of herbage mass data.

Table 2.16 Effect of herbicide (H) application at drilling on seasonal herbage accumulation (kg DM/ha).

Season[a]	Growth period[a]	Treatments +H	-H	SED	Sig.
Winter I	P	1896	2163	47.1	***
	1	1023	1002	25.8	ns
Spring I	2	1497	1498	27.7	ns
	3	2504	2503	23.2	ns
	4	1927	1892	55.1	ns
Summer I	5	3104	2913	58.5	*
	6	1460	1497	56.2	ns
	7	859	781	62.7	ns

[a] see Table 2.14

2.8 DISCUSSION

On dairy farms, pastures that are dominated by C_4 grass species are often overdrilled in autumn with C_3 grasses to help overcome feed deficits which may occur in the later-winter/spring period.

In this experiment, the autumn overdrilling of seed of the C_3 species, perennial ryegrass and prairie grass, improved sward herbage production over the winter and spring immediately following drilling, but by the second winter this advantage had disappeared (Table 2.14). The initial improvement in production of drilled plots was mainly due to a rapid increase in the ryegrass content of the sward (Table 2.11), since the addition of prairie grass did not significantly improve its prairie grass content until January 1979, some nine months after drilling (Table 2.13). The maximum increase in the ryegrass content (22% in August 1978) coincided with the maximum seasonal improvement in the production of the sward (Table 2.14).

During late-spring and summer (growths four to seven, inclusive) the production of drilled plots fell below that of undrilled plots (Table 2.14). This period coincides with the period of active herbage production from paspalum. It is possible the colder than average 1978 spring (Section 2.6) may have slowed the initial herbage growth of paspalum, reducing the magnitude of its effect on herbage production during growths four and five (Table 2.14).

Favourable conditions for germination and emergence of overdrilled grasses (Baker 1980) prevailed at the time of drilling (Section 2.3). However, the grooves left by the chisel coulter generally provided for better emergence (Table 2.3) and growth (Table 2.10) of Nui ryegrass than did those left by the triple disc coulter. These results support the findings of C.J. Baker and co-workers (Baker 1976; Choudhary & Baker 1978, 1980; Ryan et al. 1979; Baker & Mai 1982a,b) who have reported improved seed germination and seedling survival in grooves made by chisel coulters over those made by triple disc coulters. This superior germination and growth was translated into only small and probably unimportant differences in seasonal herbage production in plots overdrilled with chisel or triple disc coulters (Table 2.15).

Banding of herbicide at drilling, even though it covered 27% of the plot area, had only a limited negative effect on the herbage production of the sward (Table 2.16), and therefore the resident species within the sward, such as ryegrass (Table 2.12). Ryan et al. (1979) reported a similar finding. Conversely, over a similar period of time (Table 2.10) tiller production of the introduced grasses benefited from the action of herbicide on the resident species, providing a counterbalance to the effect of herbicide on the resident ryegrass.

The overdrilling practices used in this experiment represent those generally in use on commerical farms. Benefits from such introductions in terms of improved seasonal pasture production are likely to be small and limited to the first year after drilling, although the use of the chisel coulter rather than the triple disc coulter may be advantageous. It is suggested that the limited benefits accruing from autumn overdrilling are related to the high losses of the introduced grasses during the summer/autumn seasons (Fig. 1, 2). These losses were also modified by the actions of the grazing animal, especially for Matua prairie grass (Fig. 1, 2), and probably by the presence of the established species (King 1971). Nui ryegrass and Matua prairie grass were drilled into clumps of paspalum which are a common occurrence in the sward. These clumps were composed of a dense mass of short rhizomes located at or just below the soil surface, from which a surface mat of large tillers arose in late-spring/early-summer (Plate 1). In studying such pastures, Sturme (1977) noted that perennial ryegrass was usually excluded from paspalum clumps. This suggests that paspalum, because of its exceptional colonising ability (Hamblyn 1937; Arnold 1953), growth potential during summer (Hatch & Slack 1970), and ability to withstand treading (Hunt 1979) and severe grazing (Weinmann 1948; Harris 1978), has the potential of offering severe competition to establishing C_3 plants. Nevertheless, since paspalum occupies only 30-40% of the experimental area other resident species could also offer vigorous competition to establishing species.

Generally, treatments did not affect the survival of the overdrilled species, except for differences between the N and NM species combinations during the first winter/spring and summer after

Plate 1. Paspalum dissected from an experimental plot illustrating the prostrate, rhizomatous, and dense growth form assumed in intensively grazed dairy pastures.

drilling (Table 2.9). No explanation for the latter effects can be found.

It is unlikely that the low populations of insects such as grass grub (*Costelytra zealandia*), Argentine stem weevil (*Listronatus bonariensis*) and black beetle (*Heteronychus arator*) that were present in the swards of the experimental area, would have caused measurable sward deterioration. This observation was confirmed by regular sampling by entomologists from the Ruakura Agricultural Research Station (R.W. Watson, pers. comm.; C.F. Mercer, pers. comm.) during this series of field experiments (1978-1982). Some control of insect populations may have been achieved because of the prolonged use of high stocking rates (Section 2.2) (East & Pottinger 1983). During the present experiment, fungal infections affecting the overdrilled grasses were slight and therefore probably did not strongly influence their persistence. No visual symptoms of disease were noted on Matua prairie grass plants but in February 1979, less than 10% of the 180 Nui ryegrass plants remaining in Groups 1-3 (Fig. 3) showed various degrees of crown rust (*Puccinia coronata*) infection.

Data presented in Fig. 3 and Tables 2.5, 2.6, 2.7 and 2.8 show that plant size is an important determinant of summer survival and persistence of overdrilled perennial grasses. These findings are in general agreement with those of Langer et al. (1964), Hoen (1968) and Harris (1973). Large plants are presumably better able to survive stress periods than small plants as their size improves their chances of obtaining sufficient of the essential growth factors (nutrients, water and light), in an intensely competitive environment provided by the resident species.

2.9 CONCLUSIONS

Present overdrilling procedures are satisfactory for introducing Nui ryegrass and Matua prairie grass into swards containing paspalum . This experiment has demonstrated, however, that the improvements in seasonal herbage production are likely to be small and limited to the first year after drilling, a situation which reflects the lack of persistence of the introduced species.

This experiment has shown that large plants have a greater capacity to survive stress periods (summers) than do small plants. Hence to justify the use of overdrilling techniques as a means of renovating pastures containing paspalum, better definition of post-drilling management is required to enable a high proportion of germinated seedlings to reach a competitive size during the winter/spring following drilling.

One possibility is that the addition of nitrogen fertiliser to the sward in the late-winter/spring period may modify the relative competitive abilities of the introduced and resident species. This is examined in chapter 4.

The ability of at least some Nui ryegrass plants to rapidly increase in size (tiller numbers) after germination was reflected in an improved ryegrass content of the sward. In contrast, Matua prairie grass did not possess this ability and hence did not make a large contribution to the herbage mass of the sward during the post-drilling winter/spring period. Matua prairie grass was therefore excluded from subsequent experiments.

An understanding of the relative competitive abilities of perennial ryegrass and paspalum would be enhanced by knowledge of the morphological structure and seasonal physiological status (nonstructural carbohydrate and major element levels) of these plants. In chapter three a series of experiments designed to obtain such information are described.

CHAPTER 3

NONSTRUCTURAL CARBOHYDRATE AND MAJOR ELEMENT LEVELS IN PERENNIAL RYEGRASS AND PASPALUM

3.1 INTRODUCTION

The dominance of a particular pasture species depends on its ability to compete for limited environmental resources. The energy for obtaining these resources and for maintenance, growth and reproduction, is obtained from carbohydrate formed by the process of photosynthesis. Carbohydrates, nitrogen and other essential elements obtained in excess of immediate requirements, may be accumulated as reserves (Weinmann 1948; Cook 1966; Trlica & Singh 1979), which consist mainly of carbohydrate (Cook 1966).

Reserves may be remobilised to meet respiratory requirements during dormancy or periods of reduced growth, and for the initiation of early-spring growth. They may also be required for regrowth after foliage removal and at any time when photosynthesis cannot meet the energy demands of the plant (Cook 1966; Smith 1973; Trlica & Singh 1979). Menke & Trlica (1981) found that plants that replenish reserves rapidly after a period of depletion are least affected by defoliation and recover rapidly from severe defoliation.

Similar seasonal changes in carbohydrate reserve levels occur in all perennial grasses but may be influenced by the growth behaviour of the species and by climate (Weinmann 1952). Levels of plant reserves may affect the outcome of interactions between perennial ryegrass and paspalum. Information on the growth strategies and morphological structure of these species was sought to provide a better understanding of their relative competitive abilities in dairy pastures.

3.2 MATERIALS AND METHODS

Two experiments are described in this chapter. In Experiment 1 samples of ryegrass and paspalum were obtained over a 12 month period for chemical analysis. Experiment 2 was similar to 1 and was used to obtain estimates of the biomass of ryegrass and of paspalum; both involved regular defoliation. Mown rather than grazed pastures were used to minimise variability in plant elemental uptake caused by uneven return of elements in dung and urine, and selective grazing by dairy cows (Hodgson 1973).

3.2.1 Experimental sites and pre-experimental management

Separate plots (31 x 4.1 m) located in each of four paddocks (representing replicates) in the general experimental area (Section 2.2) were used for Experiments 1 and 2. Plots were fenced off from grazing about one month before the start of each experiment. During this time the pastures were flail-cut on three occasions from a height of about 100 mm to 25 mm, using a Swift Current Forage Plot Harvester, to reduce variability in regrowth caused by the grazing animal. All clippings were discarded. This defoliation procedure was used throughout both experiments, after each sampling.

3.2.2 Fertiliser applications

Estimates of nutrient removal in herbage from regularly mown plots were obtained by combining nutrient concentration (% of DM) data (means over 1972 to 1975) with the estimates of pre-cutting herbage mass obtained during the present experiments. The P, S and Mg concentrations in the pasture herbage showed little seasonal variation and were about 0.40, 0.37 and 0.19%, respectively, over spring, summer/autumn and winter. The K and N concentrations were at their highest in winter, ranging from 2.9 to 3.3% and 3.9 to 4.2%, respectively, over the seasons. Mean herbage mass estimates for the pastures over spring, summer/autumn and winter, were 3950, 4000 and 2150 kg DM/ha, respectively.

The amounts of P, S, Mg and K applied to the pastures to replace the losses in cut herbage were adjusted for losses in dairy cow products, and losses ex-pasture (Middleton & Smith 1978). Seventy-five percent of the N in the pasture consumed by the cows was assumed to be excreted onto the pasture (Walker et al. 1954). Adjustments were also made for an assumed pasture utilisation by the cows of 75% (Middleton & Smith 1978). The nutrients were applied at about monthly intervals as ibex (25% P), flowers of sulphur (100% S), magnesium oxide (50% Mg), potassium chloride (50% K) and urea (45% N). The appropriate quantities of each were thoroughly mixed before hand-spreading over the plots during rain or when rain was imminent, to minimise burning of herbage.

3.2.3 Sampling methods

3.2.3.1 Experiment 1 (chemical analysis)

Samples of paspalum and ryegrass were taken at 14 to 21 day intervals during spring, summer and autumn, and at intervals of 28 to 42 days during winter. Sampling took place when the pasture height reached about 100 mm, after which the plots were mown (Section 3.2.1). Paspalum samples were collected from 19.11.79 to 21.10.80 and ryegrass samples from 20.5.80 to 13.4.81. Measurements were converted to a seasonal basis by averaging data obtained in September, October and November (spring - six sample dates), December, January and February (summer - four sample dates), March, April and May (autumn - four sample dates), and July and August (winter - two sample dates).

Above- and below-ground samples of paspalum and ryegrass were obtained by inserting a 48 mm diameter corer to a depth of 150 mm.

Samples were obtained between 8 am and 12 noon on the sample day to minimise possible diurnal variation in sugar and starch levels (Smith 1973). At each sampling, two to five cores were obtained from each plot at each of 10 separate, paspalum dominant areas. From December until May the herbage mass in these areas was 50 to 80% paspalum. Cores were bulked on a plot basis and stored in a refrigerator at 4 °C. Soil and plant material were separated by washing. A representative subsample of paspalum was dissected into leaf (laminae only), pseudostem, culm (from the uppermost stem node and including the flowerhead), rhizomes, roots, and dead material (composite of above- and below-ground brown, necrotic tissues).

Fifteen to 25 cores per plot from the centres of distinctly separate plants provided the bulk ryegrass sample. These plants were growing in regions generally uninhabited by paspalum. Sample treatment was as for paspalum, but dissection was into leaf (laminae only), pseudostem, roots, and dead tissue (above- and below-ground). Flowering tillers were generally absent from ryegrass samples. Definitions of grass shoot parts are given by Thomas (1980).

All samples were rewashed before freezing (-18 °C) 24 to 48 hours after sampling. Within seven days of sampling, all frozen plant tissues were placed in a freeze drier (0.5 mm Hg, -30 °C) for 48-72 hours. Haslemore et al. (1980) considered freeze drying the most appropriate procedure when determining total nonstructural carbohydrate (TNC) levels (soluble sugars plus starch) in plant material. After drying, weights were recorded for each plant component and the tissue was ground in a Wiley mill to pass a 1.0 mm screen. Ground tissue was stored in air-tight containers at 4 to 7 °C until chemical analysis within approximately two months.

3.2.3.2 Experiment 2 (biomass)

Samples were taken on nine occasions from 22.4.81 to 10.3.82. Each sample date coincided with one used for the chemical analysis during the previous year (Experiment 1). The chemical composition data at comparable dates were combined with the yield data to obtain estimates of the amounts (kg/ha) of each measured constituent in the various plant tissues. These estimates were converted to a seasonal basis by averaging data obtained in October and November (spring - two sample dates), December and January (summer - two sample dates), March, April and May (autumn - three sample dates), and June and July (winter - two sample dates).

Regions within each plot were classified as either summer/autumn paspalum dominant (Pa) or containing little or no paspalum (NPa). Botanical dissections of herbage (see below) from Pa regions during these seasons gave paspalum and ryegrass contents of 77 and 7%, respectively, compared to 6 and 55%, for NPa regions.

At each sample date estimates of above-ground herbage mass (kg DM/ha) in Pa and NPa regions were the mean of four quadrat cuts per plot. The cutting technique was as described in Section 2.4.3.1. In addition, 10 to 20 random samples of herbage from Pa and NPa regions were hand-cut to ground level and bulked within regions before botanical dissection (Section 2.4.4). The perennial ryegrass and paspalum fractions were subdivided into shoot components as described above and the proportion of the total sample dry weight represented by each was calculated. These proportions were combined with the appropriate herbage mass data to derive the respective biomass of shoot components of ryegrass and paspalum in Pa and NPa regions.

Five ryegrass plants at least 150 mm from similar plants were selected from NPa regions in each plot for the estimation of root biomass. All herbage, plus a 50 mm soil width around each plant to a depth of 150 mm, was removed. Soil was washed from each plant before dissection into shoots, roots and dead material, oven drying and weighing. Mean shoot/root and shoot/dead ratios were calculated for each plot. These ratios were combined with ryegrass shoot biomass data obtained from botanical analysis and quadrat cuts, to estimate root biomass and dead material yield per hectare. It was not possible to sample the below-ground organs of individual paspalum plants because of their clumpy tiller growth from a network of subsurface rhizomes (Plate 1). Instead, five soil cores (48 mm diameter, 150 mm depth) were removed from Pa region quadrat sites after removal of above-ground herbage. Cores were bulked within plots, washed and dissected into rhizomes and roots, before oven drying. The total surface area (20 cores) sampled in each plot at each date was 3.6×10^{-6} ha.

Herbage mass estimates based on six quadrat cuts per plot were also made when sampling for chemical analysis (19.11.79 to 13.4.81) to provide, in combination with elemental composition data (Section 3.2.2), estimates of fertiliser applications rates.

3.2.4 **Analytical procedures**

(a) *Soluble sugars*

Plant material (200 mg of ground tissue) was extracted under reflux in 80% ethanol and filtered according to the method of AOAC (1975 - Section 3.081). The filtrates were cooled and diluted to appropriate volumes, and total sugars were determined in 1 ml aliquots using 0.05% anthrone in 70% sulphuric acid (Bailey 1958). Additional 1 ml aliquots of filtrate were periodically analysed in 70% sulphuric acid with the omission of anthrone to assess the magnitude of any possible interference. No interference was detected. Absorbances were read on a Spectronic 20 at 625 nm.

(b) *Starch*

The residue remaining after extraction by 80% ethanol was boiled in water to gelatinise the starch (MacRae & Armstrong 1968). After cooling to less than 60 °C, starch was determined as glucose by the addition of an amyloglucosidase preparation (Sigma Chemicals, *Rhizopus* genus mold) followed by treatment with glucose oxidase (AOAC 1975, Sections 31.211-31.214). Absorbances were read at 540 nm on a Spectronic 20. With every set of analyses, standards of A/R potato starch were included to assess the activity of amyloglucosidase. Recoveries of not less than 95% were considered acceptable.

(c) *Major elements - N, P, K, S, Mg, Ca and Na*

N and P were determined on a micro-Kjeldahl digest, the former by reduction with alkaline sodium-phenate (Gehrke et al. 1972) and the latter by reduction of phospho-molybdate using amino-napthol-sulphonic acid (Basson 1976). S, Mg, Ca, Na and K were determined after wet oxidation and digestion with nitric-perchloric acid mixture. S was determined turbidimetrically with barium chloride solution (Mottershead 1971). Mg was determined by atomic absorption and Ca, Na and K by flame photometry (Clinton 1967).

3.3 RESULTS

3.3.1 Seasonal changes in plant composition with regular defoliation

(a) *TNC (soluble sugars and starch) (Table 3.1) and elemental (Table 3.2) concentrations*: Leaf, 'stem' and root TNC concentrations (% of DM) for ryegrass were lowest in autumn and highest in winter. In all

Table 3.1 Seasonal concentrations (% of DM) of soluble sugars, starch and total nonstructural carbohydrate (TNC) in ryegrass and paspalum growing in mixed pasture.

		Spring	Summer	Autumn	Winter
Ryegrass					
Leaf	SS[d]	9.0(0.85)[a]	7.0(0.63)	5.3(0.74)	11.9(0.57)
	S	0.5(0.06)	0.8(0.30)	0.2(0.05)	0.3(0.06)
	TNC	9.5	7.8	5.5	12.2
'Stem'[b]	SS	6.0(0.42)	5.8(0.52)	4.2(0.81)	11.2(0.64)
	S	0.4(0.17)	0.7(0.26)	0.5(0.14)	1.0(0.29)
	TNC	6.4	6.5	4.7	12.2
Root	SS	1.9(0.22)	2.0(0.30)	1.1(0.20)	3.3(0.31)
	S	0.1(0.07)	0.1(0.09)	0.1(0.09)	0.0
	TNC	2.0	2.1	1.2	3.3
Dead	SS	0.7(0.13)	1.2(0.15)	0.9(0.19)	1.2(0.35)
	S	0.0	0.0	0.0	0.0
	TNC	0.7	1.2	0.9	1.2
Paspalum					
Leaf	SS	4.2(0.26)	3.4(0.33)	4.4(0.21)	5.8(0.10)
	S	0.1(0.05)	0.1(0.03)	0.1(0.00)	0.1(0.00)
	TNC	4.3	3.5	4.5	5.9
'Stem'[b]	SS	5.5(0.36)	4.6(0.35)	11.7(1.15)	15.5(1.24)
	S	0.3(0.06)	0.5(0.13)	1.5(0.35)	0.9(0.41)
	TNC	5.8	5.1	13.2	16.4
Culm[c]	SS	-	4.0 -	4.5(0.13)	-
	S	-	0.1 -	0.2(0.04)	-
	TNC	-	4.1	4.7	-
Rhizome	SS	5.8(0.86)	8.2(0.47)	12.1(0.52)	9.8(0.73)
	S	3.3(0.27)	1.3(0.28)	7.5(0.59)	9.1(1.15)
	TNC	9.1	9.5	19.6	18.9
Root	SS	1.6(0.30)	1.6(0.26)	2.4(0.25)	1.9(0.12)
	S	0.0	0.1(0.06)	0.1(0.05)	0.2(0.06)
	TNC	1.6	1.7	2.5	2.1
Dead	SS	0.7(0.06)	0.8(0.22)	0.8(0.14)	1.2(0.31)
	S	0.0	0.0	0.0	0.0
	TNC	0.7	0.8	0.8	1.2

[a] standard error of (replicate) mean
[b] psuedostem (leaf sheaths)
[c] insufficient tissue in summer for replicated analyses
[d] SS = soluble sugars; S = starch; TNC = total nonstructural carbohydrate (SS plus S)

Table 3.2 Seasonal concentrations (% of DM) of nitrogen (N), phosphorus (P) and potassium (K) in ryegrass and paspalum growing in mixed pasture.

		October	January	March	June
Ryegrass					
N	Leaf	4.2 (0.15)[a]	4.2 (0.26)	4.5 (0.22)	4.1 (0.19)
	'Stem'[b]	2.1 (0.27)	2.0 (0.10)	2.3 (0.10)	2.2 (0.11)
	Root	1.4 (0.14)	1.6 (0.13)	1.6 (0.14)	1.8 (0.16)
	Dead	1.3 (0.35)	1.8 (0.04)	2.1 (0.16)	1.6 (0.07)
P	Leaf	0.3 (0.01)	0.3 (0.01)	0.3 (0.04)	0.4 (0.03)
	'Stem'	0.2 (0.02)	0.2 (0.01)	0.2 (0.02)	0.3 (0.02)
	Root	0.1 (0.01)	0.1 (0.01)	0.1 (0.02)	0.2 (0.03)
	Dead	0.1 (0.01)	0.1 (0.01)	0.2 (0.01)	0.2 (0.01)
K	Leaf	3.9 (0.27)	4.1 (0.42)	3.9 (0.18)	4.4 (0.41)
	'Stem'	2.6 (0.20)	2.0 (0.37)	1.9 (0.40)	2.4 (0.08)
	Root	0.6 (0.05)	0.5 (0.02)	0.3 (0.01)	1.0 (0.33)
	Dead	0.2 (0.04)	0.3 (0.03)	0.5 (0.12)	0.5 (0.11)
Paspalum					
N	Leaf	4.1 (0.08)	3.7 (0.22)	3.6 (0.15)	3.6 (0.13)
	'Stem'[b]	3.3 (0.03)	2.9 (0.08)	1.9 (0.04)	2.6 (0.15)
	Culm	- -	- -	1.8 (0.03)	- -
	Root	1.0 (0.05)	1.1 (0.12)	1.0 (0.03)	1.1 (0.05)
	Rhizome	3.8 (0.34)	1.9 (0.28)	2.2 (0.15)	3.1 (0.39)
	Dead	1.8 (0.06)	1.6 (0.07)	1.3 (0.07)	1.4 (0.13)
P	Leaf	0.3 (0.01)	0.3 (0.01)	0.3 (0.03)	0.3 (0.04)
	'Stem'	0.3 (0.01)	0.3 (0.02)	0.2 (0.03)	0.3 (0.05)
	Culm	- -	- -	0.2 (0.01)	- -
	Root	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)
	Rhizome	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)
	Dead	0.2 (0.00)	0.1 (0.02)	0.1 (0.01)	0.1 (0.01)
K	Leaf	2.8 (0.07)	3.2 (0.30)	2.7 (0.09)	2.8 (0.12)
	'Stem'	3.4 (0.49)	4.1 (0.13)	3.0 (0.16)	3.1 (0.19)
	Culm	- -	- -	1.7 (0.04)	- -
	Root	0.6 (0.04)	0.7 (0.07)	0.8 (0.07)	0.9 (0.13)
	Rhizome	0.7 (0.12)	1.1 (0.06)	0.7 (0.07)	0.7 (0.06)
	Dead	0.4 (0.02)	0.4 (0.06)	0.3 (0.04)	0.4 (0.05)

[a] standard error of the mean
[b] pseudostem (leaf sheaths)

seasons leaf contained the highest soluble sugar and TNC concentrations. Starch concentrations were generally low in all ryegrass organs. For paspalum, TNC concentrations in all organs were lowest in spring and summer and highest in autumn and winter. The 'stem' and rhizome contained the largest soluble sugar concentrations during autumn and winter and the latter organ also contained high concentrations of starch. In all seasons, the roots and dead tissues of both ryegrass and paspalum contained the lowest TNC concentrations. Regular mowings (Section 3.2.1) during spring, summer and autumn, suppressed reproductive stem (culm) development. At all samplings, insufficient dry matter was obtained for chemical analysis of ryegrass culm and during the above seasons, culm represented less than 1% of the herbage mass of both ryegrass and paspalum.

Seasonal variations in elemental concentrations were generally small and only data obtained for one month in each season are presented. Concentrations of all major elements in ryegrass were generally highest in leaf. 'Stem' also had higher concentrations of N, P, K and Na, than did root (Table 3.2, Appendix 4). Paspalum leaf and 'stem' maintained the highest concentrations of N, P, K, S and Mg (Table 3.2, Appendix 4), although rhizome and leaf N concentrations were comparable in October and June (Table 3.2).

(b) *Biomass (Table 3.3)*: Leaf made the largest contribution (39 to 56%) to ryegrass biomass, especially over summer (December/January). Roots contributed from 30 to 36% of ryegrass biomass in winter, spring and autumn, and was lowest in summer (26%). Leaf also made the highest contribution to paspalum biomass in summer (33%) but its contribution in winter (6%) and spring (11%) was small. Rhizomes made larger contributions to paspalum biomass in winter (43%), spring (45%)

Table 3.3 Seasonal biomass (kg DM/ha) of ryegrass and paspalum growing in mixed pasture.

	Spring		Summer		Autumn		Winter	
Ryegrass in NPa regions								
Leaf	1084	(86)[a]	2253	(420)	1172	(99)	1238	(96)
'Stem'[b]	209	(14)	283	(43)	150	(29)	135	(55)
Root	700	(95)	1033	(375)	1065	(117)	719	(119)
Dead	310	(61)	476	(187)	603	(68)	297	(63)
TOTAL	2303		4045		2990		2389	
Paspalum in Pa regions								
Leaf	430	(142)	2041	(555)	2068	(353)	314	(122)
'Stem'[b]	147	(8)	624	(94)	975	(171)	468	(49)
Culm	-	-	42	(9)	34	(12)	-	-
Rhizome	1767	(352)	1844	(214)	3766	(756)	2279	(471)
Root	795	(123)	919	(168)	1463	(286)	953	(79)
Dead	831	(378)	825	(211)	1667	(203)	1234	(108)
TOTAL	3970		6253		9939		5248	

[a] standard error of (replicate) mean
[b] pseudostem (leaf sheaths)

and autumn (38%), than in summer (30%). Roots comprised a similar proportion of paspalum biomass (15 to 20%) in all seasons.

(c) *TNC (Fig. 4) and elemental (Fig. 5) levels*: Peak TNC levels in ryegrass occurred in early summer (January) and were lowest in autumn (April). Throughout the year less than 30% of the TNC yield per hectare in ryegrass was located below-ground. In paspalum, TNC levels were lowest in spring (October/November) and highest in autumn (April/May). Over all samplings, 57 to 88% of accumulated TNC was located below-ground and 52 to 81% of this resided in the rhizome.

As described for TNC, ryegrass elemental levels (kg/ha) were maximised in summer. From 52% to 95% of the total yields of the various elements in ryegrass were in above-ground tissues. In summer, the above-ground organs of paspalum contained higher levels of all elements (except Na) than below-ground organs, with the reverse occurring in winter and spring. In autumn N, P, K and Ca levels were greatest above-ground while the levels of S, Mg and Na were greatest below-ground.

3.4 DISCUSSION

The experiments described here represent the first attempt in New Zealand to obtain data on the seasonal physiological status of grass species growing in dairy pastures. Certain limitations apply. Firstly, although TNC and elemental yields were calculated from data obtained from the same paddocks within the experimental area, chemical composition data were obtained in 1980/81 and plant mass data were obtained in 1981/82. This limitation, caused by labour and sampling constraints in 1980/81, is probably of minor importance in the context of the present experiments as although dry matter yield, carbohydrate and elemental concentrations in the plants at a particular time may

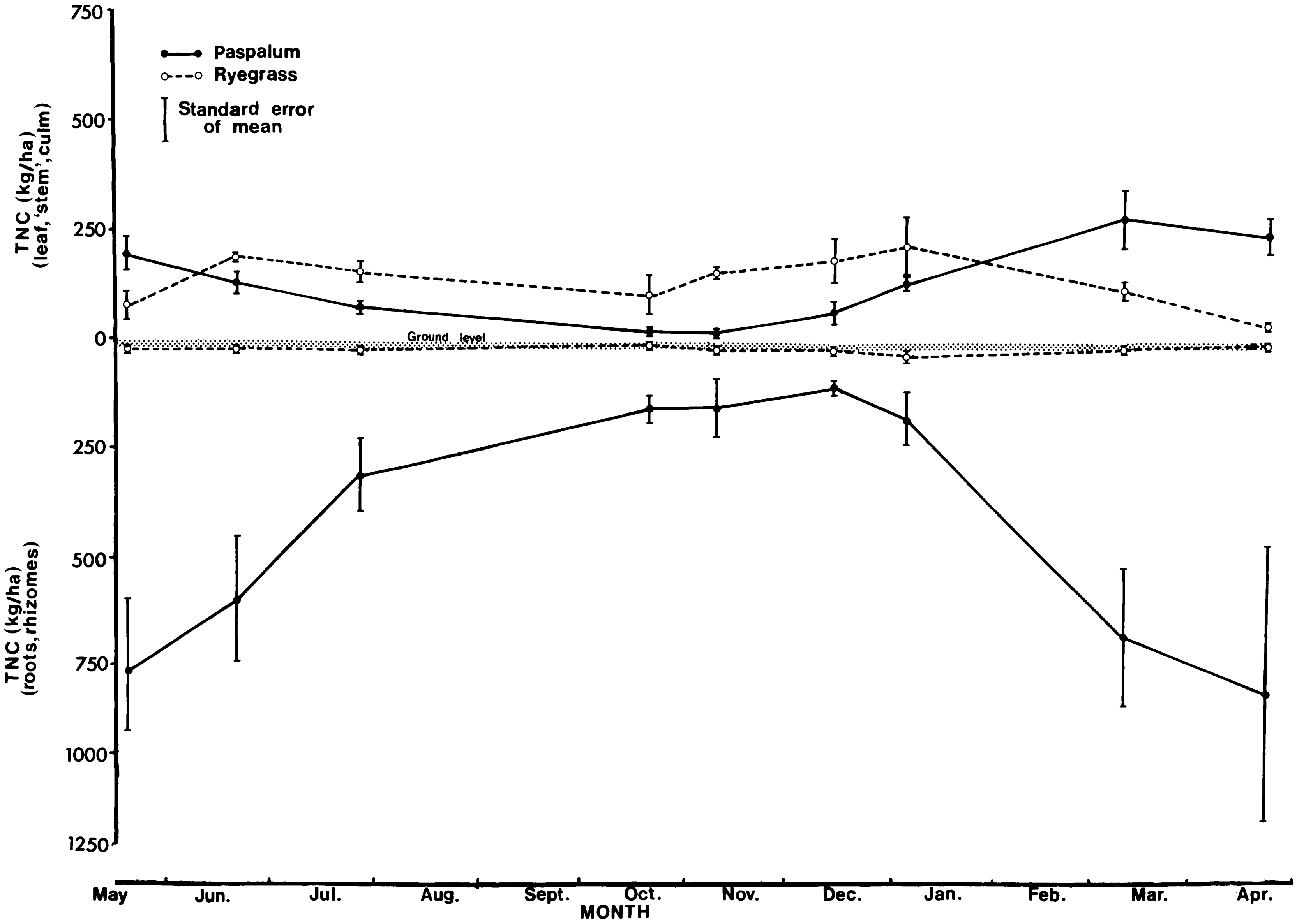

Fig. 4 Annual variation in total nonstructural carbohydrate (TNC) levels (kg/ha) in above- and below-ground organs of ryegrass and paspalum growing in mixed pasture.

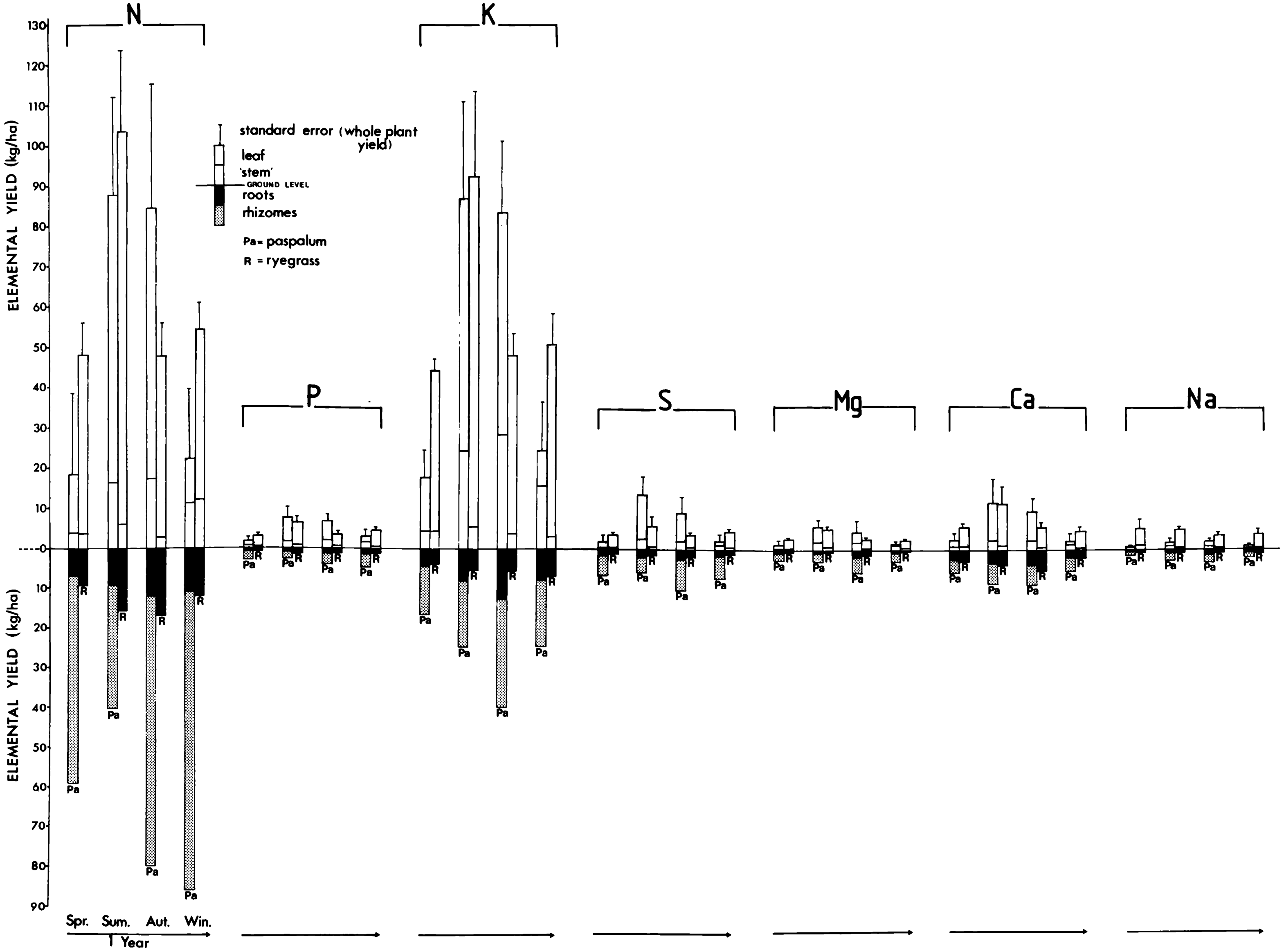

Fig. 5 Seasonal levels (kg/ha) of major elements in above- and below-ground organs of ryegrass and paspalum growing in mixed pasture.

vary between years, the seasonal patterns of carbohydrate (Noble & Lowe 1974) and elemental levels (Thompson & Warren 1979) are likely to be similar. Secondly, the use of root sampling and washing techniques to measure below-ground organ production unavoidably introduces considerable errors due to the crudity of the estimation technique as well as soil heterogeneity (Newbould 1968). Also, the use of subjective eye assessment to separate 'living' from 'dead' roots would have introduced further errors since living and dead roots not sufficiently decomposed to be unrecognisable were included in the same category. Many researchers in the past, however, have used these root sampling techniques (Troughton 1957) and they were considered the most appropriate for obtaining relative information on below-ground organ production in ryegrass and paspalum. Thirdly, the plots were mown after each sampling so that effects of regrowth interval were ignored. Samples were however taken at intervals during a 10 week regrowth period in late-spring/early-summer and summer/autumn. Concentrations of chemical constituents in paspalum (Appendix 5a,b,c,d,e) were similar to those described, indicating that chemical concentrations were not greatly influenced by regular mowing.

The outstanding finding of the experiments described in this chapter was the summer/autumn accumulation of large reserves of carbohydrates (Fig. 4, Appendix 5h) and nitrogen (Fig. 5) in the paspalum rhizome. The accumulation of high levels of reserves has implications for the maintenance of plant vigour and competitive ability. Probably the most important function of the carbohydrate reserves is to provide a respiratory substrate during the winter/spring period (May 1960; Cook 1966; Trlica & Singh 1979) when photosynthetic rate and shoot production is severely curtailed by low temperatures (less than 15 °C) (Cooper & Tainton 1968). This ensures the survival of vigorous vegetative units (rhizomes and tiller buds) (Smith et al. 1964; Lush & Evans 1974; Harris 1978) during periods when frosting can occur. The pattern of peak autumn TNC levels in paspalum, declining to a minimum close to the commencement of rapid shoot growth in November (Percival 1977) (Fig. 4) has also been described by Humphreys & Robinson (1966) for other subtropical species.

Paspalum's high growth rate during summer/autumn was reflected in large increases in leaf, rhizome and total biomass over these seasons (Table 3.3). Such increases are possible because paspalum possesses the C_4 pathway of photosynthesis (Hatch & Slack 1970) which allows for more efficient use of environmental resources (light, nutrients and water) in plant processes than does the C_3 photosynthetic pathway present in ryegrass (Slatyer 1970; Bjorkman 1971; Downton 1971; Brown 1978). The ability to rapidly increase in size during the growing season helps maintain a high competitive ability (Black et al. 1969; Grime 1979).

During summer, as growth rates increased (Table 3.3), rhizome nitrogen levels were reduced compared to spring levels. Rhizome nitrogen levels increased again during autumn/winter (Fig. 5) as growth rates slowed and presumably nitrogen supply exceeded demand. Similar seasonal changes in nitrogen reserves have also been reported by Weinmann (1948) and Sheard (1973) for other plant species.

Carbohydrate reserves may also help maintain paspalum's growth and vigour by providing a buffer against damage caused by regular severe defoliations (Weaver 1930; Weinmann 1948), or damage resulting from treading (Edmond 1966; Hunt 1979). However, according to the recent reviews of Harris (1978) and Trlica & Singh (1979), the extent to which carbohydrate reserves are used to promote regrowth after defoliation is still controversial. The argument centres around the importance of any residual leaf area in manufacturing carbohydrates for the recommencement of growth versus the use of reserve carbohydrates. It may be that in the present pastures, carbohydrate reserves are most important for the maintenance of competitive ability by combating climatic stresses and other forms of damage, rather than that due to defoliation. This is possible because of the generally prostrate growth habit assumed by paspalum, which means total removal of leaf area by cows is a rare occurrence. Thus, some highly efficient leaf area usually remains and is capable of producing carbohydrate which could be used in regrowth processes.

Ryegrass does not possess a specialised organ (eg. rhizome) for the accumulation of carbohydrate and elemental reserves. Reserves accumulate in the shoots (Fig. 4, 5), usually in young leaves and stem bases (White 1973; Vartha & Bailey 1980), and the levels were lower than for paspalum except for TNC levels in December (Fig. 4) and sodium levels in all seasons (Fig. 5). TNC levels in ryegrass shoots reached a peak in early-summer (January) before declining over summer/autumn as environmental conditions (high summer temperatures and possibly water stress) restricted their growth (Fig. 4). These trends are in general agreement with the reports of Alberda (1957) and El Hassan & Krueger (1980).

From 50 to 95% of the carbohydrate and elemental reserves accumulated by ryegrass during the year were located in leaf and 'stem' (Fig. 4, 5), and because the plant generally assumes an erect growth habit they are exposed to the risk of complete or partial loss during each grazing. On the contrary, the majority of the carbohydrate reserves accumulated by paspalum are located below-ground (Fig. 4, Appendix 5h), protected from the risk of removal by the grazing animal. By the end of the growing season (autumn) and despite regular defoliation, paspalum was also capable of accumulating considerable elemental reserves (eg. nitrogen) (Fig. 5), roughly equivalent to the amounts accumulated during uninterrupted growth (Appendix 5g). It is suggested that ryegrass would be in a more vulnerable position than would paspalum to suffer any deleterious effects due to defoliation (eg. overgrazing, trampling).

CHAPTER 4

THE EFFECTS OF NITROGEN FERTILISER ON THE GROWTH AND PERSISTENCE OF PERENNIAL RYEGRASS INTRODUCED INTO A PASTURE CONTAINING PASPALUM

4.1 INTRODUCTION

The results described in chapter 2 suggest the effect of overdrilling in autumn on pasture yield disappears in one year. This effect was associated with high losses of introduced plants during summer/autumn. Small plants and those grazed hardest prior to and during summer were most prone to loss. This chapter further investigates these effects.

It was hypothesised that the application of nitrogen fertiliser during winter/spring may modify the relative competitive abilities of the introduced and resident plants. Many experiments have shown how the application of nitrogen fertiliser can increase tillering in perennial ryegrass (eg. Davies 1971, 1977; Harris 1973; Alberda & Simba 1982) and also herbage production of ryegrass dominant swards (Reith & Inkson 1961; Minderhoud et al. 1974; Field & Ball 1978; Laidlaw 1980; MacKenzie & Daly 1982; Ball & Field 1982; O'Connor 1982). This implied increase in plant size due to nitrogen suggests that the application of nitrogen fertiliser may be an important factor influencing the survival in a pasture of introduced ryegrass plants. This possibility is investigated in this chapter.

The effects of two other factors known to modify ryegrass persistence were also examined, namely, grazing interval (Brougham 1959, 1960; Agyare & Watkin 1967) and physical damage caused by the grazing cow(Spedding 1971; Watkin & Clements 1978). The growth and persistence of ryegrass plants in plots covered by cages during grazing was compared with those exposed to grazing to measure the effects of cow grazing damage (eg. 'pulling').

In the two field experiments described, young ryegrass plants were introduced into plots that contained predominantly paspalum (Pa) or other pasture species (NPa) (chapter 3), to distinguish the effects of paspalum from other potential competitors on the growth and persistence of the introduced ryegrass. Rates of nitrogen fertiliser comprised the main treatments in both experiments. Higher rates of nitrogen were applied in Experiment 2 because of the possibility that insufficient nitrogen had been applied in Experiment 1. Experiment 2 also included grazing interval as a variable and some plots were clipped rather than grazed.

4.2 EXPERIMENTAL SITES

The experiments were conducted over two successive years in adjacent 0.12 ha (40 m x 31 m) paddocks in the general experimental area (Section 2.2). Experiment 1 commenced in April 1979 and concluded in May 1980. Respective dates for Experiment 2 were April 1980 and May 1981. A schedule of events for the experimental procedures used form Tables 4.1 (Experiment 1) and 4.2 (Experiment 2).

4.3 EXPERIMENTAL DESIGN AND TREATMENTS

(a) Experiment 1: Nitrogen treatments coded as

NW - 63 kg N/ha as urea applied on 10.8.79 (0.563 g N in 40.5 ml water per 0.09 m^2 plot area)

NS - 48 kg N/ha applied on 5.10.79 (0.429 g N in 59.5 ml water per 0.09 m^2 plot area)

No N - no nitrogen fertiliser addition

were applied to Pa and NPa plots (300 x 300 mm) according to a 2 x 3 factorial design with 10 replicates.

Table 4.1. Schedule of major events (Experiment 1).

	Grazing	Plant Dry wt.	Plant tiller no.and length	Plant vigour	Botanical composition	N applied
1979[a] 30 Jul.					■	
10 Aug.						■
17 Sept.		■	■	■		
19	■					
20			■			
5 Oct.						■
15	■					
16			■			
26					■	
11 Nov.	■					
13			■			
5 Dec.		■	■	■		
10	■					
11			■			
1980 10 Jan.	■					
11			■			
17					■	
11 Feb.		■	■	■		
13	■					
14			■			
12 Mar.	■					
13			■			
10 Apr.			■	■		
14	■	■				
15			■		■	
19	■		■			

[a] Transplanting of ryegrass plants into plots from 17 to 20.7.79

■ = Measurement date

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Table 4.2 Schedule of major events (Experiment 2).

	Defoliation		Herbage mass		Plant dry wt.		Plant tiller no. and length		Plant vigour		Botanical composition		N applied	
	S	L	S	L	S	L	S	L	S	L	S	L	S	L
1980 28 Jul.			■	☐										
29-30 Transplanting ryegrass plants into plots														
12 Aug.													■	☐
9 Sept.													■	☐
11											■	☐		
15	■		■		■		■		■					
16			■				■							
22		☐		☐		☐		☐		☐				
23				☐				☐						
29	■		■											
30			■				■							
6 Oct.													■	☐
13	■		■		■		■		■					
14			■			☐	■	☐		☐				
15		☐		☐										
16				☐				☐						
21													■	☐
28	■		■											
29			■				■							
3 Nov.				☐		☐		☐		☐				
4		☐												
5				☐				☐						
10	■		■		■		■		■					
11			■				■							
13											■			
24	■		■	☐		☐		☐		☐				
Post defol.→			■				■							
25		☐		☐				☐						
27												☐		
15 Dec.	■	☐	■	☐	■	☐	■	☐	■	☐				
16				☐				☐						
17			■				■							

	Defoliation		Herbage mass		Plan dry
	S	L	S	L	S
1981 5 Jan.	■		■		
6			■		
12		☐		☐	
13				☐	
20					
26	■		■		■
27			■		
3 Feb.					
9		☐		☐	
10				☐	
16	■		■		
17			■		
9 Mar.	■		■		■
10		☐	■	☐	
11				☐	
16					
17					
30	■		■		
31			■		
6 Apr.		☐		☐	
7				☐	
20	■		■		■
21			■		
4 May		☐		☐	
5				☐	
11	■		■		
14					
21					

■ = Measurement date : short(S) defoliation interval

☐ = Measurement date : long (L) defoliation interval

The 60 plots (30 Pa and 30 NPa) were located on 10 diagonals across the 31 m width of the paddock.

(b) Experiment 2: The effects of cage (herbage clipped) and no cage (herbage grazed), nitrogen and no nitrogen fertiliser, and a long and a short defoliation interval, were investigated in a 2^3 factorial design.

In early May 1980, 32 Pa and 32 NPa plots with similar dimensions as described above were located on diagonals running the length of the paddock (40 m). Sixteen plots of each type were located on either side of a temporary fence which divided the paddock area in half (40 x 15.5 m). Each half was grazed at a long (LI) or a short (SI) interval. Of the plots in each half, eight of each type received nitrogen fertiliser (67 kg N/ha as urea, 0.599 g N in 180 ml of water per 0.09 m^2 plot area) on four occasions (12.8, 9.9, 6.10, 21.10.80) while the remainder received no nitrogen fertiliser. In addition, half of the plots receiving nitrogen fertiliser and half those receiving no nitrogen fertiliser were covered by wooden cages during each grazing and these plots were defoliated by clipping.

4.4 EXPERIMENTAL PROCEDURES AND TECHNIQUES

4.4.1 Pre-transplanting growth of ryegrass plants

For each experiment, approximately 1000 ryegrass seeds were germinated and grown in a glasshouse in 75 mm lengths of alkathene piping (12 mm internal diameter) split four ways from one end almost through to the other and reshaped by clamping the cut end together with tape. At transplanting, the tape was removed and the soil core exposed by extending the slits the length of the tube.

The seed used in Experiment 1 was from a commercial line of certified first generation *Lolium perenne* L. 'Grasslands Nui' perennial ryegrass. Nucleus seed from a 1980 line, A3834, *Lolium perenne* L. 'Grasslands Nui' perennial ryegrass was used in Experiment 2. Seeds from each line were selected at random and sown at the rate of two per tube in May of 1979 and 1980, respectively. After germination the seedlings were thinned to one healthy plant per tube and allowed to grow for about 10 weeks before transplanting into the field. During this time the plants were cut twice to a height of 25 mm and were periodically watered. The plants were gradually acclimatised to outside conditions during the three to four weeks preceding transplanting.

4.4.2 Transplanting procedure

Fourteen soil cores (13 mm diameter to a depth of 75 mm) were removed from each plot using a miniature soil corer and a metal template. The cores, forming two rows 150 mm apart with 50 mm spacings within rows were replaced with ryegrass plants, selected at random. Two of the 14 plants were randomly chosen and labelled with blue telephone wire (Section 2.4.3.2). The remaining 12 introduced ryegrass plants per plot in Experiment 2 were labelled with red telephone wire to assist in their location during the experiment.

In 1979, transplanting and labelling took place from 17 to 20 July and in 1980 from 29 to 30 July.

4.4.3 Measurements on individual ryegrass plants

(a) Experiment 1: Tiller counts and length measurements, as described in Section 2.4.3.3, were made on plants marked with blue rings before each grazing. Prior to grazings one, four, six and eight, two of the 12 unlabelled plants in each plot were selected at random, cut to a 25 mm stubble using hand shears, and the number of cut tiller stubs counted. The herbage from each plant was then dried for 36 hours at 100 °C in a forced draught oven before weighing.

These plants were labelled with yellow rings and subsequently excluded from cutting until all the available plants had been cut once.

(b) Experiment 2: Similar measurements as described for Experiment 1 were carried out on introduced ryegrass plants labelled with blue rings at alternate grazings with SI and all grazings with LI. When a blue-labelled plant was lost from the sward it was replaced by a red-labelled plant that had been exempt from cutting for the longest period. Measurements were then continued on the replacement plant. When a single survivor was available for measurement, data for this plant were considered representative of the plot, otherwise plot data were represented by the mean of measurements on two plants. If the only survivor was subsequently lost from the plot, the frequency of the treatment means for the measured variables were reduced by one. Individual plant yield measurements and counts of cut tiller stubs were also carried out as described above on selected introduced plants in grazed plots, except that the clipping level was raised to 40 mm after harvest three (SI) and after harvest two (LI). This change coincided with the need to adjust the clipping level of caged plants that were defoliated by clipping at each harvest (Section 4.4.4). The herbage from all surviving introduced ryegrass plants growing in the caged plots was harvested, bulked and dried. The total number of cut tiller stubs for the survivors was also recorded so that the average dry weight per tiller for these plants could be calculated. Other methods were as for Experiment 1.

In both experiments, at each pre-harvest measurement a subjective vigour grade was given to each surviving introduced ryegrass plant. The scale ranged from 1 (low) to 5 (high). An average vigour was calculated for each plot as a mean of 14, assuming dead or missing ryegrass plants had a vigour of zero.

4.4.4 Defoliation management

The experimental plots were hard-grazed (Section 2.3) before the introduction of the ryegrass plants.

During Experiment 1, plots were grazed by cows at intervals of 26 to 35 days. The first grazing took place on the 19.9.79, 61 days after the introduction of the ryegrass plants.

Plots in Experiment 2 to be grazed or clipped at a SI were first defoliated 47 days after the introduction of ryegrass plants. Until grazing six (24.11.79) these plots were defoliated at 13 to 15 day intervals and at 20 to 22 days thereafter. Plots to be grazed or clipped at a LI were first defoliated 54 days after the introduction of the ryegrass plants. These plots were defoliated every 20 to 22 days until grazing five (16.12.79) and at 27 to 29 days thereafter. At each grazing appropriate plots were covered by 500 x 460 mm plywood cages. After each grazing the herbage under the cages was clipped to a 25 mm stubble using a motorised handpiece set on adjustable skids.

In both experiments, cow numbers used at each grazing were generally sufficient to achieve the desired residual herbage mass (1500 to 1800 kg DM/ha) over a four to five hour period. However, after grazings two and four during Experiment 1 this level was not achieved and the trial area was flail-cut to a 70 to 80 mm height using a Swift Current Forage Plot Harvester. In addition, after grazing five in Experiment 1 the trial area was mown to a height of 120 to 150 mm to remove excess numbers of flowering tillers.

4.4.5 Sward measurements

4.4.5.1 Plot herbage mass

Herbage mass assessments were made in Experiment 2 but not in Experiment 1. For pre- and post-defoliation herbage mass assessments under both managements, 10 quadrat areas representing the range of herbage mass present on the experimental area were marked for ground level cutting. These were given a visual grade by consensus of four observers. Subsequently, three observers independently estimated herbage mass on the treatment plots and then on the marked quadrat areas. This procedure was then repeated by the three observers. Visual estimates were adjusted using the regression of mean visual grade on herbage mass for the quadrat assessments. Correlation coefficients of the calibration regressions are presented in Appendix 6. All regressions were significant ($P<0.05$) (eight degrees of freedom) except for post-defoliation 13 (SI, 22.4.81). At this date, observers consistently underestimated by about 600 kg DM/ha the herbage mass in two calibration quadrats, possibly because of the influence of high litter levels in the pasture in autumn (Section 4.7.5). This combined with a narrow range of herbage mass present on the plots lead to a low correlation between visual grade and herbage mass per quadrat.

4.4.5.2 **Botanical composition**

The point quadrat method of Radcliffe & Mountier (1964a) was used in both experiments to determine plot botanical composition during winter, spring, summer and autumn. Total hits on all plant species for 30 points per plot were recorded from five positions of the linear frame (containing six points spaced 50 mm apart) located at random over the whole length of each plot, and at right angles to the rows of introduced ryegrass plants. Data for each species were expressed as a proportion of the total hits per plot for all species. Measurements were usually within one week of defoliating the plots in an attempt to minimise variation in herbage height at each analysis (Radcliffe & Mountier 1964b).

4.4.6 **Fertiliser policy and weed control**

In April 1979, 5 kg K, 2.5 kg P and 2.5 kg S were applied to the 0.12 ha trial area used for Experiment 1. A further 5.8 kg K, 1.2 kg P and 1.2 kg S were applied in November 1979. Both trial areas received 2.5 kg K, 1.3 kg P and 1.3 kg S in April 1980 while the 0.12 ha area used for Experiment 2 also received 5.9 kg K, 2.9 kg P and 2.9 kg S, and 6.0 kg Mg in August 1980.

Both trial areas were sprayed with 4-(4-chloro-2-methylphenoxy butyric acid) (MCPB) for the control of celery-leaved buttercup (*Ranunculus sceleratus* L.). Experiment 1 received 3 *l* MCPB in 235 *l* water/ha in November 1979, and Experiment 2 received 4.5 *l* MCPB at the same dilution rate in December 1980.

4.4.7 **Soil tests**

Soil samples from Pa and NPa plots in Experiment 1 were analysed (Cornforth 1980) for pH, P, K and Mg status before the experimental treatments were applied. Nine 25 mm diameter soil cores to a depth of 75 mm were taken at random from each plot, but without disturbing the immediate environment of the introduced ryegrass plants. The results in Appendix 7 are categorised according to paspalum frequency in summer (17.1.80). As results were similar for Pa and NPa plots, these data were not collected during Experiment 2.

4.5 STATISTICAL METHODS

Analysis of variance models were used to detect treatment differences with initial tiller number of the ryegrass plants at the time of introduction to the plots being used as a covariate. For the analysis of data from Experiment 1 an extra covariate was included to account for certain plots visually assessed (May 1980) as having a low frequency of paspalum, but producing a high paspalum frequency during summer and vice versa.

Plots of residual variances against fitted values for the model indicated when transformations of the data were required to obtain errors that resembled the normal distribution with constant variance. For Experiment 2, the relationship between residual variances and mid-summer paspalum frequency in the plots for each variable was examined for any effect not already accounted for by the analysis of treatment data. The effects of treatments on plant losses were examined using analysis of deviance (Nelder & Wedderburn 1972).

Data from plants or plots visually affected by cow excrement (dung and/or urine) were excluded from analyses. Separate analyses of variance were applied to all data (except plot botanical composition) derived from plots that were clipped or grazed (Experiment 2). Except for plant loss data, lack of replication precluded statistical analyses of the effects of different grazing interval treatments (Experiment 2).

4.6 CLIMATIC DATA

Monthly averages over the study periods (April 1979 to May 1981) and long-term averages for selected variables form Appendix I.

The 1979/80 summer (December, January, February) was much wetter than average (374 mm vs 241 mm) while the 1980/81 summer was drier than average (179 mm vs 241 mm). Water balance estimates (Appendix 3) indicate the likelihood of restricted pasture growth because of water shortages in January, February and March 1980. Screen temperatures from December 1979 until April 1980 were about average (Appendix I) but over the same period for 1980/81 maximum and minimum screen temperatures were up to 1.6 and 3.6 °C, respectively, above average. Over spring 1979 and 1980 (September, October, November) the mean 10 cm soil temperatures were similar to the long-term averages.

4.7 RESULTS

4.7.1 Tillers per plant at transplanting

Tiller counts at transplanting were made on the 120 plants labelled with blue rings in Experiment 1. Eighty-six had a single tiller, 16 had two, 16 had three, one had four and one had five tillers. In Experiment 2, of the 128 plants counted, 92 had one tiller, 30 had two, five had three and one had four tillers.

In spring 1979, 19 of the 840 plants formed reproductive tillers, while in spring 1980, the comparable figures were 10 out of 896 plants. Thus the majority of introduced plants remained totally vegetative during both experiments.

4.7.2 Seasonal losses of introduced plants

(a) Experiment 1: In an attempt to quantify the importance of direct affects of the grazing animal on losses, the most likely cause of plant loss was categorised as follows:

1 - physical removal ('pulled') from the sward by the cow during grazing
2 - previous severe grazing (stubble height less than 10 mm)
3 - dung or urine - damage by cow excrement
4 - trampling - damage by hoof action of the cow
5 - dead - no visible green herbage and no obvious animal or insect damage

Of the number of plants lost (Table 4.3) in spring, 89% of plant losses were associated with 'animal effects', especially those related

Table 4.3 Number and season of loss of introduced ryegrass plants defoliated at intervals of 26 to 35 days. Total number of introduced plants was 840.

Season	Category of loss[a] 1	2	3	4	5	TOTAL
LW/ES[b] (20.7.79-20.9.79)	2	-	-	1	3	6
Spring (20.9.79-13.11.79)	3	5	25	-	4	37
Summer (13.11.79-13.3.80)	8	12	21	17	278	336
Autumn (13.3.80-19.5.80)	10	-	4	-	164	178
TOTAL	23	17	50	18	449	557

[a] see text
[b] late-winter/early-spring

to damage caused by animal excrement (category three), while category five accounted for the largest numbers of losses in summer and autumn. By the end of the study, category five represented 81% of all losses. Total losses were highest in summer, coinciding with the greatest number of losses in category five.

Losses of plants (Table 4.4) due to effects of dung, urine and 'pulling' were excluded from the data analysis. No significant treatment effects on ryegrass losses were detected by this analysis.

Table 4.4 The effects of plot type (Pa, NPa) and additions of nitrogen fertiliser on seasonal deaths of ryegrass plants.

Treatment[a]		SEASON(S)		
		Winter/spring (20.7.79-13.11.79)	Summer (13.11.79-13.3.80)	Autumn (13.3.80-19.5.80)
	NW	3/139[b](2)[c]	53/131 (40)	33/76 (43)
Pa	NS	1/138 (1)	49/125 (39)	31/76 (41)
	No N	1/140 (1)	63/138 (46)	25/71 (35)
	NW	5/139 (4)	56/127 (44)	20/68 (29)
NPa	NS	1/125 (1)	38/122 (31)	25/82 (30)
	No N	2/128 (2)	48/124 (39)	30/73 (41)

[a] NW = 63 kg N/ha applied 10.8.79
NS = 48 kg N/ha applied 4.10.79
No N = no nitrogen fertiliser applied

[b] data are ratios of numbers of deaths during the season over the number of survivors at the beginning of the season (random losses due to dung, urine and 'pulling' excluded)

[c] ( ) ratio as a percentage

(b) Experiment 2: Category five plants accounted for 80 and 81% of the total losses of ryegrass plants with a SI and LI, respectively, while direct 'animal effects' accounted for only 20 and 19% of total losses (Table 4.5). As in Experiment 1, the greatest losses were in summer when category five losses were also at a maximum. With a SI, however, category two losses (plants previously severely grazed) comprised 53% of total direct 'animal effects' while with a LI, category one ('pulled' plants) losses were in the majority (66%) (Table 4.5). In Experiment 2, total losses directly related to deposition of dung and urine were approximately one third the number

in Experiment 1 (Table 4.3, 4.5). As grazing interval lengthened (Experiment 2, LI, and Experiment 1) direct losses from 'pulling' were higher than for a shorter grazing interval (Experiment 2). Only about 2% of total losses (SI and LI combined) occurred in LW/ES.

Table 4.5 Number and season of loss of introduced ryegrass plants, defoliated at a SI (13 to 22 days) and a LI (20 to 29 days).

	Category of loss[a]					
Season	1	2	3	4	5	TOTAL
SI[c]						
LW/ES[b] (30.7.80-16.9.80)	1	2	-	-	-	3
Spring (16.9.80-25.11.80)	2	3	1	-	40	46
Summer (25.11.80-10.3.81)	11	18	9	-	160	198
Autumn (10.3.81-12.5.81)	3	9	1	-	43	56
TOTAL	17	32	11	-	243	303
LI[c]						
LW/ES (30.7.80-23.9.80)	4	-	-	-	6	10
Spring (23.9.80-25.11.80)	8	4	3	1	38	54
Summer (25.11.80-11.3.81)	17	5	3	-	105	130
Autumn (11.3.81-5.5.81)	6	2	-	-	70	78
TOTAL	35	11	6	1	219	272

[a] see text
[b] late-winter/early-spring
[c] total number of introduced plants was 448

Of the category five losses in LW/ES, two and six plants in Experiments 1 and 2, respectively, died between transplanting and the first defoliation. Thus, only eight plants out of the 1736 transplanted may have been adversely affected by the transplanting procedure.

Spring and summer losses of ryegrass plants were greater in grazed than in clipped plots (Table 4.6, 4.7), but in summer this was only true for Pa plots (Table 4.7). Summer deaths of ryegrass plants were significantly higher when defoliated at a short interval (21 days) as opposed to a long interval (27 to 29 days). Results in autumn were inconsistent.

Table 4.6 The effects of plot type (Pa, NPa), nitrogen fertiliser additions, caging (clipping or grazing) and defoliation interval on deaths of ryegrass plants in spring (16.9.80 to 25.11.80).

Treatment	Total[a]	Number of deaths[b]	Deaths (%)	Sig.
P	428	39	9.1	ns
NP	442	49	11.1	
+N	434	50	11.5	ns
-N	436	38	8.7	
Clipped	444	32	7.2	**
Grazed	426	56	13.1	
SI	444	45	10.1	ns
LI	426	43	10.0	

[a] total present at the beginning of spring
[b] deaths during spring (random losses due to dung, urine and 'pulling' excluded)

Table 4.7 The effects of plot type (Pa, NPa), nitrogen fertiliser additions, caging (clipping or grazing) and defoliation interval on deaths of ryegrass plants in summer (25.11.80 to 11.3.81) .

Treatment		Total[a]	Number of deaths[b]	Deaths (%)	Sig.
Pa	Clipped	210	76	36.2	**
	Grazed	152	82	53.9	
NPa	Clipped	201	73	36.3	ns
	Grazed	169	57	33.7	
+N		356	131	36.8	ns
-N		376	157	41.8	
SI		367	178	48.5	***
LI		365	110	30.1	

[a] total present at the beginning of summer

[b] deaths during summer (random losses due to dung, urine and 'pulling' excluded)

Losses of ryegrass plants were higher in Pa (38%) than NPa plots (21%), but this difference failed to reach significance. Late-winter/spring applications of nitrogen fertiliser did not influence deaths of ryegrass plants in any season.

4.7.3 Responses of ryegrass plants to nitrogen fertiliser and plot paspalum frequency (% of total hits).

(a) Experiment 1: Tillering of ryegrass plants (blue rings) was stimulated by the application of nitrogen fertiliser (Fig. 6) but on only one occasion (16.10.79) was this significant. Log transformation of the data did not improve the sensitivity of the analysis so untransformed data are presented in Fig. 6. Treatment differences were maintained until March 1980 and were greatest in January/February

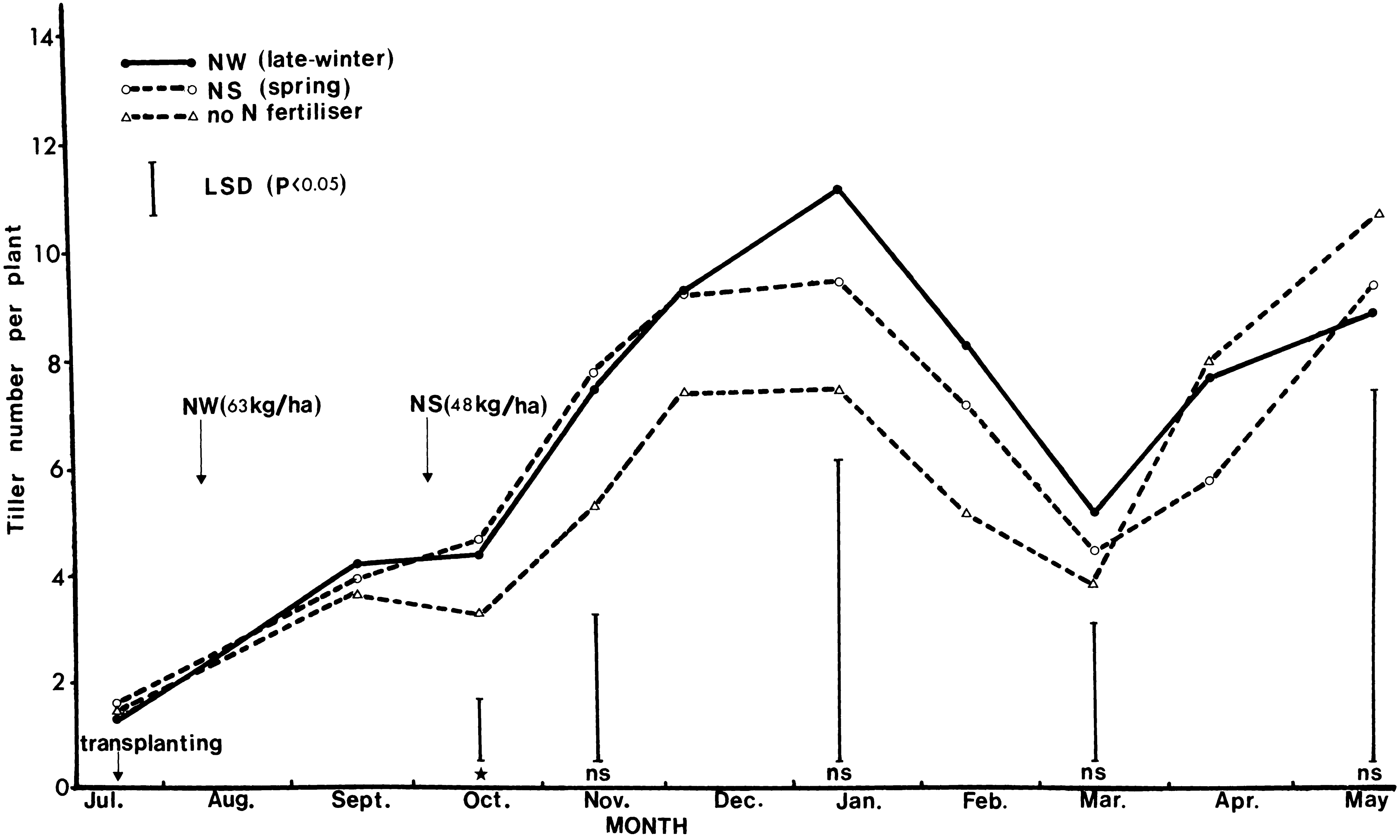

Fig. 6 Effect of nitrogen fertiliser application in August (NW) and October (NS) on tiller number per ryegrass plant.

when tillers per plant for those receiving nitrogen were on average about 1.4 times greater than for the control plants.

Plant dry weight (above 25 mm stubble) for survivors other than blue-labelled plants increased up until December in response to the late-winter application of nitrogen fertiliser, but there was no significant responses to spring applied nitrogen (Table 4.8). Trends in tiller dry weight were similar.

Table 4.8 Effect of late-winter and spring applications of nitrogen fertiliser on plant dry weight (mg) for ryegrass.

		Plant dry weight		
Treatment[a]	17.9.79	5.12.79	11.2.80	10.4.80
NW	54.2	290.5	221.9	396.6
NS	35.2	171.9	347.4	251.1
No N	39.3	150.5	276.8	195.1
LSR	1.39	1.85	2.42	3.28
Sig.	*	*	ns	ns

[a] see Table 4.4

Nitrogen fertiliser in late-winter and spring increased tiller length by 24% and 43% respectively, relative to controls (Table 4.9). This occurred even though the latter response was modified by grazing.

Table 4.9 Effect of late-winter and spring applications of nitrogen fertiliser on ryegrass pre- and post-grazing tiller length (mm).

Date	Nitrogen treatment[a] NW	NS	No N	SED[c]	Sig.
17. 9.79 (PR)[b]	184.6	143.5	148.3	12.82	**
20. 9.79 (PT)	105.2	77.9	88.4	13.73	ns
16.10.79 (PT)	69.9	84.6	59.1	11.41	(†)
13.11.79 (PT)	105.5	96.5	107.9	14.44	ns
5.12.79 (PR)	235.5	217.4	197.1	29.20	ns
11.12.79 (PT)	110.6	99.8	96.0	21.50	ns
11. 2.80 (PR)	201.1	186.3	160.4	23.28	ns
14. 2.80 (PT)	84.7	104.1	71.3	16.69	ns
10. 4.80 (PR)	190.1	166.4	227.5	26.07	(†)
15. 4.80 (PT)	57.7	61.9	84.1	17.33	ns

[a] see Table 4.4
[b] PR = pre-grazing, PT = post-grazing measurements

Subsequent to 16.10.79 responses were variable and often not significant as at grazings in December, February and April.

Average vigour at the first grazing (17.9.79) of ryegrass plants receiving nitrogen fertiliser in late-winter (2.75) was higher ($P<0.05$) than the control plants (2.48). Vigour at subsequent grazings or following nitrogen fertiliser was not affected.

An alternative approach to assessing effects of paspalum on ryegrass growth was by examining the relationship between plot paspalum frequency and selected variables, using covariance analysis. Negative slopes were generally found for the regression of tiller number, dry weight, length, plant dry weight and average vigour on plot paspalum content at each measurement time. For example, in January/February a 10% increase in plot paspalum frequency was associated with a reduction of about one tiller per plant, two mg tiller dry weight, 81 mg plant dry weight and 10 mm in tiller length.

(b) Experiment 2: Tillering responses to nitrogen fertiliser applications were generally small for clipped and grazed plants regardless of defoliation interval (Table 4.10). Exceptions were in December and January for plants grazed at a SI, but only the latter was significant.

During October, November and December, grazed ryegrass plants in Pa plots produced significantly more tillers than plants in NPa plots (Table 4.11). The reverse effect occurred over summer/autumn (January to May) but this was significant only for SI grazing. Similar effects occurred in clipped plots, although with a LI during spring, ryegrass plants in Pa plots did not consistently produce more tillers than those in NPa plots. Overall, larger ryegrass plants were generally found in grazed than in clipped plots (Table 4.10, 4.11).

Significant improvements in pre-grazing tiller length in response to nitrogen fertiliser applications were confined to ryegrass plants defoliated at a LI over September, October and November. However, this trend was maintained throughout the study for these plants and to a lesser extent for those grazed at a SI (Table 4.12). Pre-clipping tiller length was markedly increased during September by the addition of nitrogen fertiliser but the response steadily declined during spring to become negative over summer.

Pre-grazing tiller length was less over September, October and November for ryegrass plants in Pa than in NPa plots and defoliated at

Table 4.10 The effect of nitrogen (N) fertiliser additions on tillers per ryegrass plant (pre-defoliation), with clipping or grazing at a short (SI) or a long (LI) interval.

	SI[a]								LI[b]							
Date	Clipped				Grazed				Clipped				Grazed			
	+N[c]	-N	LSR	Sig.	+N	-N	LSR	Sig.	+N	-N	LSR	Sig.	+N	-N	LSR	Sig.
1980																
14 Sept.	3.5	3.0	1.40	ns	3.8	3.2	1.31	ns								
22									4.8	3.3	1.39	*	4.1	4.2	1.50	ns
13 Oct.	3.5	3.1	1.43	ns	3.5	3.2	1.34	ns								
14									3.6	2.7	1.41	ns	4.2	3.8	1.79	ns
3 Nov.									3.5	2.4	1.57	ns	6.5	4.2	1.72	ns
10	4.5	2.6	1.63	*	4.8	4.4	1.85	ns								
24									3.9	2.4	1.70	ns	6.2	5.3	1.55	ns
15 Dec.	6.1	4.0	2.02	ns	12.2	7.0	1.93	ns	4.0	3.7	1.75	ns	7.0	5.9	1.73	ns
1981																
12 Jan.									5.5	4.3	2.03	ns	7.0	8.0	1.74	ns
26	4.9	4.8	2.00	ns	10.3	4.1	1.75	**								
9 Feb.									4.5	3.9	2.03	ns	5.9	6.2	2.21	ns
9 Mar.	3.1	2.5	1.74	ns	3.2	3.8	1.69	ns								
10									3.5	3.7	2.03	ns	4.4	5.4	2.66	ns
6 Apr.									3.0	2.8	1.77	ns	4.8	4.7	2.42	ns
20	4.0	4.1	2.09	ns	3.8	5.2	1.95	ns								
4 May									4.0	3.2	1.86	ns	4.0	4.8	2.69	ns

[a] 13 to 15 days until 24.11.79, thereafter 20-22 days (measurements restricted to alternate defoliations)
[b] 20 to 22 days until 16.12.79, thereafter 27 to 29 days
[c] 67 kg N/ha (equivalent) applied to same plots on 12.8, 9.9, 6.10 and 21.10.80

Table 4.11 The effect of plot type (Pa, NPa) on tillers per ryegrass plant (pre-defoliation), with clipping or grazing at a short (SI) or a long (LI) interval.

Date	SI								LI							
	Clipped				Grazed				Clipped				Grazed			
	Pa	NPa	LSR	Sig.	Pa	NPa	LSR	Sig.	Pa	NPa	LSR	Sig.	Pa	NPa	LSR	Sig.
1980																
15 Sept.	3.4	3.1	1.40	ns	3.9	3.2	1.29	ns								
22									3.6	4.5	1.40	ns	4.4	4.0	1.50	ns
13 Oct.	3.7	3.0	1.43	ns	4.2	2.7	1.32	**								
14									3.0	3.2	1.42	ns	4.7	3.4	1.79	ns
3 Nov.									3.0	2.8	1.58	ns	7.5	3.6	1.72	*
10	4.4	2.7	1.63	*	6.0	3.5	1.80	ns								
24									3.0	3.2	1.72	ns	7.8	4.2	1.55	*
15 Dec.	5.7	4.3	2.02	ns	9.6	8.9	1.87	ns	4.0	3.7	1.77	ns	8.6	4.9	1.73	*
1981																
12 Jan.									4.4	5.1	2.06	ns	8.1	6.8	1.74	ns
26	4.9	4.9	2.00	ns	5.0	8.4	1.70	*								
9 Feb.									3.6	4.8	2.06	ns	4.8	8.5	2.21	ns
9 Mar.	2.3	3.3	1.74	ns	2.4	5.1	1.67	*								
10									2.8	4.8	2.07	ns	5.4	8.4	2.66	ns
6 Apr.									2.0	4.3	1.79	*	5.1	10.3	2.42	ns
20	2.9	5.5	2.09	ns	2.7	7.5	1.92	*								
4 May									2.6	4.9	1.88	ns	8.0	9.4	2.69	ns

Table 4.12 The effect of nitrogen (N) fertiliser additions on ryegrass tiller length (mm) (pre-defoliation), with clipping or grazing at a short (SI) or a long (LI) interval.

Date	SI								LI							
	Clipped				Grazed				Clipped				Grazed			
	+N	-N	SED	Sig.	+N	-N	SED	Sig.	+N	-N	SED	Sig.	+N	-N	SED	Sig.
1980																
15 Sept.	181	113	17.6	**	152	129	21.5	ns								
2									213	152	11.9	***	238	132	19.2	***
13 Oct.	126	108	14.6	ns	128	111	9.4	(†)								
14									173	149	14.3	ns	206	155	25.0	(†)
3 Nov.									137	116	13.9	ns	185	117	17.4	**
10	133	107	10.4	*	112	104	21.4	ns								
24									121	119	12.3	ns	167	119	24.2	(†)
15 Dec.	118	121	9.8	ns	119	105	15.6	ns	103	116	13.2	ns	145	112	28.6	ns
1981																
12 Jan.									113	143	19.7	ns	184	157	41.0	ns
26	131	162	19.2	ns	151	108	20.0	(†)								
9 Feb.									114	152	17.2	(†)	165	145	39.2	ns
9 Mar.	80	76	12.0	ns	91	89	16.3	ns								
10									94	125	13.5	*	176	139	34.7	ns
6 Apr.									104	106	16.0	ns	170	139	34.0	ns
20	113	99	17.3	ns	99	107	15.7	ns								
4 May									110	127	13.9	ns	184	157	28.9	ns

a LI, but no trend was evident with a SI (Table 4.13). Similarly pre-clipping tiller length was less in Pa than NPa plots in September for both LI and SI, the latter being consistent throughout the study (Table 4.13).

In summary, tiller number and tiller length responses of ryegrass to additions of nitrogen fertiliser were most likely in spring (September, October, November), while growth of ryegrass plants in Pa plots was restricted during summer/autumn (January to May), compared to NPa plots.

Over the whole study period the average post-grazing tiller lengths for ryegrass plants defoliated at a LI and a SI were 82 and 65 mm, respectively. Comparable data for clipped plots were 35 and 42 mm. Clipping therefore represented a more severe defoliation than did grazing.

For ryegrass plants grazed at a SI, significant plant dry weight responses to additions of nitrogen fertiliser occurred in September and November (Table 4.14). With a LI, however, responses were more consistent and continued until mid-summer (February). Clipped ryegrass plants responded in a similar manner to grazed plants with a SI, but with a LI significant dry weight responses occurred in all spring months (September, October and November).

The summer/autumn (January to March) growth of ryegrass plants in grazed Pa plots was consistently less, but not significantly so, than in NPa plots for SI but not LI (Table 4.15). For clipped plants, however, the growth of ryegrass plants in Pa plots was consistently less than in NPa plots over summer/autumn, and the effect was highly significant from February to May for plants clipped at a LI. Generally similar trends in ryegrass tiller dry weight responses to

Table 4.13 The effect of plot type (Pa, NPa) on ryegrass tiller length (mm) (pre-defoliation), with clipping or grazing at a short (SI) or a long (LI) interval.

Date	SI								LI							
	Clipped				Grazed				Clipped				Grazed			
	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.
1980																
15 Sept.	125	169	17.6	*	135	146	20.4	ns								
22									171	195	12.2	(†)	164	207	19.2	*
13 Oct.	115	120	14.6	ns	119	121	8.9	ns								
14									152	170	14.6	ns	157	204	25.0	(†)
3 Nov.									130	123	14.2	ns	124	178	17.4	**
10	115	125	10.4	ns	115	101	20.4	ns								
24									125	114	12.6	ns	132	153	24.2	ns
15 Dec.	116	124	9.8	ns	118	106	14.9	ns	120	98	13.5	ns	122	136	28.6	ns
1981																
12 Jan.									143	144	20.2	ns	163	179	41.0	ns
26	133	160	19.2	ns	129	130	19.0	ns								
9 Feb.									151	115	17.6	(†)	163	148	39.2	ns
9 Mar.	65	90	12.0	(†)	80	100	16.1	ns								
10									119	100	13.8	ns	165	150	34.7	ns
6 Apr.									108	102	16.3	ns	137	172	33.6	ns
20	102	111	17.3	ns	88	118	15.3	(†)								
4 May									118	119	14.2	ns	154	188	28.9	ns

Table 4.14 The effect of nitrogen (N) fertiliser additions on ryegrass plant dry weight (mg), with clipping or grazing at a short (SI) or a long (LI) interval.

Date	SI								LI							
	Clipped				Grazed				Clipped				Grazed			
	+N	-N	LSR	Sig.	+N	-N	LSR	Sig.	+N	-N	LSR	Sig.	+N	-N	LSR	Sig.
1980																
15 Sept.	35.4	20.0	1.36	**	34.8	19.7	1.41	**								
22									60.3	28.9	1.33	***	75.0	25.8	1.35	***
13 Oct.	24.4	16.9	1.60	ns	27.5	30.1	1.70	ns								
14									30.6	17.7	1.20	***	96.1	34.3	1.99	*
3 Nov.									18.2	9.6	1.36	**	151.6	38.6	2.39	**
10	24.6	14.7	1.64	*	69.8	19.6	2.42	*								
24									20.4	15.1	1.42	ns	202.8	56.4	2.08	**
15 Dec.	39.1	32.7	1.56	ns	77.4	39.2	2.39	ns	18.8	18.4	1.38	ns	91.0	40.9	2.13	*
1981																
12 Jan.									33.0	35.2	1.48	ns	110.0	102.6	2.97	ns
26	44.6	44.6	1.54	ns	78.5	64.2	3.69	ns								
9 Feb.									29.7	33.2	1.58	ns	359.0	98.8	2.92	*
9 Mar.	11.2	12.7	2.19	ns	43.3	16.9	3.61	ns								
10									17.4	22.4	1.99	ns	47.1	21.4	2.87	ns
6 Apr.									21.0	21.5	1.97	ns	43.2	31.1	3.23	ns
20	21.8	28.8	3.25	ns	82.9	26.3	3.72	ns								
4 May									39.4	43.6	2.10	ns	79.8	41.6	3.03	ns

Table 4.15 The effect of plot type (Pa, NPa) on ryegrass plant dry weight (mg), with clipping or grazing at a short (SI) or a long (LI) interval.

Date	SI								LI							
	Clipped				Grazed				Clipped				Grazed			
	Pa	NPa	LSR	Sig.	Pa	NPa	LSR	Sig.	Pa	NPa	LSR	Sig.	Pa	NPa	LSR	Sig.
1980																
15 Sept.	24.2	29.0	1.36	ns	24.2	28.2	1.39	ns								
22									43.2	40.4	1.34	ns	45.7	42.4	1.35	ns
13 Oct.	24.4	16.9	1.60	ns	37.5	21.8	1.66	ns								
14									26.7	20.3	1.20	ns	56.5	58.9	1.99	ns
3 Nov.									15.9	11.0	1.37	*	76.8	76.8	2.39	ns
10	23.4	15.5	1.64	ns	41.9	32.3	2.32	ns								
24									18.2	16.9	1.43	ns	123.0	92.0	2.08	ns
15 Dec.	43.6	29.3	1.56	ns	57.9	52.4	2.29	ns	20.2	17.1	1.39	ns	52.0	70.9	2.13	ns
1981																
12 Jan.									30.1	38.6	1.49	ns	79.9	139.9	2.97	ns
26	38.7	51.2	1.54	ns	49.5	101.8	3.47	ns								
9 Feb.									20.7	48.0	1.59	**	222.1	159.7	2.92	ns
9 Mar.	7.6	18.8	2.19	*	15.1	48.3	3.49	ns								
10									10.1	39.2	2.02	**	23.2	43.9	2.87	ns
6 Apr.									10.7	42.8	2.00	**	35.7	37.5	3.23	ns
20	18.6	33.8	3.25	ns	26.0	84.6	3.90	ns								
4 May									22.3	77.1	2.14	**	66.6	49.9	3.03	ns

nitrogen fertiliser and plot type (Pa, NPa) treatments were found, so these data are not presented.

Dry weight responses of introduced ryegrass plants to nitrogen fertiliser additions were more consistent over all treatments (defoliation interval; clipped or grazed), then they were for tiller number or tiller length. As noted for the latter parameters, ryegrass plant dry weight was generally less in Pa than NPa plots over summer/autumn.

Average vigour of grazed plants and those clipped at a LI was increased by nitrogen fertiliser applications (Table 4.16).

During spring there was a tendency for the average vigour of the ryegrass plants in Pa plots to be greater than for those in NPa plots when clipped or grazed at a SI and when clipped at a LI (Table 4.17). However the reverse tended to be true during summer/autumn for the average vigour of plants clipped or grazed at a LI, and for those grazed at a SI.

Significant interactions between nitrogen fertiliser and the paspalum frequency in the plots were inconsistent and were therefore considered not to have an important influence on the above measures of ryegrass growth.

4.7.4 Herbage accumulation

Seasonal accumulations of herbage dry matter in Experiment 2 were obtained by summing the growths between successive post- and pre-defoliation estimates. The late-winter/early-spring (LW/ES) season began with a post-defoliation assessment (28.7.80) at the time the ryegrass plants were transplanted into the plots. The spring, summer and autumn periods are defined in Table 4.18.

Table 4.16 The effect of nitrogen (N) fertiliser additions on the average vigour[a] of ryegrass plants, with clipping or grazing at a short (SI) or a long (LI) interval.

Date	SI								LI							
	Clipped				Grazed				Clipped				Grazed			
	+N	-N	SED	Sig.	+N	-N	SED	Sig.	+N	-N	SED	Sig.	+N	-N	SED	Sig.
1980																
15 Sept.	1.8	1.9	0.17	ns	2.2	1.8	0.17	*								
22									2.1	1.6	0.18	*	2.3	1.5	0.22	**
13 Oct.	1.8	1.8	0.21	ns	2.1	1.6	0.17	**								
14									1.8	1.4	0.18	(†)	2.1	1.5	0.23	*
3 Nov.									1.6	1.3	0.16	(†)	2.3	1.5	0.21	**
10	1.8	1.8	0.22	ns	2.0	1.8	0.25	ns								
24									1.6	1.5	0.17	ns	2.0	1.8	0.17	ns
15 Dec.	1.9	1.8	0.22	ns	2.0	2.0	0.20	ns	1.5	1.5	0.19	ns	1.9	1.7	0.20	ns
1981																
12 Jan.									1.7	1.6	0.22	ns	1.7	1.6	0.29	ns
26	1.8	1.8	0.23	ns	1.5	1.4	0.20	ns								
9 Feb.									1.6	1.5	0.17	ns	1.5	1.3	0.27	ns
9 Mar	1.1	1.0	0.26	ns	0.8	0.6	0.22	ns								
10									1.2	1.2	0.23	ns	1.2	1.0	0.28	ns
6 Apr.									0.9	1.0	0.24	ns	1.1	0.8	0.23	ns
20	0.9	0.7	0.26	ns	0.7	0.5	0.12	(†)								
4 May									1.0	1.0	0.19	ns	1.0	0.9	0.24	ns

[a] calculated on a scale of one (low) to five (high), data are means for 14 plants per plot assuming dead or missing plants have a vigour of zero.

Table 4.17 The effect of plot type (Pa, NPa) on the average vigour[a] of ryegrass plants, with clipping or grazing at a short (SI) or a long (LI) interval.

Date	SI								LI							
	Clipped				Grazed				Clipped				Grazed			
	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.
1980																
15 Sept.	1.8	1.9	0.17	ns	2.2	1.8	0.16	*								
22									2.1	1.7	0.19	(†)	1.9	1.9	0.22	ns
13 Oct.	1.9	1.7	0.21	ns	2.1	1.7.	0.15	*								
14									1.8	1.4	0.19	(†)	1.8	1.8	0.23	ns
3 Nov.									1.7	1.3	0.16	*	1.9	1.9	0.21	ns
10	2.1	1.6	0.20	*	2.0	1.8	0.24	ns								
24									1.7	1.4	0.18	ns	2.0	1.8	0.17	ns
15 Dec.	2.1	1.7	0.22	(†)	2.0	2.0	0.19	ns	1.6	1.7	0.22	ns	1.5	1.8	0.29	ns
1981																
12 Jan.									1.6	1.7	0.2	ns	1.5	1.8	0.29	ns
26	1.9	1.6	0.23	ns	1.3	1.7	0.19	*								
9 Feb.									1.5	1.6	0.18	ns	1.2	1.6	0.27	ns
9 Mar.	1.2	1.0	0.26	ns	0.5	0.9	0.21	(†)								
10									1.0	1.4	0.23	ns	0.9	1.4	0.28	ns
6 Apr.									0.7	1.2	0.24	(†)	0.7	1.2	0.23	*
20	0.8	0.8	0.26	ns	0.3	0.9	0.12	***								
4 May									0.6	1.4	0.19	**	0.6	1.2	0.24	*

[a] calculated on a scale of one (low) to five (high), data are means for 14 plants per plot assuming dead and missing plants have a vigour of zero

Table 4.18 The effects of nitrogen (N) fertiliser additions and plot type (Pa, NPa) on seasonal accumulation of herbage (kg DM/ha) in plots defoliated at short (SI) and long (LI) intervals.

Season	Clipped				Grazed				Clipped				Grazed			
	+N	-N	SED	Sig.	+N	-N	SED	Sig.	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.
<u>SI</u>																
LW/ES (28.7-15.9.80)	1935	1110	131	***	1735	1233	131	***	1306	1738	130	**	1241	1727	130	**
Spring (17.9-24.11.80)	2864	2700	355	ns	4255	3123	355	**	2789	2774	351	ns	3676	3702	351	ns
Summer (25.11.80-16.2.81)	1973	2546	320	(†)	2930	3446	320	ns	2092	2427	319	ns	3572	2804	319	*
Autumn (18.2-11.5.81)	786	686	281	ns	1181	1436	281	ns	598	873	278	ns	1191	1426	278	ns
ANNUAL TOTAL	7558	7042	540	ns	10101	9238	540	ns	6785	7812	538	ns	9680	9659	538	ns
<u>LI</u>																
LW/ES (28.7-22.9.80)	2382	1898	207	*	2338	1698	207	**	1820	2460	207	**	1800	2236	207	*
Spring (23.9-24.11.80)	3600	3106	358	ns	4205	4026	358	ns	3648	3058	359	ns	4311	3920	359	ns
Summer (25.11.80-9.2.81)	4031	4366	527	ns	4478	4845	527	ns	4668	3730	528	(†)	5763	3559	528	***
Autumn (10.2-4.5.81)	1550	1710	466	ns	2646	2378	466	ns	1933	1327	467	ns	2695	2329	467	ns
ANNUAL TOTAL	11563	11080	1054	ns	13667	12947	1054	ns	12069	10575	1056	ns	14569	12044	1056	*

Nitrogen fertiliser increased herbage accumulation in all treatments in LW/ES and also in spring for plots grazed at a SI (Table 4.18). Herbage accumulations in NPa plots were consistently greater than in Pa plots during LW/ES but with the exception of plots clipped at SI, this trend was reversed during spring and summer.

4.7.5 **Botanical composition**

As expected, Pa plots contained more paspalum than did NPa plots (Table 4.19) but since hits on paspalum were not recorded in many of the latter plots, statistical analyses comparing these treatments were often not possible. NPa plots always contained more ryegrass than Pa plots. They also contained more *Poa* in September and white clover during summer/autumn (February to May) than did Pa plots (Table 4.19).

Nitrogen fertiliser increased ryegrass and *Poa* frequencies, especially in spring (September, November), and there was a compensatory decline in the frequency of white clover (Table 4.20). After a September decline in the paspalum frequency of plots receiving nitrogen fertiliser, this tendency reversed and became progressively stronger over summer/autumn with a SI, but was inconsistent with a LI.

Grazed plots contained more ryegrass than clipped plots and a consistent significant effect was found from November until May for plots defoliated at a LI (Table 4.21). This was compensated for by a decline in the *Poa* and paspalum frequencies in grazed plots.

The March frequency of 'summer' grasses (mainly *Digitaria sanguinalis* and *Panicum dicotomiflorum*) for LI was less for plots receiving nitrogen than for those receiving no nitrogen (12 vs 7%), and was higher in clipped rather than grazed plots (31 vs 8%). With a SI 'summer' grass frequencies were low (1 to 2%). The frequency of litter in the plots was highest in March (33 and 27% for plots

Table 4.19 Effect of plot type (Pa, NPa) on the ryegrass, paspalum, *Poa* spp. and white clover frequencies (% of total hits) in plots defoliated at short (SI) and long (LI) intervals.

	Ryegrass				Paspalum				*Poa* spp.				White clover			
Date	Pa	NPa	SED[a]	Sig.	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.
SI																
11. 9.80	37.4	68.4	4.28	***	6.7	0.2	-	-	29.6	8.6	4.0	***	21.3	18.5	2.85	ns
13.11.80	32.6	55.0	5.94	***	34.8	1.6	-	-	12.6	10.0	3.84	ns	15.0	26.2	4.51	**
3. 2.81	10.8	38.2	3.99	***	60.8	5.3	3.62	***	-	-	-	-	7.7	27.1	4.62	***
17. 3.81[b]	5.5	24.4	3.32	***	56.8	4.2	-	-	4.7	2.7	1.30	ns	2.9	23.7	-	-
21. 5.81	7.9	38.0	3.79	***	47.4	2.5	-	-	15.6	3.9	2.16	***	8.5	31.4	4.43	***
LI																
11. 9.80	28.1	69.2	6.85	***	4.2	0.1	-	-	37.9	12.9	6.19	***	24.9	12.6	4.12	**
13.11.80	16.9	52.4	4.97	***	39.3	0.6	-	-	17.2	17.2	3.92	ns	16.8	16.0	3.60	ns
3. 2.81	13.8	54.6	5.17	***	58.8	4.3	-	-	-	-	-	-	15.5	24.8	4.65	ns
17. 3.81	6.9	29.2	2.77	***	43.6	1.4	-	-	-	-	-	-	7.8	15.5	3.19	*
21. 5.81	11.3	44.2	2.65	***	43.0	1.3	-	-	12.1	4.4	1.66	***	14.4	28.5	4.50	**

[a] approximate standard error of mean differences
[b] analysis restricted to NPa plots

Table 4.20 Effect of nitrogen (N) fertiliser additions on the ryegrass, paspalum, *Poa* spp. and white clover frequencies (% of total hits) in plots defoliated at short (SI) and long (LI) intervals.

	Ryegrass				Paspalum				*Poa* spp.				White clover			
Date	+N	-N	SED[a]	Sig.	+N	-N	SED	Sig.	+N	-N	SED	Sig.	+N	-N	SED	Sig.
SI																
11. 9.80	58.3	47.5	4.28	*	3.4	9.9	3.46	*	23.4	14.7	4.00	*	14.9	24.9	2.85	**
13.11.80	53.1	34.6	5.94	**	34.7	37.4	2.34	ns	14.3	8.2	3.84	ns	10.4	30.7	4.51	***
3. 2.81	26.8	22.3	3.99	ns	34.8	31.3	3.62	ns	-	-	-	-	11.6	23.2	4.62	**
17. 3.81	16.3	13.6	3.32	ns	61.1	52.4	4.49	(†)	1.8	5.5	1.30	**	18.3	29.0	8.74	ns
21. 5.81	25.0	21.0	3.79	ns	52.6	42.1	4.70	*	8.8	10.7	2.16	ns	16.6	23.4	4.43	(†)
LI																
11. 9.80	51.4	45.9	6.85	ns	3.1	5.3	2.45	ns	26.1	24.7	6.19	ns	17.7	19.8	4.12	ns
13.11.80	39.1	30.1	4.97	*	34.4	44.1	6.33	ns	21.3	13.1	3.92	(†)	11.1	21.1	3.60	*
3. 2.81	35.8	32.6	5.17	ns	60.3	57.3	6.39	ns	-	-	-	-	16.0	24.3	4.65	ns
17. 3.81	21.6	14.5	2.77	*	39.0	48.1	6.76	ns	-	-	-	-	11.5	11.8	3.19	ns
21. 5.81	27.3	28.2	2.65	ns	45.1	40.9	5.98	ns	7.3	9.3	1.66	ns	20.4	22.5	4.50	ns

[a] approximate standard error of mean differences

Table 4.21 Effect of method of defoliation on the ryegrass, paspalum, *Poa* spp. and white clover frequencies (% of total hits) in plots defoliated at short (SI) and long (LI) intervals).

	Ryegrass				Paspalum				*Poa* spp.				White clover			
Date	Clipped	Grazed	SED[a]	Sig.	Clipped	Grazed	SED	Sig.	Clipped	Grazed	SED	Sig.	Clipped	Grazed	SED	Sig.
SI																
11. 9.80	49.4	56.4	4.28	(†)	6.4	6.9	3.46	ns	19.5	18.6	4.00	ns	23.6	16.2	2.85	*
13.11.80	39.1	48.6	5.94	(†)	36.1	35.9	2.34	ns	14.0	8.5	3.84	ns	23.4	17.8	4.51	ns
3. 2.81	23.0	26.1	3.99	ns	29.6	36.5	3.62	ns	-	-	-	-	19.0	15.7	4.62	ns
17. 3.81	14.0	15.8	3.32	ns	42.3	61.2	4.49	(†)	4.0	3.3	1.30	ns	21.9	25.4	8.74	ns
21. 5.81	22.5	23.5	3.79	ns	38.7	56.1	4.70	**	14.8	4.7	2.16	***	19.5	20.5	4.43	ns
LI																
11. 9.80	48.1	49.2	6.85	ns	2.6	5.8	2.45	ns	27.6	23.2	6.19	ns	20.0	17.5	4.12	ns
13.11.80	28.8	40.5	4.97	*	38.1	40.5	6.33	ns	23.2	11.2	3.92	**	16.7	16.0	3.60	ns
3. 2.81	25.4	43.1	5.17	**	62.2	55.5	6.39	ns	-	-	-	-	25.4	14.9	4.65	ns
17. 3.81	10.8	25.3	2.77	**	34.4	52.7	6.76	*	-	-	-	-	13.2	10.1	3.19	ns
21. 5.81	21.8	33.7	2.65	***	40.7	45.3	5.98	ns	13.3	3.2	1.66	***	24.2	18.7	4.50	ns

[a] approximate standard error of mean differences.

defoliated at a LI and a SI, respectively), but the levels were not affected by nitrogen or manner of defoliation. Autumn (May) litter levels were about half the March levels and were higher in Pa than in NPa plots ($P<0.05$).

The interactions between treatment variables were seldom significant suggesting variables generally acted independently of each other.

4.8 DISCUSSION

These experiments confirm the principal finding of chapter 2, namely high summer losses of the introduced ryegrass plants. A major advance is that there was no improvement in seasonal survival of ryegrass due to nitrogen fertiliser. This lack of effect on survival occurred even though in both experiments significant differences were detected between the seasonal growth and vigour of ryegrass plants receiving nitrogen fertiliser and those that did not (Fig. 6, Table 4.8, 4.9, 4.10, 4.12, 4.14, 4.16). Other workers (Harris 1973; Davies 1977; Alberda & Simba 1982) have reported similar responses to nitrogen fertiliser, but in the present experiments responses were generally small and confined to the period of application (late-winter/spring).

Additions of nitrogen fertiliser also modified the botanical composition of the plots. In particular, in spring the frequency of ryegrass and *Poa* spp. increased, as was the case for paspalum (Table 4.20) in late-summer/autumn in nitrogen treated plots compared to untreated plots. Others (Hagger & Squires 1979; Ball & Field 1982) have reported increases in *Poa* spp. in pastures treated with nitrogen fertiliser. Haggar & Squires (1979) suggested this could affect the growth of young ryegrass plants, since Wells (1974) noted *Poa annua* was capable of forming a mat of small tillers, especially when nitrogen fertiliser was added. Nevertheless, the results suggest that nitrogen was not the factor limiting the survival of the introduced ryegrass plants. Both the introduced ryegrass (see above) and resident species responded equally to the addition of nitrogen fertiliser (Table 4.18), negating the possibility of the introduced plants gaining a competitive advantage over the resident species.

In Experiment 1, deaths of introduced ryegrass plants with predominantly paspalum (Pa plots) or other resident species (NPa plots) as close neighbours were similar in all seasons (Table 4.4). This was also true in spring (Table 4.6) and autumn for Experiment 2, but in summer, deaths of ryegrass plants were highest for ryegrass plants in grazed Pa plots (Table 4.7). The latter effect did not occur in grazed NPa plots. This result suggests that the extra stress of grazing in summer was necessary to expose the introduced ryegrass plants to the detrimental effects of summer growing paspalum. Others (Weaver 1930; Weinmann 1948; Harris 1978; Hunt 1979) have recognised the superiority of rhizomatous (eg. paspalum) over non-rhizomatous (eg. ryegrass) species in the maintenance of growth when subjected to severe defoliation, heavy treading and periods of water stress. Evidence of paspalum's ability to influence the growth of introduced ryegrass plants is provided by reduced summer growth of ryegrass in Pa compared to NPa plots (Section 4.7.3, Table 4.11, 4.13, 4.15, 4.17).

The procedure of covering certain plots during grazing proposed a dilemma since ungrazed plots had to be artificially harvested using a clipping technique. This in itself may have influenced the survival of the introduced ryegrass plants, as pastures cut at intervals behave differently to rotationally grazed pastures in terms of tiller density, botanical composition and annual herbage accumulation (Frame

1966; Shaw et al. 1966; Frame & Hunt 1971; Smith 1979; Hodgson et al. 1981). Differences also occurred in the present experiment and may have been emphasised by more severe defoliation by clipping than grazing. The ryegrass and paspalum frequencies (Table 4.21) and annual herbage accumulation (Table 4.18) were generally higher in grazed than in clipped plots, while the reverse was true for *Poa* spp. and white clover (Table 4.21).

As suggested (Table 4.3, 4.5), defoliation by dairy cows involves greater opportunity for plant damage than does defoliation by clipping. However, even after removal of data directly related to losses attributed to factors extraneous to severing and removal of herbage (dung, urine and 'pulling' effects) (Table 4.6, 4.7), losses were still higher for grazed than for clipped plants. It is possible that 'patch' grazing by cattle (Hughes & Jackson 1974) could have contribued to this result, as reflected by the incidence of severe defoliations (tiller length less than 10 mm) leading to plant deaths (Table 4.5). Deaths of ryegrass plants as a consequence of severe grazing during summer have been reported by Brougham (1960, 1961). Deaths attributed to severe grazing during summer were higher with a short than with a long grazing interval (Table 4.5) as were total ryegrass deaths during summer (Table 4.7) over all treatments.

Despite the additions of nitrogen fertiliser significantly improving the ryegrass frequency in the plots relative to those receiving no nitrogen fertiliser, their ryegrass levels steadily declined from greater than 50% of total hits in September, to less than half this level in March (Table 4.20). This phenomenon coincided with increasing maximum daily screen temperatures (Appendix 1) and the occurrence of dry periods (Section 4.6). Over the 1979/80 and 1980/81 warm seasons (December, January, February, March) maximum daily screen temperatures exceeded 25 °C (upper limit for ryegrass growth - Mitchell 1956; Langer 1972; McWilliam 1978) on 18 to 36% of the days. It is possible that temperature restrictions on growth combined with periods of water stress were climatic factors involved in restricting the competitiveness of the introduced ryegrass. Rather than having a direct effect on survival these factors may be mediated through other factors affecting the competitive ability and survival of the introduced ryegrass, namely, the presence of summer growing paspalum. For these reasons similar comparisons were made for introduced ryegrass plants in Pa and NPa plots, and an irrigation treatment was included in the final field experiment (chapter 6).

4.9 CONCLUSIONS

The persistence of introduced ryegrass plants in a grazed pasture containing paspalum is unlikely to be improved by the addition of nitrogen fertiliser during late-winter and spring. Despite immediate growth responses by the ryegrass plants to the application of nitrogen fertiliser, these responses were small and shortlived.

It is possible that seasonal growth of established sward species, particularly growth of *Poa* spp. in spring and paspalum in summer (both of which were stimulated by application of nitrogen fertiliser), caused stress for the introduced ryegrass plants by reducing their light interception through shading. Such a mechanism, in combination with climatic or managerial stresses, may weaken some ryegrass plants to the point of extinction. Alternatively, growth of resident ryegrass and *Poa* spp. in NPa plots may also provide considerable competition to establishing ryegrass plants, since losses were equally as high in these plots. Further study of this hypothesis was provided for in the final field experiment (chapter 6) when shading of introduced ryegrass plants was prevented by clipping of the surrounding resident herbage.

The results described here implicate defoliation interval as a factor modifying the competitive environment, the growth of individual ryegrass plants and therefore their persistence. Because of this the design of the final experiment allowed for statistical comparison of the defoliation interval effect.

CHAPTER 5

THE COMPETITIVE INTERACTION OF PASPALUM AND RYEGRASS

5.1 INTRODUCTION

In field experiments (chapter 4) the growth, vigour and persistence of ryegrass growing in Pa and NPa plots were compared under various nitrogen fertiliser and defoliation managements. Nitrogen fertiliser did not improve the persistence of the introduced ryegrass plants, and about 20% of total losses were attributed to direct 'animal effects'. Ryegrass plants introduced into plots (Pa) containing predominantly paspalum and grazed during summer had significantly higher losses than those in plots (NPa) containing other resident species. Climatic factors (eg. periods of water stress) may be implicated in the paspalum effect.

This chapter describes a complementary experiment in which paspalum/ryegrass interactions and the influence of nitrogen fertiliser were studied under relatively controlled environmental conditions. A replacement series experimental design (de Wit 1960) was used. Monocultures and various combinations of paspalum and ryegrass were grown in containers of soil located in a glasshouse from late-spring until autumn.

5.2 MATERIALS AND METHODS

5.2.1 Preparation of plant material

Paspalum plantlets, each comprising a small rhizome portion (5 mm or less) supporting a single tiller and roots, were obtained by dissecting rhizome cuttings of paspalum originally growing in the field experimental area. Each rhizome cutting provided several plantlets after a period (27.6.79 to 21.9.79) of growth in pots containing sieved topsoil from the experimental area, and located in a controlled environment growth chamber. Air temperature was 24 °C with eight hour nights and 16 hour days, and an irradiance level of 450 W/m^2. Cuttings were transferred on the 6.9.79 to the chamber containing the ryegrass seedlings.

Ryegrass seedlings were derived from seeds of a commercial line of certified first generation *Lolium perenne* L. 'Grasslands Nui' perennial ryegrass that were sown on 10.8.79 into flat trays containing sand. The seedlings were grown in a controlled environment chamber until 21.9.79. Air temperature was 18 °C with 15 hour nights and nine hour days, and an irradiance level of 250 W/m^2.

Ryegrass seedlings and paspalum plantlets were transplanted (8.11.79) into plastic containers (surface diameter 232 mm, vertical height 215 mm) containing sieved topsoil from the field experimental area (Section 2.2). The plants were equidistantly spaced in each container, ensuring maximum interspecific separation. Stress was minimised by trimming shoots and roots before replanting and by thorough watering after replanting. No deaths occurred immediately following transplanting.

The surfaces of the growing medium for both species were kept moist by daily watering. After transplanting and the imposition of the experimental treatments the same watering procedure was maintained throughout the experimental period.

On 31.8.79 the paspalum shoots were clipped to a 50 mm stubble after which full strength 'Bollards Solution' (Bollard 1966) (Appendix 8) was applied to both paspalum and ryegrass. All plants were clipped on 6.9.79 after which full strength and half strength 'Bollards Solution' was applied twice weekly to the ryegrass and paspalum, respectively.

The containers of paspalum and ryegrass plants were transferred from the controlled environment chamber to a glasshouse on 21.9.79, where similar nutrient application procedures were maintained until the end of October when the experimental design was first imposed. The glasshouse was located at the University of Waikato, approximately 1 km west of the field experimental area on Ruakura Agricultural Research Station.

5.2.2 Experimental layout

The plants were arranged as a replacement series with the following numbers of each species per container:

Paspalum (P)	Ryegrass (R)	Code
26	0	100P
20	6	75P 25R
13	13	50P 50R
6	20	25P 75R
0	26	100R

Twenty containers comprising four replicates of the five ratios of the ryegrass/paspalum replacement series, were positioned at random but with upper rims touching on a table in the glasshouse. Positions were re-randomised at monthly intervals, using a table of random digits, to reduce edge effects.

5.2.3 Nitrogen treatment

On 30.11.79, a hand-held 'Cambrian' CSP14 pressure sprayer was used to apply nitrogen fertiliser as liquid urea (45% N) to half the containers (two replicates of the replacement series). Sheet metal (150 mm high) fitted around the container perimeter was used to minimise spray drift. Urea (58.8 ml of 0.78% w/v, equivalent to

50.6 kg N/ha) was applied to each container in 10 seconds and was washed in with water (100 ml).

5.2.4 Herbage measurements

At 41, 62, 84, 109, 130, 153 and 174 days after transplanting (8.11.79), tillers on each plant were counted and cut to a 25 mm stubble. The number of cut tillers per plant was also counted to allow for the estimation of tiller dry weight. Harvested herbage from each container was dissected into the component species and weighed after drying for 24 hours at 100 °C in a forced draught oven, and its nitrogen concentration (% of DM) (Section 3.2.4) was subsequently determined. Per plant dry weight was obtained by dividing the total weight for each species by the number of plants transplanted into the containers in November 1979. Dead plants therefore had zero dry weight.

5.2.5 Data analysis

Data on tiller number per plant, tiller and plant dry weight for ryegrass and paspalum, and total plant biomass per container, were subjected to analysis of variance to separate the effects of nitrogen fertiliser and species ratio.

The concepts of plant relative yield (Trenbath 1974) and relative yield total (RYT), based on per area relative yields of de Wit & van den Bergh (1965), were used to describe competitive interactions between plants in mixtures.

According to the two species competition model of de Wit (1960) the biomass of each component is strictly proportional to the share of limited environmental resources (eg. light, water, nutrients) it can acquire. Thus if sharing is uneven, plants of one species will be larger in mixture than in monoculture while plants of the other species will be correspondingly smaller. If the plant relative yield of a component i is $Ri = Oij/Mi$ where Oij is the yield of species i in a mixture with species j, and Mi, is the yield of species i in its monoculture, then the plant relative yield of the aggressor will be greater than unity and that of the subordinate less than unity. That is, if species i is the aggressor, $Oij/Mi>1$ and $Oji/Mj<1$.

When the components of a mixture are competing for the same limited environmental resources the sum of the relative yields or the RYT has a value close to unity. Values of RYT>1.0 suggest that the species make different demands on resources or avoid competition with each other. A RYT<1 implies mutual antagonism.

5.3 CLIMATIC DATA

Daily maximum and minimum air temperatures were recorded throughout the experiment. These data are summarised as monthly averages in Appendix 9.

5.4 RESULTS

5.4.1 Plant deaths

No deaths of paspalum plants occurred during the experiment. Deaths of ryegrass plants occurred only in mixtures with paspalum and the first were recorded on 25.2.80, 109 days after transplanting (Table 5.1). By 9.4.80 10 ryegrass deaths had occurred with a further 18 by 30.4.80.

The addition of nitrogen fertiliser had no affect on ryegrass deaths; 15 plants receiving nitrogen and 13 receiving no nitrogen fertiliser died over the experimental period (Table 5.1).

Table 5.1 Pattern of mortality of ryegrass plants growing in mixtures with paspalum.

Date	Rep.	Species ratio 75P 25R (24)[a]	 50P 50R (52)	 25P 75R (80)
25.2.80	1	-	-	-
(109)[b]	2	-	-	-
	3	-	-	-
	4	-	1	1
17.3.80	1	-	-	1
(130)	2	-	-	1
	3	-	-	-
	4	-	-	-
9.4.80	1	-	1	1
(153)	2	-	-	-
	3	-	3	1
	4	-	-	-
30.4.80	1	-	4	1
(174)	2	2	2	-
	3	6	-	1
	4	2	-	-
Total deaths		10	11	7

[a] total (over four replicates) of established ryegrass plants
[b] days from transplanting (8.11.79)

5.4.2 **Competitive interactions**

Data from the first, third, fifth and last harvests are presented to illustrate important trends. At all harvests there were no significant interactions between nitrogen and species ratio.

Over summer/autumn (1.2.80 to 30.4.80) the relative yield per plant for ryegrass (Rr) progressively declined with increasing proportion of paspalum in the mixture (Fig. 7). On the contrary, the relative yield per plant for paspalum (Rp) increased with increasing ryegrass proportion, and the trend was strongest at the end of the

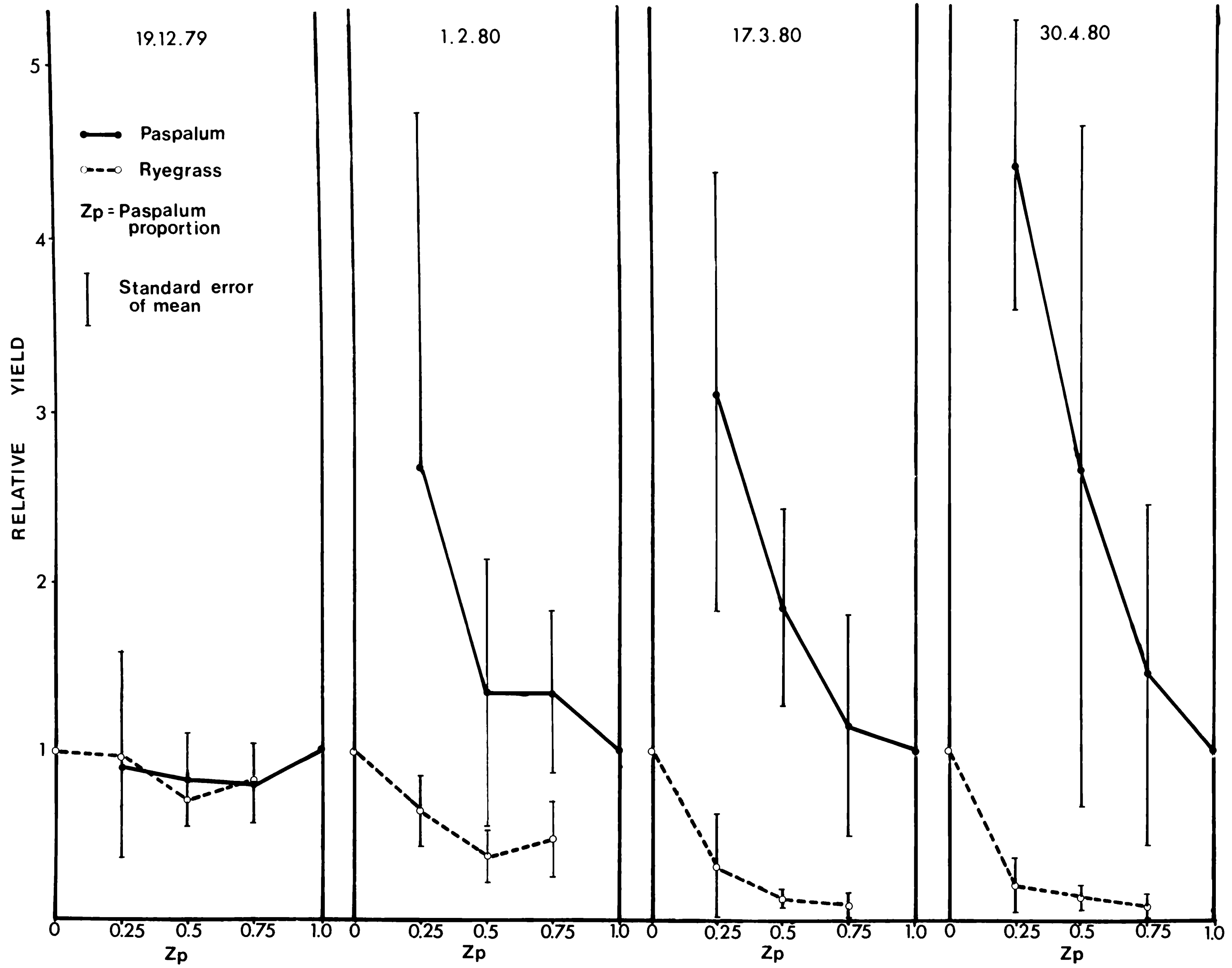

Fig. 7 The influence of relative proportion of paspalum and ryegrass on relative yield per plant.

study (30.4.80). Although the data were variable, on average at this date, Rp had reached a maximum of 4.4 in the 25P 75R mixture while Rr had reached its lowest value (0.2) for this mixture. On average for all mixtures over summer/autumn, Rp was greater than 1.0 and Rr less than 1.0.

Generally throughout the experiment, average RYT values were close to 1.0 although on 30.4.80, RYT for all mixtures were slightly above 1.0 (Table 5.2). Re-calculation of RYT values for 30.4.80 on a survivors basis did not change the trends in the data. However, since there were no ryegrass survivors for replicate three of the 75P 25R treatment (Table 5.1), the relative yield for ryegrass was considered to be zero for both calculations.

Table 5.2 Relative yield total[a] for paspalum and ryegrass mixtures at four harvests.

Date		Species ratio	
	75P 25R	50P 50R	25P 75R
19.12.79	0.8 (0.17)[b]	0.8 (0.20)	1.0 (0.25)
1. 2.80	1.1 (0.33)	0.9 (0.45)	1.1 (0.44)
17. 3.80	0.9 (0.49)	1.0 (0.26)	1.0 (0.27)
30. 4.80	1.2 (0.74)	1.4 (1.00)	1.2 (0.17)
30. 4.80[c]	1.2 (0.73)	1.4 (1.00)	1.2 (0.18)

[a] data are means over four reps.
[b] standard error of the mean
[c] calculated on a survivors basis

From February 1980, tillers per paspalum plant increased with increasing ryegrass ratio (Table 5.3). A similar tendency occurred

Table 5.3 Overall effect of species ratio on tiller numbers per plant for paspalum and ryegrass growing in monocultures and mixtures.

Date		100P	75P 25R	50P 50R	25P 75R	100R	SED[a]	Sig.
19.12.79	P[+]	10.6	9.9	10.4	10.1	-	1.62	ns
	R	-	8.3	8.4	9.0	9.9	1.22	ns
9. 1.80	P	10.5	9.3	11.9	10.7	-	1.56	ns
	R	-	8.1	8.5	9.4	9.9	1.20	ns
1. 2.80	P	10.1	10.2	11.5	15.6	-	3.20	ns
	R	-	7.8	8.0	9.0	9.8	1.24	ns
25. 2.80	P	10.7	11.0	15.5	20.1	-	2.16	**
	R	-	7.3	7.3	8.3	9.3	1.19	ns
17. 3.80	P	10.0	10.7	16.1	22.9	-	2.87	**
	R	-	4.9	6.2	6.7	9.2	1.12	*
9. 4.80	P	13.4	11.5	14.0	23.0	-	2.84	**
	R	-	5.4	4.6	5.5	9.0	1.31	*
30. 4.80	P	9.5	12.6	18.2	24.9	-	2.26	***
	R	-	2.4	3.5	4.6	7.8	0.87	***

[+] P = paspalum, R = ryegrass

[a] standard error of differences between treatment (species ratio) means

for paspalum tiller dry weight but differences between species ratios did not reach significance (Table 5.4). Tiller numbers per ryegrass plant declined with increasing paspalum ratio, and on 9.4.80 and 30.4.80 were significantly greater in monocultures than in all mixtures with paspalum (Table 5.3). A similar but stronger trend existed for ryegrass tiller dry weight and this was significant from early-February until the end of the experiment (Table 5.4).

Table 5.4 Overall effect of species ratio on tiller dry weight (mg) for paspalum and ryegrass grown in monocultures and mixtures.

Date		100P	75P 25R	50P 50R	25P 75R	100R	SED[a]	Sig.
19.12.79	P[+]	23.5	21.0	18.8	19.6	-	5.14	ns
	R	-	22.8	18.2	24.0	22.8	2.15	ns
9. 1.80	P	17.9	18.0	16.2	22.5	-	5.08	ns
	R	-	16.7	14.2	15.6	13.8	3.25	ns
1. 2.80	P	20.2	25.3	20.8	31.8	-	5.37	ns
	R	-	7.4	6.0	9.1	13.3	1.75	*
25. 2.80	P	21.6	22.7	23.6	24.4	-	3.50	ns
	R	-	7.2	6.8	7.6	15.3	2.85	(†)
17. 3.80	P	12.5	13.4	14.7	21.9	-	3.63	ns
	R	-	1.9	2.3	4.8	12.0	1.59	*
9. 4.80	P	7.5	12.4	13.0	15.3	-	2.35	(†)
	R	-	2.3	3.4	3.9	10.7	1.28	**
30. 4.80	P	7.0	6.8	8.7	11.0	-	2.07	ns
	R	-	2.3	3.4	2.8	8.4	1.07	**

[+] P = paspalum, R = ryegrass

[a] standard error or differences between treatment (species ratios) means

At each harvest the total plant biomass of mixtures were not significantly greater than those for the monocultures (Table 5.5) although on 30.4.80, the biomass of all mixtures equalled or slightly exceeded the biomass of each monoculture.

Table 5.5 Plant biomass per container (g) for mixtures and monocultures of paspalum and ryegrass.

Date	100P	75P 25R	50P 50R	25P 75R	100R	SED	Sig.
19.12.79	6.5	5.3	4.4	5.4	5.8	1.34	ns
9. 1.80	4.8	4.2	3.8	4.3	3.6	0.83	ns
1. 2.80	5.3	5.4	3.7	4.2	3.3	0.86	ns
25. 2.80	5.8	5.2	5.3	4.3	3.7	0.86	ns
17. 3.80	3.2	3.0	3.2	3.0	2.8	0.80	ns
9. 4.80	2.6	2.7	2.5	2.5	2.4	0.54	ns
30. 4.80	1.6	1.7	2.3	1.9	1.7	0.48	ns

5.4.3 **Plant responses to nitrogen fertiliser**

Significant tiller number and tiller and plant dry weight responses to nitrogen fertiliser were detected at the first harvest (19.12.79), 13 days after its application (Table 5.6). The significant effects on ryegrass tiller number per plant and tiller dry weight were reflected in plant dry weight, but by February 1980 they were small or had completely disappeared. The only effect of nitrogen fertiliser on paspalum was on tillers per plant and this response declined with time (Table 5.6).

Table 5.6 The effect of nitrogen (N) fertiliser on tiller number per plant, tiller and plant dry weight (mg) and total biomass (g) per container for ryegrass and paspalum in mixtures and monocultures[a].

	Paspalum				Ryegrass			
	+N	-N	SED	Sig.	+N	-N	SED	Sig.
(a) Tillers per plant:								
19.12.79	11.7	8.8	1.14	*	9.7	8.1	0.86	(†)
9. 1.80	11.2	10.0	1.10	ns	9.7	8.2	0.85	ns
1. 2.80	12.4	11.3	2.26	ns	9.4	7.9	0.87	ns
(b) Tiller dry weight:								
19.12.79	22.0	19.4	3.63	ns	23.9	20.0	1.52	*
9. 1.80	20.0	17.3	3.59	ns	15.6	14.6	2.30	ns
1. 2.80	23.3	25.8	3.80	ns	8.5	9.4	1.24	ns
(c) Plant dry weight								
19.12.79	253	161	51.7	ns	233	161	29.3	*
9. 1.80	214	165	41.0	ns	153	120	25.6	ns
1. 2.80	290	291	68.4	ns	82	70	17.4	ns
(d) Plant biomass per container (ryegrass + paspalum)								
19.12.79	6.7	4.3	0.85	*				
9. 1.80	4.9	3.4	0.53	*				
1. 2.80	4.7	4.1	0.54	ns				

[a] data are means across all species ratios

Total plant biomass per container was increased by the addition of nitrogen fertiliser up until the second harvest 34 days after application (Table 5.6). This effect had disappeared by early-February.

Effects of nitrogen fertiliser on the nitrogen concentrations in shoots (Table 5.7) were small and confined to the first harvest.

Table 5.7 Effect of nitrogen (N) fertiliser on the nitrogen concentration (% of DM) in shoots of paspalum and ryegrass.

Date	Paspalum[a] +N	Paspalum[a] -N	Ryegrass[a] +N	Ryegrass[a] -N
19.12.79	3.3 (0.43)[b]	2.9 (0.25)	3.8 (0.53)	3.4 (0.28)
9. 1.80	2.1 (0.05)	2.2 (0.12)	2.3 (0.17)	2.3 (0.21)
1. 2.80	1.9 (0.13)	2.1 (0.10)	2.3 (0.38)	2.4 (0.43)
25. 2.80	2.0 (0.13)	2.0 (0.15)	2.2 (0.59)	2.3 (0.44)
17. 3.80	2.5 (0.33)	2.6 (0.13)	[c] -	-
9. 4.80	2.8 (0.16)	3.0 (0.07)	-	-
30. 4.80	3.4 (0.12)	3.0 (0.20)	-	-

[a] data are means over all species ratios
[b] standard error of the mean
[c] insufficient dry matter prevented analysis

5.5 DISCUSSION

The major finding of this experiment was the dominance of paspalum over ryegrass during the summer/autumn (1.2.80 to 30.4.80). Paspalum was the more aggressive species in the mixtures during this period since its relative yield was greater than 1.0 and that of ryegrass was less than 1.0 (Fig. 7).

Paspalum dominance from late-February to the end of April was reflected in about a two fold increase in tillers per plant as the paspalum ratio decreased from 1.0 to 0.25 (Table 5.3). Ryegrass tiller numbers per plant (Table 5.3) and tiller dry weight (Table 5.4) declined as the ryegrass ratio decreased from 1.0 to 0.25, so that the size of ryegrass plants was reduced as the number of associated paspalum plants increased. Harris et al. (1981b) concluded that increases in the competitive power of grass species was associated with increases in tiller numbers per plant. They studied competitive interactions between *Paspalum dilatatum* Poir. 'Grasslands Raki' and *Lolium perenne* L. 'Grasslands Nui' perennial ryegrass in a replacement series growth chamber experiment with a low (14 °C day/8 °C night) and a high (24 °C/18 °C) temperature regime, and various cutting managements. On average, the temperature regime in the present experiment from October 1979 to March 1980 was similar to the high temperature regime of Harris et al. (1981a,b). This temperature regime (Appendix 9) was closer to the optimum for paspalum (29 to 35 °C) than that of ryegrass (18 to 24 °C) (Mitchell 1956; McWilliam 1978) and therefore presumably favoured the growth of paspalum. As found by Harris et al. (1981a,b), paspalum became the dominant grass with a high temperature regime.

The superior growth of paspalum plants at the lowest paspalum ratio in mixtures (Table 5.3) may have been assisted by reduced intraspecific competition. That is, paspalum growth per plant was greatest where the lowest number of the strongest competitor (paspalum) were present (25P 75R treatment). It is therefore suggested that the associated ryegrass plants generally offered weak interspecific competition under the conditions of the experiment. Carbohydrate and nitrogen reserves in the rhizome portions of the paspalum plantlets may have assisted paspalum's attainment of a competitive advantage over ryegrass. Nevertheless, significant differences in the growth of ryegrass in mixtures compared to monocultures did not occur until 1.2.80, 85 days after transplanting.

Despite the increase in the size of paspalum plants with decreasing ratio of paspalum to ryegrass, deaths of the latter tended to be greatest at high ratios of paspalum to ryegrass (Table 5.1).

The mechanisms (eg. competititon, day temperatures, allelopathy) contributing to reduced size (Table 5.3,5.4) and eventual death of some ryegrass plants (Table 5.1) may be more effective when individual ryegrass plants are surrounded by more paspalum than ryegrass plants.

As paspalum dominance over ryegrass increased throughout summer/autumn (Fig. 7) the mean RYT for all mixtures by the end of April slightly exceeded 1.0 (Table 5.2). Furthermore, on 30.4.80 the biomass of mixtures equalled or exceeded the biomass of the highest yielding monoculture (Table 5.5), a condition referred to by Trenbath (1974) as transgressive overyielding. However, the latter effect was not significant and there have been few reports in the literature of significant overyielding for grass mixtures (Trenbath 1974; Harris et al. 1981b). In the present study high experimental error could have contributed to the effect. The behaviour of paspalum and ryegrass in mixtures in this experiment can be generally described as being of the 'compensating type'. The yield of paspalum (aggressor) was higher in mixtures than monocultures and that of ryegrass (subordinate) was correspondingly lower so that the mixture biomass tended to be kept between the monoculture values (Donald 1963; Trenbath 1974). According to the de Wit (1960) model, paspalum and ryegrass in the present experiment are likely to be competing for the same supplies of environmental resources, the requirements for growth. As shown by van den Bergh (1968), when this occurs the RYT for mixtures has a value of about 1.0 (Table 5.2) which is the most common occurrence for grass mixtures (Trenbath 1974).

Addition of nitrogen fertiliser had a small short-lived effect on the growth of paspalum and ryegrass plants and on the nitrogen concentration in their shoots. These effects occurred despite the possibility of high levels of mineralised nitrogen being present in the soil used for the growing medium for this experiment. The soil was obtained from heavily stocked pasture regarded to be of high fertility. Some nitrogen may have been lost by volatilisation of ammonia from the soil surfaces as a high air temperature (28 °C maximum) was recorded on the day of application. Furthermore, root growth and development after three weeks from transplanting may have been insufficient for efficient uptake of applied nitrogen which could then have been leached from the containers by successive daily waterings. The latter argument is supported by the generally low nitrogen concentrations (Table 5.7) measured in the paspalum and ryegrass shoots. Even though a high proportion of leaf was sampled (cutting height 25 mm), the nitrogen concentrations in the herbage were lower than have been reported elsewhere (McNaught 1970).

The overall effect of the addition of nitrogen fertiliser was to improve the early summer growth of both competing species and therefore the plant biomass per container (Table 5.6). Although the response was more variable for paspalum than for ryegrass, the former species was still able to dominate the latter when experimental conditions during summer/autumn favoured its growth.

5.6 CONCLUSIONS

The results of this experiment suggest that the presence of paspalum as a competing species during summer/autumn is likely to be an important factor in determining the performance of associated perennial ryegrass plants. When ryegrass was included in mixtures with paspalum, its growth was reduced to the point of extinction of some plants during summer/autumn. This supports the finding of the field experiment (chapter 4, Experiment 2) where paspalum, rather than other pasture species as close neighbours, reduced the survival of introduced ryegrass plants during summer. As found in this and the field experiments (chapter 4), the application of nitrogen fertiliser during late-spring did not modify this effect. Although the exact mechanism of paspalum/ryegrass interactions leading to suppression of the latter species is not clear from this experiment, interference by paspalum in the growth of ryegrass is likely to contribute to the observed field results (chapter 2, 4).

CHAPTER 6

THE EFFECTS OF DEFOLIATION MANAGEMENT AND IRRIGATION ON RYEGRASS GROWTH AND PERSISTENCE

6.1 INTRODUCTION

The interval between defoliations can influence seasonal herbage accumulation on dairy pastures (chapter 4). Defoliation, by changing the structure of the sward may also change the competitive environment for individual plants (Hughes & Jackson 1974; Davies 1977). It has been recognised (Stern & Donald 1962) that shading can cause changes in the botanical composition of pastures, presumably by reducing shoot and root growth and the general competitive ability of affected plants (Black 1957; Donald 1963). These effects could have influenced the results described in chapters 2 and 4 where high summer losses (greater than 30% of marked plants) of introduced plants were found with various defoliation intervals.

Independent of defoliation interval, cow grazing is selective and of variable intensity within a paddock. This fact has lead to reduced persistence of grasses (Hodgson 1973; Hughes & Jackson 1974). In under-utilised areas, reduced viability and development of basal tiller buds may occur because of excessive shading (Langer 1972). Shading and competition for light are also important factors influencing the survival of ryegrass tillers in pastures (Langer et al. 1964; Spiertz & Ellen 1972; Ong et al. 1978). It is therefore likely that competition for light will have an important influence on the growth and persistence of ryegrass plants introduced into established pasture, the structure of which is periodically changed by cow grazing of variable intensity.

Throughout the previous summers (1978/79, 1979/80, 1980/81) periods of dry weather often accompanied by high screen maximum temperatures were recorded (Section 2.2). The interaction of these conditions with the defoliation regime (Harris 1978) may have been involved in reducing the contribution of introduced ryegrass to pasture production, since a single severe grazing during summer may weaken or kill ryegrass plants (Brougham 1960, 1961).

In the field experiment described in this chapter, young ryegrass plants were introduced into Pa and NPa areas of the sward and subjected to contrasting defoliation intervals. The experimental design incorporated a 'crossover' of defoliation treatments during early-summer so that any interactions between defoliation interval and season could be studied. The effects of reduced competition for light on the growth and persistence of the introduced ryegrass plants was examined by using periodic clipping to control the growth of resident herbage surrounding some of the introduced ryegrass plants. Effects of irrigation during dry periods on the growth and persistence of introduced ryegrass was also studied.

The effects of grazing interval, irrigation and clipping of resident herbage on the growth of ryegrass plants introduced into different plot types were examined using a 2^4 factorial experimental design.

6.2 EXPERIMENTAL SITE

Two 0.12 ha paddocks that were part of the general experimental area were used (Section 2.2). None of the plots in the present experiment had been previously used. Electric fencing subdivided each paddock into eight experimental areas bounded at each end by a two metre wide access strip.

6.3 EXPERIMENTAL DESIGN AND TREATMENTS

The experimental areas were grazed at either a short (SI) or a long (LI) interval defined as follows:

Treatment code	No. of reps	Period	Approximate grazing interval (days)
SS	4	21.9.81 to 11.6.82	14
SL	4	21.9.81 to 30.12.81	14
		18.1.82 to 2.6.82	28
LL	4	29.9.81 to 2.6.82	28
LS	4	29.9.81 to 22.12.81	28
		11.1.82 to 11.6.82	14

In May 1981, four 600 x 600 mm plots (two NPa and two Pa) were located on 18 m diagonals in each experimental area (7.75 x 18 m) representing a grazing treatment. On 7.8.81, perennial ryegrass plants were transplanted into each plot in two rows of seven plants. Plant spacing within rows were 50 mm and between rows 300 mm to allow a border area between clipped and unclipped areas of the plots (see below). Each plant was labelled with a coloured ring (Section 4.4.2). Throughout the experiment (May 1981 to June 1982) the resident herbage on half of the plot area (300 x 600 mm) surrounding one row of introduced plants was kept trimmed to a five to 10 mm stubble. Thus only half of the introduced ryegrass plants in each plot were subjected to full interactions with above ground herbage (modified by grazing). In addition, from mid-December one of the Pa and NPa plots in each experimental area was irrigated at frequent intervals. A schedule of events for the experimental procedures used forms Table 6.1.

Table 6.1 Schedule of major events.

KEY:

■ Short grazing interval
SS&SL, 21.9.81-30.12.81
SS&LS, 11.1.82-11.6.82

□ Long grazing interval
LL&LS, 29.9.81-22.12.81
LL&SL, 18.1.82- 2.6.82

	Grazing		Herb.mass tiller no. and length		Plant dry wt.		Plant vigour		Botan. comp.		Light inter-ception		Soil analysis		Irrigation	
	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L
1981																
21 Sept.			■		■		■									
23	■															
24			■													
28				□		□		□								
29		□							■							
30				□												
5 Oct.			■		■		■									
6	■															
7			■							□						
19			■		■		■									
20	■		■													
26				□		□		□								
27		□		□												
29											■					
2 Nov.			■		■		■									
3	■		■													
4												□				
12											■					
16			■		■		■									
17	■		■													
23				□		□		□								
24		□							■							
26				□							■					
30			■		■		■									
1 Dec.	■		■							□						
4												□				
10													■	□		
11											■					
14			■		■		■									
15	■		■													
16															■	□
21				□		□		□								
22		□		□												
24											■				■	□
29			■		■		■					□				
30	■		■												■	□
1982																
8 Jan.											■					
11			■		■		■									
12	■		■													
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18				□		□		□								
19		□								□					■	□
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2 Feb.															■	□
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15				□		□		□								
16		□		□												
18															■	□
22			■		■		■									
23	■		■													
2 Mar.													■	□		
8			■		■		■									
9	■		■													
15				□		□		□								
16		□		□											■	□
17									■							
22			■		■		■									
23	■		■													
25										□					■	□
29													■	□		
5 Apr.			■		■		■									
6	■		■													
13				□		□		□								
14		□		□												
19			■		■		■									
20	■		■													
29															■	□
3 May			■		■		■									
4	■		■													
10				□		□		□								
11		□		□												
17			■		■		■									
19	■															
20			■													
21										□						
25													■	□		
27									■							
1 June				□		□		□								
2		□		□												
10			■		■		■									
11	■		■													

6.4 EXPERIMENTAL PROCEDURES AND TECHNIQUES

6.4.1 Pre-transplanting growth of ryegrass plants

Seeds of a commercial line of certified first generation *Lolium perenne* L. 'Grasslands Nui' perennial ryegrass were sown on 2.6.81 in alkathene tubes containing soil from the general experimental area (Section 2.2). Approximately 1000 seedlings were grown (Section 4.4.1) in a glasshouse except for a 'hardening off' period before transplanting into the experimental plots on 7.8.81. At 17, 30 and 50 days from planting the seedling shoots were trimmed to a height of 25 mm. Nutrient solution (Appendix 11) was applied 48 days after planting.

6.4.2 Measurements on individual ryegrass plants

Tiller counts and length measurements (Section 2.4.3.3) were made before and after each grazing on two plants marked with blue rings. One of these plants was located in the clipped (C) and the other in the unclipped (NC) area of each plot. One of the red-labelled ryegrass plants in each of the C and NC was cut to a 40 mm tiller length for the estimation of pre-grazing plant yield (Section 4.4.3). If a blue-labelled plant died or was removed from the pasture it was replaced by the red-labelled plant from the same row which had been exempt from cutting for the longest period. Measurements were then continued on the replacement plant. At the end of the experiment, yield measurements were made on all surviving blue-labelled plants as follows: shoot dry weight above 40 mm tiller length; shoot dry weight below 40 mm and above the stem apex (ground level), and below-ground organs (mainly roots) to a depth of 150 mm. A 48 mm diameter soil corer was used to harvest the below-ground organs. Four such cores were also taken at random from C and NC to assess the below-ground yield (rhizomes and roots) of paspalum. The latter cores were bulked on a treatment basis and after washing and dissection into components, all plant material from both species were dried in a forced draught oven for 36 hours at 100 °C.

Vigour of individual ryegrass plants were subjectively asessed before each grazing. Plot vigour was calculated as follows:

(i) average vigour - mean of the vigour scores of the seven plants with dead or missing plants given a vigour of zero and a frequency of one.

(ii) survival vigour - the mean vigour for the surviving ryegrass plants in each plot. When the seven plants had died or were missing survival vigour had no value and the frequency of the treatment mean was reduced by one.

The scale of the vigour grades ranged from one (low) to five (high).

6.4.3 Grazing management

The experimental areas were hard-grazed (Section 2.3) before the introduction of the ryegrass plants to the plots.

At each grazing, cow numbers were adjusted to achieve a residual herbage mass of 1500-1800 kg DM/ha over a four to five hour period. From six to 12 cows were used to graze each defoliation treatment area. However, in late spring (November/December) when the above residual level was not achieved, they were flail-cut to a 50-70 mm stubble using a Swift Current Forage Plot Harvester. This was repeated in mid-January for areas grazed in the LL and SL sequences. Pre-grazing herbage mass assessments on plots were adjusted for herbage removed by the mechanical harvester.

6.4.4 Sward measurements

6.4.4 1 Herbage mass

Assessment of pre- and post-grazing herbage mass was by a visual scoring technique described in Section 4.4.5.1, and except for the final pre-grazing assessment in June 1982 was restricted to unclipped plot areas. On each occasion, the calibration was based on 16 quadrat cuts (Section 2.4.3.1). The correlations between the mean visual grade and the herbage mass per quadrat form Appendix 10. All were significant ($P<0.01$, 14 degrees of freedom).

6.4.4.2 Botanical composition

The point quadrat method (Section 4.4.5.2) was used on five occasions during the experiment to determine plot botanical composition and percentage of total hits on bare ground. Separate measurements were made on C and NC areas. Thirty point quadrats were recorded in each area from three randomly located positions of the linear frame containing 10 points located 50 mm apart.

6.4.4.3 Light interception measurements

Measurements of the photosynthetically active radiation (400 to 700 nm) were made in C and NC areas using a 'LICOR' light meter with a 'Quantum' sensor (23.8 mm diameter) (Lambda Instrument Corp., Nebraska). Measurements were made at solar noon at the sward surface and at ground level, midway between the sward surface and at ground level midway between the lines of ryegrass plants and the confluence of the C and NC areas. They were confined to clear or overcast days without rapid cloud movement, so that interference from varying light conditions was minimised. To reduce any effect of varying post-grazing pasture height on light interception and reflection by the pasture, measurements were made after seven to 10 days regrowth.

6.4.5 Fertiliser policy

On 4.6.81 a maintenance dressing of 5.7 kg K, 3.4 kg P and 3.4 kg S and 6.0 kg Mg were applied to each 0.12 ha paddock.

6.4.6 Irrigation

Fifteen irrigations representing a total of 263 mm of water were applied between 16.12.81 and 29.4.82. For the first 12 irrigations water was applied when the estimated soil moisture deficit reached 15 to 21 mm. To avoid possible waterlogging in autumn, water deficits of about 31 mm were allowed to develop before applying sufficient water (irrigations 13 to 15) to reduce the deficit to 15 mm. The deficit was calculated by summing the difference between 0.76 of the daily open-pan evaporimeter measurement (McAneney & Judd, unpublished data) recorded at the Ruakura Climatological Station and the daily rainfall recorded at the trial site.

The plot plus a 50 mm border was irrigated (total area, 700 x 700 mm). Untreated bore water of high purity was applied using a watering can with a fan rose. Surface runoff was prevented by a metal frame with the dimensions of the irrigated area and a vertical height of 150 mm driven into the ground to a depth of 10 to 20 mm prior to each irrigation. The frame remained in place until any surface water had soaked into the ground.

6.5 SOIL TESTS

Effects of sequential irrigations on the soil nutrient status were examined on five occasions during the experiment. The first sample (10.12.81) was taken before the commencement of irrigation. A bulk sample of nine soil cores (25 mm diameter, 75 mm depth) were randomly sampled from each plot at each sampling with the constraint that the immediate environment of the introduced plants was not disturbed. Standard methods were used to test the soil samples for pH, available P, K, Mg, Ca (Cornforth 1980), NH_4^+ (Brown 1973), NO_3^- (Kamphake et al. 1967) and $SO_4^=$ (Sinclair & Enright 1982). Similar relationships between soil nutrient levels in irrigated and unirrigated plots were generally maintained throughout the experiment (Appendix 12).

6.6 STATISTICAL METHODS

Analysis of variance models were used to determine treatment effects using methods described previously. Examination of plots of residual variances against fitted values for the model indicated when transformation of the data was necessary to obtain errors that were normally distributed with constant variance. The relationship between residual variances and mid-summer (19.1.82) paspalum frequency (% of total hits) of the plots grazed at a SI and LI was also examined for each variable for any effect not already accounted for by the analysis of treatment data. A combined analysis of botanical composition data obtained on 19.1.82 from plots grazed at a SI and LI was possible, as botanical composition measurements for all plots were made on this day.

6.7 CLIMATIC DATA

Monthly averages over the study period (May 1981 to June 1982) and long term averages for selected variables are presented in Appendix 1.

Rainfall during the 1981/82 summer (December, January, February) was slightly below average. From 9.12.81 to 30.12.81 there was only 5.9 mm of rain; from 8.1.82 to 18.2.82 there was 5.0 mm and from 4.3.82 to 22.3.82 there was only 0.4 mm of rain. Water balance estimates (Appendix 3) suggest possible restrictions in pasture growth because of water shortages in January and February.

From the beginning of December until the end of March the daily screen maximum temperature reached 25 °C or greater on 36 days, including seven days (8.2.82 to 14.2.82) when the range was 24.8 to 29.7 °C with a mean of 26.6 °C.

6.8 RESULTS

6.8.1 Herbage accumulation

Grazing interval did not influence herbage accumulation (NC plot areas) during late-winter/early-spring (LW/ES) (Table 6.2). During spring it was greater for LI than SI. Because the 'crossover' of grazing interval treatments occurred seven days apart in January for SI (11.1.82) and LI (19.1.82), treatment comparisons in early- and late-summer are confounded by varying regrowth lengths. In early-summer, even though LI plots had 12 more days growth than SI plots, herbage accumulations were similar. During late-summer, however, SS and LS plots (39 days regrowth) accumulated twice as much herbage as SL and LL plots (26 days regrowth). The significant differences between treatments during late-summer (Table 6.2) were largely due to differences in length of regrowth, since growth rates (kg DM/ha/day) were not significantly different for SS (54.8) and LS (55.0) (means over three regrowth periods), and for SL (48.9) and LL (35.5) (SED = 6.92). For the regrowth period immediately following the January 'crossover' of grazing interval treatments, significant differences in pre-grazing herbage mass occurred. For SS, SL, LS and LL plots, respectively, they were 1980, 2600, 2800 and 3500 kg DM/ha.

The autumn herbage accumulation in LI plots since the 'crossover' was about sevenfold greater than that for SI plots. Of the 32 SI

Table 6.2 The effects of grazing interval, plot type (Pa, NPa) and irrigation (I) on seasonal herbage accumulation (kg DM/ha) in NC plot areas.

	Grazing interval[c]						Plot type				Irrigation[d]			
		S	L		SED	Sig.	Pa	NPa	SED	Sig.	+I	-I	SED	Sig.
Late-winter/early-spring (7.8-28.9.81)[a] (7.8-5.10.81)[b]		1621	1533		113.6	ns	1348	1805	85.7	***	-	-	-	-
Spring (30.9-23.11.81) (7.10-30.11.81)		2510	3213		140.6	**	2790	2932	106.7	ns	-	-	-	-
Early-summer (26.11.81-18.1.82) (1.12.81-11.1.82)		2459	2495		136.6	ns	2813	2137	134.3	***	2686	2268	134.3	**
	SS	SL	LS	LL										
Late-summer (20.1-15.2.82) (12.1-22.2.82)	2146	1273	2137	922	190.0	***	1806	1433	88.4	***	2023	1216	88.4	***
Autumn (16.2-11.5.82) (23.2-19.5.82)	307	2271	247	2485	204.4	***	1416	1238	157.6	ns	1426	1228	157.6	ns

[a] seasonal limits for plots grazed at long interval
[b] seasonal limits for plots grazed at short interval
[c] 'crossover' dates for grazing interval at end of early-summer
[d] first irrigation on 16.12.81, last irrigation on 29.4.82

plots, seven LS and six SS plots recorded negative growth rates during autumn (16.2.82 to 19.5.82) and of these plots, 10 were classified as NPa. There were no negative growth rates recorded for LL or SL plots, for regrowths from January to May.

During LW/ES herbage accumulation was greater in NPa than Pa plots being reversed during the summer (Table 6.2).

Irrigation substantially improved herbage accumulation over summer but had only a small effect on herbage accumulation in autumn (Table 6.2).

On average throughout the experiment, post-grazing herbage mass estimates for SS plots were about 300 kg DM/ha less than for LL plots (1600 vs 1900 kg DM/ha). Following the 'crossover', SL plots had on average similar post-grazing herbage mass to LS plots (about 1750 kg DM/ha). Thus residual herbage was least with a SS.

In June 1982, with a SI, herbage mass on NC exceeded that on C by about 1400 kg DM/ha (1786 vs 377, $P<0.001$). A much smaller margin (800 kg DM/ha) existed between these plot areas grazed at a LI (1734 vs 910, $P<0.001$).

6.8.2 Seasonal losses of ryegrass plants

Seasonal losses of ryegrass plants are categorised in Table 6.3. Total seasonal losses were highest in summer (75%), coinciding with the highest losses in all categories. Only one plant was lost from transplanting until the first pre-grazing measurement and less than 1% of total losses occurred in late-winter/early-spring. Over all treatments and seasons 'animal effects' (categories 1 to 4) accounted for 51% of ryegrass loss.

Of the 224 plants in each grazing treatment, the percentage surviving at the end of the experiment were SS, 36%; SL, 48%; LS, 35%;

LL, 46%. Overall, 42% of the 896 introduced ryegrass plants survived the study period (Table 6.3).

Ryegrass plants grazed at a short interval from January to May (SS, LS) had the highest losses associated with severe grazing (category 2) while those grazed at a long interval from September to January (LL, LS) had the highest losses associated with cow excreta (category 3). The SL treatment was distinguished by a very low incidence of category 3 losses (Table 6.3).

Continual removal by clipping of the herbage surrounding introduced ryegrass plants significantly reduced deaths in all seasons (Table 6.4). This effect was modified in late-summer by a significant interaction with grazing interval, largely due to the SS treatment which, relative to other treatments, had high losses with clipping but lower losses without clipping.

Before the 'crossover' (spring, early-summer), grazing interval did not affect ryegrass deaths. Late-summer deaths were highest for the LS treatment (36%), followed by the SS (26%), SL (19%) and the LL treatments. However, during the autumn total deaths were highest in the SS treatment (28% vs 16, 9 and 7 for the SL, LL and LS treatments respectively). This effect may be partly explained by a significant plot type x grazing interval interaction whereby deaths in Pa plots for the SS treatment were almost threefold above those in the SL treatment, which sustained the next highest number of deaths. Deaths were significantly higher in Pa plots than NPa plots during late-summer but no differences were detected during spring, early-summer and autumn. Irrigation throughout summer and autumn did not influence deaths.

Table 6.3 Number and season of loss of introduced ryegrass plants with short (SS=14 days), long (LL=28 days) and combinations of short and long (SL, LS) grazing intervals - 'crossover' January 1982.

Loss category[a]	SS					SL					LS					LL					TOTAL
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
Season																					
LW/ES[b] (6.8-30.9.81)	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-	-	-	4
Spring (30.9-25.11.81)	7	2	2	-	2	7	-	1	-	1	5	1	6	-	4	3	-	3	1	9	54
Summer (25.11.81-16.3.82)	11	30	12	-	41	10	11	1	-	64	3	24	32	-	61	3	16	43	-	30	392
Autumn (16.3-19.5.82)	6	11	3	-	15	1	3	-	1	16	-	1	-	-	6	1	2	1	-	7	74
TOTAL	25	43	17	-	58	18	14	2	1	81	8	26	38	-	72	9	18	47	1	46	524

[a] 1 - physical removal ('pulled') from the sward by the cow during grazing
2 - previous severe grazing (stubble height less than 10 mm)
3 - dung or urine - damage by cow excrement
4 - trampling - damage by hoof action of cow
5 - dead - no visible green herbage and no obvious animal or insect damage

[b] late-winter/early-spring

Table 6.4 The effects of plot type (Pa, NPa), clipping of surrounding herbage (C, NC), grazing interval (LI, SI) and irrigation (+I, -I) on spring, summer and autumn deaths of ryegrass plants.

	Spring (29.9.81-24.11.81)		Early-summer (26.11.81-18.1.82)		Late-summer (20.1.82-16.3.82)		Autumn (16.3.82-19.5.82)	
		Sig.		Sig.		Sig.		Sig.
Pa	9/432[a] (2)[b]	ns	74/387 (19)	ns	79/287 (28)	*	Plot type x grazing interval interaction (P<0.05) - *(ii) below*	
NPa	11/426 (3)		64/390 (16)		61/297 (21)			
+I	-		68/389 (18)	ns	61/291 (21)	ns	26/221 (12)	ns
-I	-		70/338 (18)		79/293 (27)		35/210 (17)	
C	2/440 (0.5)	***	16/414 (4)	***	Clipping x grazing interval interaction (P<0.05) - *(i) below*		30/316 (10)	***
NC	18/418 (4)		122/363 (34)				31/115 (27)	
LI	15/428 (4)	ns	65/370 (18)	ns				
SI	5/430 (1)		73/407 (18)					

(i) Late-summer (20.1.82-16.3.82)

	SS	SL	LS	LL	Totals
C	17/90 (19)	7/99 (7)	16/88 (18)	5/90 (6)	45/367(12)
NC	24/67 (36)	23/59 (39)	32/47 (68)	16/44 (36)	95/217(44)
Totals	41/157(26)	30/158(19)	48/135(36)	21/134(16)	

(ii) Autumn (16.3.82-19.5.82)

	SS	SL	LS	LL	Totals
Pa	21/53 (40)	9/64 (14)	2/39(5)	5/49(10)	37/205 (18)
NPa	11/60 (18)	12/64 (19)	4/47(9)	5/63 (8)	32/234 (14)
Totals	32/113(28)	21/128(16)	6/86(7)	10/112(9)	

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[a] data are ratios of numbers of deaths during the season over the number of survivors at the beginning of the season (random losses due to dung, urine and 'pulling' excluded)

[b] ratio as a percentage

6.8.3 Tiller production

Tiller numbers for ryegrass plants in C reached a higher peak in November/December 1981 with a LI (49) than with a SI (28) (Fig. 8). The superiority of the plants in C was maintained for the remainder of the experiment with tiller production falling over summer to a minimum in March and then increasing again during autumn. This tillering pattern was absent for ryegrass plants in NC as production did not exceed 9 tillers per plant until April 1982, after which a maximum of 15 tillers per plant was achieved at the end of the study by plants grazed at a SI (Fig. 8).

While tiller numbers for plants in C were significantly greater than in NC over the period 21.9.81 to 8.3.82, on 18.1.82 and 15.2.82 these effects were modifed by interactions with the irrigation treatment (see below). The 'crossover' of grazing interval treatments (January 1982) had no effect on tiller numbers per plant. Further statistical analyses of the effect of the clipping treatment on tiller production was not possible from 16.3.82 (LI) and 22.3.82 (SI) because of loss of data points through death of plants in NC.

With a LI, tiller production in Pa plots was not significantly different from in NPa plots. For example, mean tiller numbers per plant in Pa and NPa plots were 16.7 and 20.9, respectively, (LSR, 1.59) on 18.1.82 and 61.5 and 66.5 (LSR, 1.94) on 10.6.82. Similar effects were evident until January 1982 for plants grazed at a SI but thereafter tiller production for Pa plots was less than NPa, the differences reaching the 10% level of significance on 8.3.82. Significant differences were detected at all subsequent harvests. From 19.4.82 to 1.6.82 these effects were due mainly to tiller numbers in the LS treatment Pa plots increasing at a lesser rate than all other treatment combinations. Data for selected dates illustrating these effects form Table 6.5.

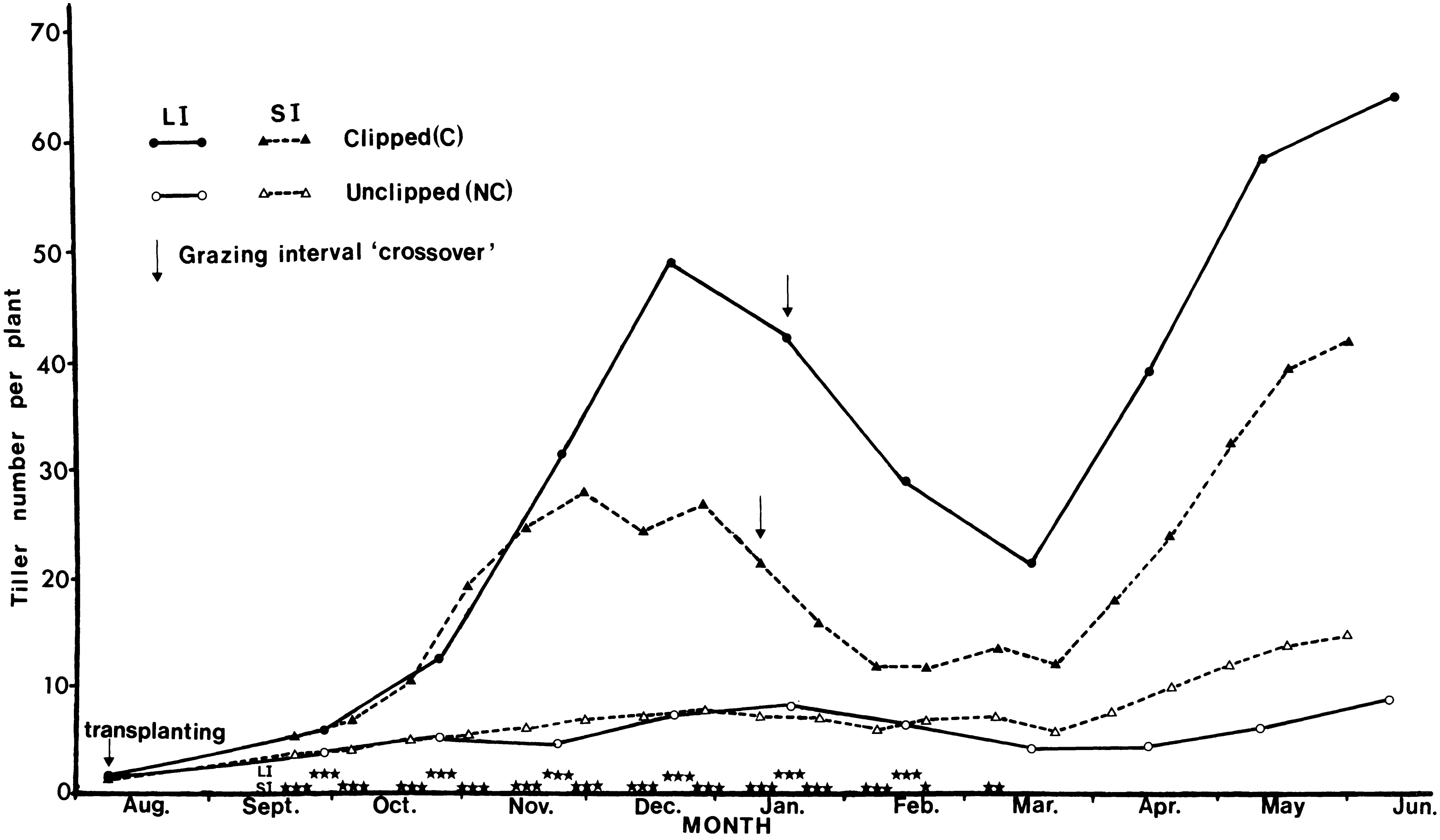


Fig. 8 Tiller numbers for ryegrass plants in clipped (C) and unclipped (NC) areas of plots defoliated at a short (SI) or long (LI) interval.

Table 6.5 The effect of plot type (Pa, NPa) on pre-grazing tiller number for ryegrass plants grazed at a SI (LS, SS) over summer/autumn.

Date		Plot type Pa	 NPa	LSR	Sig.
11.1.82		11.9	12.8	1.44	ns
8.2.82		8.5	8.5	1.50	ns
8.3.82[a]		8.2	11.6	1.46	(†)
5.4.82		13.3	23.8	1.74	*
3.5.82	LS	14.2	49.2	2.48[b]	*
	SS	36.8	41.5		
1.6.82	LS	20.1	56.2	1.99[b]	*
	SS	47.0	56.2		

[a] from 8.3.82 to 1.6.82 analyses restricted to data from C plot areas
[b] LSR for comparison of interaction means

For LI (LL, SL) over January/February, the superior tiller production in C compared to NC (Fig. 8) was due mainly to irrigation (Table 6.6). Subsequently, when analyses were restricted to C a similar response occurred in March but thereafter differences failed to reach significance. With a SI (LS, SS), there was a significant interaction on 8.2.82 between the irrigation and clipping treatments.

Table 6.6 The effect of irrigation on pre-grazing tiller number for ryegrass plants grazed at a LI (LL, SL) over summer/autumn.

Date		+I[a]	-I	LSR	Sig.
18.1.82	C	60.2	29.6	1.78[c]	(†)
	NC	8.5	8.1		
15.2.82	C	45.6	18.4	1.72[c]	**
	NC	6.5	6.5		
16.3.82[b]		36.7	13.0	2.01	**
13.4.82		58.8	25.9	2.30	(†)
10.5.82		76.7	44.3	2.26	ns
10.6.82		76.6	53.5	1.94	ns

[a] irrigations began on 16.12.81 and ceased on 29.4.82
[b] from 16.3.82 to 10.6.82 analyses restricted to data from C plot areas
[c] LSR for comparison of interaction means

Unirrigated plants in NC had significantly lower tiller numbers (4.1) than those receiving irrigation (8.4) and also irrigated (12.0) and unirrigated (12.6) plants in C. The LSR for comparison of interaction means was 1.72. At all other defoliations at a SI up to 19.4.82, irrigation had no significant effect on ryegrass tiller production. Thereafter there was a negative effect of irrigation for plants receiving the LS treatment. Averaged over the four measurements from 19.4.82 to 1.6.82, tillers per plant for the LS treatment in irrigated and unirrigated plots were 16.0 and 47.6, respectively, and comparable data for the SS treatment were 47.7 and 38.1 tillers per plot.

Table 6.7 The effects of clipping of surrounding herbage (C, NC) and irrigation (I) on pre-grazing tiller length (mm) of ryegrass plants.

	S[a]				L[b]				S				L			
Date	C	NC	SED	Sig.	C	NC	SED	Sig.	+I[c]	-I	SED	Sig.	+I	-I	SED	Sig.
21. 9.81	49.6	86.6	3.60	***												
28. 9.81					51.2	105.2	5.36	***								
5.10.81	52.9	79.1	3.42	***												
19.10.81	64.5	82.6	3.79	(†)												
26.10.81					103.3	161.4	7.69	***								
2.11.81	81.3	90.7	4.70	ns												
21.12.81					128.7	153.0	13.05	(†)					150.7	130.9	13.83	ns
11. 1.82	87.0	84.8	9.61	ns					93.0	88.8	9.35	ns				
18. 1.82					119.3	122.8	10.9	ns					132.7	109.4	19.36	ns
15. 2.82													107.2	75.1	16.11	(†)
8. 3.82[d]									79.3	78.8	6.30	ns				
15. 3.82													161.8	101.9	19.90	**
10. 5.82													134.9	102.9	15.74	(†)
11. 5.82									72.6	96.3	9.10	*				

[a] from 21.9.81 to 29.12.81 S is represented by a mean of SS and SL treatments; thereafter SS and LS treatments

[b] from 28.9.81 to 21.12.81 L is represented by a mean of LL and LS treatments; thereafter LL and SL treatments

[c] irrigations began on 16.12.81 and ceased on 29.4.82

[d] at this date and henceforth, analyses restricted to date obtained from C plot areas

6.8.4 **Tiller length**

Initially, pre-grazing tiller lengths were greater in NC than C although by late-December tiller lengths in both were similar (Table 6.7).

With a LI, irrigation increased tiller lengths (Table 6.7). With a SI, except for the measurement on 11.1.82, significant interactions between irrigation and clipping treatments occurred from 29.12.81 to 8.2.82 (Table 6.8). Unirrigated ryegrass plants in NC had shorter tillers than those receiving other treatment combinations. During March irrigation did not affect ryegrass tiller length but for measurements made on 5.4., 3.5. and 17.5.82, significant interactions between irrigation and grazing interval treatments were revealed by the analyses of data from C. These effects were due mainly to irrigated LS plants having shorter tillers than in all other treatment combinations. Mean tiller lengths over the three measurements for irrigated and unirrigated LS plants were 51.8 and 79.7 mm,

Table 6.8 The effect of the interaction of irrigation (I) and clipping treatments (C, NC) on ryegrass tiller length (mm) during summer for plants grazed at a short interval (SS, LS).

Date		C	NC	SED	Sig.
29.12.81	+I[a]	92.2	104.4	11.15	*
	-I	92.9	74.9		
25. 1.82	+I	68.5	74.8	8.83	(†)
	-I	73.1	53.5		
8. 2.82	+I	58.5	66.3	7.20	**
	-I	69.9	39.8		

[a] irrigations began on 16.12.81 and ceased 29.4.82

Table 6.9 The effects of plot type (Pa, NPa) and the 'crossover' of grazing interval treatments on pre-grazing tiller length (mm) of ryegrass plants.

Date	S[a]				L[a]											
	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.	LS	SS	SED	Sig.	LL	SL	SED	Sig.
21. 9.81	60.3	75.9	4.17	**												
28. 9.81					66.9	89.5	6.21	**								
5.10.81	61.1	70.9	5.97	ns												
26.10.81					122.6	142.1	12.06	ns								
2.11.81	76.4	95.5	9.94	(†)												
21.12.81					139.7	142.0	13.83	ns								
29.12.81	86.3	95.9	9.17	ns												
11. 1.82[c]	90.0	91.8	9.35	ns					105.6	76.2	8.44	**				
18. 1.82[c]					123.1	119.0	19.36	ns					147.8	94.2	17.84	*
25. 1.82	67.6	67.4	5.21	ns					74.7	60.3	6.40	(†)				
15. 2.82					85.7	96.6	16.11	ns					103.7	78.6	22.16	ns
8. 3.82[b]	78.0	80.1	6.30	ns					84.4	73.7	7.89	ns				
15. 3.82					122.3	141.4	19.90	ns					136.5	127.2	22.19	ns
5. 4.82	48.6	71.1	6.72	**					58.9	60.8	14.47	ns				
13. 4.82					105.4	144.4	17.45	*					132.4	117.4	16.47	ns
3. 5.82	63.1	81.6	7.41	*					70.2	74.5	12.64	ns				
17. 5.82	72.5	96.4	9.10	*					82.6	86.3	14.88	ns				

[a] see Table 6.7
[b] at this date and henceforth, analyses restricted to data obtained from C plot areas
[c] first measurements after 'crossover' of grazing interval

respectively; comparable data for the SS treatment were 76.7 and 62.5 mm.

Ryegrass plants changed from a long to a short grazing interval (LS) in January 1982 had longer tillers than those regularly grazed at a short interval (SS). In contrast, SL plants had shorter tillers than LL plants (Table 6.9). In both cases the effects were strongest at the first measurement after the 'crossover'.

Tiller lengths were generally greater for NPa than Pa, significantly so in spring and late-summer/autumn (Table 6.9).

Data in Table 6.10 indicates that plants in C were generally less severely grazed than those in NC.

Table 6.10 The effect of clipping surrounding herbage (C, NC) on post-grazing tiller length (mm) of ryegrass plants, and post-grazing tiller length as a percentage of pre-grazing tiller length.

	S[a]				L[b]			
Date	C	NC	SED	Sig.	C	NC	SED	Sig.
24. 9.81	49.6 (100)[c]	61.5 (71)	4.83	*				
30. 9.81					50.8 (99)	64.6 (61)	4.91	**
7.10.81	54.2 (103)	61.3 (78)	3.96	(†)				
20.10.81	64.6 (100)	55.3 (67)	5.44	(†)				
27.10.81					84.4 (82)	90.1 (56)	10.59	ns
3.11.81	65.7 (81)	50.8 (56)	5.14	**				

[a] data represented by mean of SS and SL treatments
[b] data represented by mean of LL and LS treatments
[c] percentage of pre-grazing tiller length

Post-grazing tiller lengths generally reflected the pre-grazing tiller lengths for SS, SL, LS and LL, Pa and NPa, +I and -I comparisons so these data are not presented.

6.8.5 **Plant dry weight**

Where plants had not reached the cutting height (40 mm from ground level) for yield assessments, as in some C in September and October, zero values were included in the analysis of variance.

The initial smaller size of C compared to NC plants prevailed until early-October (5.10.81) with a SI, and only for the first grazing (28.9.81) at a LI. Thereafter the effect was strongly reversed, as shown for selected dates in Table 6.11.

Irrigation generally increased plant dry weight except during the post-irrigation period with a SI when unirrigated plants outyielded irrigated plants (Table 6.11).

Where significant differences occurred in plant dry weight between Pa and NPa plots, those of the former were always the smaller (Table 6.12).

Dry weights were initially higher for LS relative to SS plants and LL relative to SL plants (Table 6.12). Dry weights at the end of the experiment for plants grazed at a LI over summer (LL, SL) were about sixfold higher (700 vs 120 mg) than those grazed at a SI (SS, LS).

6.8.6 **Plant vigour**

(a) *Survivors*: The vigour of surviving plants was always greater in C than in NC. Selected data (Table 6.13) illustrate this trend. The response to clipping at LI was larger in irrigated than unirrigated plots on 18.1.82 and 15.2.82.

Table 6.11 The effects of clipping of surrounding herbage (C, NC) and irrigation (I) on dry weight (mg) of ryegrass plants.

	S[a]				L[a]				S				L			
Date	C	NC	LSR	Sig.	C	NC	LSR	Sig.	+I[b]	-I	LSR	Sig.	+I	-I	LSR	Sig.
21. 9.81	7.6	13.4	1.62	*												
28. 9.81					6.6	22.4	1.68	***								
5.10.81	4.2	7.7	1.46	**												
19.10.81	13.7	13.7	1.57	ns												
26.10.81					58.3	25.9	1.50	***								
2.11.81	64.2	33.8	1.65	*												
14.12.81	153.2	39.2	1.43	***												
21.12.81					542.0	119.3	2.09	***					314.6	198.6	2.00	ns
29.12.81	129.2	41.3	1.67	***					99.6	53.6	1.74	*				
18. 1.82[c]					328.0	98.8	2.23	***					172.9	185.5	3.65	ns
25. 1.82[c]	87.3	19.5	2.19	**					46.0	36.9	2.96	ns				
22. 2.82									48.7	15.0	3.00	*				
15. 3.82													1359.4	163.2	2.86	***
5. 4.82									74.6	36.3	3.13	ns				
13. 4.82													418.7	210.0	2.77	ns
19. 4.82									73.1	88.4	2.82	ns				
17. 5.82									78.5	235.7	3.59	ns				
1. 6.82									57.0	200.9	2.48	*				
10. 6.82													1010.6	482.1	3.50	ns

[a] see Table 6.7

[b] irrigations began on 16.12.81 and ceased on 29.4.82

[c] analyses restricted to data from C plot areas subsequent to these dates

Table 6.12 The effects of plot type (Pa, NPa) and the 'crossover' of grazing interval treatments on dry weight (mg) of ryegrass plants.

	S[a]				L[a]				S				L			
Date	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.	SS	LS	SED	Sig.	SL	LL	SED	Sig.
21. 9.81	8.6	11.9	1.48	(†)												
28. 9.81					9.4	15.7	1.61	*								
5.10.81	4.9	6.7	1.51	ns												
26.10.81					42.3	36.1	1.57	ns								
2.11.81	41.8	52.1	1.75	ns												
21.12.81					181.5	344.3	2.00	(†)								
29.12.81	75.3	70.2	1.74	ns												
11. 1.82	46.5	72.1	2.36	ns					36.9	90.8	2.10	*				
18. 1.82[b]					169.5	191.1	3.05	ns					91.2	355.2	1.95	**
25. 1.82[b]	48.4	34.8	2.96	ns					35.8	47.4	1.80	ns				
15. 2.82					213.1	1368.7	3.72	*					208.8	1396.4	2.50	**
8. 3.82	56.5	79.4	2.51	ns					49.6	89.5	1.99	ns				
15. 3.82					300.3	746.1	2.86	(†)					315.7	702.6	2.76	ns
22. 3.82	23.1	58.6	2.90	(†)												
5. 4.82	28.3	95.8	3.13	*					59.9	45.2	5.34	ns				
13. 4.82					223.0	394.3	2.77	ns					367.6	241.5	1.80	ns
3. 5.82	39.6	200.1	3.68	*												
17. 5.82	76.1	240.5	3.59	(†)												
1. 6.82	61.7	185.5	2.48	*												
10. 6.82					657.4	733.8	3.50	ns								

[a] see Table 6.7

[b] analyses restricted to data from C plot areas subsequent to these dates

Table 6.13 The effect of clipping of surrounding herbage (C, NC) on the vigour of surviving ryegrass plants.

	S[a]						L[a]			
Date	C	NC	SED	Sig.	Date		C	NC	SED	Sig.
21. 9.81	2.1	1.8	0.07	***						
					28.9.81		2.3	1.7	0.09	***
5.10.81	2.4	1.5	0.07	***						
					26.10.81		2.7	1.4	0.10	***
2.11.81	2.9	1.9	0.11	***						
30.11.81	2.8	2.0	0.19	***						
					21.12.81		3.3	1.8	0.19	***
11. 1.82	3.0	1.5	0.12	***						
					18.1.82	+I	3.4	1.6	0.16[b]	**
						-I	3.0	1.8		
					15.2.82[c]	+I	3.2	1.6	0.17[b]	***
						-I	2.2	1.5		
22. 2.82	2.4	1.5	0.13	***						
8. 3.82[c]	2.3	1.5	0.13	***						

[a] see Table 6.7

[b] standard error of the difference within irrigation (I) means, for the clipping x irrigation interaction

[c] analyses restricted to data from C plot areas subsequent to these dates

During February, March and April irrigation significantly improved the vigour of LI plants. Expressed as means over the three measurements, the vigours of irrigated and unirrigated plants were 2.9 and 2.3, respectively. With a SI, irrigation had no effect on vigour until 5.4.82 and thereafter until 17.5.82 when a significant interaction with grazing interval occurred. With the LS treatment there was a negative vigour response to irrigation but with the SS treatment there was a positive response. As means over the four measurements, vigours of irrigated and unirrigated plants for the LS treatment were 2.7 and 3.2, respectively; comparable data for the SS treatment were vigours of 3.1 and 2.5, respectively.

Plot type had no effect on plant vigour until March. Thereafter the vigour of ryegrass plants in Pa plots were significantly less than for those in NPa plots (Table 6.14).

Table 6.14 The effect of plot type (Pa, NPa) on the vigour[a] of surviving ryegrass plants over late-summer/autumn.

	S[b]				L[c]			
Date	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.
15.3.82					2.4	2.8	0.25	ns
22.3.82	1.9	2.4	0.25	*				
5.4.82	2.2	2.9	0.22	**				
13.4.82					2.7	3.4	0.26	*
19.4.82	2.5	3.1	0.28	*				
3.5.82	2.8	3.5	0.26	*				
10.5.82					3.0	3.5	0.19	*
17.5.82	2.6	3.3	0.28	*				

[a] analysis restricted to C plot areas
[b] S is represented by a mean of SS and LS treatments
[c] L is represented by a mean of LL and SL treatments

There was no effect of previous management on the vigour of SS and SL plants subsequent to the 'crossover'. For the two measurements immediately following the 'crossover' LL and SL differed significantly ($P<0.05$). On 18.1.82, vigours were 2.7 and 2.2 for LL and SL treatments, respectively, (SED = 0.18) and on 15.2.82 comparable data were 2.3 and 1.9 (SED = 0.15).

(b) *Average vigour*: This measurement was affected by losses of ryegrass plants and therefore declined with time.

Highly significant differences in vigour for plants in C and NC were found. As these effects were similar to those for survivor vigour the data are not presented.

Average vigour was slightly greater in LI than SI plots but during summer/autumn it was reduced in Pa plots compared to NPa plots (Table 6.15).

Table 6.15 The effect of plot type (Pa, NPa) on the average vigour of ryegrass plants during summer/autumn.

	S[a]				L[a]			
Date	Pa	NPa	SED	Sig.	Pa	NPa	SED	Sig.
18.1.82					1.7	1.7	0.13	(†)
25.1.82	1.4	1.4	0.17	ns				
15.2.82					1.3	1.6	0.10	**
22.2.82	1.0	1.1	0.17	ns				
15.3.82					1.1	1.5	0.12	**
22.3.82	0.7	1.0	0.14	*				
13.4.82					1.2	1.5	0.14	(†)
19.4.82	0.8	1.1	0.19	ns				
10.5.82					1.3	1.6	0.15	(†)
17.5.82	0.8	1.2	0.19	*				

[a] see Table 6.14

Irrigation had no affect on average vigour of SI plants and so the data are not presented. With a LI, however, summer/autumn average vigour was improved by irrigation, especially in C in February and March (Table 6.16).

Table 6.16 The effect of irrigation (I) on the average vigour of ryegrass plants grazed at a LI (LL, SL) over summer/autumn.

Date		+I	-I	SED	Sig.
18.1.82		2.0	1.7	0.13	*
15.2.82	C	2.8	1.8	0.18[a]	**
	NC	0.6	0.6		
15.3.82	C	2.5	1.8	0.20[a]	***
	NC	0.5	0.5		
13.4.82		1.4	1.2	0.14	(†)
10.5.82		1.5	1.3	0.15	ns

[a] standard error of difference between means for the interaction of clipping (C, NC) and irrigation treatments

6.8.7 Plant component yields at termination of the experiment (June 1982)

As 24 of the 64 NC had no ryegrass survivors, the analyses of grazing interval, plot type and irrigation effects were restricted to data from C. Nevertheless, as only seven of the 24 plots with no ryegrass survivors were NPa plots, an analysis restricted to data from these plots was used to obtain an estimate of the effect of the clipping treatment on the component yields of the introduced ryegrass plants.

Total and component yields of ryegrass plants were substantially greater in C than in NC (Table 6.17). The average total weight of ryegrass plants in the former was sevenfold greater than in the

Table 6.17 The effects of grazing interval (SS, LS, SL, LL)[a], plot type (Pa, NPa)[a], irrigation (I)[a] and clipping of surrounding herbage (C, NC)[b] on the component yields (mg) of ryegrass and paspalum plants in June 1982.

	SS	LS	SL	LL	SED	Sig.	Pa	NPa	SED	Sig.	+I	-I	SED	Sig.	C	NC	SED	Sig.
(a) Ryegrass																		
Shoot (>40 mm tiller length)	130	85	570	827	190.7	**	359	447	194.8	ns	527	279	194.8	ns	447	41	98.4	***
Shoot (<40 mm and above ground level)	512	409	1008	1134	168.7	**	613	918	211.8	ns	925	606	211.8	ns	918	84	147.1	***
Root[c]	248	182	390	505	58.7	**	298	365	78.3	ns	399	263	78.3	(†)	365	116	40.6	***
Totals	890	676	1968	2466	367.5	**	1270	1730	466.7	ns	1851	1148	466.7	ns	1730	241	264.9	***
(b) Paspalum																		
Rhizomes[d]	1696	1717	1061	1392	260.9	(†)	2691	242	174.3	***	1492	1441	174.3	ns	1528	1405	159.9	ns
Roots[d]	1339	1251	1111	1219	170.4	ns	1481	999	106.1	***	1184	1276	106.1	ns	898	1562	82.9	***
Totals	3035	2968	2172	2611	276.8	*	4152	1241	230.5	***	2676	2717	230.5	ns	2426	2967	212.8	*

[a] data from C plot areas only
[b] data from NP plots only
[c] yield in a 48 mm diameter soil core to a depth of 150 mm
[d] yield in four 48 mm diameter soil cores to a depth of 150 mm

latter. Plots grazed at a SI over summer (LS, SS treatments) were disadvantaged relative to those grazed at a LI (LL, SL treatments). The average total weight of plants receiving the latter treatments was 280% greater than for those receiving the former. Although total and component yields of ryegrass plants were lower in Pa than in NPa plots and in unirrigated compared to irrigated plots, all differences failed to reach significance at the 5% level (Table 6.17).

As expected, the rhizome and root yields of paspalum were higher in Pa than in NPa plots (Table 6.17). Assuming homogeneity of paspalum density within each Pa plot before imposition of the clipping treatment, the data indicate that this treatment severely reduced root growth. Even though C contained slightly more rhizome than did NC, total below-ground yield of paspalum was reduced by clipping. There was a tendency for plots receiving the SL treatments to contain less paspalum rhizome than other grazing treatments. This difference was reflected in a lower total below-ground yield for SL plots than for those grazed at a SI over summer/autumn (SS, LS) (Table 6.17).

6.8.8 The effect of clipping on light interception

On average, over the 11 occasions when light readings were made (29.11.81 to 3.2.82), 96% of above-sward photosynthetically active radiation reached the base of clipped swards, while 66% reached the base of unclipped swards. No other treatments influenced these results.

6.8.9 Botanical composition

Grazing interval and irrigation treatments did not influence plot botanical composition.

Pa plots contained less ryegrass than did NPa plots and C usually contained less ryegrass than NC (Table 6.18). However, in January, March and May significant interactions between these treatments were apparent with NC areas in NPa plots having higher ryegrass frequencies than C. There were no differences in the ryegrass frequencies in C and NC areas of P plots, but NC contained the lower ryegrass frequency.

As expected, Pa plots contained more paspalum than NP plots during summer (Table 6.19). C contained more paspalum than NC although the effect only reached significance with a LI.

In September and October, Pa plots contained more *Poa* spp. than did NP plots but the effect had disappeared by November/December as paspalum began its growth (Table 6.20). C also maintained a high *Poa* frequency than did NC and this effect was still evident in May for plots grazed at a SI.

Throughout the experiment, NPa plots contained more white clover than did Pa plots (Table 6.21), and over summer/autumn (January to May), clipping reduced the white clover frequency in the plots.

The frequency of litter was not affected by plot type but from March to May there was more litter in C than NC (24 vs 15%, $P<0.001$), regardless of grazing interval. Litter frequency was highest in all treatments from March to May.

Bare ground was more prevalent in NPa than Pa plots (Table 6.22). There was also more bare ground in C than NC and differences between treatments increased throughout summer/autumn, although there was usually about twice as much bare ground in C and NC NPa areas than in Pa areas.

Summer grasses (mainly *Digitaria sanguinalis* and *Panicum dicotomiflorum*) were present in some plots from January until March.

Table 6.18 The effects of plot type (Pa, NPa) and clipping (C, NC) of plot areas on the frequency (% of total hits) of ryegrass.

	S[a]					S				L[a]				L			
Date	Pa	NPa	SED	Sig.		C	NC	SED	Sig.	Pa	NPa	SED	Sig.	C	NC	SED	Sig.
29. 9.81	29.5	44.0	3.40	***		32.6	40.8	2.84	**								
7.10.81										24.1	36.9	3.47	**	22.2	38.8	3.19	***
24.11.81	20.8	38.1	3.40	***		26.6	32.3	2.67	*								
1.12.81										19.1	30.1	3.62	**	23.4	25.8	2.76	**
19. 1.82					Pa	11.3	11.3	2.12[b]	***	14.0	29.7	3.20	**	17.9	25.8	2.89	*
					NPa	20.5	32.3										
17. 3.82					Pa	11.2	8.2	3.33[b]	*								
					NPa	18.9	25.9										
25. 3.82										12.1	36.2	3.73	***	22.3	26.0	4.02	ns
21. 5.82										30.5	45.5	4.12	**	40.7	35.3	3.70	ns
27. 5.82					Pa	23.2	21.2	4.66[b]	*								
					NPa	37.7	51.5										

[a] see Table 6.7

[b] standard error of mean differences within plot type treatments

Table 6.19 The effects of plot type (Pa, NPa) and clipping (C, NC) of plot areas on the frequency (% of total hits) of paspalum.

	S[a]				S				L[a]				L			
Date	Pa	NPa	SED	Sig.	C	NC	SED	Sig.	Pa	NPa	SED	Sig.	C	NC	SED	Sig.
29. 9.81[b]	-	-	-	-	11.2	8.8	1.45	ns								
7.10.81[b]									-	-	-	-	14.3	7.5	1.15	***
24.11.81[b]	-	-	-	-	16.4	14.4	3.34	ns								
1.12.81[b]									-	-	-	-	27.6	19.7	3.48	*
19. 1.82	52.0	13.3	3.42	***	33.9	31.4	3.00	ns	48.7	9.4	3.42	***	35.7	22.4	3.00	***
17. 3.82	51.9	11.7	3.65	***	32.5	31.2	3.71	ns								
25. 3.82									51.9	7.1	3.51	***	31.2	27.9	3.08	ns
21. 5.82									34.1	5.7	3.26	***	22.9	16.9	2.81	**
27. 5.82	35.5	7.6	3.01	***	23.3	19.8	2.24	ns								

[a] see Table 6.7

[b] insufficient hits in NP plots for valid statistical analyses of plot type effect

Table 6.20 The effects of plot type (Pa, NPa) and clipping (C, NC) of plot areas on the frequency (% of total hits) of *Poa* spp.

	S				S				L				L			
Date	Pa	NPa	SED	Sig.	C	NC	SED	Sig.	Pa	NPa	SED	Sig.	C	NC	SED	Sig.
29. 9.81	25.5	19.8	2.71	*	25.7	19.6	2.47	*								
7.10.81									32.7	23.1	3.99	*	33.4	22.4	2.60	***
24.11.81	11.4	11.4	2.87	ns	12.5	10.3	1.56	ns								
1.12.81									5.4	5.7	1.62	ns	8.7	2.4	1.37	***
19. 1.82[b]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17. 3.82[b]	-	-	-	-	-	-	-	-								
25. 3.82[b]									-	-	-	-	-	-	-	-
21. 5.82[b]									-	-	-	-	-	-	-	-
27. 5.82	11.0	9.3	2.36	ns	12.7	7.7	2.02	*								

[a] see Table 6.7

[b] *Poa* spp. absent from most plots

Table 6.21 The effects of plot type (Pa, NPa) and clipping (C, NC) of plot areas on the frequency (% of total hits) of white clover.

	S[a]				S				L[a]				L			
Date	Pa	NPa	SED	Sig.	C	NC	SED	Sig.	Pa	NPa	SED	Sig.	C	NC	SED	Sig.
29. 9.81	23.5	25.1	2.11	ns	23.2	25.3	2.11	ns								
7.10.81									20.8	27.7	2.37	**	25.7	22.8	2.17	ns
24.11.81	23.2	33.6	2.68	***	27.3	29.6	2.80	ns								
1.12.81									25.1	31.4	3.03	*	23.7	32.8	2.28	***
19. 1.82	17.0	34.5	2.88	***	21.3	30.1	2.27	***	13.9	25.3	2.88	***	15.9	23.2	2.27	**
17. 3.82	8.7	14.1	1.72	**	7.8	15.0	1.65	***								
25. 3.82									8.5	19.8	1.97	***	8.6	19.7	2.12	***
21. 5.82									12.2	20.8	2.36	**	7.1	26.0	1.99	***
27. 5.82	12.2	21.8	2.77	***	9.5	24.5	2.66	***								

[a] see Table 6.7

Table 6.22 The effects of plot type (Pa, NPa) and clipping (C, NC) of plot areas on the frequency (% of total hits) of bare ground.

	S[a]					S				L[a]					L			
Date	Pa	NPa	SED	Sig.		C	NC	SED	Sig.	Pa	NPa	SED	Sig.		C	NC	SED	Sig.
29. 9.81	8.0	11.6	1.58	*		16.0	3.5	1.83	***									
7.10.81										5.4	7.8	1.48	ns		11.0	2.2	1.41	***
24.11.81	7.0	8.0	1.24	ns		11.1	3.9	1.23	***									
1.12.81										5.5	7.2	1.57	ns		8.3	4.4	1.51	*
19. 1.82	4.0	10.4	1.56	**		11.4	3.0	1.73	**	9.2	13.6	1.56	*		17.3	5.4	1.73	***
17. 3.82					Pa	12.5	3.5	3.52^b	*									
					NPa	27.9	2.7											
25. 3.82														Pa	20.0	4.0	3.01^b	**
														NPa	39.4	8.1		
24. 5.82														Pa	27.1	6.9	3.18^b	**
														NPa	40.2	7.1		
27. 5.82					Pa	24.4	4.8	3.64^b	***									
					NPa	45.6	8.3											

[a] see Table 6.7
[b] standard error of mean difference within clipping treatments

The mean frequency of summer grasses over all plots during this period was 8.7% (range 0 to 58%). The greatest infestation occurred in March for NPa plots grazed at a SI (SS, LS treatments) over summer. Seventeen percent of plots receiving these treatments had greater than 20% of total hits on summer grasses and three such plots in excess of 50% of hits on these species. The overall frequency of weeds in the plots throughout the study was low (3.6%).

In summary, throughout the experiment NPa plots contained more ryegrass than did Pa plots, especially in NC over summer. There was also more white clover in NPa than Pa plots from late-spring (October) to autumn, and in NC than C. The reduced frequencies of ryegrass and white clover in Pa plots were largely compensated by greater frequencies of *Poa* in spring (September/October) and paspalum in summer/autumn, compared to NPa plots. This compensation also occurred to a lesser extent in C but over the whole experimental period and especially in NPa plots in summer, C had more bare ground than did NC.

6.9 DISCUSSION

The highest proportion (75%) of the total losses of ryegrass plants occurred during the summer following their introduction to the sward (Table 6.3). This confirms the results of previous experiments (chapter 2, 4). The present experiment also confirmed (chapter 4) that a SI (SS, LS) over summer/autumn was associated with higher total losses (64% for each treatment) than was a LI (LL, 54%; SL, 52%). The grazing interval used during late-winter/spring did not alter this trend as total losses were relatively small over this period (Table 6.3).

In contrast to the results of the previous experiments (chapter 4), total ryegrass losses associated with 'animal effects' were equivalent to total losses due to unexplained effects (category 5). In the present experiment there were higher total losses associated with severe grazing and cow excreta, the former being a summer/autumn effect with a SI, and the latter a spring/early-summer effect with a LI (Section 6.8.2). These results may reflect to some extent, differences in stocking densities (Hodgson 1979). Smaller areas were grazed in the present experiment with an average stocking density of 660 cows per hectare (range 430-1075) compared to 600 cows per hectare (range 400-800) in Experiment 2 (chapter 4). The highest stocking densities were used on the areas grazed at a LI since these had the highest pre-grazing herbage yields, which allowed greater opportunity for plant damage from cow excreta. As the milk yields of the cows were often being measured in other experimental programmes, it was not possible to regulate their intakes to minimise defecations on the trial areas.

The effects of grazing interval on measured plant and plot parameters were confounded by variations in the severity of grazing. Residual herbage (Hodgson 1979) (Section 6.8.1) and ryegrass tiller lengths (Table 6.9) on plots grazed at a short interval were less than at a long grazing interval. The summer grazings at a SI relative to a LI were associated with increased plant losses, which agrees with the findings of Brougham (1960, 1961).

As the highest late-summer losses of ryegrass plants in C (where above-ground competition was severely reduced) were in plots receiving the SS and LS treatments, similar findings were expected for NC where the competitive environment was modifed only by periodic grazings. However, this was only true for the latter treatment (Table 6.4). The reason for this inconsistency is not clear but losses subsequent to severe grazing were similar (30 vs 24) for the SS and LS treatments. Other losses (category 5) were higher (41 vs 61) for the latter treatment (Table 6.3), suggesting the possibility that the 'crossover' from a long to a short grazing interval over summer was more stressful to the ryegrass plants than was regular grazing at a short interval. In addition, root, shoot and consequently total plant dry weight at the end of the study for ryegrass plants receiving the SS and LS treatments were substantially less than for those receiving the SL and LL treatments (Table 6.17). This result emphasises the importance of grazing interval as a determinant of ryegrass performance during summer/autumn, as it was obtained for plants grown in an artificially reduced competitive environment (C areas). The ryegrass plants subjected to frequent grazing over summer suffered most damage and deaths, especially if this was preceded by less frequent defoliations.

In this experiment, treatment differences in size and vigour (eg. Table 6.5, 6.12, 6.14) did not occur until autumn when death rates of introduced ryegrass plants had slowed from a high level in summer. Treatment differences therefore did not occur when death rates were at their highest. This lack of coincidence may be a consequence of the measurement procedure. When a blue-labelled plant died or had been removed from the plot areas the measurements were made on a plant randomly selected from the survivors in the same area (C or NC). As the population of introduced plants declined with time, selections of replacements were made from a population biased towards the most vigorous plants. Measurements on replacement plants did not represent the true effect of each treatment on ryegrass growth, since measurements on blue-labelled plants dying during the previous regrowth period were obviously excluded.

A better alternative may have been to measure ryegrass growth characteristics on a per unit area or plot basis. This procedure would have entailed making measurements on all survivors (assuming the measurement to be zero for dead or missing plants) and dividing the total for a particular parameter, by the number of ryegrass plants introduced into the plot. The assessment of treatment effects on ryegrass growth may have been improved still further if measurements had been made more regularly, that is, once or twice during each regrowth as well as pre- and post-grazing, especially during summer when death rates were high. However, these alternatives demanded increased labour inputs which was the overriding factor against their implementation.

Generally, for ryegrass plants experiencing a change in grazing interval (first measured in January), the effect of the previous management on pre-grazing tiller length (Table 6.9), plant dry weight (Table 6.12) and vigour (Section 6.8.6a), and pre-grazing herbage mass (Section 6.8.1) was shortlived. There were large differences between treatments (SS vs LS and LL vs SL) for the above parameters at the 'crossover' date but since the LS and LL treatments had eight days more growth before this measurement than did the SS and SL treatments, these differences have been overestimated.

Herbage accumulation in autumn on plots grazed at a SI over summer/autumn was severely reduced compared to those grazed at a LI (Table 6.2). Most reviewers agree (Hedrick 1958; Jameson 1963; Harris 1978) that the more frequent and intense the defoliation of the pasture the greater the reduction in herbage yield. A high proportion (63%) of the NPa plots grazed at a SI over summer/autumn, compared to 19% of the Pa plots lost dry matter (Section 6.8.1) for at least one regrowth period during autumn, when litter frequencies in the plots were highest (Section 6.8.9). This suggests the plants occupying the former plots were less able to maintain growth during autumn. NPa plots were dominated by ryegrass during summer/autumn (Table 6.18, 6.19, 6.21), although by May (Table 6.22) bare ground had a large influence on the botanical composition of C.

In C introduced ryegrass plants markedly increased their size (tiller numbers and dry weights) (Fig. 8, Table 6.11), vigour (Table 6.13) and survival in all seasons (Table 6.4) relative to those growing in NC. These changes reflect the increased competitive ability of the ryegrass plants introduced into a less competitive environment and consequently their enhanced ability to survive managerial and environmental stresses.

Evidence that the clipping treatment profoundly altered the above-ground competitive environment was that it allowed for the penetration on average of a further 30% of photosynthetically active radiation to the base of the sward in comparison with the swards in NC. It is considered that this factor was important in determining the rapid spring (October/November) tillering responses (Fig. 8) and subsequent superior growth (Table 6.11) of ryegrass plants in C, since there have been many reports in the literature (eg. Mitchell 1953a,b; Donald 1958; Spiertz & Ellen 1972; Hunt & Halligan 1981) that tiller production in ryegrass is favoured by a high light intensity.

It should be noted, however, that the growth habit of the introduced ryegrass plants in C was initially more prostrate than those in NC (Table 6.7), as competition for light from the surrounding species in the latter caused upward growth of their tillers, a phenomenon also noted by Norman (1960). Consequently, ryegrass plants in C were only slightly grazed during September/October (Table 6.7, 6.10) and any stress subsequent to substantial defoliation (eg. removal of excessive photosynthetic leaf area, restricted root growth) (Weaver 1930; Brouwer 1966; Evans 1971; Ennik et al. 1980) had a delayed effect in comparison to ryegrass plants in NC. This probably assisted ryegrass plants in C to reach a large average size by mid-November (25 to 30 tillers, Fig. 9) and with dry weights (above a 40 mm stubble) of more than twice those of ryegrass plants in NC (Table 6.11) before the commencement of summer. By the end of the study, even larger differences in above- and below-ground yields of surviving ryegrass plants were measured (Table 6.17). Ryegrass plants relieved of excessive competition were able to maintain a relatively large size throughout summer/autumn, despite regular grazings and other periodic environmental stresses (eg. high temperatures, Section 6.7), a condition that was associated with much reduced losses (Table 6.4). This result supports the hypothesis of Hoen (1968).

It is recognised that the clipping technique used in this experiment did not separate the effects of interspecific shoot and root competition, nor did it allow for interactions between the shoots and roots of the individual introduced ryegrass plants. However, an indirect indication of the possible importance of these factors in determining the observed effects of the clipping treatment was provided by an assessment of changes in the botanical composition of C.

Despite increasing the growth of introduced ryegrass plants, clipping reduced the overall ryegrass and white clover frequencies (Table 6.18, 6.21) and on occasions these changes were greater in NPa than Pa plots (Table 6.18) as the former usually contained more of these species. On the other hand, C generally contained more paspalum and *Poa* spp. than did NC (Table 6.19, 6.20). Thus the clipping treatment reduced the frequency of the main competitors (ryegrass and white clover) for the ryegrass plants introduced into NPa plots, while increasing the frequency of the main competitors (paspalum and *Poa* spp.) for the ryegrass plants introduced into Pa plots. Nevertheless, their above-ground competitive ability was curtailed by the maintenance of a 10 mm stubble by clipping. These changes in the botanical composition of clipped NPa and Pa areas were reflected in the development of a higher proportion of the total points striking bare ground in the former compared to the latter (Table 6.22). Despite the development by March of substantial bare ground in clipped NPa areas (Table 6.22) there were also niches available in some of these areas to support considerable growth (frequencies of >20%) of annual summer grasses, particularly when grazed at a SI (Section 6.8.9). This also suggests a high loss of resident perennial species (ryegrass and white clover) with the clipping treatment and by implication, less competition for the introduced ryegrass plants. Herbage mass estimates obtained at the end of the study (June) provide further evidence of the severity of the clipping treatment on the growth of the resident species. On average, C yielded only 21 and 52% of the estimated dry matter of NC when grazed at a short or a long interval, respectively (Section 6.8.1).

Even though clipping increased the frequency of paspalum in the Pa plots (presumably via an increased rhizome contribution providing more sites for shoot growth, Table 6.17), its root biomass was reduced by this treatment, as has earlier been reported by Lovvorn (1945). Frequent severe defoliations reduced functional leaf area and therefore carbohydrate supplies to roots, causing less elongation and increased root death (Davidson & Milthorpe 1966; Evans 1971). Consequently, the overall influence of paspalum on the survival of the introduced ryegrass plants may have been reduced as only small differences in losses of these plants from Pa and NPa plots occurred during late-summer and autumn. However, in combination with the extra stress of a short grazing interval (SS), autumn losses of introduced ryegrass plants were higher than in any other treatment (Table 6.4).

The larger differences between Pa and NPa treatments from February/March until June for tiller length (Table 6.9), plant dry weight (Table 6.12) and vigour (Table 6.14) (after restriction of the analyses to data from C) presumably reflects the greater influence of root and/or rhizome competition with paspalum than with other species on ryegrass growth, or possibly the negative effect of an allelopathic secretion (Tukey 1969; Remison & Snaydon 1978) from paspalum's underground organs.

Even though irrigation eliminated water shortage as a factor restricting pasture growth during summer/autumn (Appendix 3), this treatment only slightly improved the survival of the introduced ryegrass plants (Table 6.4). The positive effects of irrigation on tiller numbers per plant (Table 6.6), tiller length (Table 6.7), plant dry weight (Table 6.11), survival vigour (Section 6.8.6a) and average vigour (Table 6.16) were generally restricted to plants grazed at a LI rather than a SI, and these effects were sometimes highlighted for plants growing in C (Table 6.6, 6.13, 6.16). For ryegrass plants in C and receiving the LS treatment, irrigation seemed to reduce tiller numbers per plant and pre-grazing tiller lengths in autumn, with a carryover effect into the post-irrigation period. During May/June there was also a negative response to irrigation for the dry weight of plants grazed at a SI (Table 6.11). Irrigated plants receiving the LS treatment had a lower dry weight than plants receiving other treatment combinations, but the interaction of irrigation and grazing interval treatments did not reach significance. No explanation can be found for these effects.

Generally variable tillering responses to irrigation have been reported (Garwood 1969; Hebblethwaite 1977) but often management and seasonal differences influence the validity of such comparisons. However, field (Korte & Chu 1983) and pot (Owen 1977) experiments suggest that as moisture levels fall with increasing length of dry spells, tiller number and weight and therefore the size of ryegrass plants were reduced. The present results generally agree with these findings. It is suggested that the positive effects of irrigation with a LI and the negative effects with a SI tended to negate any overall effect of irrigation on ryegrass plant component yields (Table 6.17) and persistence (Table 6.4). Resident species and introduced ryegrass responded similarly to irrigation so that the latter did not gain any advantage from the treatment.

The botanical composition of the plots were not influenced by the irrigation treatment, nor were there any substantial changes in the nutrient status of the soil in irrigated and unirrigated plots (Appendix 12). These results are in agreement with those of Hutton (1978), which were obtained from the same experimental area, except that he reported an increase in available magnesium in soil irrigated over a four year period, but gave no explanation for this result.

During summer (November to February) the herbage accumulated on unirrigated plots was only 0.74 of the irrigated production. This represented a yield response to irrigation of 35% (Table 6.2). McAneney et al. (1982) reported a similar ratio (0.73) for herbage accumulation on unirrigated relative to irrigated plots over four years (November to April), on a Horotiu sandy loam soil of similar origins to those at the present experimental site. Hutton (1978) also reported an average yield response to irrigation over three successive seasons (October to March) of 15% (expressed as kg DM/ha/day) for the pastures used in the present experiment.

6.10 CONCLUSIONS

To obtain an improvement in the persistence of perennial ryegrass plants on their introduction into established pasture, it was necessary to control the growth of the surrounding resident species by severe clipping over a prolonged period. This result suggests that the immediate elimination of competition for light between the establishing ryegrass plants and the established species is an important factor in achieving the desired persistence. Reduced competition for light enabled a much higher proportion of the ryegrass plants to attain a competitive ability (expressed as larger plants) more conducive to surviving the managerial and environmental stresses encountered. The largest plants were obtained under conditions of the least stress, namely, long grazing interval, clipping of surrounding resident herbage, and irrigation during summer/autumn.

A short grazing interval over late-summer was detrimental to ryegrass growth and survival, especially if the plants had been grazed less often during spring/early-summer. The effect of paspalum as a stronger competitor than other resident species was recognised in late-summer and when the ryegrass plants were suffering additional stress due to grazing at a short interval over autumn.

CHAPTER 7

GENERAL DISCUSSION

Over the last 10 to 15 years there has been an increasing ingress of volunteer species such as paspalum into dairy pastures in the Waikato (Percival 1977). This reflects the continued intensification of dairying (Brougham 1981). These volunteers have better long-term survival than sown species (eg. ryegrass) because of their ability to resist effects such as soil compaction, trampling and overgrazing that high grazing pressures impose (Brougham 1961; Frame 1971; Watkin & Clements 1978; Scott 1978). Dominance of the sward by volunteer summer growing species can lead to feed shortages in late-winter/spring which farmers have attempted to combat by autumn overdrilling of perennial grasses, particularly ryegrass. This thesis is concerned with the fate of perennial ryegrass after its introduction into dairy pastures containing summer growing paspalum. The major findings were that the persistence of introduced ryegrass was poor because of high summer losses. A large plant size in spring was necessary for summer survival, which was influenced by the prevalence of environmental and management stresses.

This chapter discusses possible mechanisms influencing the fate of ryegrass introduced into dairy pastures containing paspalum, and the effects of treatments designed to increase the competitive ability of the ryegrass, or alternatively, reduce the competitive ability of the resident species. Practical implications are outlined and future research suggested.

The grouping of ryegrass plants according to the season they were lost from the sward (chapter 2 - Fig. 3, Table 2.7), showed that larger plants (>10 tillers per plant) had better summer survival than smaller plants. Subsequent work (chapter 4, 6) resulted in less emphatic conclusions because of the measurement procedure used for blue-labelled plants (chapter 6).

Although the size (tiller number, tiller length, dry weight) and vigour of introduced ryegrass plants were increased by spring application of nitrogen fertiliser (chapter 4), they were insufficient to reduce summer/autumn losses. The increased growth of *Poa* spp. (especially in Pa plots) and resident ryegrass (especially in NPa plots) in response to nitrogen fertiliser, suggests the growth of resident species and introduced ryegrass was equally limited by nitrogen availability. That is, no differential advantage was gained by the introduced species over the resident species in response to nitrogen fertiliser.

Irrigation during summer/autumn improved the size and vigour of the introduced ryegrass plants (chapter 6) but again failed to improve their survival. Irrigation did not modify the botanical composition of the plots (chapter 6). The resident and introduced species, therefore, contributed proportionally to the summer herbage response to irrigation (1200 kg DM/ha, Table 6.2), dependent on their relative contributions to above-ground herbage mass. The effect of irrigation on the growth of resident species and introduced ryegrass was similar to that of nitrogen fertiliser. It is interesting to note that responses to irrigation were largest and most consistent when the ryegrass plants were suffering the least stress, namely, when grazed less frequently and severely, and when not subjected to above-ground competition from the surrounding vegetation (C plot areas). This finding may help explain the variable tillering responses to irrigation reported in the literature (Garwood 1969; Hebblethwaite 1977; Korte & Chu 1983).

Ryegrass growth in Pa plots was less than in NPa plots over summer/autumn, the period of active growth for paspalum (Percival 1977). The prevalence of *Poa* spp. in Pa rather than NPa plots during spring (chapter 4) could have started the process of elimination of some ryegrass plants. The substitution of *Poa* by paspalum from the beginning of summer (Table 2.1) allowed for further suppression of ryegrass. In two of the three field experiments when paspalum was a close neighbour to ryegrass (Pa plots), summer mortality of the latter was higher than when it was associated with other resident species (NPa plots). But the effect of paspalum on ryegrass summer mortality was usually significant when the plants were simultaneously affected by other stress factors eg. grazing at a short interval. Paspalum's aggressiveness towards ryegrass was also demonstrated in the glasshouse experiment (chapter 5), when ryegrass was present as the only competitor. In these circumstances paspalum was capable of suppressing ryegrass growth during summer to the point of extinction of some plants. In the field another example of paspalum's aggressiveness towards ryegrass was that its underground organs apparently remained competitive in clipped areas. This was possible since the growth (Table 6.9, 6.12) and vigour (Table 6.14, 6.15) of ryegrass plants in clipped areas of Pa plots were less than for clipped areas of NPa plots from February/March until June.

The ecological strategies displayed by paspalum (possession of the C_4 pathway of photosynthesis; ability to accumulate large reserves of carbohydrate; adoption of a prostrate growth habit; ability to spread laterally via branching rhizomes) could influence interactions with subordinate species such as ryegrass, as outlined below.

Shoot growth rates over summer of up to 61 kg DM/ha/day have been reported for paspalum (Baars 1976; Taylor et al. 1976) with a maximum in January of 160 kg DM/ha/day (Sithamparanathan 1979). Comparable growth rates for ryegrass were about 30% of these values. The C_4 pathway of photosynthesis, possessed by paspalum, allows higher growth rates at high temperatures than can be achieved by ryegrass (Hatch & Slack 1970; Bjorkman 1971; Downton 1971). Rapid increases in biomass during the growing season helps maintain a high competitive ability (Black et al. 1969; Grime 1979). Any photosynthate surplus to paspalum's immediate requirements is accumulated in the underground rhizome.

High levels of reserves (carbohydrates, nitrogen and other elements) are accumulated in the paspalum rhizome during the growing season (chapter 3). In the present pastures, paspalum survives in hard-grazed areas partly because it assumes the prostrate growth habit characteristic of subtropical species growing in a temperate environment (Harris et al. 1981a). This strategy restricts the removal of leaf area during defoliations (Pike et al. 1979) and eliminates losses of plant units by 'pulling'. It is therefore possible that in the present situation, carbohydrate reserves in paspalum are most important for combating climatic stresses and other forms of damage rather than those due to removal of leaf area by the cows. In comparison to paspalum, ryegrass possess low levels of reserves (Fig. 4, 5) and these are largely contained in above-ground organs. They are therefore subject to complete or partial removal during grazing because of the tufted semi-erect growth habit (Langer 1972; Armstrong 1977) of common perennial ryegrass cultivars. Repeated defoliations may progressively weaken ryegrass plants, especially if they occur during summer (Brougham 1960, 1961) when growth is further constrained by high temperatures and possibly water stress. Ryegrass can therefore be at a competitive disadvantage compared to paspalum and the sward may shift towards paspalum dominance.

The final ecological strategy of importance relates to paspalum's colonising ability. This is achieved by lateral spread of branching rhizomes (Plate 1) to form dense clumps of shoots and below-ground organs (rhizomes and roots), representing a large below-ground biomass (Table 3.3, 6.17). The less vigorous ryegrass plants are not capable of extensive vegetative spread during a growing season (Harris et al. 1979; Minderhoud 1980). Their characteristics were high rates of mortality and low rates of reproduction (chapter 2, 4, 6). It is interesting to note that even though only 38 of the 896 introduced ryegrass plants (chapter 6) flowered during November/December, 36 were located in C areas where above-ground competition for light had been markedly reduced by severe clipping of resident herbage. The ecological strategies displayed by paspalum suggest its long-term survival in the pastures under present managerial and environmental conditions is more likely than is that of ryegrass.

In the final field experiment (chapter 6) a clipping technique was used to provide the introduced ryegrass plants with a less competitive environment. Presumably this technique reduced competition for light between the introduced ryegrass and the resident species, but root competition could also have been modified since interactions between shoot and root competition can occur (Donald 1958; Milthorpe 1961).

In response to clipping of resident species, the introduced ryegrass plants rapidly increased their size (Fig. 8), reaching a peak of 49 tillers per plant in early-summer compared to less than 10 tillers per plant for those in unclipped areas. Losses of ryegrass plants in all seasons were substantially reduced in clipped compared to unclipped areas, especially in summer (Table 6.4). Since clipping was maintained throughout all seasons it was not possible to distinguish seasonal effects of this treatment. It is possible that a large size at the beginning of summer (achieved by plants in clipped areas) was an important factor in their superior summer survival. This suggestion is supported by the reports of other workers (Charles 1961; Langer et al. 1964; Hoen 1968; King 1971; Grime 1979). However, grazing the ryegrass plants frequently and severely in spring as with SI, had little effect on their survival. Less frequent and less severe grazings during summer, as with LI, favoured ryegrass survival, a result which tends to contradict the first suggestion, since both clipping and grazing modified the light environment of the introduced ryegrass plants.

As herbage accumulation was least with a short grazing interval, it was expected that the short grazing interval over spring would have improved the light environment and therefore the growth of the introduced ryegrass plants. That it did not may have been because 47 days elapsed from transplanting until the first grazing of the plots (chapter 6) (23.9.81) by which time a large herbage mass (about 2000 kg DM/ha) had accumulated. The introduction of the treatment that reduced the competition for light may have been too late for maximum benefits. Apart from this possibility, plants grazed at a SI were grazed to a lower residual dry matter than were those grazed at a LI and as a consequence contained a higher proportion of small ryegrass plants. Thus more frequent and severe defoliation lead to greater summer losses of ryegrass plants because of their increased susceptibility to the additional stresses of high temperatures and water shortages in summer. The death rate is likely to be higher if management is changed from a long (spring/early-summer) to a short interval over late-summer (Table 6.4). When etiolated plants (LL treatment (Table 6.9) were grazed more frequently and harder (LS) after the 'crossover' of treatments their chance of suffering a severe grazing was increased (Table 6.4), and higher numbers of deaths occurred (Table 6.4). These findings support those of Brougham (1960, 1961) who showed that a single severe grazing in summer could weaken or kill ryegrass plants, whereas a similar occurrence in spring had little effect.

About 20% of the losses of introduced ryegrass plants could be directly related to obvious damage caused by the cows, namely, severe grazing, 'pulling', dung and urine deposition and trampling. Such losses seem inevitable in pastures grazed by cows and because of their random occurrence, they add to the difficulties in determining treatment effects in long-term experiments. It is likely, however, that more subtle damage caused by the grazing animal also interacted with other mechanisms in deciding the fate of individual ryegrass plants. For example, variable degrees of damage to plant growth points, leaves, stems or roots (Edmond 1966; Campbell 1966; Frame 1971; Watkin & Clements 1978) may eventually become part of the mechanism whereby the plant fails to persist. These effects, although not immediately apparent, may be important where stocking densities are high as in the present experiments (Watkin & Clements 1978).

In summary, it is clear that the loss of ryegrass from the sward is due to a combination of factors. Competition from resident species, in particular *Poa* in spring and paspalum in summer, and summer water, temperature and management stresses. The extent of the loss emphasises its practical significance and the importance of determining ways to reduce its impact. This thesis provides some important guidelines. Reducing competition from resident species is a major practical consideration.

Band-spraying of herbicide at overdrilling is one possible procedure which has proved attractive because of cost benefits (Haggar 1978; Kunelius et al. 1982) compared to blanket-spraying or conventional cultivation. However, little experimental work has been carried out to determine the appropriate band-width representing a reasonable compromise between providing an adequate localised reduction in the dominance of resident species, and loss of production from the sward during the establishment phase (Baker et al. 1979c). In a recent experiment, B.M. Smallfield (pers. comm.) has attempted to improve the ryegrass frequency in a ryegrass/white clover pasture located in Otago. He overdrilled Nui ryegrass into herbicide band-widths of 80 mm (52% of the area sprayed) and 40 mm (27% of the area sprayed), the latter being similar to that used in the experiment described in chapter 2. Ryegrass yields one year after drilling were 1300 and 970 kg DM/ha for the 80 and 40 mm band-widths, respectively although the total production of the former did not equal that from the latter until 10 months after drilling. To obtain greater benefits than just slightly improved dry matter production in the spring immediately following the introduction of improved perennial grass cultivars (chapter 2), it will be necessary to kill a high proportion of resident species. However, the use of wide bands or blanket-spraying has disadvantages of increased cost and reduced total production in the first year after drilling.

Another alternative to the use of herbicides to kill resident vegetation would be to use various forms of partial cultivation. This procedure has the added advantage of breaking up dense paspalum clumps and forming more favourable niches for the establishment of the introduced species. Allo (1952b) suggested making several passes with discs over paspalum dominant pastures before using heavy penetrating harrows to create a less competitive environment for the introduced ryegrass. Various proportions of the resident species could be left intact depending on the intensity of cultivation. Few farmers, however, seem to favour such techniques although some have successfully used the variant of severely treading pastures during early winter before overdrilling in June or July. Paspalum dominance has been eliminated for up to five years in the Matamata district using the latter procedure. Where poor ryegrass persistence is a problem, the majority of farmers use overdrilling procedures (triple disc and chisel coulters, described in chapter 2) to introduce improved perennial ryegrass cultivars (usually Nui or Elletts) into some of their paddocks each year (Sangakkara et al. 1982). Late-winter/spring pasture production may be improved if some or all of the perennial ryegrass seed was replaced by seed of annual cultivars such as *Lolium multiflorum* Lam. 'Grasslands Moata'. Annual ryegrass cultivars possess better initial seedling vigour and growth potential than do perennial cultivars (Langer 1973).

The persistency of C_3 species in pastures containing paspalum may be improved if most of the ryegrass was replaced by species such as *Phalaris* and *Festuca* because they are better able to tolerate periods of water stress and overgrazing. However, these species are slow to establish compared to ryegrasses (Langer 1973) and so their early post-drilling growth would be severely inhibited, probably reducing their effectiveness as persistent species.

Pastures to be autumn overdrilled are commonly hard-grazed before drilling to reduce competition from resident species and then are left for about two months before being regrazed. This procedure is designed to protect the young seedlings from damage by cow grazing and to reduce the risk of 'pulling', and has merely been adopted from accepted management practices for pastures established after cultivation. It ignores the likely suppression of the seedlings by the established species which as shown by the present study is an important determinant of seedling survival. The use subsequent to overdrilling of frequent hard-grazings may be desirable as a means of controlling the growth of resident species and preventing etiolation of the introduced plants. This possibility was recognised by Miller (1973) who, based on dairy farm observations in Taranaki, recommended hard grazing the pasture immediately after overdrilling (before the seedlings had emerged) and thereafter at weekly intervals for the following three months. Apparently 'successful establishment' of overdrilled ryegrass was achieved using this method but no measure of persistence was reported.

The three alternatives of band-spraying, partial cultivation and grazing management are aimed at reducing the competitiveness of the environment in which the seedlings are establishing. They may represent the closest practical approximations to the effects of the clipping treatment (chapter 6), but they require experimental verification. Indications are that a high proportion of overdrilled ryegrass is capable of persisting over summer (Table 6.4) if a satisfactory practical method can be devised for reducing the competitive environment.

The pastures used in the present study were subjected to high stocking rates (4.1 to 5.5 cows per hectare) (Bryant & Parker 1971; Hutton 1973, 1978) during the previous 10 years. Intensive management of dairy pastures usually aims at preventing or reducing seedhead formation of sown species such as ryegrass (eg. Davis et al. 1979).

This results in a lower proportion of ryegrass seeds in the soil seed reservoir. If sown species were permitted to set seed occasionally or seed was broadcast at an appropriate time, the bare or sparsely covered areas they might be recolonised by sown rather than volunteer species, reducing the need for overdrilling.

As previously indicated for the intensive dairying areas of northern New Zealand, volunteer paspalum is capable of colonising gaps in the sward caused by deaths of sown species. Once established, paspalum can exclude species like perennial ryegrass (Sturme 1977). This change in pasture composition is favoured by frequent (and often severe) grazings (eg. LS and SS, chapter 6) during summer, which is in agreement with the report of Baars et al. (1980). When feed shortages arise in summer, the chances of overgrazing ryegrass in renovated or established pastures are high. Combined with favourable climatic and soil conditions, volunteer paspalum is therefore likely to increase its occupancy of the pasture, unless a more persistent perennial ryegrass is found.

Where paspalum dominance creates management problems it may be desirable to grow high yielding annual crops such as maize to produce supplementary feed (silage) for use during periods of pasture shortfall. Paspalum dominance on a farm scale could then be progressively reduced by cropping different paddocks in successive years. At present, however, using cropping primarily to reduce the incidence of paspalum dominance, is of doubtful profitability.

Farmers have been encouraged to renovate established pastures using the results of an extensive machinery research effort conducted by C.J. Baker and others over the previous 10 to 15 years. This programme has markedly improved the reliability of overdrilling techniques as a means of introducing species into pastures. Although emergence of overdrilled seed has been studied, detailed agronomic information on the persistence and contribution of the introduced species to seasonal pasture production has not. This is surprising since such information determines the ultimate value to the farmer of using overdrilling techniques to renovate pastures. Baker (1980) cites 'difficulty in getting the new species to survive for any length of time' as a possible reason for a decline in the popularity of overdrilling as a means of renovating pastures. The present series of experiments emphasise the poor persistence of overdrilled ryegrass and the small short-term improvement in late-winter/spring pasture production. This suggests that present management practices for overdrilled pastures (chapter 2). are inappropriate, especially in intensive dairying areas where the pasture can be dominated by paspalum.

The intensity of competition from resident species largely determines the long-term contribution of overdrilled species to pasture production. Practical treatments are required to reduce the destructive influence of the resident species on the growth of the introduced species. In particular, experiments are required to test the practical options of increased use of herbicides at overdrilling, partial cultivation before drilling, and post-drilling grazing management, to minimise the influence of resident species on the early growth of the introduced species.

Appendix 1 Monthly observations made at the Ruakura Climatological Station, located 1 km northwest of the experimental area.

			Temperature (°C)									
	Rainfall (mm)		Screen				Mean daily grass minimum		Mean 10 cm earth		Number of ground frosts	
Year	Total	Av.[a]	Max.	Av.	Min.	Av.		Av.		Av.		Av.
1978												
Apr.	168	99	22.0	19.8	11.3	8.3	7.7	5.1	15.4	14.4	0	2.8
May	21	112	17.1	16.5	6.4	5.7	2.4	2.4	10.5	11.3	12	5.5
Jun.	149	132	13.5	13.9	4.2	3.7	0.5	0.5	8.1	8.8	14	8.1
Jul.	168	117	13.4	13.3	3.5	3.0	-0.3	-0.4	7.0	7.8	14	10.8
Aug.	90	117	15.0	14.5	4.7	4.1	0.8	0.6	8.3	8.8	14	9.1
Sept.	102	97	16.2	16.2	6.0	5.4	2.1	1.8	10.4	10.9	9	6.0
Oct.	59	107	17.3	17.9	5.5	7.3	1.2	4.1	12.0	13.5	9	3.0
Nov.	117	91	20.3	19.9	9.2	8.9	5.6	5.8	15.2	15.8	2	1.1
Dec.	93	89	22.0	22.0	11.0	10.6	7.1	7.4	17.1	17.8	0	0.6
1979												
Jan.	10	71	24.5	23.5	11.8	11.5	7.2	8.3	18.8	19.0	1	0.1
Feb.	184	81	23.4	24.0	12.8	12.0	9.0	8.7	18.1	18.9	0	0.2
Mar.	145	84	23.1	22.6	14.1	10.6	10.8	7.1	18.2	17.3	0	0.8
Apr.	118	99	19.8	19.8	9.2	8.3	5.1	5.1	14.4	14.4	1	2.8
May	135	112	16.2	16.5	6.3	5.7	2.9	2.4	10.9	11.3	10	5.5
Jun.	63	132	14.9	13.9	6.6	3.7	2.5	0.5	9.6	8.8	11	8.7
Jul.	209	117	13.6	13.3	4.0	3.0	0.2	-0.4	8.1	7.8	15	10.8
Aug.	89	117	14.7	14.5	5.2	4.1	1.4	0.6	8.9	8.8	11	9.1
Sept.	104	97	16.3	16.2	7.4	5.4	2.9	1.8	10.9	10.9	6	6.0
Oct.	126	107	17.7	17.9	8.5	7.3	5.3	4.1	13.1	13.5	4	3.0
Nov.	159	91	20.6	19.9	10.5	8.9	7.2	5.8	15.8	15.8	0	1.1
Dec.	148	89	21.9	22.0	10.6	10.6	6.0	7.4	17.2	17.8	0	0.6
1980												
Jan.	143	71	23.4	23.5	12.4	11.5	9.5	8.3	18.4	19.0	0	0.1
Feb.	83	81	23.5	24.0	13.0	12.0	9.2	8.7	18.5	18.9	0	0.2
Mar.	110	84	21.2	22.6	11.0	10.6	8.0	7.1	16.2	17.3	2	0.8
Apr.	82	99	18.9	19.8	8.0	8.3	4.2	5.1	13.5	14.4	0	2.8
May	35	112	16.3	16.5	6.8	5.7	3.4	2.4	11.7	11.3	7	5.5
Jun.	152	132	13.9	13.9	4.3	3.7	1.0	0.5	9.0	8.8	14	8.7
July	107	117	12.9	13.3	3.6	3.0	-0.1	-0.4	7.5	7.8	15	10.8
Aug.	118	117	13.9	14.5	4.4	4.1	0.7	0.6	8.1	8.8	12	9.1
Sept.	83	97	16.0	16.2	7.8	5.4	3.4	1.8	11.1	10.9	3	6.0
Oct.	34	107	18.7	17.9	9.4	7.3	5.8	4.1	14.1	13.5	2	3.0
Nov.	132	91	18.4	19.9	9.9	8.9	5.7	5.8	15.1	15.8	1	1.1
Dec.	92	89	21.1	20.0	11.6	10.6	8.8	7.4	17.3	17.8	0	0.6

Appendix 1 cont.

			Temperature (°C)									
Year	Rainfall (mm) Total	Av.[a]	Max.	Screen Av.	Min.	Av.	Mean daily grass minimum	Av.	Mean 10 cm earth	Av.	Number of ground frosts	Av.
1981												
Jan.	49	71	25.1	23.5	14.0	11.5	11.8	8.3	20.1	19.0	0	0.1
Feb.	38	81	23.9	24.0	14.0	12.0	11.1	8.7	19.5	18.9	0	0.2
Mar.	80	84	24.1	22.6	14.2	10.6	10.9	7.1	18.6	17.3	0	0.8
Apr.	134	99	20.9	19.8	9.5	8.3	5.7	5.1	14.5	14.4	0	2.8
May	44	112	16.8	16.5	5.5	5.7	2.3	2.4	10.4	11.3	9	5.5
Jun.	193	132	15.2	13.9	5.4	3.7	2.5	0.5	9.3	8.8	9	8.7
Jul.	135	117	13.8	13.3	3.4	3.0	0.2	-0.4	7.2	7.8	13	10.8
Aug.	113	117	13.9	14.5	4.4	4.1	0.9	0.6	7.9	8.8	11	9.1
Sept.	87	97	14.9	16.2	7.2	5.4	3.2	1.8	10.0	10.9	3	6.0
Oct.	78	107	17.7	17.9	7.7	7.3	4.2	4.1	12.8	13.5	6	3.0
Nov.	88	91	19.9	19.9	10.9	8.9	7.9	5.8	15.5	15.8	0	1.1
Dec.	[b](55) 94	89	22.9	22.0	13.1	10.6	10.3	7.4	18.3	17.8	0	0.6
1982												
Jan	(77) 60	71	23.7	23.5	12.0	11.5	8.1	8.3	18.4	19.0	0	0.1
Feb.	(82) 80	81	25.3	24.0	14.0	12.0	10.2	8.7	19.2	18.9	1	0.2
Mar.	(33)119	84	22.0	22.6	9.7	10.6	5.8	7.1	15.8	17.3	2	0.8
Apr.	(16)121	99	18.7	19.8	6.5	8.3	2.6	5.1	12.1	14.4	8	2.8
May	89	112	16.7	16.5	5.4	5.7	1.5	2.4	9.7	11.3	10	5.5
Jun.	55	132	13.1	13.9	2.1	3.7	-1.5	0.5	6.7	8.8	17	8.7

[a] Av. = long-term average (at least 29 years)

[b] ( ) = mm of irrigation water added to plots (chapter 6) during the month

Appendix 2 Linear correlation (r) coefficients for regression of mean visual grade on herbage mass (g. DM/quadrat).

Grazing No.[a]	Pre-grazing	Post-grazing
1	0.91	0.76
2	0.90	0.88
3	0.79	0.80
4	0.62	0.77
5	0.87	0.91
6	0.94	0.96
7	0.90	0.93
8	0.93	0.80
9	0.86	0.95
10	0.95	0.85
11	0.79	0.88
12	0.89	0.80
13	0.92	0.93
14	0.93	0.92

[a] See Table 2.2 (Grazing 1 occurred on 29.6.78)

Appendix 3 Monthly water balance estimates for the experimental area from April 1978 until May 1982

The use of water balance information has been advocated by McAneney & Kerr (1984) to estimate:

(i) the size and extent of seasonal moisture deficits for comparisons within and between years;

(ii) the reduction in total dry matter production under dryland conditions relative to that achieved in the absence of water deficits.

Recent publications (McAneney et al. 1982; McAneney & Judd 1983) illustrate the use of these concepts for sites in the Waikato.

The methods described by McAneney & Kerr (1984) for estimating effects of seasonal water deficits on pasture production require an estimate of readily available soil water storage (RAW). Until the RAW is exhausted, plant water use is controlled largely by weather and growth continues at the maximum possible rate. The approach adopted in this study involved making water content measurements when the soil profile was close to field capacity (Θ_{fc}) and again when wilting was first observed (Θ_c). As these measurements were made only in the top 20% of the rooting zone, assumed here to be equal to a depth of 1 m, RAW was estimated using the following extrapolation formula due to Schockley (1955) and Borg (1980) (cited by McAneney & Kerr 1984):

$$\text{RAW} = 3.0\ \rho_b\ (\Theta_{fc} - \Theta_c)\ (0.2L) \qquad (1)$$

where ρ_b is the bulk density, Θ is the soil water content on a dry weight basis and the factor of 3.0 accounts for the fact that the soil profile within the rooting depth (L) does not contribute equally to the RAW (McAneney & Judd 1983).

From 6.7.80 to 15.7.80, rainfall on the experimental area was 53 mm; three days drainage was then allowed before sampling at four separate sites for estimation of Θ_{fc}. An attempt was made to minimise surface exchanges of moisture during the drainage period by covering the sample sites with black polythene. Eight soil cores (diameter = 25 mm, length = 200 mm) were sampled from each site and were subdivided into three portions (0-50 mm, 51-100 mm, 101-200 mm). Each of these were immediately sealed in separate plastic bags. In the laboratory, comparable core portions within sample sites were bulked before weighing, drying (100 °C for 48 hours) and reweighing. The mean water contents on a dry weight basis for the above core portions were 76.9, 53.9 and 50.5%, respectively, to give a mean value for Θ_{fc} of 60.4%. Measurements of Θ_c were made on 10 soil core samples (diameter = 25 mm, length = 150 mm) taken on 24.2.81 from separate sample sites in the experimental area. This date was preceded by a 31 day dry period during which no rain fell on 21 days. On the 10 rain days during this period, total rainfall was 17 mm. Ryegrass plants at each sampling site showed visual signs of wilting the day before sampling. The same procedure as described above was used in obtaining and processing the soil samples, except the cores were not subdivided. The mean water content (Θ_c) was 28.4%, and the mean bulk density (0-200 mm) was 0.81; 0.2L = 150 mm. Substitution in equation (1) gives a value for RAW of 117 mm.

Monthly rainfall totals (R) for April 1978 to May 1982 recorded at the Ruakura Climatological Station are given in Appendix 1. This station is located 1 km northwest of the experimental area. Penman estimates of the mean monthly maximum weather dependent evapotranspiration (ET_{max}), provided by the NZ Meteorological Service, are presented in Table A3. From these data the available soil moisture storage (S_n mm) at the end of the each month was calculated (Table A3) using the method suggested by Dr D. Scotter (McAneney & Kerr 1984):

$$S_n = S_{n-1} - ET_{max} + R \quad \text{where } 0<S_n<RAW \qquad (2)$$

and where the subscript n corresponds to the month in question and n-1 to the previous month. S_n is assumed to equal RAW at the end of August. The water available for growth (A mm) was then calculated for each month (Table A3):

$$A = S_{n-1} + R - 30 \qquad \text{where } 0<A<ET_{max} \qquad (3)$$

The 30 mm subtraction in equation (3) is an arbitrary factor which Scotter uses to account for

(i) rainfall, which usually does not arrive exactly when needed during the month; and

(ii) the amount of water required to stimulate pasture growth after a dry period.

The monthly water availability index (A/ET_{max}) was then calculated (Table A3). Where this ratio is less than one, there was insufficient water available for maximum pasture growth during that month and reductions in dry matter production due to water deficits are likely.

Table A3 Estimates of monthly Sn, A and A/ET_{max} from April 1978 to May 1982 (all data in mm of water). Rainfall data are presented in Appendix 1.

Year		Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
	ET_{max}	47.8	26.2	17.3	20.3	33.6	53.6	82.0	106.4	125.3	129.8	104.4	83.6
1978/79	Sn	117.0	112.8	117.0	117.0	117.0	117.0	94.0	104.6	72.3	0	79.6	117.0
	A	47.8	26.2	17.3	20.3	33.6	53.6	82.0	106.4	125.3	52.3	104.4	83.6
	A/ET_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.4	1.0	1.0
1979/80	Sn	117.0	117.0	117.0	117.0	117.0	117.0	117.0	117.0	117.0	117.0	95.6	117.0
	A	47.8	26.2	17.3	20.3	33.6	53.6	82.0	106.4	125.3	129.8	104.4	83.6
	A/ET_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1980/81	Sn	34.2	43.0	117.0	117.0	117.0	117.0	69.0	94.6	61.3	0	0	0
	A	47.8	26.2	17.3	20.3	33.6	53.6	82.0	106.4	125.3	80.3	8.0	50.0
	A/ET_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.6	0.1	0.6
1981/82[a]	Sn	117.0	117.0	117.0	117.0	117.0	117.0	113.0	94.6	63.3	0	0	35.4
	A	47.8	26.2	17.3	20.3	33.6	53.6	82.0	106.4	125.3	93.3	50.0	83.6
	A/ET_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.5	1.0
1982	Sn	117.0	117.0	117.0									
	A	47.8	26.2	17.3									
	A/ET_{max}	1.0	1.0	1.0									
1981/82[b]	Sn	117.0	117.0	117.0	117.0	117.0	117.0	113.0	94.6	117.0	117.0	117.0	117.0
	A	47.8	26.2	17.3	20.3	33.6	53.6	82.0	106.4	125.3	129.8	104.4	83.6
	A/ET_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1982	Sn	117.0	117.0	117.0									
	A	47.8	26.2	17.3									
	A/ET_{max}	1.0	1.0	1.0									

[a] Without irrigation from December 1981 to April 1982

[b] With irrigation (see Appendix 1)

Appendix 4 Seasonal concentrations (% of DM) of sulphur (S), magnesium (Mg), calcium (Ca) and sodium (Na) in ryegrass and paspalum growing in mixed pasture.

Element		Ryegrass				Paspalum			
		Oct.	Jan.	Mar.	Jun.	Oct.	Jan.	Mar.	Jun.
S	Leaf	0.3 (0.03)[a]	0.3 (0.03)	0.3 (0.03)	0.3 (0.02)	0.3 (0.02)	0.5 (0.05)	0.4 (0.01)	0.3 (0.02)
	'Stem'[b]	0.2 (0.01)	0.2 (0.01)	0.2 (0.02)	0.2 (0.02)	0.2 (0.05)	0.4 (0.03)	0.2 (0.01)	0.2 (0.01)
	Culm	-	-	-	-	-	-	0.2 (0.01)	-
	Root	0.2 (0.01)	0.1 (0.02)	0.2 (0.02)	0.2 (0.03)	0.2 (0.01)	0.2 (0.01)	0.2 (0.01)	0.2 (0.01)
	Rhizome	-	-	-	-	0.3 (0.02)	0.2 (0.01)	0.2 (0.01)	0.2 (0.01)
	Dead	0.2 (0.00)	0.2 (0.02)	0.2 (0.01)	0.1 (0.04)	0.2 (0.03)	0.2 (0.05)	0.2 (0.01)	0.2 (0.02)
Mg	Leaf	0.2 (0.02)	0.2 (0.02)	0.3 (0.02)	0.2 (0.02)	0.2 (0.02)	0.2 (0.01)	0.2 (0.01)	0.1 (0.02)
	'Stem'	0.01(0.01)	0.1 (0.01)	0.1 (0.02)	0.1 (0.01)	0.3 (0.02)	0.3 (0.02)	0.2 (0.02)	0.2 (0.02)
	Culm	-	-	-	-	-	-	0.2 (0.01)	-
	Root	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.02)	0.1 (0.00)	0.1 (0.01)	0.1 (0.02)	0.1 (0.01)
	Rhizome	-	-	-	-	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.02)
	Dead	0.1 (0.01)	0.1 (0.01)	0.2 (0.01)	0.1 (0.03)	0.2 (0.02)	0.1 (0.30)	0.2 (0.02)	0.1 (0.03)
Ca	Leaf	0.4 (0.05)	0.5 (0.04)	0.4 (0.06)	0.3 (0.06)	0.4 (0.04)	0.4 (0.07)	0.4 (0.03)	0.3 (0.03)
	'Stem'	0.4 (0.02)	0.4 (0.04)	0.3 (0.05)	0.2 (0.03)	0.4 (0.03)	0.3 (0.02)	0.3 (0.01)	0.2 (0.02)
	Culm	-	-	-	-	-	-	0.2 (0.01)	-
	Root	0.4 (0.03)	0.4 (0.02)	0.5 (0.05)	0.3 (0.07)	0.2 (0.03)	0.3 (0.03)	0.3 (0.02)	0.2 (0.02)
	Rhizome	-	-	-	-	0.1 (0.01)	0.2 (0.01)	0.1 (0.02)	0.1 (0.02)
	Dead	0.4 (0.03)	0.7 (0.01)	0.6 (0.03)	0.4 (0.12)	0.7 (0.04)	0.6 (0.13)	0.7 (0.09)	0.6 (0.12)
Na	Leaf	0.39(0.190)	0.17(0.062)	0.14(0.033)	0.1 (0.100)	0.05(0.010)	0.0 (0.005)	0.06(0.008)	0.07(0.001)
	'Stem'	0.36(0.111)	0.19(0.066)	0.12(0.021)	0.2 (0.089)	0.12(0.013)	0.0 (0.010)	0.09(0.013)	0.11(0.006)
	Culm	-	-	-	-	-	-	0.03(0.009)	-
	Root	0.14(0.015)	0.08(0.019)	0.06(0.005)	0.13(0.010)	0.06(0.010)	0.10(0.015)	0.10(0.013)	0.08(0.010)
	Rhizome	-	-	-	-	0.03(0.005)	0.11(0.035)	0.05(0.010)	0.05(0.010)
	Dead	0.05(0.001)	0.10(0.007)	0.08(0.006)	0.10(0.007)	0.07(0.005)	0.07(0.013)	0.08(0.008)	0.08(0.013)

[a] standard error of the mean

[b] pseudostem (leaf sheaths)

Appendix 5a Soluble sugar (SS), starch (S) and TNC concentrations (% of DM) in paspalum during uninterrupted growth of mixed pasture in late-spring/early-summer (LS/ES) and summer/autumn (S/A).

	LS/ES[a]				S/A					
	1.10.80	27.10.80	16.11.80	8.12.80	21.1.80	5.2.80	20.2.80	5.3.80	19.3.80	1.4.80
Leaf										
SS	5.2(0.94)[b]	4.2(0.19)	5.7(1.31)	3.9(0.24)	2.4(0.11)	4.1(0.14)	3.3(0.29)	3.3(0.28)	4.3(0.51)	5.6(0.49)
S	0.2(0.09)	0.3(0.03)	0.1(0.03)	0.0	0.1(0.05)	0.1(0.01)	0.1(0.01)	0.1(0.01)	0.1(0.02)	0.1(0.2)
TNC	5.4	4.5	5.8	3.9	2.5	4.2	3.4	3.4	4.4	5.7
'Stem'[c]										
SS	7.1(2.29)	5.4(0.67)	6.3(0.90)	5.1(0.54)	3.3(0.11)	5.5(0.67)	5.2(0.13)	5.4(0.82)	9.5(1.24)	11.4(0.54)
S	0.6(0.23)	0.0	0.2(0.07)	1.5(0.41)	0.2(0.18)	0.2(0.14)	0.1(0.06)	0.6(0.20)	0.9(0.22)	1.8(0.55)
TNC	7.7	5.4	6.5	6.6	3.5	5.7	5.3	6.0	10.4	13.2
Culm[d]										
SS	-	-	-	-	3.5 -	4.2 -	3.1 -	5.3(0.22)	4.0(0.49)	4.0(0.25)
S	-	-	-	-	0.0	0.1 -	0.4 -	0.9(0.30)	0.9(0.29)	0.9(0.25)
TNC	-	-	-	-	3.5	4.3	3.5	6.2	4.9	4.9
Rhizome										
SS	7.3(1.08)	6.9(1.19)	6.7(1.48)	7.5(1.42)	10.8(1.07)	10.4(1.26)	11.7(1.03)	11.7(0.56)	12.6(1.18)	13.2(0.89)
S	5.7(1.31)	2.1(0.54)	1.0(0.58)	2.2(1.19)	1.4(0.33)	1.8(0.39)	4.6(0.38)	5.4(0.57)	9.2(1.20)	10.0(0.51)
TNC	13.0	9.0	7.7	9.7	12.2	12.2	16.3	17.1	21.8	23.2
Root										
SS	1.7(0.26)	1.8(0.44)	1.2(0.15)	1.8(0.90)	1.3(0.05)	1.7(0.26)	2.1(0.53)	1.7(0.14)	2.0(0.15)	2.2(0.57)
S	0.0	0.1(0.04)	0.0	0.0	0.0	0.0	0.1(0.08)	0.1(0.06)	0.1(0.04)	0.2(0.17)
TNC	1.7	1.9	1.2	1.8	1.3	1.7	2.2	1.8	2.1	2.4
Dead										
SS	0.6(0.17)	0.4(0.07)	0.6(0.10)	0.7(0.30)	1.1(0.46)	0.4(0.20)	0.4(0.24)	0.5(0.06)	0.8(0.37)	0.8(0.30)
S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TNC	0.6	0.4	0.6	0.7	1.1	0.4	0.4	0.5	0.8	0.8

[a] culm absent

[b] standard error of the mean

[c] pseudostem (leaf sheaths)

[d] during January and February, insufficient dry matter for replicated analyses

Appendix 5b Nitrogen (N), phosphorus (P) and potassium (K) concentrations (% of DM) in paspalum during uninterrupted growth of mixed pasture in late-spring/early-summer.

Element		1.10.80	27.10.80	16.11.80	8.12.80
N	Leaf	3.4 (0.08)[a]	3.6 (0.24)	3.0 (0.06)	2.8 (0.18)
	'Stem'[b]	2.3 (0.41)	2.6 (0.21)	2.1 (0.40)	1.8 (0.11)
	Root	0.9 (0.08)	0.9 (0.10)	0.8 (0.14)	1.0 (0.17)
	Rhizome	2.6 (0.16)	2.5 (0.25)	2.6 (0.23)	2.1 (0.19)
	Dead	1.4 (0.35)	1.3 (0.14)	1.2 (0.19)	1.2 (0.21)
P	Leaf	0.4 (0.05)	0.3 (0.04)	0.3 (0.04)	0.2 (0.02)
	'Stem'	0.3 (0.07)	0.3 (0.06)	0.2 (0.06)	0.2 (0.03)
	Root	0.1 (0.01)	0.1 (0.02)	0.1 (0.01)	0.1 (0.01)
	Rhizome	0.2 (0.04)	0.1 (0.04)	0.1 (0.02)	0.1 (0.02)
	Dead	0.1 (0.04)	0.1 (0.03)	0.1 (0.02)	0.1 (0.02)
K	Leaf	2.5 (0.31)	2.9 (0.23)	2.8 (0.53)	2.7 (0.45)
	'Stem'	2.4 (0.24)	3.7 (0.08)	3.5 (0.75)	3.2 (0.16)
	Root	0.7 (0.13)	0.5 (0.05)	0.4 (0.05)	0.4 (0.05)
	Rhizome	0.8 (0.15)	0.8 (0.21)	0.7 (0.17)	0.7 (0.11)
	Dead	0.4 (0.12)	0.2 (0.05)	0.3 (0.08)	0.2 (0.06)

[a] standard error of the mean
[b] pseudostem (leaf sheaths); culm absent

Appendix 5c Nitrogen (N), phosphorus (P) and potassium (K) concentrations (% of DM) in paspalum during uninterrupted growth of mixed pasture in summer/autumn.

Element		21.1.80	5.2.80	20.2.80	5.3.80	19.3.80	1.4.80
N	Leaf	4.0 (0.05)[a]	3.4 (0.13)	3.0 (0.26)	2.5 (0.38)	2.9 (0.20)	2.4 (0.28)
	'Stem'[b]	2.4 (0.04)	1.9 (0.05)	1.4 (0.16)	1.4 (0.25)	1.2 (0.05)	1.2 (0.09)
	Culm[c]	2.2 -	1.8 -	1.6 -	1.6 (0.07)	1.5 (0.13)	1.5 (0.15)
	Root	0.9 (0.07)	0.8 (0.13)	0.9 (0.10)	0.8 (0.06)	0.9 (0.11)	0.8 (0.13)
	Rhizome	1.4 (0.14)	1.5 (0.09)	1.4 (0.12)	1.4 (0.27)	1.5 (0.17)	1.5 (0.21)
	Dead	1.3 (0.01)	1.2 (0.10)	1.2 (0.13)	1.1 (0.12)	1.1 (0.13)	1.0 (0.21)
P	Leaf	0.4 (0.02)	0.3 (0.01)	0.3 (0.01)	0.3 (0.05)	0.2 (0.04)	0.2 (0.02)
	'Stem'	0.4 (0.02)	0.3 (0.04)	0.2 (0.02)	0.2 (0.01)	0.2 (0.02)	0.2 (0.01)
	Culm	0.3 -	0.3 -	0.2 -	0.3 (0.01)	0.2 (0.02)	0.2 (0.02)
	Root	0.1 (0.01)	0.1 (0.02)	0.1 (0.02)	0.1 (0.01)	0.1 (0.02)	0.1 (0.01)
	Rhizome	0.1 (0.03)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.02)	0.1 (0.01)
	Dead	0.1 (0.02)	0.1 (0.03)	0.1 (0.02)	0.1 (0.01)	0.1 (0.01)	0.1 (0.03)
K	Leaf	2.7 (0.07)	3.0 (0.09)	2.7 (0.13)	2.4 (0.12)	2.4 (0.06)	2.4 (0.25)
	'Stem'	3.6 (0.15)	3.4 (0.09)	3.3 (0.19)	3.0 (0.15)	2.9 (0.26)	2.6 (0.27)
	Culm	2.2 -	2.0 -	1.4 -	1.4 (0.07)	1.5 (0.07)	1.4 (0.15)
	Root	0.6 (0.05)	0.5 (0.11)	0.6 (0.13)	0.4 (0.09)	0.5 (0.10)	0.6 (0.06)
	Rhizome	1.0 (0.13)	1.0 (0.10)	1.1 (0.12)	0.8 (0.10)	0.8 (0.06)	0.7 (0.10)
	Dead	0.4 (0.08)	0.3 (0.06)	0.3 (0.06)	0.2 (0.04)	0.2 (0.05)	0.3 (0.06)

[a] standard error of the mean
[b] pseudostem (leaf sheaths)
[c] in January and February, insufficient dry matter for replicated analyses

Appendix 5d Sulphur (S), magnesium (Mg), calcium (Ca) and sodium (Na) concentrations (% of DM) in paspalum during uninterrupted growth of mixed pasture in late-spring/early-summer.

Element		1.10.80	27.10.80	16.10.80	8.12.80
S	Leaf	0.4 (0.03)[a]	0.4 (0.04)	0.4 (0.03)	0.4 (0.04)
	'Stem'[b]	0.2 (0.04)	0.3 (0.03)	0.3 (0.03)	0.3 (0.04)
	Root	0.2 (0.01)	0.2 (0.01)	0.2 (0.01)	0.2 (0.01)
	Rhizome	0.3 (0.01)	0.2 (0.01)	0.3 (0.02)	0.2 (0.02)
	Dead	0.2 (0.04)	0.2 (0.03)	0.2 (0.01)	0.2 (0.03)
Mg	Leaf	0.3 (0.04)	0.2 (0.02)	0.2 (0.02)	0.3 (0.02)
	'Stem'	0.3 (0.03)	0.3 (0.02)	0.3 (0.01)	0.2 (0.03)
	Root	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)
	Rhizome	0.1 (0.02)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)
	Dead	0.1 (0.02)	0.1 (0.01)	0.1 (0.02)	0.1 (0.02)
Ca	Leaf	0.5 (0.12)	0.5 (0.08)	0.5 (0.07)	0.5 (0.07)
	'Stem'	0.3 (0.10)	0.4 (0.03)	0.4 (0.04)	0.3 (0.05)
	Root	0.3 (0.03)	0.3 (0.02)	0.4 (0.05)	0.3 (0.07)
	Rhizome	0.2 (0.01)	0.2 (0.02)	0.2 (0.07)	0.2 (0.01)
	Dead	0 7 (0.11)	0.8 (0.13)	0.8 (0.09)	0.7 (0.10)
Na	Leaf	0.11(0.017)	0.05(0.006)	0.04(0.010)	0.05(0.008)
	'Stem'	0.14(0.053)	0.10(0.010)	0.10(0.015)	0.09(0.017)
	Root	0.11(0.027)	0.09(0.013)	0.10(0.021)	0.08(0.013)
	Rhizome	0.08(0.025)	0.07(0.010)	0.08(0.014)	0.08(0.017)
	Dead	0.09(0.013)	0.08(0.013)	0.09(0.013)	0.07(0.010)

[a] standard error of the mean
[b] pseudostem (leaf sheaths); culm absent

Appendix 5e Sulphur (S), magnesium (Mg), calcium (Ca) and sodium (Na) concentrations (% of DM) in paspalum during uninterrupted growth of mixed pasture in summer/autumn.

Element		21.1.80	5.2.80	20.2.80	5.3.80	19.3.80	1.4.80
S	Leaf	0.6 (0.02)[a]	0.5 (0.01)	0.5 (0.02)	0.5 (0.03)	0.5 (0.04)	0.4 (0.08)
	'Stem'	0.5 (0.04)	0.4 (0.03)	0.3 (0.01)	0.3 (0.02)	0.3 (0.02)	0.3 (0.01)
	Culm[c]	0.3 -	0.2 -	0.2 -	0.2 (0.01)	0.2 (0.02)	0.2 (0.02)
	Root	0.2 (0.01)	0.2 (0.01)	0.2 (0.01)	0.2 (0.01)	0.1 (0.01)	0.2 (0.01)
	Rhizome	0.2 (0.02)	0.2 (0.02)	0.2 (0.02)	0.2 (0.02)	0.2 (0.02)	0.2 (0.04)
	Dead	0.3 (0.02)	0.3 (0.03)	0.2 (0.01)	0.2 (0.01)	0.2 (0.02)	0.3 (0.01)
Mg	Leaf	0.2 (0.02)	0.2 (0.01)	0.2 (0.02)	0.2 (0.03)	0.2 (0.02)	0.1 (0.03)
	'Stem'	0.3 (0.02)	0.2 (0.03)	0.2 (0.01)	0.2 (0.02)	0.2 (0.06)	0.2 (0.01)
	Culm	0.2 -	0.2 -	0.2 -	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)
	Root	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)
	Rhizome	0.1 (0.01)	0.1 (0.02)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)
	Dead	0.1 (0.02)	0.1 (0.03)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)
Ca	Leaf	0.4 (0.01)	0.4 (0.03)	0.4 (0.04)	0.5 (0.05)	0.4 (0.05)	0.4 (0.07)
	'Stem'	0.3 (0.02)	0.3 (0.01)	0.2 (0.02)	0.2 (0.04)	0.2 (0.05)	0.2 (0.03)
	Culm	0.2 -	0.2 -	0.2 -	0.2 (0.04)	0.2 (0.01)	0.2 (0.02)
	Root	0.3 (0.01)	0.3 (0.01)	0.3 (0.04)	0.3 (0.03)	0.3 (0.02)	0.3 (0.01)
	Rhizome	0.2 (0.03)	0.2 (0.03)	0.2 (0.03)	0.2 (0.04)	0.2 (0.03)	0.1 (0.01)
	Dead	0.6 (0.09)	0.7 (0.06)	0.7 (0.02)	0.7 (0.05)	0.7 (0.08)	0.7 (0.04)
Na	Leaf	0.09 (0.006)	0.06 (0.008)	0.05 (0.013)	0.06 (0.014)	0.07 (0.013)	0.08 (0.013)
	'Stem'	0.13 (0.021)	0.11 (0.015)	0.07 (0.014)	0.11 (0.006)	0.11 (0.017)	0.13 (0.026)
	Culm	0.06 -	0.05 -	0.04 -	0.08 (0.010)	0.09 (0.021)	0.08 (0.010)
	Root	0.11 (0.016)	0.10 (0.008)	0.09 (0.021)	0.11 (0.022)	0.10 (0.012)	0.12 (0.025)
	Rhizome	0.12 (0.031)	0.10 (0.039)	0.10 (0.038)	0.11 (0.040)	0.07 (0.029)	0.10 (0.042)
	Dead	0.09 (0.013)	0.07 (0.005)	0.07 (0.010)	0.08 (0.010)	0.07 (0.005)	0.08 (0.010)

[a] standard error of the mean
[b] pseudostem (leaf sheaths)
[c] during January and February, insufficient dry matter for replicated analyses

Appendix 5f Paspalum biomass (kg DM/ha) over periods of uninterrupted growth in mixed pasture during late-spring/early summer (LS/ES) and summer/autumn (S/A).

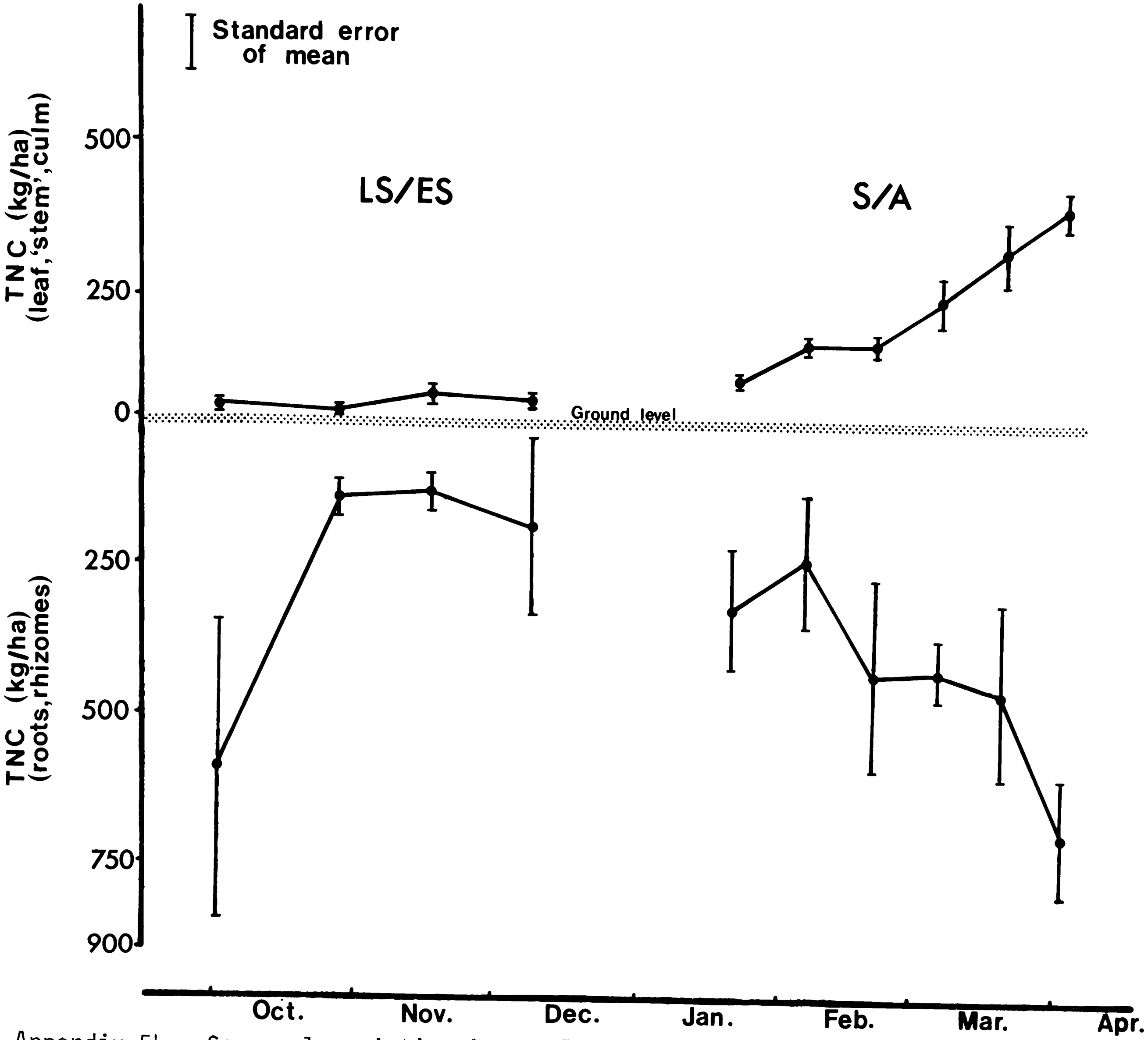
	LS/ES[a]				S/A					
	30.9.81	28.10.81	24.11.81	9.12.81	20.1.82	3.2.82	16.2.82	4.3.82	18.3.82	1.4.82
Leaf	131 (48)[b]	144 (70)	366 (182)	286 (132)	1441 (91)	2200 (317)	2183 (275)	1980 (158)	2000 (308)	1419 (156)
'Stem'[c]	135 (35)	97 (50)	189 (78)	145 (61)	744 (192)	595 (225)	810 (239)	1641 (532)	1423 (100)	1650 (153)
Culm	-	-	-	-	-	59 (39)	225 (153)	533 (220)	737 (435)	957 (457)
Rhizome	2995 (879)	1216 (399)	1741 (790)	1278 (792)	2519 (943)	1749 (683)	2449 (1064)	2325 (308)	2032 (680)	2885 (284)
Root	1037 (205)	471 (163)	802 (317)	551 (313)	1276 (194)	816 (99)	1273 (425)	1227 (361)	544 (90)	1156 (362)
Dead	1033 (608)	673 (428)	726 (257)	582 (416)	1097 (410)	751 (231)	1423 (755)	1102 (371)	1070 (178)	1257 (479)
TOTAL	5331	2601	3824	2842	7077	6170	8363	8828	7816	9314

[a] culm absent at all samplings
[b] standard error of the mean
[c] pseudostem (leaf sheaths)

Appendix 5g Major element levels (kg/ha) in paspalum over periods of uninterrupted growth in mixed pasture, during late-spring/early-summer (LS/ES) and summer/autumn (S/A).

	LS/ES		S/A	
Element	Leaf & 'stem'	Roots & rhizome	Leaf, 'stem' & culm	Roots & rhizome
N	9 (4.1)[a]	50 (6.8)	80 (4.9)	42 (4.6)
P	1 (0.4)	3 (0.8)	8 (0.6)	3 (0.3)
K	11 (4.0)	18 (2.8)	89 (7.7)	26 (3.0)
S	1 (0.4)	6 (1.1)	14 (0.7)	7 (0.5)
Mg	1 (0.4)	2 (0.7)	6 (0.3)	3 (0.2)
Ca	2 (0.7)	5 (1.1)	12 (1.0)	7 (0.4)
Na	0.3 (0.1)	2 (0.8)	3 (0.2)	3 (0.9)

[a] standard error of the mean



Appendix 5h Seasonal variation in total nonstructural carbohydrate (TNC) levels (kg/ha) in above- and below-ground organs of paspalum growing in mixed pasture.

Appendix 6 Linear correlation (r) coefficients for regression of mean visual grade on herbage mass (kg DM/ha).

	SI[a]		LI[b]	
Defoliation No.[c]	Pre-defoliation	Post-defoliation	Pre-defoliation	Post-defoliation
P[d]	-	0.78	-	0.78
1	0.97	0.87	0.94	0.95
2	0.96	0.87	0.70	0.90
3	0.90	0.78	0.96	0.96
4	0.87	0.95	0.81	0.96
5	0.95	0.92	0.89	0.79
6	0.97	0.96	0.86	0.98
7	0.79	0.96	0.88	0.91
8	0.89	0.93	0.94	0.93
9	0.76	0.94	0.91	0.97
10	0.85	0.89	0.91	0.89
11	0.87	0.93		
12	0.70	0.82		
13	0.90	0.40		
14	0.81	-		

[a] SI = short grazing interval

[b] LI = long grazing interval

[c] see Table 4.2 (defoliation 1 occurred on 15.9.80 for SI and 22.9.80 for LI)

[d] herbage mass assessment before instigation of different defoliation managements. Same regression equation used to adjust visual grades on all treatment plots.

Appendix 7 Soil fertility status of experimental plots on 6.8.79.

	Plot type[a]	
Soil test	Pa	NPa
pH	5.7 (0.12)[b]	5.8 (0.13)
K	12.4 (5.65)	14.7 (6.09)
P	18.2 (5.43)	20.1 (6.99)
Mg	18.9 (3.84)	20.9 (6.22)

[a] Pa = paspalum dominant plots; data are means of 26 samples
NPa = plots containing little or no paspalum; data are means of 27 samples

[b] ( ) = standard error of the mean

Appendix 8 Inorganic nutrient solution ('Bollard's Solution').

The complete solution contains the following nutrients (ppm):

Macronutrients				Micronutrients			
N	224	Mg	48	Cl	0.68	Zn	0.05
P	31	Ca	80	B	0.50	Cu	0.02
K	156	S	160	Mn	0.50	Mo	0.02

The following stock solutions were required for production of the complete and the nitrogen-free (-N) solutions:

A	1 M	$Mg(NO_3)_2$	$Mg(NO_3)_2.6H_2O$	256 g/ℓ
B	1 M	$Ca(NO_3)_2$	$Ca(NO_3)_2.4H_2O$	236 g/ℓ
C	0.2 M	$K H_2PO_4$	KH_2PO_4	27 g/ℓ
D	0.25 M	K_2SO_4	K_2SO_4	44 g/ℓ
E	0.01 M	$CaSO_4$	$CaSO_4.2H_2O$	1.7 g/ℓ
F	1 M	$MgSO_4$	$MgSO_4.7H_2O$	246 g/ℓ
G	Fe	EDTA		
H	Micronutrients		Cl, B, Mn, Zn, Cu, Mo	

The following quantities of each stock solution were added to 500 ml of deionised water which was then made up to 1 ℓ of nutrient solution

	Solution required (ml)	
Nutrient	Complete	-N
A	2.0	-
B	2.0	-
C	5.0	5.0
D	8.0	8.0
E	-	200.0
F	-	2.0
G	0.6	0.6
H	1.0	1.0

(after Bollard 1966)

Appendix 9 Mean monthly maximum and minimum air temperatures (°C) for glasshouse conditions (chapter 5).

	Air Temperature (°C)	
	Max.	Min.
1979		
September	21.5 (3.57)[a]	11.9 (1.85)
October	23.0 (2.47)	14.6 (2.18)
November	26.7 (1.90)	17.7 (2.55)
December	28.5 (2.10)	17.2 (3.03)
1980		
January	27.7 (2.73)	17.4 (2.23)
February	27.7 (3.32)	16.4 (1.39)
March	26.0 (2.17)	14.9 (1.78)
April	23.5 (1.91)	12.4 (1.51)

[a] standard error of the mean

Appendix 10 Linear correlation (r) coefficients for regression of mean visual grade on herbage mass (kg DM/ha).

Grazing No[c]	SI[a] Pre-grazing	SI[a] Post-grazing	LI[b] Pre-grazing	LI[b] Post-grazing
P[d]	-	0.64	-	0.64
1	0.87	0.91	0.94	0.96
2	0.93	0.95	0.93	0.94
3	0.90	0.95	0.95	0.92
4	0.97	0.93	0.81	0.82
5	0.93	0.92	0.92	0.94
6	0.92	0.88	0.94	0.88
7	0.91	0.92	0.86	0.66
8	0.91	0.80	0.92	0.84
9	0.95	0.82	0.91	0.92
10	0.92	0.94	0.92	-
11	0.88	0.96		
12	0.93	0.83		
13	0.86	0.82		
14	0.82	0.77		
15	0.82	0.67		
16	0.91	0.68		
17	0.86	0.64		
18	0.75	0.93		
19	0.85	-		

[a] SI = short grazing interval (SS and SL for grazings 1-8; SS and LS for grazings 9-19)

[b] LI = long grazing interval (LL and LS for grazings 1-4; LL and SL for grazings 5-10)

[c] see Table 6.1 (grazing 1 occurred on 23.9.81 for SI and 29.9.81 for LI)

[d] herbage mass assessment before instigation of the various grazing managements. Same regression equation used to adjust visual grades on all treatment plots

Appendix 11 Nutrient solution applied to ryegrass plants growing in alkathene tubes (after Smith et al. 1983).

	Nutrient concentrations (g/4.5 ℓ of water)			
Stock solution A				
$Mg(NO_3)_2$	Mg	2.66	N	3.06
$Ca(NO_3)_2$	Ca	34.04	N	23.78
NaCl	Na	0.59	Cl	0.91
Stock solution B				
KH_2PO_4	K	2.24	P	1.78
K_2SO_4	K	8.57	S	3.51
K_2HPO_4	K	2.15	P	0.85
KCl	K	7.04	Cl	6.38

Minor element solution containing Cl, B, Mn, Zn, Cu, Mo, Co.

The dilute nutrient solution was made up as follows:

	0.2 ℓ	of solution A
	0.2 ℓ	of solution B
	0.1 ℓ	of minor elemental solution
	0.025 ℓ	of ferric citrate (5 ppm Fe)
	3.975 ℓ	of water
Total	4.500 ℓ	

On 20.7.81, 1 ml of this solution was applied to the moistened soil enclosed in alkathene tubing which provided the environment for growth of a single ryegrass plant.

Appendix 12 The effect of irrigation on the soil nutrient status of the plots.

	Soil test[a]																				
	pH			P			K			Mg			SO_4			NH_4			NO_3		
Date	+I[b]	-I	SED[c]	+I	-I	SED	+I	-I	SED	+I	-I	SED	+I	-I	SED	+I	-I	SED	+I	-I	SED
10.12.81	5.5	5.5	0.04	36.3	33.0	2.54	12.8	10.2	1.40	18.8	19.4	1.14	29.1	27.7	2.56	32.7	31.4	4.64	25.3	21.8	7.96
5.2.82	5.3	5.3	0.03	38.2	35.6	3.37	16.2	14.2	1.69	23.1	22.9	1.03	35.7	30.1	2.90	39.6	31.8	10.61	43.3	49.1	10.81
2.3.82	5.4	5.4	0.03	37.8	37.0	3.80	17.6	12.7	1.79	22.5	23.5	1.04	30.2	25.6	2.03	32.9	28.8	4.97	47.0	35.0	9.62
29.3.82	5.4	5.4	0.03	34.4	32.8	3.09	15.7	12.3	1.59	22.5	24.8	1.09	28.7	24.0	1.75	31.5	33.9	8.88	42.8	28.8	9.60
25.5.82	5.4	5.4	0.03	36.5	37.8	4.10	16.1	13.5	1.27	21.3	22.9	1.09	22.1	21.2	1.12	37.6	39.8	3.78	23.1	25.3	2.80

[a] see Section 6.5

[b] irrigations began on 16.12.81 and ceased on 29.4.82

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